Washington Forest Practices

Board Manual:

Standard Methodology for

Conducting Watershed Analysis

Under Chapter 222-22 WAC

Version 5.0 May 2011

Washington Forest Practices Board

SECTION 11
STANDARD METHODOLOGY FOR CONDUCTING WATERSHED ANALAYIS

Table of Contents

Part 1 Introduction to Watershed Analysis

1.1 Background

The 1974 Forest Practices Act provides authority for state regulation of forest practices on Washington's 12.5 million acres of state and private lands. Regulations are primarily designed to protect public resources by preventing erosion from roads, to protect water quality and provide fish and wildlife habitat with streamside buffers, to protect wetlands and to ensure long-term supply of forests with reforestation requirements. Since 1974, significant changes have been made in the rules, reflecting improved scientific knowledge and efforts to promote efficient regulation and effective resource protection while ensuring industry stability.

Until the cumulative effects rules were adopted, forest practices were considered one activity at a time. Although the regulations provide protection on a site by site basis, there are concerns that the watershed as a whole may be affected by the "cumulative effects" of all of the activities in the basin. Cumulative effects have been defined as "the changes to the environment caused by the interaction of natural ecosystem processes with the effects of two or more forest practices." These changes may be taken to include effects on water quality, wildlife, fish habitat, and other public resources.

Although it is desirable to consider watersheds as a whole in regulations of forest practices, there are practical and conceptual difficulties in doing so. These arise from several sources:

1. Watershed ecosystems involve a complex dynamic between many watershed and biological processes operating at many spatial scales. Scientific understanding of these processes is limited, and comprehensive reliable techniques for evaluating watersheds are lacking.

2. The physical and biological characteristics of a watershed and sub-areas within it reflect the local geology, terrain, climate, vegetation and so on. Consequently, every watershed is unique, with its own distribution of these factors as well as effects due to the history of past disturbance including natural events or land use.

3. Because of these differences in landscape features, the sensitivity of watersheds and sub-areas within them to forest practices also varies from place to place. While one location may generate no likelihood of local or cumulative effects from an activity, the same activity conducted in the same way in another location with heightened sensitivity could have both local and cumulative impacts.

For all of these reasons, there appears to be no simple method that can be uniformly applied to watersheds throughout the state to reliably guide management activities at the basin scale to prevent cumulative effects. When evaluating forest activities one-by-one, it is difficult to adequately weigh all the possible effects of an activity for the entire watershed. Even though local site conditions are taken into account when conditioning forest practices applications for a site, the "one-size-fits-all" approach of forest rules based on "best management practices" that formed the basis for the forest practice regulatory process is not well suited to tailoring practices to local basin-wide situations as needed.

1.2 Recent History of Cumulative Effects Leading To A Policy Framework

In recent years, efforts have been initiated to review regulations to ensure more systematic treatment of cumulative effects.

The Timber/Fish/Wildlife (TFW) Agreement concluded in February of 1987, contained the following summary of a recommended approach to cumulative effects:

1. **State, regional, and basin goal-setting.** Goals and objectives should be developed that reflect local conditions and resource sensitivities. Participants should include TFW cooperators, such as tribes, landowners, and environmental groups.

2. **Use of risk assessment techniques for problem identification.** Methods and techniques should support the setting of goals and objectives. They should anticipate or predict future problems as well as define existing ones.

3. **Implementation of an adaptive management process** in which assessment tools, management and regulation are revised based upon experience and the feedback from monitoring.

4. **Monitoring and evaluation to determine if goals are being met.** Monitoring programs should be developed that are tailored to regional and local landscape variability.

5. **Reevaluation of goals as new information becomes available.**

In 1989, the TFW Policy Group approved a cumulative effects issue paper that recommended development of a system which would focus on individual basins. Problems assessment would address spatial and temporal issues, with efforts to define impact thresholds and recovery rates for affected resources.

The report went on to reinforce the role of the Cooperative Monitoring Evaluation and Research (CMER) Committee in providing the tools needed for addressing cumulative effects. CMER is composed of resource scientists with a number of technical disciplines who represent agencies, landowners, tribes and environmental groups. Their responsibility is to guide the development and application of TFW-sponsored research to improve forest management. In response to the specific recommendations from the policy group, CMER began working on a method that would provide a science-based approach for assessing watershed problems and sensitivities to be used as a basis for developing appropriate prescriptions.

The Sustainable Forestry Roundtable, which met periodically from 1989 through most of 1990, built the concepts on which CMER was working into the proposals that it considered. Even though the negotiations resulted in neither an agreement nor legislation, they did form an important point of reference for later consideration.

In 1991, proposed changes in the state forest practices rules drew upon these efforts, calling for the Department of Natural Resources (DNR) to continue work with CMER in developing a method for use in conditioning proposed forest practices for cumulative effects. The result of the work involving scientists and policy-makers was a recommendation that the Forest Practices Board adopt a process for developing a watershed forest practices plan tailored to each watershed based on scientific understanding. They termed the process "watershed analysis". The method defines areas of sensitivity within each watershed with explicit consideration of resource vulnerabilities based on the potential for specific impacts to public resources. This method was adopted by the Forest Practices Board into regulation in 1992 (chapter 222-22 WAC). (The Forest Practices Board decided not to include wildlife in the current watershed analysis rules.) Watershed analysis is a principle but not an exclusive section of the forest practice rules that addresses cumulative watershed effects.

As part of the watershed analysis rule, the state has been divided into approximately 800 watersheds ranging in size of approximately 10,000 to 50,000 acres. These watersheds are termed Watershed Administrative Units (WAUs). Their boundaries can be found on the DNR Watershed Administrative Unit Map.

1.3 The Washington Approach to Forest Watershed Management - Watershed Analysis

Watershed analysis is a structured approach to developing a forest practices plan for a WAU based on a biological and physical inventory. It is a collaborative process involving resource scientists and managers representing landowners, agencies, tribes and other interested public. Once initiated, the team conducts the assessment within a specific time-frame. (See figure I-1). The forest practices rules provide a policy structure to the process by encoding the steps, operating rules, key linkages and decision requirements for the team. This manual guides the specific technical steps of the process in support of the policy laid out in the rule. The application of the process is expected to evolve as scientific knowledge and experience with the process grows, and those improvements will be included in future versions of the Watershed Analysis Manual. The watershed analysis process can best be viewed as a work in progress.

Components of Watershed Analysis

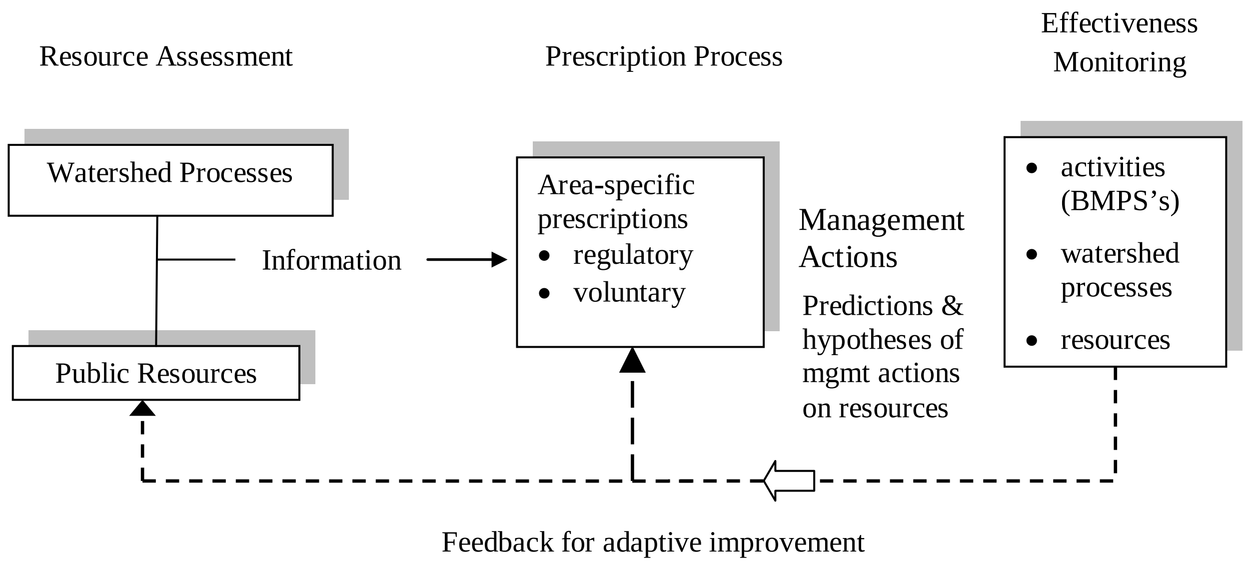


Figure I-1 The Major Components of Watershed Analysis

In watershed analysis, the scientists first develop information and interpretations of resource conditions and sensitivities at a watershed scale guided by a series of key questions. These findings include maps locating sensitive areas (which may include all or parts of the watershed) and reports describing the nature of the sensitivity and its risk to public resources supported with facts and data generated by the team. These then feed into a prescription process where local land managers and agencies develop a tailored management plan for the watershed that responds to the resource concerns identified by scientific investigation. Provisions are made for the public review of the findings of the watershed study and management prescriptions before final acceptance of the plan. Total time to completion is two to five months depending on the size and complexity of the watershed and the chosen level of assessment.

Once the watershed plan is developed, further forestry activities in the watershed must be conducted within the provisions of the watershed analysis prescriptions for each sensitive area, unless an alternative plan is approved, with compliance regulated by the DNR. Products of the watershed analysis are assumed to be valid for a period of five years, at which time the process may be repeated if necessary.

The watershed plan is designed to be adaptive. Provisions are included for design of an optional monitoring plan to be implemented by landowners, agencies, tribes, and others interested in the watershed to track the effectiveness of the prescriptions and the assessments on which they were based. Monitoring is designed to provide feedback on where resources were actually protected or improving as a result of prescriptions.

By encoding into regulations a science-based assessment process rather than a one-size-fits-all set of "Best Management Practices (BMPs)", the watershed analysis process represents a departure from conventional approaches to forest land regulation. The new system not only requires local scientific assessments but relies upon diligent revision as monitoring provides feedback on whether resources are improving or degrading. It also relies on stakeholders within each watershed to make it work.

Some of the important features of the watershed analysis process for regulating forest practices on state and private lands include:

- A recognition that watersheds are different and effects of forest practices are not uniform. Therefore, watershed information is required as part of the process for generating watershed prescriptions.
- Watershed activities are prescribed based on information generated by qualified scientists defining the watershed conditions.
- The plan containing a comprehensive set of prescriptions designed with respect to the landscape is constructed by qualified managers with provisions encouraging all stakeholders to participate in the process.
- The managers and scientists work together on the geography to conduct a watershed analysis.

1.4 Overview of the Scientific Framework and Assumptions

A basic premise of the watershed analysis is that a change in erosion, hydrology, or riparian function resulting from forest practices is significant when it is sufficient to cause an adverse change in a public resource of fish habitat, water quality, or public works. To adequately relate changes in watershed processes (sources or "causes") to effects on public resources they must be linked. Hillslope processes are linked to stream-related resources by the flow of geomorphic products of sediment, water, wood, and energy that shape and determine the stream environment. This linkage is depicted in Figure I-2.

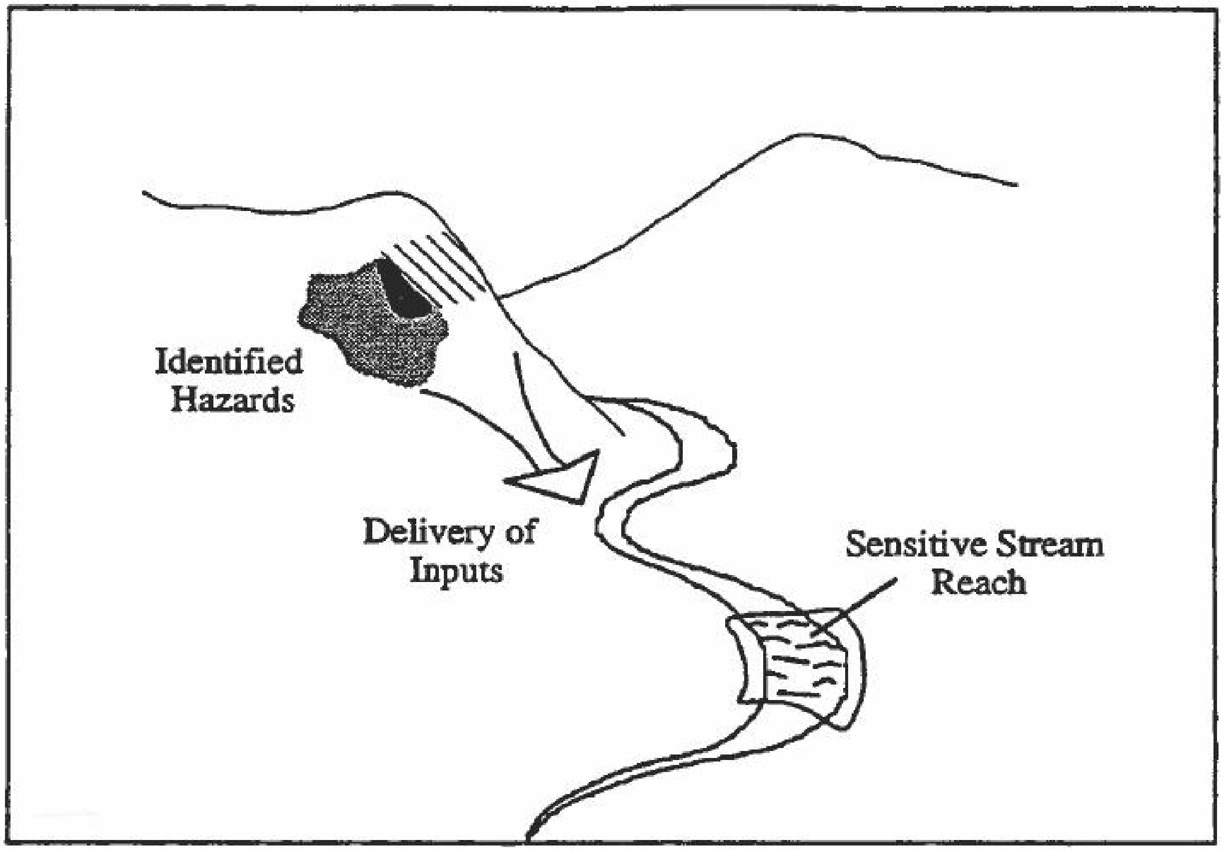


Figure I-2. Watershed analysis perspective of the spatial relationship between hillslope activities and stream effects through changes in input factors of sediment, water, wood or energy.

Forest practices may affect the amount of geomorphic products produced and delivered to streams in an area (i.e., increased erosion, changes in water available for runoff, altering wood loading to streams, or changing the temperature of water by removing shade). The mechanisms determining the effect of forest practices on the rate of input of geomorphic inputs are relatively well understood and approaches for assessing them are straightforward. Since each watershed possesses distinct environmental conditions, resource characteristics, and sensitivities, watershed analysis assessment is premised on the need to define locally active watershed processes that pose a significant risk to public resources. Each of these general processes includes more specific processes, and those addressed explicitly in the current version of watershed analysis are shown in Figure I-3.

Changes in geomorphic inputs, if large enough, may express themselves in stream channels in measurable ways. In turn, these changes in the physical characteristics of streams as they respond to sediment, water, wood and energy may have impacts on the biologic communities inhabiting them or public works located on or near them. Streams and associated resources such as fish habitat may be affected by changes in peak flows and timing of discharge. Higher sediment loading, arising from erosion and mass wasting, may cause pool filling or gravel siltation which may reduce the productive potential of a stream or stream segment. Reductions in large organic debris (LOD) recruited to channels may result in fewer pools and unstable stream beds. Other cumulative watershed effects include changes in stream temperature, nutrient levels and turbidity.

Although mechanisms for response are reasonably well understood, methods for correlating the extent of response of channels and biologic communities to changes in geomorphic factors are not well developed. For determination of impact potential or risk, a link must be made between the resource and a mechanism that can affect it. The procedure provides for this by defining resource vulnerability in terms of a specific susceptibility to change in flows of wood, water, energy, and sediment and the susceptibility is related to the manner in which resource functions respond to changes in physical conditions.

While individual models exist for assessing specific processes, no "off-the shelf" method is available that comprehensively links hillslope processes to resource impacts at a watershed scale. This reflects the inherent complexity of the many processes at work in the forest landscape as well as the immaturity of several of the scientific disciplines. Because of these deficiencies, individual methods and models must be linked in less comprehensive, less quantitative fashion.

Processes, Variables, and Resources Addressed in Watershed Analysis

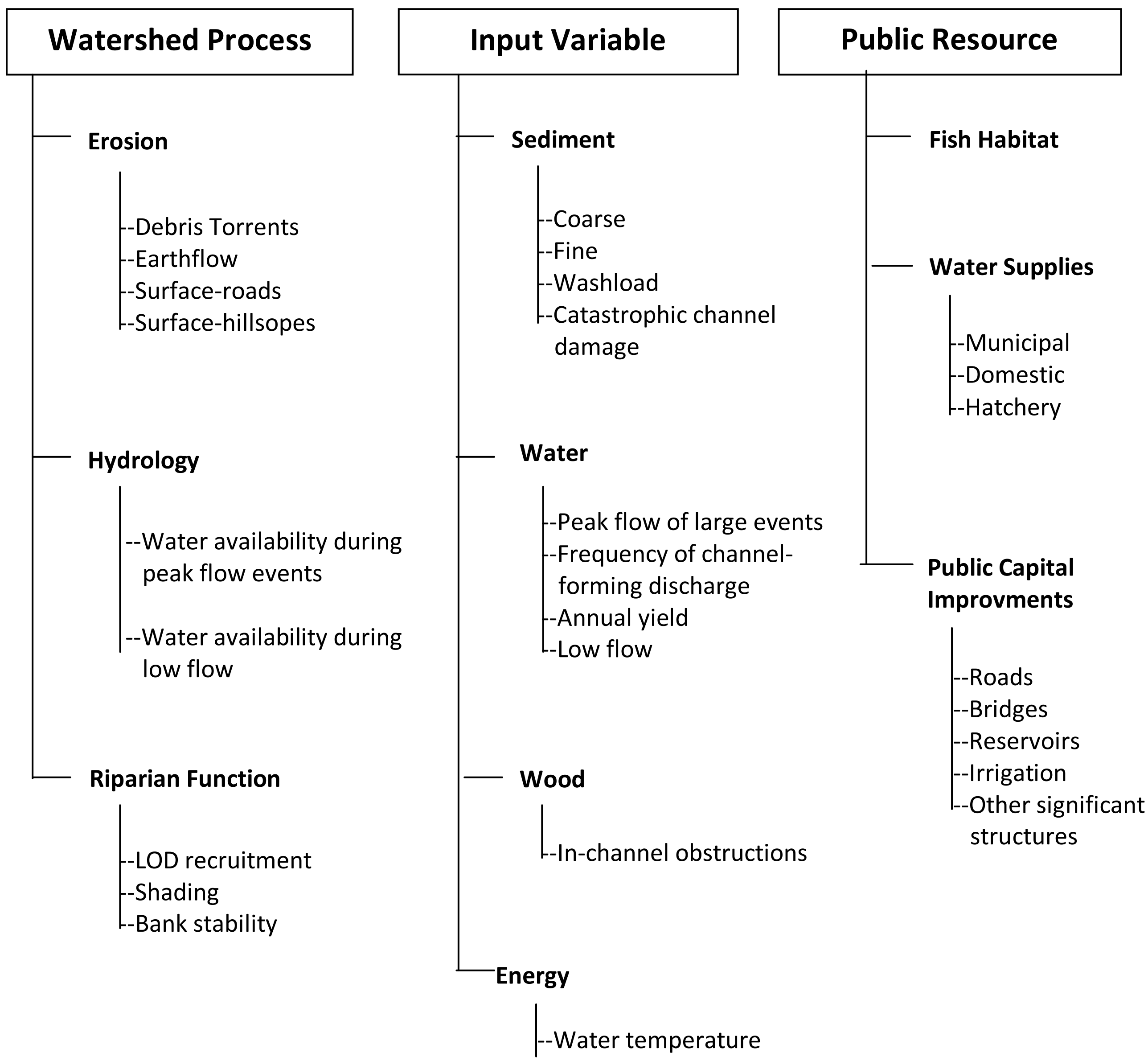
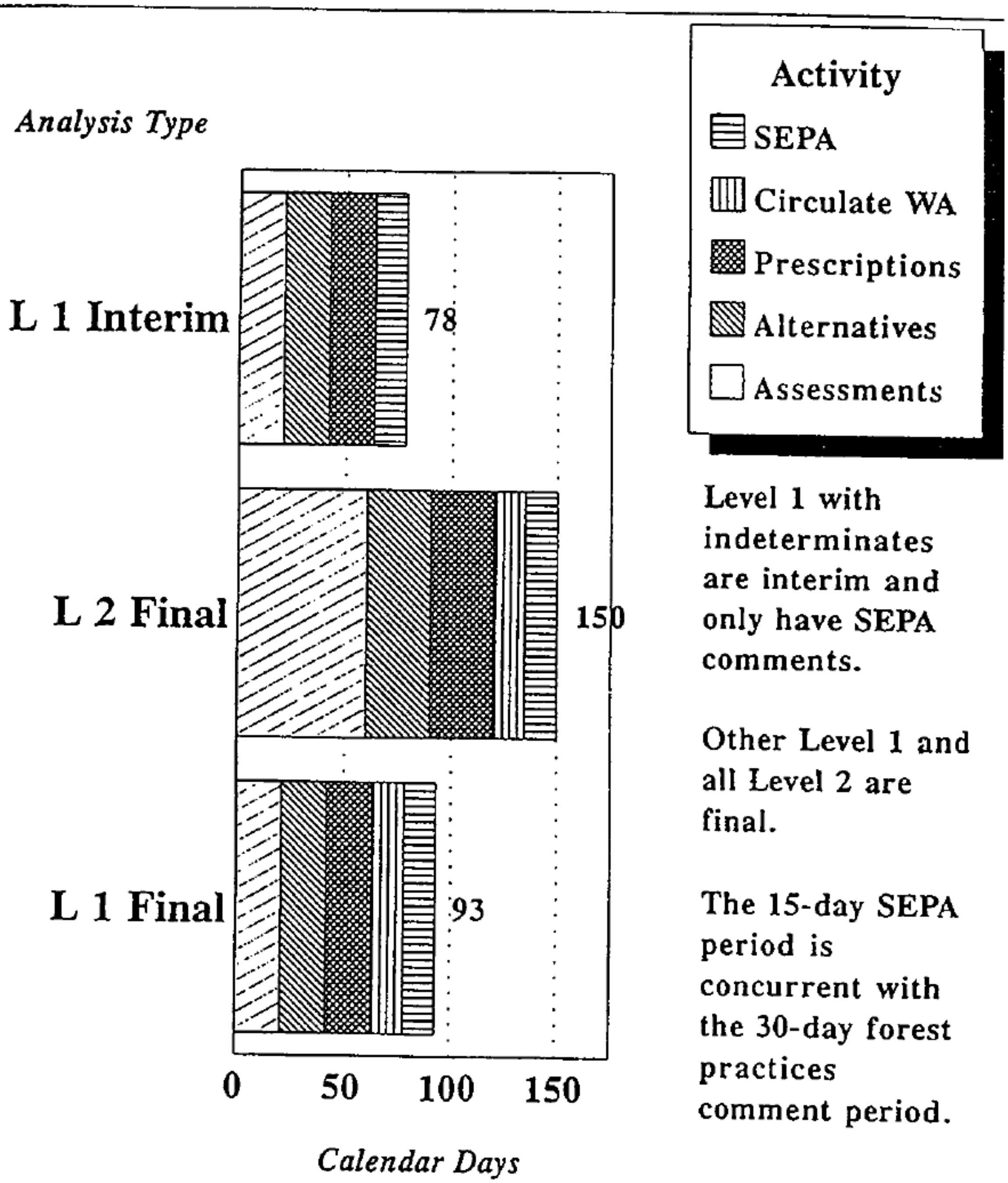


Figure I-3. Processes, Variables and Resources Addressed in Watershed Analysis

Maximum Projected Time by Activity



Level 1 with indeterminates are interim and only have SEPA comments.

Other Level 1 and all Level 2 are final.

The 15-day SEPA period is concurrent with the 30-day forest practices comment period.

Additional time required to assemble data and evaluate SEPA comments.

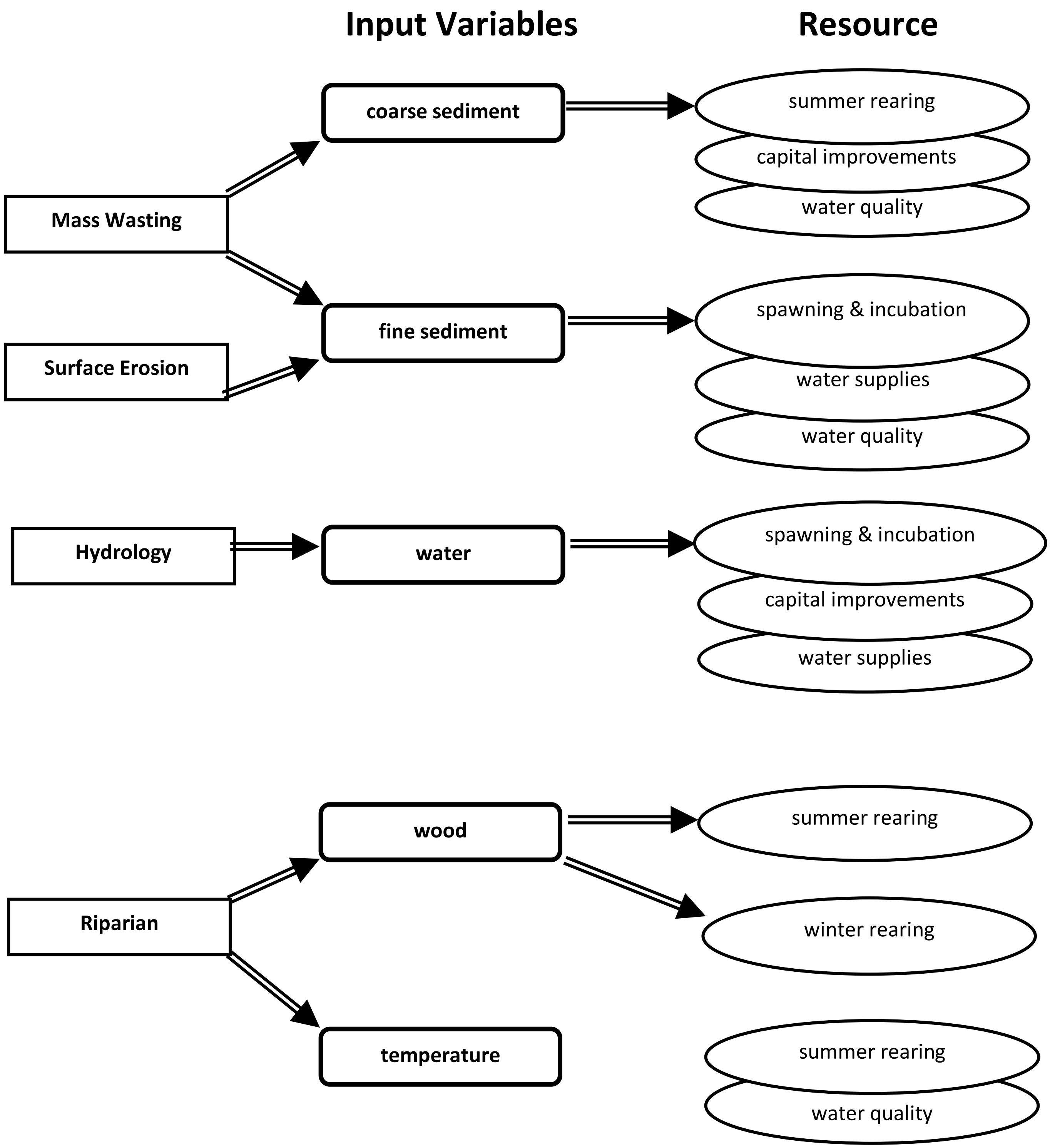


Figure I-4. Relationships among watershed processes, input variables, and effects on public resources.

1.5 Overview of the Operational Approach to Watershed Analysis

Cumulative effects may occur in two ways. Cumulative effects may result from the accumulation of the small effects of many forest practices that are insignificant at any one site, including practices conducted over time or space. This mechanism of cumulative effects may be most relevant for hydrologic changes and for some aspects of erosion from forest roads and stream-side buffers. Cumulative effects may also result from changes in dominant watershed processes, even when activities triggering effects are limited in spatial extent. This mechanism is operative in "sensitive areas" where watershed processes are particularly susceptible to change based on the local conditions. Cumulative effects are most likely for sensitive areas dominated by mass wasting, hillslope surface erosion, and some aspects of forest roads and streamside riparian zones.

A fundamental assumption of watershed analysis is that by applying standard forest practices in less sensitive areas and managing sensitive areas appropriately, the overall watershed condition will be protected and cumulative effects will not occur. The mission of the scientific assessment is to identify sensitive areas, which may include the entire watershed or sub-areas within it. (An area may be sensitive to a type or a rate of activity, and both are examined in watershed analysis.) Resource specialists gather information and interpret watershed processes and conditions. This information is used to identify resource sensitivities that require special management prescriptions to solve potential or existing problems not normally handled by standard forest practices. An assumption of watershed analysis is that resource sensitivities can be identified by qualified individuals at a scale appropriate for developing a sound watershed plan.

Once sensitivities are identified the field managers team develops prescriptions for the area with the justification that they are likely to solve the identified problem. An assumption of watershed analysis is that management plans should be developed by those with the skills and experience to conduct forest management activities. In addition, those with the responsibility to implement prescriptions should be involved in their development. It is a fundamental philosophy of the process that the best solutions will result when the scientists that develop the information for a geography work collaboratively with the resource managers responsible for developing and implementing the plan for the area.

1.6 Overview of the Watershed Analysis Team Process

Once a watershed analysis is started, the team process progresses through a series of steps beginning with resource assessment, followed by prescription writing, and concluding with wrap-up steps that assure a handoff of responsibilities for monitoring and voluntary activities to stakeholders in the watershed. This manual provides instructions and guidelines on how to perform each step of watershed analysis.

Startup

Watershed analysis is initiated with startup. In this step, the maps, photographs and data are collected. The various teams are formed, responsibilities are defined, and notifications are distributed. The resource assessment team also develops a plan for performing the required evaluations of the watershed.

Resource Assessment

The resource assessment takes an interdisciplinary team approach that requires inventories of watershed processes and resources following a structured approach to problem definition that is framed by a series of critical questions. Team members possessing skills in forestry, forest hydrology, fisheries, forest soils science or geology, and geomorphology locate and map sensitive areas, evaluate potential impacts of delivery, and assess the potential or existing impacts on resources. The inventories and subsequent interpretations provide a basis for area-specific problem statements and rule calls linking forest practices, watershed processes, and resource effects.

Prescription Process

Based on the findings of the resource assessment, a field managers team made up of managers and analysts determines the required and voluntary forest practices for each identified area of resource assessment. Managers and resource specialists visit the sensitive areas and identify one or more practices or strategies for each that are likely to prevent, avoid, or minimize problems. Problems associated with non-forest activities are referred to the appropriate agency. Prescriptions are included in the watershed analysis report. The report is provided to the Department of Natural Resources, which manages the public review.

Wrap-up

Once the watershed analysis report is complete, the watershed analysis team may perform one last task - develop a plan to measure the effectiveness of the prescriptions. The group identifies appropriate monitoring variables and protocols to test the effectiveness of the plan using the information gathered in the assessments as a basis. These will depend on (1) the findings of the watershed analysis, (2) the variables most useful for determining whether long-term resource goals are met, and (3) the financial and personnel resources available. Two steps are useful: a prognosis step, in which the team hypothesizes their expectation of likely future conditions, given management prescriptions; and a monitoring selection step, in which specific characteristics are selected for tracking whether those expectations are met. These are passed on to stakeholders in the watershed for implementation.

1.7 Watershed Analysis Products

The watershed analysis team produces a number of products during the assessment. The resource specialists produce:

- Resource condition reports describing watershed conditions;
- Maps of sensitive areas requiring prescriptions;
- Causal Mechanism reports describing the sensitive area and the nature of potential problems; and
- Rule calls based on resource vulnerability that determine standards of performance for the rule call.

The field managers produce:

- Prescriptions with justification for each mapped sensitive unit.

The entire team produces the final watershed report and may develop a monitoring proposal for the watershed to be handed off to stakeholders in the watershed.

Part 2 Process Overview

2.1 Introduction

This manual is designed to provide a step-by-step approach for performing watershed analysis. The manual includes steps which are required, as well as suggestions that may improve the watershed analysis process. It leads the members of the team through the steps to create the resource assessment for a watershed, define problems and sensitivities, produce management prescriptions, and monitor effectiveness. Individuals leading and/or participating in a watershed analysis should be familiar with the appropriate rules and regulations (chapter 222-22 WAC) in addition to the information contained in this manual.

The process includes assessments of current and potential watershed and resource conditions by resource specialists. Assessments identify existing and potential hazards and their relationship to resource vulnerabilities. Subsequently, the field managers team develops prescriptions based on information generated in the resource assessment. (Figure 1 indicates the general steps involved in the watershed analysis process, and Table 1 provides an overview of the specific steps.)

2.2 Start-up

Watershed analysis begins with start-up. Whether the watershed analysis is initiated by the DNR or by a private landowner, identification of all landowners in the WAU is a key starting point. The maps, photographs and available data are collected, the working teams are formed, responsibilities are defined, and required notifications are distributed. The resource assessment team then develops a plan for performing the required evaluations of the watershed.

Prior to actual start-up, it can be useful to call an initial "scoping" meeting for landowners and other interested parties so that they may understand what watershed analysis entails and the team may determine the landowner's abilities to participate and provide helpful input.

Resource Assessment

Once underway, the scientific team follows a two-phase process for performing resource assessment. In the inventory phase, data is gathered and interpreted for individual watershed processes and resources, with analysts working relatively independently from one another. In the synthesis stage, the analysts work together to develop a watershed scale perspective of cause and effect linkages between hillslope and stream processes. They identify resource sensitivity areas requiring additional prescriptions reported in the causal mechanism report.

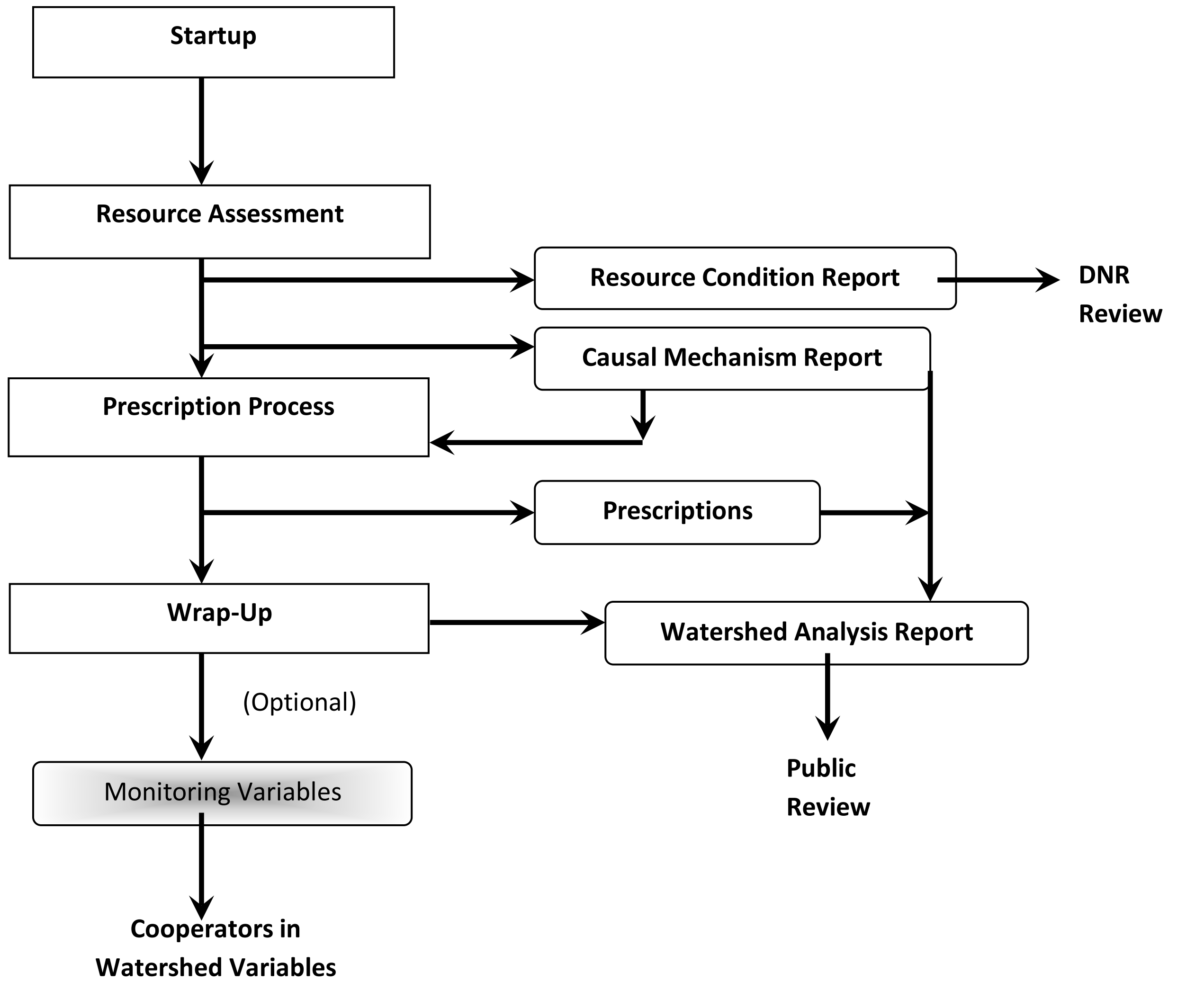


Figure 1. Watershed Analysis Team Process Steps

2.3 Prescription Process

Based on the findings of the resource assessment compiled in the causal mechanism report, a field managers team made up of managers and analysts determines the required or voluntary forest practices for each identified area of resource sensitivity. For each area, the team should prescribe one or more practices or strategies that are likely to avoid, prevent, or minimize problems. When necessary, managers and resource specialists should visit the sensitive areas. Voluntary enhancement opportunities can be noted at this point. Problems associated with non-forest practice related activities are referred through the DNR to the appropriate agency. Prescriptions are reviewed with the resource assessment team to assure that the correct resource sensitivities are addressed and are included in the watershed analysis report.

2.4 Final Steps

Report

Watershed analysis for the WAU is completed when the team produces the watershed analysis report. Prescriptions are attached to each resource sensitivity identified in the causal mechanism report. The proposed monitoring plan is also attached.

Review

The team leader must also complete the environmental checklist, as required under the State Environmental Policy Act (SEPA).

The full report and checklist is forwarded to the responsible official (DNR Resource Protection and Service Assistant Regional Manager) for Threshold Determination.

The DNR will coordinate review as specified in WAC 222-22-080.

Wrap-up

Once the watershed analysis is completed, the entire watershed analysis team may perform one last task. The group may select appropriate monitoring variables and protocols to measure the effectiveness of the prescriptions and resource response. These will depend on (1) the findings of the watershed analysis, (2) the variables that are likely to be most useful for determining whether long-term resource goals are met, and (3) the financial and personnel resources available. Two steps are useful: a prognosis step, in which the team hypothesizes their expectation of likely future conditions, given management prescriptions; and a monitoring selection step, in which specific characteristics are selected for tracking whether those expectations are met.

Forms and Worksheets

Various data forms and worksheets are provided in the manual to assist the assessment team and field managers team. Use of these forms is encouraged in that they provide some tracking and accountability to the data gathering and interpretation. It is expected that these forms can be used in place of lengthy written documents, encouraging the team to spend time writing only where judgment or deviations from methods are used and brief narratives are useful. The use of forms and worksheets will need to be flexible, especially for Level 2. Analysts may be using different methods than those for which the forms were designed.

It is recommended that some narrative be included in the final report for the benefit of land managers and others who become involved with the watershed several years after the original analysis is completed.

Table 1. Overview of the Specific Steps of Watershed Analysis.

1. Startup

   Identify leader(s). An overall project manager is recommended in addition to the required team leaders.

   - Identify and notify landowners in the WAU.
   - Notify affected Indian tribes, county and city governments in the WAU, and the public (prior to starting the analysis).
   - Hold a "scoping" meeting, if desired.
   - Appoint qualified individuals to perform assessments and fill team roles.
   - Notify DNR of intent to start watershed analysis (as set forth in WAC 222-22-040(3)); the analysis may begin within thirty (30) days after this notification is received by the DNR.
   - Gather starting information (maps, aerial photographs, management history).
   - Schedule first meeting.
     - Develop team schedule and responsibility list.
     - Develop plan for common sampling and coordination of fieldwork.

2. Resource Assessment
   - Qualified analysts (Level 1) or specialists (Level 2) implement inventory modules of resource assessment.
   - Team meets (preferably with field managers present) to perform synthesis of watershed information gathered in inventory.
   - Team completes causal mechanism report for identified watershed sensitivities and resource condition reports describing watershed conditions.
   - Team makes recommendations on indeterminates and the need for Level 2 if appropriate.
   - Schedule hand-off of resource assessment to field managers.
   - Schedule Level 2 if necessary (can occur immediately or at a later time).
   - Circulate the products (including supplying copies to the DNR region when the assessment is completed).

- If no consensus see WAC 222-22-050(3), -060(4).

3. Prescription Process
   - Convene field managers team (managers, engineers, and analysts as needed).
   - Develop prescriptions for each identified resource sensitivity.
   - Attach prescriptions to causal mechanism report.
   - Review with the assessment team (recommended).
   - Complete compilation of watershed analysis report.
   - Complete the environment (SEPA) checklist.
   - Forward the report to the responsible official (DNR Resource Protection and Service Assistant Regional Manager).

4. Wrap-up
   - Reconvene resource analysts and managers.
   - Develop prognosis for watershed considering current conditions and hypothesized condition given management prescriptions.
   - May recommend monitoring program considering useful measures and financial resources.
   - Pass on to watershed stakeholders.

Part 3 Start-up

3.1 Overview

Start-up of the watershed analysis team involves administrative functions of notification of other landowners, the DNR, other state agencies, local governments, Indian tribes, and the public; identification of the assessment and field manager teams; and assembly of the maps, aerial photographs, and management history required by the resource assessment team. Whether conducted by a landowner-sponsored team or the DNR, the efficiency of watershed analysis is affected by the openness of the process, landowner support and involvement, availability of local knowledge, team composition and function, GIS capabilities and prior assembly of required information.

It is recommended that a scoping meeting be held with other landowners in the watershed analysis unit and affected agency and tribal representatives prior to official startup. The intent of this meeting is to explain the process and outcome of watershed analysis and solicit their participation, if appropriate.

This is also the time to hold the first meeting with the teams, preferably both resource assessment and field managers. Prior to this first team meeting, team leaders should ensure that their team has an approved WAU base map with the updated WAU boundary, and all maps and aerial photos they will need. At this first meeting, the team should develop a schedule and recognize the importance of staying on that schedule.

3.2 Watershed Analysis Initiation

A watershed analysis for a WAU is initiated either by landowners whose lands comprise 10% or more of the watershed or by the DNR according to its priority based on the DNR watershed screening. The WAU boundaries are determined by DNR and are available in digital form. These boundaries were pre-delineated at 1:100,000 scale. Prior to official start-up, the WAU boundary needs updating to 1:24,000 scale and approval from DNR. Updates to this larger scale may be provided by either landowners or DNR. These boundary corrections require approval from DNR Forest Practices prior to further data acquisition.

Landowners may initiate either a Level 1 or Level 2 assessment and are responsible for arranging for the appropriate analysts or specialists and field managers required to complete the process. A list of qualified analysts and specialists is available from the DNR, Forest Practices Division, (360) 902-1400. Qualification requires that an individual have appropriate skills, experience and education and has completed the DNR training in watershed analysis. (A Level 1 team has 21 calendar days to complete the assessment while a Level 2 team has 60 calendar days.)

Retraining is advisable if substantial revisions are made to the watershed analysis manual.

Team Roles and Expertise
There are a variety of functions that must be performed for a team to successfully and efficiently accomplish watershed analysis. These include administrative, scientific, management decision-making, and support functions.

The success of the team may be determined by the energy and skills of the team leader.

The project manager's job is to complete the watershed analysis. The project manager acts as a facilitator between the assessment team and the field managers team and keeps the entire process on the time track that has been established.

Weekly status reports from the module leaders to the team leader may be an effective way of keeping track of their progress. It is recommended that the team leader not assume the role of a module leader.

Observers may be allowed in the watershed analysis process. Their presence is up to the initiator of the watershed analysis. If they are allowed, their roles should be clearly defined during the start-up procedure.

Project Manager
- Notifies landowners and requests start-up information, including official basemap;
- Appoints qualified members to the team (forest landowners conducting watershed analyses are encouraged to include available, qualified expertise from state and federal agencies, affected Indian tribes, other landowners, local government entities, and the public.) Early notification will facilitate securing qualified personnel;
- Notifies DNR that a watershed analysis is to be performed;
- Obtains list of landowners and other interested/affected parties in the WAU, sends letter of notification, and requests start-up information.
- Sets up contacts with local expertise and requests other additional information;
- Monitors timelines for notification/products; coordinates meetings; and
- Completes environmental (SEPA) checklist.

Assessment Team Leader
- Schedules first team meeting; and
- Oversees team performance and ensures quality of completed product.

Resource Assessment Analysts and Specialists

- Implement the inventory modules (see Resource Assessment section of this manual):
  - Mass Wasting
  - Surface Erosion
  - Hydrology
  - Riparian Function
  - Fish Habitat
  - Water Quality
  - Public Capital Improvements
- Conduct watershed synthesis identifying resource sensitivities and rule calls described in the causal mechanism report.

Field Managers Team

- Produce prescriptions for areas of resource sensitivity; team may include members with expertise in the following disciplines:
  - Forestry
  - Forest Engineering
  - Fisheries
  - Forest Hydrology and/or Water Quality

Data Technician (Optional, *Recommended*)

- Produces or acquires official basemap, assists with compiling other maps and photographs for start-up.
- Acquires digital datasets from the DNR of other GIS compatible sources.
- Assimilates 'canned' computer programming for use in map and report generation.
- Provides special GIS/Cartographic products and analysis in support of management decision-making, time management, and prescription writing.
- Compiles digital data for ARS's (Areas of Resource Sensitivity).
- Helps produce the watershed analysis report.

Landowners

- Participate in watershed analysis process through qualified representation on resource assessment and/or field managers teams;
- Facilitate assessment process by providing information and materials;
- Ensure access to area; and
- May submit prescriptions to field managers team.

Tribal Representative

- Participate in watershed analysis process through qualified representation on resource assessment and/or field managers teams;
- Facilitate assessment process by providing information and materials; and

- Can cooperatively implement watershed analysis with the department depending on tribal resources.

Observers (Optional)

- Observe watershed analysis process and/or may perform field work under supervision of qualified analysts or specialists.
- Additional participation is at the option of the project manager.

Start-up Materials

Timelines for completion of Level 1 and Level 2 watershed analysis are set forth in the rule (WAC 222-22-070, -080). The availability and quality of materials and data at the start of the analysis are keys to meeting required timelines. A common set of maps and aerial photographs is needed by all of the resource assessment modules and must be gathered by the team or project leader prior to the team's first start-up meeting. If this is done, the team will be able to begin field assessment immediately and will be more likely to meet the time requirement for producing a causal mechanism report. Table 2 lists the information, maps, and aerial photographs that should be produced prior to assembling the assessment team. The notification letter should request landowners to provide the key management information specified in the table. If possible, the information from all landowners should be consolidated onto the official basemap.

Table 2. Startup Materials for Each WAU

What	Detail to be included	Where obtained
Official DNR Base Map 1:24,000 scale 1:2,000 ft.)	• Official base map with township and ranges • WAU study area boundary • All streams and surface water typed according to the DNR water type map	• Forest Practices Division, Department of Natural Resources (Olympia)
Topographic Map	• USGS 7.5 minute topographic maps (or better) **Note:** Digitized elevation data from the USGS is usually of insufficient resolution.	• USGS or • DNR Photo and Map Sales • Local vendors
Vegetation Age Maps	• Forest stand age map in 10-year increments • Hydrologic maturity map	• Landowners • DNR GIS Group
Road Map	• Complete road map color coded according to the attached table	• Landowners
Soil Erosion Map	• Soil erosion potential map for the WAU	• DNR maps and cartography
Aerial Photographs	• All available photography, with a special emphasis on the (1) oldest and (2) most current photo sets **Note:** Flight lines for all photo series should be clearly keyed to location in the study area.	• Landowners or • DNR Photo and Map Sales
Management Activities	• Logging history by logging type (with general areas of tractor, highlead, or railroad logging noted) • Areas of INTENSE burns (natural or prescribed) • Known locations of splash-damming • Known locations of stream cleaning	• Landowners • Landowners • Landowners or anecdotal information • Landowners or Dept. of Fish & Wildlife personnel
Other	• Fish distribution questionnaires • Local expertise familiar with the watershed	• Local agency representatives for Dept. of Fish & Wildlife and • Tribal representative • Leader and team's familiarity

GIS Support
Although all of the resource assessment methods are designed to be performed with standard maps and photography, these assessments are facilitated by accessing information through a Geographic Information System (GIS). The GIS database can greatly ease the time and effort in capturing and mapping information. The DNR GIS has most, if not all, of the information requested in Table 2.

For watershed analyses conducted by parties other than the DNR, the initiating parties are solely responsible for obtaining the GIS start-up kit from the DNR Forest Practices Division. Indicate types of software and media to be used in the analysis.

Specific information for the GIS team members:

Provide each resource analyst with:
- Copies of team base map
- Copy of specific module base map
- Mylar overlays with new WAU boundary at 1:24,000 scale, USGS 7.5' corner tics, quad boundaries, township and range boundaries, map # and label (i.e., C-1 Hydrology base map) standard map legend for each module

Information on GIS products and official WAU boundaries may be obtained from the Forest Practices Division at (360) 902-1400.

3.3 Level of Assessment

Resource assessment can begin at either Level 1 or 2. It may have only Level 1 or Level 2 assessment or a combination of both. Level 1 is a reconnaissance assessment, relying predominantly on maps and remotely sensed information with some field checking. The assessment is designed to take one to two week's effort by the team. Level 2 may be similar but results in a more detailed assessment of the overall watershed, or it may be focused on specific resource issues identified by Level 1. More experience and education is required for Level 2 specialists and more time may be needed to perform a Level 2 analysis.

Begin at Level 1:
If the assessment begins at Level 1, then the analysts complete the assessment as specified in this manual and determine the resource sensitivities and the rule calls. If the Level 1 assessment contains any areas in which the delivered hazard or resource vulnerability are identified as indeterminate, or if the Level 1 methodology recommends it, then a Level 2 team may be assembled. The uncertainties can only be resolved by a Level 2 team.

Begin at Level 2:
If resource assessment begins at Level 2, then the specialist must complete the standard products required of Level 1, except that the Level 2 team shall not have any indeterminates in the calls. Level 2 products may vary somewhat in detail or substance from Level 1 products.

Level 1 followed by Level 2:
If the Level 1 assessment results in any indeterminate ratings, then Level 2 analysis may be assembled for the primary task of resolving the uncertainties. The Level 2 specialists have flexibility in methods which allows the team to develop and test hypotheses, responding to the findings of the Level 1 assessment. The manual allows the specialists to exercise judgment in selecting methods to answer the critical questions and asks for justification of their use. The Level 2 team in this situation may not have the full complement of resource analysts to perform each method.

Level 1 followed by Level 2 for review:
A Level 2 team may be convened to review all or part of the Level 1 assessment. The team may revise the ratings as appropriate.

3.4 Specific Start-up Steps

Before actually beginning a watershed analysis, interested parties should consider updating stream types for the WAU. Stream types should generally **not** be updated **during** analysis because parts of the analysis depend on the stream type. Prescriptions often hinge on stream type, so it is advantageous to all concerned to have a good idea of correct stream types **prior to analysis**.

Identify leader(s).
A representative of the DNR or private landowner initiating the watershed analysis must be identified as project manager or the team leader (although the task can be reassigned after the team has been convened). This person is responsible for conducting the initial steps before the full team is convened.

Identify landowners in the WAU.
If there are few landowners in the WAU, the team leader/initiating landowner, or local DNR forester may be sufficiently familiar with them to compile the appropriate list.

If there is uncertainty of ownership, the county tax assessor may be a good source for this information. If the assessor's forest tax information base is computerized, it may be queried according to township/ranges to yield an ownership list.

Notify landowners in the WAU and request information/participation.
A reasonable attempt will be made to notify landowners in the WAU. The project manager should send out a letter to the landowners with the purpose of (1) notifying them that a watershed analysis is to be conducted, (2) inviting them to participate or observe, (3) requesting the information listed in Table 2, and (4) defining the official starting date and contact person.

Provisions should be made for the team to obtain access to all lands within the WAU.

Notify DNR in writing of intent to start a watershed analysis (as set forth in WAC 222-22-040(3)).

Send out the fisheries and capital improvements questionnaire.
A list of state and tribal representatives is available for each WAU from DNR regional offices.

Gather starting information (maps, aerial photographs, management history).
Start-up materials specified in Table 2 should be assembled. If maps or aerial photographs or GIS data are to be obtained from the DNR, an order should be placed several weeks prior to assembling the team. The team leader is ultimately responsible for securing all information and for adherence to mapping and data standards.

The official DNR base map WAU boundary is the boundary for the watershed analysis. This map can be obtained by acquiring the start-up ARC/INFO macro package from the DNR Forest Practices Division. It is important that standards established within these macros be maintained since the data sets prepared by watershed analysis will be entered into the DNR GIS and used to track ARS's and related prescriptions.

Be certain you are using the official WAU boundary by contacting DNR Forest Practices Division in Olympia at (360) 902-1400. Use of an incorrect boundary may result in delays in completion and approval of the analysis.

Official start-up GIS macros (ARC/INFO) generating products at 1:24,000 and 8.5 x 11 includes:

- Team base maps aml
- Hydro module aml
- Contour aml
- Landsat aml
- Soil erosion module aml
- and related reports

Official Start-up data sets (ARC/INFO export format) include: WAU boundary (1:24,000 scale)

- ___ Hydro
- ___ Trans
- ___ Soils
- ___ POCA
- ___ Canopy
- ___ Annual precipitation
- ___ Storm 2, 5, 10, 25, 50, 100
- ___ Precipitation Zones
- ___ Slope morphology
- ___ Stream temperature
- ___ 303d (Department of Ecology)
- ___ FPWET
- ___ LAT75 (DEM's)

- Topographic maps - USGS 7.5'
- Aerial photos

It may be useful to prepare mylar overlays for the basemap to be used by each of the resource analysts:

- Transfer boundaries of the WAU onto each.
- Put register marks on the map layers and transfer onto mylars.
- Label mylar layers with map number and title.
- Decide where the legend will go on all maps and what the legend design will be.

Identify resource assessment team and other participants in the process.
It is recommended that the field managers team also be identified early in the process. Complete the team information form.

Schedule first meeting:

- Develop team schedule and responsibility list.
- Develop plan for common sampling and coordination of fieldwork.

Begin Resource Assessment.

3.5 Products of Start-up

- Notification sent by DNR or initiating landowner.
- Official WAU boundary map at 1:24,000 scale.
- Work map identifying landowners who need to be notified of watershed analysis and contacted for access.
- Team schedule.
- Team Information Form(s) 1 lists members of the Resource Assessment Team; Form 2, the Field Manager's Team. The WAU, date of notification, and initiating landowner should be clearly identified on each form.

Form 1. Team Information Form

WAU: _____________ Start Date: ___________ Initiated by:_________

Position	Name	Address	Phone Home/FAX	Cert. ? Y/N
Team Leader				
Administrator				
Resource Specialist				
• Mass Wasting				
• Surface Erosion				
• Hydrology				
• Fish Habitat				
• Riparian Function				
• Stream Channel				
• Water Supply Public Works				
Data Technician				
Landowner Representatives				
Tribal Representatives				

Form 2. Field Manager's Team Information

WAU: __________ Start Date: _________ Initiated by: _________

Position	Name	Address	Phone Home/FAX	Cert. ? Y/N
Team Leader				
Participant				
Participant				
Participant				
Participant				
Participant				
Participant				
Observer				
Observer				
Observer				
Observer				

Part 4 Resource Assessment

4.1 Overview

The resource assessment takes an interdisciplinary team (ID) approach with team members possessing skills in forestry, forest hydrology, fisheries, forest soils science, geology, and geomorphology. The primary objectives of the scientific team are: (1) to develop an understanding of the past and present factors influencing watershed condition and a comprehensive view of the cumulative effects of practices, and overall vulnerabilities of the watershed as a whole, and (2) to locate any areas sensitive to erosion, hydrologic change and riparian functions, establishing the level of sensitivity based on the risk to public resources, for which prescriptions must be developed. The inventories and subsequent interpretations provide a basis for area-specific problem statements and rule calls, linking forest practices, watershed processes, and resource effects. The expectation is that the team can construct a complete picture of a watershed and how it works at a scale appropriate for guiding land use decision-making.

To accomplish this, the various TFW cooperators envisioned a watershed resource assessment method that meets the following specifications:

Comprehensive: a framework appropriate for the assessment of a variety of watershed processes and potentially affected public resources, including fish, water quality, water supply, and public capital improvement. The framework should be compatible with wildlife assessment needs, even though a wildlife component is initially excluded.

Area-Specific Focus of Analysis: methods should confront problems of scale, resolution, and natural variability of landscapes. The method should be designed for more detailed and intensive focus (at higher resolution) when so dictated by processes under evaluation.

Scientific Grounding: evaluations should be based on the best science available.

Repeatability: methods should be specified to ensure that the same conclusions and results could be reached by independent reviewers.

Explicit Treatment of Uncertainty: key assumptions should be displayed; potential for error should be clearly defined.

Accountability: all assessments and determinations should be supported by a written record that provides a basis for decisions and interpretations.

Delivering the expected products while satisfying these criteria poses a challenge for design of the resource assessment method since none of the watershed assessment or cumulative effects methods currently available satisfy all of them. To meet the specifications as closely as possible, the resource assessment procedure included in this manual includes a mixture of analytical and qualitative assessments performed by the individual scientific disciplines and the team as a whole.

4.2 Basic Features and Design of Resource Assessment

To comprehensively address the sensitivity of multiple watershed processes to forest practices, and to determine the current condition and vulnerability of a variety of public resources, a two-stage process was developed.

In the first stage, the interdisciplinary team members develop data, observations, and interpretations for each watershed and public resource component. This stage of resource assessment is termed the "Inventory Stage" (see Figure 2). Assessing multiple watershed processes is accommodated by analysts first working relatively independently from one another, with each focusing on a particular aspect of watershed function and identifying conditions at whatever scale is appropriate for that process. Thus, during the inventory stage each analyst takes an area-specific focus using a "top-down" approach. Data is gathered and interpreted for individual watershed processes and resources with the intent of identifying and mapping specific areas of sensitivity or resource concern (these areas can include the entire watershed).

Most of the time spent in resource assessment will be taken up accomplishing the various inventories and most of the data that will be collected for the watershed is done during this stage. The inventory stage provides the preliminary identification of sensitive areas, contributing forest practices, and resource vulnerabilities. Assessment products and interpretations completed during the inventory stage are passed along to later phases for integration at the watershed scale.

Once the individual watershed processes have been evaluated, the collective team considers the individual locations and potential impacts in a broader spatial and temporal context in the second stage of resource assessment -- "Synthesis". During this stage, the team considers a "bottom up" perspective of the watershed. They view the potential for changes in watershed processes to affect specific stream segments or resource locations, thus allowing the consideration of cumulative watershed effects on specific public resources. Based on the information gathered in inventory, the assessment team confirms the existence of resource sensitivities by linking the identified potential impacts (causes) to the identified or existing or potential resource vulnerabilities (effects).

Although the resource assessment is presented as a staged process, the boundary between phases will not necessarily be sharp. Although most interdisciplinary dialogue occurs during the synthesis or second stage, it should be recognized that interteam dialogue may be very helpful during the inventory stage as well. In addition, even though most of the data used by the team is generated during the inventory stage, the group may find it necessary to gather additional data during the synthesis stage to resolve uncertainties that arise during watershed hypothesis building.

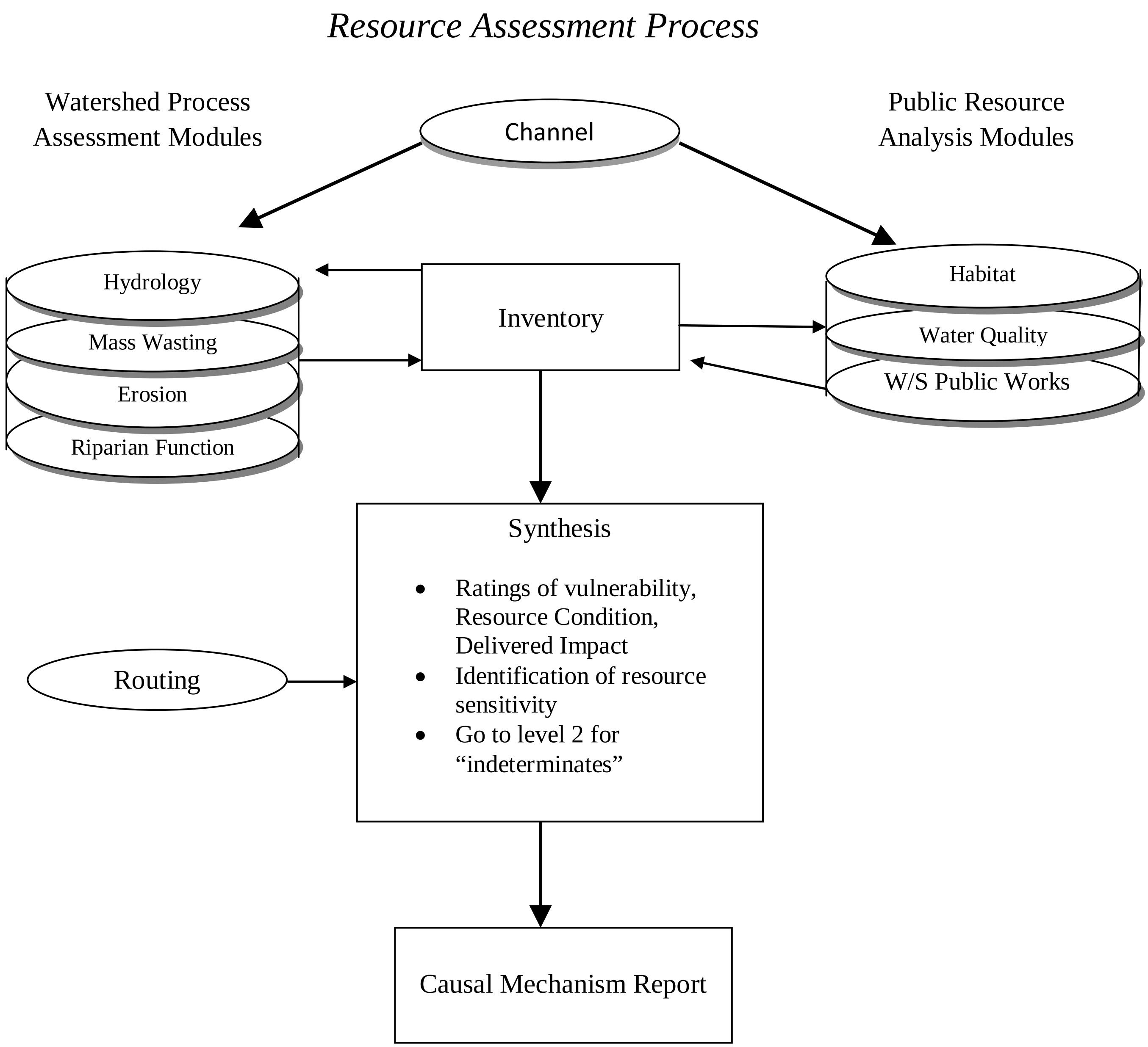


Figure 2. Diagram of the Principle Elements of Resource Assessment

4.3 Scientific Structure

The status of scientific knowledge today is such that we cannot say we know all of the answers leading to full interpretation of all of the watershed processes to be included in watershed analysis. We do feel reasonably certain, however, that science has identified the appropriate questions to ask, so that if they were answered with data from a watershed, its status would be reasonably well understood. Therefore, all of the methods for individual processes and the watershed as a whole that are described in this manual have a question based framework, where critical questions define what is to be addressed by the assessment team. The questions are framed at an overview conceptual level and establish important points of understanding that should be established if sound interpretations are to be made. These questions, rather than the methods, are probably the best representation of the scientific understanding of watershed processes that CMER believes would yield correct watershed interpretations.

The methods provided in the manual reflect a CMER consensus on the best techniques currently available that are recommended for answering the critical questions given our current knowledge, as well as personnel and time allocations. It is assumed that as better techniques are developed for answering each of the critical questions, they can be replaced in future versions of the manual. Adhering to the critical questions as a framework allows such improvements to be made without fundamentally altering the intent and structure of the watershed assessment.

Methods that address the critical questions suffer from the immaturity of some of the scientific disciplines and lack of experience with analyzing processes on the watershed scale. The mechanisms determining potential for forest practices to change the rate of geomorphic inputs are relatively well understood and the module methods for mass wasting, surface erosion, hydrology and riparian function are semi-quantitative. Methods for correlating the extent of response of channels and biologic communities to changes in geomorphic inputs are not as well developed, even though mechanisms for response are reasonably well understood. Therefore, methods for determining resource vulnerabilities (fish habitat, channels, public works) are necessarily more qualitative. Furthermore, the systematic linkage of multiple processes, practices, and resources at the watershed scale in a reliable process has no precedent in the scientific literature. Because of these deficiencies, individual methods and models must be linked in less comprehensive, less quantitative fashion. However, it appears that qualitative interpretations supported by observations are likely to be informative at the scale appropriate for land use decision-making in the watershed.

Although the methods are designed to be as quantitative as possible, nearly all of the methods included in the manual rely heavily on the ability of the scientists and managers to use a scientific process of hypothesis development tested by observation, rather than a "cookbook recipe" approach. The critical questions guide the line of inquiry, no matter what the qualifications of the analyst or level of assessment. The standard methods described in detail in Appendices A-I direct the analyst to develop a minimum set of data to address the critical questions. The modules are designed to provide as much flexibility as possible to the resource assessment team, by allowing them to suggest alternative methods and to spend more time addressing particular critical questions as appropriate in a particular watershed.

Despite the flexibility allowed in the assessments, a reasonable degree of repeatability of a scientific interpretation and products is ensured by (1) the critical question framework, (2) the description of techniques provided in each module, (3) the explicit requirements of certain analysis products, and (4) the retention of records, observations and methods used for analysis of variance from manual methods.

4.4 Explicit Treatment of Uncertainty

The reliability of the resource assessments is dependent on the quality of the specified procedures, the skills of the assessment team members, and the time and resources provided for the assessment. It is expected that the assessment methods provide problem determinations with reasonable confidence, although it is recognized that errors can be made. Reliability can be expressed in terms of the potential or likelihood for correct and incorrect calls. Two types of errors (or incorrect calls) are possible:

1. **False positives** - concluding that a problem exists or condition is present, or a cause effect linkage exists when it really doesn't.

2. **False negatives** - concluding that a problem doesn't exist when it does.

Although greater reliability is ordinarily attained through more intensive analysis providing greater resolution, the widespread application of such intense procedures is not practical given personnel and financial limitations (Figure 3). The proposed methodologies attempt to strike a balance between certainty requirements and the resources available to achieve them. Where considerable uncertainty exists, the methods are designed to err on the side of a decision conservative for the public resource.

Watershed analysis confronts this tradeoff by allowing for two different levels of analysis.

Level I - about three weeks for the assessment by a team of five or six; emphasis on remote analysis with limited field work. Cooperators have indicated that Level 1 should be within the capability of current TFW ID teams whose skills would be augmented with additional training. A typical Level 1 team would possess college degree level expertise.

Level 2 - three to eight weeks, with greater emphasis on field work; analysis designed to resolve Level 1 indeterminate calls and offer greater resolution and certainty. A Level 2 team would possess higher skill levels and greater experience in each of the individual disciplines. A typical Level 2 team would possess Bachelor's and probably advanced degrees in relevant disciplines.

In developing and testing hypotheses, the Level 1 team will attempt to reduce the potential for either type of error. The assessment teams are expected to attempt to resolve uncertainties as much as possible. In cases where significant residual potential exists, the team will conclude that a situation is "indeterminate," warranting clarification through a Level 2 analysis. The specific likelihood threshold for making a call that a situation is "indeterminate" has not been developed, although guidance is provided in the manual for when indeterminate calls may be appropriate.

To date, the reliability of the procedures provided in the manual have not been determined. It is the hope that the CMER research program will provide improved scientific knowledge so that gaps can be bridged, eventually leading to more balanced but simultaneously reliable decisions.

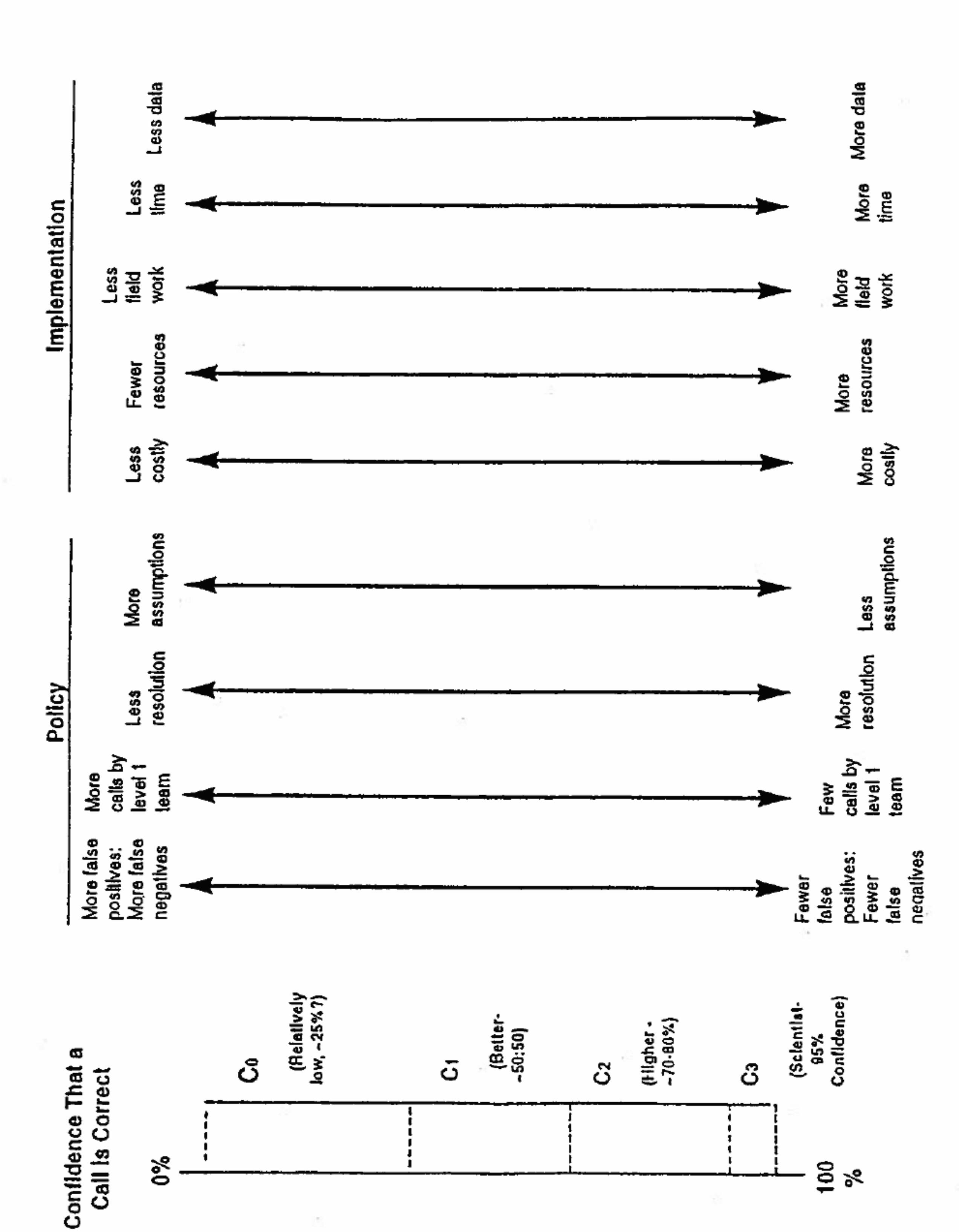


Figure 3. Tradeoffs Among Cost, Resolution and Certainty

4.5 Accountability

Accountability is accomplished by specification of a number of analysis products. These include maps, worksheets recording data and key observations leading to interpretations, and brief narratives summarizing findings. It is recognized that the time limitations imposed by the rule prevent elaborate report writing. The required products allow the resource assessment team to convey key findings systematically but efficiently.

4.6 Resource Inventory

Overview

With basic background information assembled, the team begins the assessments, applying methods identified in the resource assessment modules (Appendices A-H). Inventory calls for assessing the watershed processes (mass wasting, surface erosion, hydrology and riparian function) that generate wood, water, energy, and sediment and the condition of resource characteristics shaped by them (stream channels, fish habitat, water quality, and public works). The scientific investigation includes assessments of current and potential watershed and resource conditions. Existing and potential sensitive areas and their relationship to resource vulnerabilities are identified. Each of the process assessments results in maps, data sheets and narratives. These are used during synthesis to support the ratings of resource vulnerability, resource condition and delivered potential impact and form the basis for causal mechanism reports forwarded to the prescription team.

Each module is organized around a series of primary questions designed to identify the important scientific issues relevant to the process or resource condition under assessment. Generally, it will be possible to answer the module questions without a great deal of interdisciplinary dialogue. Answers are based upon decision criteria specified in each of the modules, resulting in maps, forms, and worksheets that provide an accounting trail and support the integration that occurs under synthesis. Although the inventory assessments will generally be conducted independently, team members may choose to interact to define areas and issues of mutual concern.

Inventory assessments require a mix of office and field work guided by the methods specified in the individual assessment modules. The specific steps to be followed in each of the assessments to answer the critical questions are defined within the modules. The methods provided in the modules represent the standard methods for watershed analysis. That is, all teams regardless of specified level produce the standard set of products and address each critical question. The expectations of the teams differ in the degree of resolution each achieves in answering the questions. Level 1 assessments are likely to have less field work and less quantitative products and more indeterminate calls. Level 2 assessments are likely to have greater resolution, more quantitative supporting data, and additional products that they generate to address uncertainties.

The timing of the resource assessment can be important to gathering good data and could affect the certainty of the results. For example, especially in the higher elevations, much of the landscape is covered by snow during the winter months, possibly hiding some of the information needed for thoroughly analyzing the resources. However, it is not expected that all assessments should be done in the summer months.

Critical questions, assessment methods and interpretations differ between watershed processes (causes) and public resources (effects).

4.7 Watershed Processes

Watershed Process critical questions are designed to identify sources of sediment, water, and wood; the conditions under which processes are activated; reference conditions; and delivery to streams. Although the questions in each module are specific to the watershed process being evaluated, the questions generally address:

- Locations and descriptions of hazard areas for each process based on mapped landscape potential.
- Management activities associated with the process (e.g., road building).
- Delivery of materials to the stream system.
- Geomorphic inputs potentially affected by the process (e.g., coarse or fine sediment, wood, etc.).
- Baseline or reference conditions for each process that provide a basis for potential impact evaluation. (Note that this is not consistent among the modules.)

4.8 Public Resources

Resource questions establish existing conditions, reference conditions, and sensitivities of segments to potential changes in inputs of wood, water, heat energy and sediment. Public Resource assessments are guided by questions that address the following:

- Channel locations susceptible to changes in inputs of wood, water, energy, and sediment (response segments);
- Current channel conditions and sensitivities (e.g., transport capacity);

- Resource potential of segments (fish habitat module only);
- Current resource conditions; and
- Sensitivity (or responsiveness) of resource conditions to changes in inputs of wood, water, energy and sediment.

Public resource assessment teams gather facts and data to characterize resource characteristics sensitivities. Maps are developed locating resources that may be susceptible to changes in flows of fine and coarse sediment, wood, water, and energy (response segment identification). The team then evaluates current conditions based on defined indicators. For fish habitat, these indicators include spawning gravel condition and pool: riffle ratio. Resource analyses also relate current conditions to segment potential which takes into account physical characteristics of segments (e.g., gradient and confinement). Each of the public resource assessments results in maps and data sheets that are used by the team in synthesis and support the rule matrix calls.

4.9 Procedure

Detailed methods for conducting the resource assessments are provided in modular form in Appendices A-I of this manual.

1. **Mass Wasting Module (*Appendix A*)**
   - shallow rapid landslides
   - undifferentiated debris torrents
   - deep-seated mass movements

2. **Surface Erosion Module (*Appendix B*)**
   - surface erosion from roads
   - surface erosion from hillslopes

3. **Hydrology Module (*Appendix C*)**
   - change in channel forming flows

4. **Riparian Function Module (*Appendix D*)**
   - riparian wood recruitment
   - riparian shade provisions

5. **Stream Channel Module (*Appendix E*)**
   - Effects of regimes of wood, water, coarse sediment, and fine sediment

6. **Fish Habitat Module (*Appendix F*)**

7. **Water Quality Module (*Appendix G)***

8. **Water Supplies/Public Works Module (*Appendix H*)**

4.10 Module Project Management

This section describes the steps in an inventory module of the resource assessment from a project management perspective. It is directed primarily to the module leader who is working with others to complete the module, especially in the situation where the team may consist of observers or guest analysts from different organizations. We encourage all module participants to read this section, however, since it may help them to understand project tasks and timelines and clarify expectations of the module leader regarding their involvement. Careful attention to project management considerations will greatly facilitate review and consensus on module products in later stages. Module products and team support will be superior when the team is able to fully and effectively participate in their development.

The module leader must be technically qualified to complete the module assessment according to the criteria listed in the manual and by the DNR official process of skills review and training. Ensuring that the products are complete and as technically correct as possible is the primary responsibility of the module leader. S/he is also the primary representative of the team in communicating analysis results and interacting at later stages of assessment and prescriptions in watershed analysis. The module leader may call upon team members to assist in those efforts.

Managing the module team through the assessment process is also an important function of the module leader, especially where there are observers or qualified analysts participating on a full or part-time basis. The module leader must facilitate review of the products within the team and help to resolve concerns as the assessment proceeds. It is important that team members understand how and when intermediate and final work products are developed and when critical review points are reached so that they can effectively participate in the assessment. The module leader will need to be clear about the team's certainty and level of agreement on the key findings of the assessment as they carry their results forward. Specific tasks and milestones are provided in a Module Project Task checklist provided in each module. We suggest that the module leader review the module methods and expected products with the team at the outset of the assessment, and that the team complete the schedule together so that expectations are clear.

Startup

The module leader's tasks begin during preparatory steps preceding watershed analysis. S/he should be sure that information needs such as aerial photographs and maps are accessible as early as possible. At the startup meeting, the module leader should identify the interested participants, if s/ he has not already done so. S/he will review the module methods with the team, explain when and what critical reviews will occur and schedule the sequence of project tasks.

Resource Assessment

The module leader may enlist team members to help conduct office and field work, or may involve team members primarily in review of the products as they are developed. Regardless of the approach the team chooses, scheduling will be critical to timely delivery of module products within the short time frames that the team must work.

The checklist identifies a number of points during the assessment where various interim products are completed and interpretations and decisions are made. It is strongly recommended that the module leader ensure that all module team members are invited to participate at these critical points and that all products necessary to complete the interim review are available for review. The module team should recognize that once these checkpoints are passed and the team moves on, the team will not entertain additional discussion unless later stages of the assessment reveal uncertainties that the module team was not aware of. Team members and observers are strongly encouraged to bring forth questions and concerns at these checkpoints where the team can most effectively address them. Questions or concerns not brought forward in a timely fashion may undermine the effectiveness of the team's process.

The module leader should ensure that all the products are completed and contacts with other modules are established. The module leader will serve as the primary representative of those products and team discussions during the synthesis stages of the resource assessment.

4.11 Prescriptions

If resource sensitivities are identified in the resource assessment, there may be a need for technical expertise to advise the field managers team during the prescription phase of watershed analysis. The module leader serves as the primary contact to provide that expertise to the team as requested.

If you have been assigned responsibility for a resource assessment,

Go to the Pertinent Assessment Module and Perform the Assessment.

If you are not performing the assessment, but are interested in knowing the specific procedures and products of each module, you may want to read the

Overview of Assessment Methods and Products section of each module which provides a brief summary of what is done in each module.

Part 5 Synthesis

5.1 Overview

Once the module analysts have worked through the methods addressing the critical questions, they will reach a point where they cannot go much further in developing a more comprehensive picture of the watershed and linkages between sources, channels and public resources without interaction with other team members. This begins the second major stage of resource assessment where the team works together to complete the watershed interpretation. Like the inventory stage where modules are completed, synthesis is a stepped and iterative process that may require inter-module and full group meetings, and could include additional data gathering if the team finds it necessary to test hypotheses. The primary qualities that distinguish the synthesis stage of resource assessment is the inter-disciplinary nature of the dialogue and the focus of the group at the watershed scale.

The purpose of synthesis is to bring together the information gathered in the inventory stage (resource assessment modules) to link resource effects to existing or potential hazards and to consider the existing and potential cumulative effects of forest practices. To determine whether the contributing activities in the sensitive area will cause significant changes in the stream, a watershed assessment team must work both ends of an input pathway (Figure 4), defining the likelihood of a change in an input and the effect on a resource if a change occurs. This development of watershed scale linkages and hypotheses is currently performed qualitatively by the interdisciplinary resource assessment team. It is the hope that future versions of this manual will be able to include more quantitative methods for establishing linkages and testing hypotheses. Level 2 teams are encouraged to attempt more quantitative assessments but must provide rationale and justification.

As with the resource assessment modules, the team is guided by a series of critical questions as they attempt to synthesize the results of the individual module assessments into a comprehensive watershed story:

- What and where are the potential impacts altering the input variables?
- Are the inputs delivered to the response segments of concern and if so in what quantity?
- What is the channel sensitivity to the inputs?

- What is the habitat or public resource vulnerability to the inputs? The team answers the questions with empirical evidence developed primarily in the inventory modules. The evidence will include:

- Presence of activities are altering (or may alter) inputs related to the process under consideration (e.g., logging road failures generating coarse materials).

- Input reaching the stream system (or is likely to).

- Routing through the stream system to locations of vulnerable resources.

- Public resources sensitive to the input are present in the reach under consideration (e.g., rearing habitat is sensitive to inputs of coarse sediment).

- Resource conditions in a stream segment that can be adversely affected or the current rate of inputs is such that an already affected/degraded condition will not improve (the coarse material that is generated is likely to accumulate in pools with expected reduction in pool volume).

The team focuses on representative indicator areas selected as likely locations of resource effects. The initial delineation of areas is provided by the Fish and Channel teams. Watershed processes and resource conditions are linked along common themes of the effects on or responses to the five input variables (i.e., coarse and fine sediment, wood, water, and heat energy).

Confirmation procedures establish what is required in terms of evidence and indicators; these are used to establish cause and effect with reasonable confidence. The team uses an iterative approach of hypothesis development and testing based on the strength of the supporting evidence; alternative hypotheses are developed if the signals of cause and effect are present but weak. The team may decide to generate more information to resolve uncertainties.

A confirmed hypothesis results in the identification of a sensitive area. The problem statement is referred to as a situation sentence which has supporting evidence; the "sentence" is a statement or paragraph that summarizes key processes and relationships. This is captured in a causal mechanism report that describes location, impact mechanisms, linkage to vulnerable resources and the rule call. The rule matrix is performed to determine the Rule Call, which sets the standard of performance in preventing changes in watershed processes for the prescriptions to be developed for the sensitive area. The sensitive areas are the mapped units resulting from the Mass Wasting, Surface

Erosion, Hydrology and Riparian Function Modules. The units are termed "sensitive areas" once an effect on public resources is established. The causal mechanism report is given to the field managers team to develop appropriate prescriptions.

A problem statement for each resource sensitivity includes identification of active processes (e.g., surface erosion), contributing management activities, channel effects, and effects on a resource characteristic (e.g., loss of spawning habitat). Synthesis also produces the ratings of resource vulnerability, resource condition, and delivered hazard required under the cumulative effects rules (WAC 222-22-050).

The team may conclude that insufficient evidence is available from the Level 1 analysis to make a rating of vulnerability or hazard for a given area. In this case, Level 2 problem solving would be initiated to answer the unresolved questions. When a Level 1 or Level 2 assessment is complete, the products of resource assessment are forwarded to the DNR and to the watershed field managers team for prescription setting and monitoring.

5.2 Procedure

The general approach for conducting synthesis is qualitative, where key data and observations from the individual assessments are brought together to determine the strength of the signal in determining the likelihood of a cause and effect linkage between hillslope and stream conditions. This process is intended to be a guide for this key component of the analysis. Importantly, synthesis is not a cookbook approach. Synthesis is an iterative process requiring repeated questioning and evaluation of watershed processes by the assessment team.

Synthesis includes the steps of resource assessment that require interdisciplinary dialogue. There is a logical sequence for performing tasks and producing products, but there is no set recipe for how a team works this process. A general sequence that the team may follow includes:

1. **Individual modules present results to the rest of the team**. This will get everyone up to speed on the general stories for each watershed process in the watershed.

2. **Inter-team dialogues** resolving any linkage products they have been assigned responsibility for, and to fill in any gaps.

   Fish Vulnerability: Fish habitat/Stream channel teams.

Public Works Vulnerability: Public works/hydrology, mass wasting, riparian function.

Others as needed: The need for other inter-team dialogue should become apparent when module products are presented.

3. **Watershed Condition Hypothesis Development and Testing**
   The entire team works together to establish the watershed condition and cause and effect linkages. The resource condition reports are produced.

4. **Resource Sensitivities**
   Once the overall functioning of the watershed is understood and cause and effect linkages established, the team needs to formally designate the sensitive areas from the module unit maps and use the rule matrix to determine the rule call. The causal mechanism reports are completed and prepared for forwarding to the field managers team.

5. **Resource Assessment Report Completion**
   Complete products and package them in reviewable fashion.

6. **Prepare for the Hand-off Meeting with the field managers.**

Presentation of Module Products
Synthesis begins with reporting of the findings from each of the inventory modules to a full group meeting. Assessment products (i.e., maps, summary data, and text) are reviewed and explained among the team. Potential hazard areas are displayed for each watershed process. A clear description of what, if any, components of forest management activities affecting hazards are identified. The location and vulnerability of each important resource (e.g., fish habitat or capital improvements) is identified and described.

If appropriate, each presentation includes a discussion of why and where indeterminate calls were made and what additional information may be needed to resolve these calls. The confidence in work products is discussed.

5.3 Inter-Team Dialogue

There are a number of points specified in the modules where the analysts are expected to interact in order to mutually develop some of the interpretations and rule calls. Since most of these calls occur at or near the completion of the module products, these discussions may be conducted either prior to any group interaction during synthesis or during its early stages. They are discussed as a second step here because it may be useful for the analysts to learn what the other modules have discovered prior to assigning calls. Modules will also benefit from conferring among teams as resource assessment proceeds.

In particular, most of the resource vulnerability calls are made as a product of team dialogue. The public works module specifies that the analyst should consult with the hydrology, mass wasting, and riparian function module analysts to determine the vulnerability call. Fish habitat vulnerability is determined by dialogue between the fish habitat and stream channel teams. Because of the complex nature of fish habitat, the procedure for establishing vulnerability is described in detail.

5.4 The Fish/Channel Linkage-Making Vulnerability Calls

Prior to the synthesis steps that involve all of the assessment modules, the information and maps from the channel and fish habitat assessments must be brought together in order to define the habitat vulnerability calls. The following steps describe the general process by which the two resource assessments are used to create the vulnerabilities. It is important to bear in mind that habitat issues not covered in this manual may arise. The analysts must then rely on the data describing the situation and their knowledge of fluvial geomorphology and fish biology to create vulnerability calls.

The channel assessment produces a summary report which presents the results of the channel assessment. The report provides the context for interpreting the causes of historic channel change, identifies current channel condition, and presents a diagnosis of how current channel condition may react to changes in the various input factors. For each geomorphic unit (defined as a group of segments that respond similarly to the inputs), the relative potential for the channel to respond to each of the input factors will be rated. Accompanying this report will be a geomorphic unit response map which compliments the summary report by showing the spatial context of the potential channel responses.

The fish habitat assessment identifies the existing and historical distribution of the various fish species in the WAU. In addition, the assessment produces four maps showing areas of concern from the standpoint of fish habitat. Each of the maps will focus on one of the four life history stages (upstream migration, spawning and incubation, summer rearing and winter rearing). Each map will display reaches that have been identified as areas of concern (areas of degraded habitat, limiting habitats, refuge areas, etc.). Accompanying each map will be narrative descriptions of each area of concern and summaries of habitat conditions in the WAU.

Typically these two summaries will be organized at different spatial scales. For example, an area of resident cutthroat trout may encompass a large portion of a WAU that includes portions of a number of geomorphic units. It is recommended that the vulnerability calls be organized around the species distribution, and that within each zone of the species distribution the analysts review the results of the two assessments for each geomorphic unit and identify processes influencing habitat formation.

Proceeding through geomorphic units one at a time, the channel analyst describes the potential response ratings and any relevant historical and current condition information. The fish habitat analyst describes the distributions of fish species and life history stages and emphasizes areas of special concern in the unit. Together, the analysts work through combinations of life history stage and channel sensitivity (Table 3) and identify the input factors that influence habitat formation in the unit. For each sensitivity rating, the analysts review the general and special habitat concerns for each life phase to determine if the fish habitat is or could potentially be vulnerable to an input factor in the geomorphic unit. The fish habitat analyst is responsible for reviewing the channel sensitivity calls and for determining whether the potential response ratings to each of the input variables are appropriate for protection of fish habitat. In some cases the habitat vulnerability may need to be raised or lowered from the channel response rating depending on fish habitat interpretations. Fish habitat is considered vulnerable if there is a causal linkage between the channel response and life history stage (e.g., Table 3) for input factor.

In many cases the level of habitat vulnerability to an input factor will be equivalent to the potential channel response rating. For example, if there is an area of special habitat concern due to spawning gravel degradation from sediment that corresponds to a geomorphic unit with a high sensitivity to fine sediment, then the habitat vulnerability to sediment is high. If a potential impact to a life history stage cannot be linked to a channel response for a specific input factor, then the habitat for the life stage is not vulnerable to the input factor.

In some cases, the fish habitat information and potential channel response rating will be inconsistent with respect to making vulnerability calls. This may occur in several ways:

1. Habitat conditions are poor due to the influence of an input factor for which the channel response has been rated low or moderate.

2. A unit rated as low or moderately sensitive to an input factor is an area of concentrated fish use (e.g., an area of high density spawning).

3. A unit rated as low or moderately responsive to an input factor is a habitat of limited availability (e.g., off channel refugia are a limiting habitat in the WAU).

These and other inconsistencies may arise in a watershed analysis and must be addressed. The biologist and the channel module leader will need to work together to identify factors causing the inconsistency. Based on this evaluation, the problems may be discovered and the appropriate corrections made. In all cases, the fish biologist is responsible for determining whether the channel sensitivity rating appropriately describes the habitat vulnerability. If the cause of an inconsistency cannot be explained and resolved, the biologist will make the final vulnerability call. The biologist will rely on the results of the fish habitat diagnostic evaluation as a basis for the call. The relative condition of the habitat for a life phase and the parameter responsible for this condition is evident from the diagnostic evaluation. Habitat vulnerability would be determined from the relative condition indices.

Note: In some cases it may be possible to empirically determine the amount of an input that causes an adverse change in a resource condition. This additional information may be used to qualify the vulnerability call. For example, the use of a diagnostic sediment budget may allow the channel and fish habitat assessments to determine amount of coarse sediment that degrades summer rearing habitat.

Combinations of life history stage and input factors must be addressed in creating vulnerability calls. Table 3 presents a list of the most commonly encountered situations that must be addressed in each watershed analysis. Other combinations of channel sensitivity and life history stage may be addressed in addition to these.

Table 3. Combinations of Life-history Stage and Input Factors

Life-history Stage	**Potential Channel Response**
Upstream Migration	Coarse sediment (holding ponds)
Spawning and Incubation	fine sediment (incubation environment) peak flows (redd scour)
Summer Rearing	coarse sediment (pool filling) wood debris (pool formation and cover) temperature (appropriate temperature ranges)
Winter Rearing	woody debris (in channel refuge and cover) coarse sediment (pool filling) factors that create and maintain off-channel refugia

5.5 Watershed Condition Assessment

The next steps of synthesis are performed by the team as a whole. The team first develops the comprehensive watershed picture by examining the linkage between hillslope processes and resources for the indicator areas selected by the team. (The geomorphic units supplied by the stream channel assessment will serve as a basis for these units, although they may be modified.) The team will systematically work through the critical synthesis questions for each geomorphic input factor (change in coarse or fine sediment, change in peak flows, recruitment of large woody debris, or change in energy loading) for the indicator areas. It is strongly recommended that the field managers team observe the synthesis sessions of the assessment team. This will help them to understand how the resource sensitivity calls are made.

If the team is large, they may wish to use a facilitator for this part of the assessment. If so, it is strongly recommended that the facilitator be a knowledgeable resource specialist given the hypothesis development/testing nature of this exercise.

Questions are designed to capture the following:

1. Activities generating an input (e.g., coarse sediment).

2. Process triggered by activities (e.g., mass wasting associated with logging road failures).

3. Delivery to the stream.

4. Delivery of an effect - whether an input can be transported to a sensitive segment (and whether a material effect can be registered).

5. Public resources impact - whether resources can be or will be degraded.

Data and interpretations relevant to each of these points has been developed within the assessment modules as critical questions are addressed. Tables 4 to 8 list each of the primary synthesis questions and identify the associated questions and information that were asked and answered during inventory assessments. Sources of information to address the synthesis questions can therefore be found in the products of the assessment modules. The specified work products provide the evidence weighed by the team to answer the associated synthesis questions. The resource assessment team will find it useful to have the module summary reports and products in hand, and to have interim work products available for reference.

Table 4. Key Questions and Information Relating to Fine Sediment Processes

Primary Synthesis Questions	Primary Inventory Questions	Required Information	Module
What is the channel sensitivity to fine sediment?	Are there locations sensitive to changes in inputs of fine sediment?	Form E-5	Channel
	What do the current channel conditions indicate about existing levels of fine sediment inputs?	Sediment supply/transport capacity relationship	Channel
	Is there evidence that channel conditions relative to fine sediment are changed from historic conditions?	Supplemental Information	Channel
What is the habitat sensitivity to fine sediment?	What is the production potential rating for spawning and incubation?	Good, Fair, Poor calls from Worksheet F-4	Habitat
	What is the current habitat condition?	% fine sediment content of spawning gravels and other supplemental information. (Worksheet F-1)	Habitat
	Is there evidence that habitat conditions have changed from historic?	Supplemental information (Worksheet F-2)	Habitat
What and where are the potential impacts producing fine sediment?	Is there potential for shallow rapid failures?	Maps and Descriptions Map A-1	Mass Wasting
	Is there potential for debris torrents?	Map A-1	Mass Wasting
	Is there potential for deep-seated movement?	Map A-1	Mass Wasting
	Is there potential for road surface erosion?	Road surface erosion worksheet	Surface Erosion
	Is there potential for hillslope surface erosion?	Hillslope erosion worksheet	Surface Erosion
	Is fine sediment generated by management activities?	Maps A-1, B-1, B-2	Mass Wasting & Surface Erosion
Is fine sediment delivered to segment of concern?	Is fine sediment routed from the contributing impact to a susceptible location?	Worksheet I-1	Routing
	Will the delivery of fine sediment change the channel or habitat conditions?	Form E-5 Map F-3	Habitat or Channel

Table 5. Key Questions and Information Relating to Coarse Sediment Processes

Primary Synthesis Questions	Primary Inventory Questions	Required Information	Module
What is the channel sensitivity to coarse sediment?	Are there locations sensitive to changes in inputs of coarse sediment?	Form E-5	Channel
	What do the current channel conditions indicate about existing levels of coarse sediment inputs?	Sediment supply/transport capacity relationship	Channel
	Is there evidence that channel conditions relative to coarse sediment are changed from historic conditions?	Supplemental Information	Channel
What is the habitat sensitivity to coarse sediment?	What is the production potential rating for summer rearing?	Good, Fair, Poor calls from Worksheet F-4	Habitat
	What is the current habitat condition?	See percent pools and other supplemental information. (Worksheet F-1)	Habitat
	Is there evidence that habitat conditions have changed from historic?	Check supplemental information (Worksheet F-2)	Habitat
What and where are the potential impacts producing coarse sediment?	Are there potential shallow rapid failures?	Maps and Descriptions Map A-1	Mass Wasting
	Are there potential debris torrents?	Map A-1	Mass Wasting
	Are there potential deep-seated failures?	Map A-1	Mass Wasting
	How much coarse sediment is generated naturally for each impact? How much coarse sediment is generated by management activities for each impact?	Map A-1	Mass Wasting
Is coarse sediment delivered to segment of concern?	How much coarse sediment is generated naturally from all impacts in this basin?	Worksheet I-1	Routing
	Is coarse sediment routed from the contributing impact to a susceptible location?	Form E-5	Routing
	Will the delivery of coarse sediment change the channel or habitat conditions?	Map F-2	Channel & Habitat

Table 6. Key Questions and Information Relating to Peak Flow Processes

Primary Synthesis Questions	Primary Inventory Questions	Required Information	Module
What is the channel sensitivity to changes in flood frequency and magnitude?	Are there locations sensitive to changes in peak flows?	Form E-5	Channel
	What do the current channel conditions indicate about existing flow conditions?	Transport capacity (Form E-5)	Channel
	Is there evidence that channel conditions are changed from historic conditions?	Supplemental Information (Form E-5)	Channel
What is the habitat sensitivity to changes in flood frequency and magnitude?	What is the production potential rating for spawning and incubation?	Good, Fair, Poor calls (from Worksheet F-4)	Fish Habitat
	What is the current habitat condition?	Supplemental Information (from Worksheet F-1)	Fish Habitat
	Is there evidence that habitat conditions have changed from historic?	Supplemental Information from (Worksheet F-2)	Fish Habitat
What and where are the potential impacts producing changes in flood frequency and magnitude?	Where are potential rain-on-snow impact areas?	Watershed hydrologic condition map	Hydrology
	What % of each potential impact area is hydrologically immature?		Hydrology
Are increased flows delivered?	What is the magnitude of the 2-year flood under mature forest conditions?	Hydrographs for 2-year, 5-year, and 10-year floods	Hydrology
	What is the magnitude of the 5-year flood under mature forest conditions?		
	Is increased water delivered to indicator segments during storm events?		

Table 7. Key Questions and Information Relating to LOD Recruitment Processes

Primary Synthesis Questions	Primary Inventory Questions	Required Information	Module
What is the channel sensitivity to changes in the size or frequency of large organic debris?	Are there locations sensitive to changes in LOD?	Map (Form E-6, Map E-2)	Channel
	What do the current channel conditions indicate about existing levels of LOD?	Counts of LOD, size or volume information by channel width (from Form E-5)	Channel
	Is there evidence that channel conditions relative to LOD are changed from historic conditions?	Bilby and Ward target LOD loading levels (from form E-5)	Channel
What is the habitat sensitivity to changes in LOD size or frequency?	What is the production potential rating for summer rearing?	Good, Fair, Poor calls (from Worksheet F-4)	Habitat
	What is the current habitat condition?	Percent pools and other supplemental information (Worksheet F-1)	Habitat
	Is there evidence that habitat conditions have changed from historic?	Supplemental Information (Worksheet F-2)	Habitat
What and where are potential impacts impairing the recruitment of large organic debris to the channel?	Does the riparian zone stand age tree density, and species composition indicate current and continued supply of LOD?	Maps and Descriptions (Map D-1)	Riparian Function

Table 8. Key Questions and Information Relating to Temperature Regulating Processes

Primary Synthesis Questions	Primary Inventory Questions	Required Information	Module
What is the channel sensitivity to increased water temperature? Is this different from habitat module?	Are there locations sensitive to changes in heat energy? What do the current shade conditions indicate about existing stream temperatures? Is there evidence that channel conditions relative to heat energy have changed?	Map D-2 Shade conditions relative to target conditions (Form D-2) Supplemental Information (Form D-2)	Riparian Function
What is the water quality sensitivity to changes in heat energy inputs?	What is the production potential rating for summer rearing? What is the current maximum stream temperature relative to water quality standards? Is there evidence that temperature conditions have changed from historic?	Good, Fair, Poor calls (from Worksheet F-4) Maximum temperature value from Ambient Monitoring Supplemental Information (Worksheet F-2)	Habitat Habitat Habitat
What and where are the potential riparian shade impacts?	Is existing shade less than target shade?	Comparative shade values (Map D-2)	Riparian Function
Is warmer water delivered to the segment of interest?	Is temperature delivered from upstream segments?	Temperature data and/or shade conditions 1,000 ft. (305 m) above the response segment	Riparian Function

Identify Indicator Areas

Due to limitations of time and resources, the team will not be able to directly evaluate the potential cumulative effects on all stream segments, especially for widely distributed public resources such as fish habitat or water quality. They will need to select representative areas that are appropriately distributed in the watershed as indicators of local or watershed scale responses. The stream channel module has determined geomorphic units that include stream areas with similar condition and sensitivity to changes in geomorphic inputs. These units should provide the nucleus for synthesis of watershed scale cause and effects, although the full team may wish to modify them somewhat to accommodate other factors.

Develop Watershed Process Hypotheses

Information from the inventory work products is used to develop understanding of the existing or potential effects of management activities on watershed processes and resource characteristics. Linkages among management activities, watershed processes, stream segments, and vulnerable resources are established through a hypothesis development process. Empirical evidence, process theory, or both are used during this assessment to confirm or examine the acceptability of each hypothesis.
The team begins the assessment by assuming the perspective of field investigator at an indicator area. Maps, tabular data and summary reports are available from the habitat, channel and process modules. Routing considerations are of primary importance.

The team now attempts to integrate and associate the information to produce hypotheses for watershed processes. This process is similar to the way a medical team might diagnose a patient's condition, utilizing tests, and historical workup that are coupled with the skills and knowledge of specialists and generalists.

For reliable results, the watershed analysis team should identify competing hypotheses for each segment. Through team dialogue and association of current and historical data, it should be possible to dismiss certain hypotheses while defining others as more likely. For each segment, the existing channel conditions are characterized by the channel and habitat modules. Supporting data is recorded on appropriate forms (e.g., pool/riffle ratio, levels of coarse sediment loading). Points in the photographic record are noted where stream channel conditions may have changed. Before evaluation of causal mechanisms, the team should reach common understanding on current and recent trends in channel and habitat conditions. This will help focus the evaluation and facilitate hypothesis development and testing. A dialogue between the habitat analyst and the channel analyst is essential.

As hypotheses begin to form, the team should be aware of the potential for either erroneous acceptance or rejection of the hypotheses. For example, limited pools and aggradation may not necessarily be derived from management activities. The cause may be a natural sediment source. The team should qualitatively analyze alternative explanations. Using the module information, they should identify the most likely hypothesis or explanation. If the team does not reach agreement on cause and effect, an indeterminate call may be appropriate (Level 1).

The linking or routing of impacts from hillslope processes to stream segments is a critical element of the hypothesis development process. The team members need to define how routing processes work within the various response segments. The evaluation of these linkages for sediment and peak flow impacts requires an assessment of the evidence and processes affecting routing. The application of routing to potential hazards is fundamental in reading the landscape; the result is a translation of data into useful information used directly in the rule matrix. Beyond the regulatory context, the information may have other valuable uses for voluntary or cooperative actions. A routing assessment for these input variables is described in Module I: Routing. At this time, this routing assessment is very qualitative. It is hoped that this may become more quantitative in the future with sediment and water budgeting.

Because impacts from riparian processes are not likely to be routed downstream and are directly adjacent to the stream segment of concern, these impacts do not require a routing analysis.

The plausibility or strength of the signal for the hypotheses should be evaluated by a qualitative certainty assessment. For example, for some impacts, such as delivery, channel conditions and habitat conditions, there will be clear correlation (Figure 5). In other cases the connections will be less clear; this is the result of natural variability, level of resolution of the assessment methodology, and other factors. Here, potential problems may still be identified and hypotheses may still be constructed, but at a lower level of certainty. Lower levels of certainty will dictate Level 2 analysis.

Observed Habitat Sensitivity

Observed Impacts		YES	NO
	YES	*HIGHER CERTAINTY* Clear impacts and clearly discernable habitat effect.	*LOWER CERTAINTY* Clearly active impact with no discernable habitat effect.
	NO	*LOWER CERTAINTY* No discernable potential impact, but unexpected habitat effect present.	*HIGHER CERTAINTY* No discernable potential impact and no discernable habitat effect.

Figure 5. Simplified example circumstances which result in higher or lower certainties in hypothesis development. When the certainty is low, the watershed analysis team will usually go to Level 2 analysis.

This hypothesis generating process yields an interpretation of resource conditions within the watershed. This is discussed in the Resource Condition Report, which focuses on describing the watershed from the stream system view. This is a narrative describing the public resource(s) condition and vulnerabilities, and the interpretation of watershed processes affecting it.

The suggested format for the Resource Condition Report for each analysis unit is provided in Form 3.

An Example from the Tolt River

A resource condition report for the Lynch Creek indicator area is provided at the end of this section illustrating a compilation of information for the area. This area was one of 14 identified in the WAU. The format on this report is flexible. This example represents one team's interpretation of how to present the appropriate information.

Form 3. Suggested Resource Condition Report format. Alternative formatting should address the key points indicated.

I. Location Information
- A map indicating the area
- Watershed Location Information
- Streams Observed
- Applicable to Other Streams

II. Resource Condition
(This section is a narrative describing key watershed interpretations)
- Public Resources Situation
- Overall Interpretation
- Confidence
- Discussion Points or Remaining Questions

III. Key Observations and Notes
This section captures some of the key observations contributing to the interpretations presented above). These observations are drawn from all of the modules.
- Coarse sediment
- Fine Sediment
- Peak Flows
- Large Woody Debris
- Temperature

IV. Discussion of Vulnerability Call

Resource Sensitivities
When existing or potential hillslope hazards can be linked to their existing potential effect on resource characteristics then a resource sensitivity is established. The evidence is compiled and interpreted in Synthesis; hypothesis testing supports the team's conclusion.

Linking Mapped Units to Public Resources
Generally, the hazards are mapped areas or "polygons" within the watershed where specific watershed processes are found likely to be significantly affected by the management practices. Each hazard area is differentiated by a unique "triggering mechanism." That is, potential changes in specific watershed processes are isolated to a reasonable degree. Examples could include the following: shallow debris flows within valley inner gorges; ancient deep-seated earthflows from a glacial terrace; surface erosion from road cut and hillslopes; increased available water from rain-on-snow; or lack of shade from past harvest of riparian stands. Differentiating hazard areas by triggering

mechanisms related to specific processes (not activities) facilitates the development of appropriate management prescriptions for the area.

Hillslope impacts that may affect vulnerable resources are identified by superimposing the resource vulnerability maps (Maps F-2 to F-6, H-I & H-2) on the hillslope impact maps (Maps A-2, B-1 & B-2, C-1, D-1 & D-2). Working with one impact map and the corresponding vulnerable resource map (e.g., for coarse sediment, use mass wasting impact Map A-2 and fish habitat Map F-2), identify the stream segments that are least likely to be affected by the impact.

Consider this step to be a coarse screen with the objective of removing mapped units and blocks of segments from further consideration. Areas and segments not excluded are examined further for potential cumulative effects.

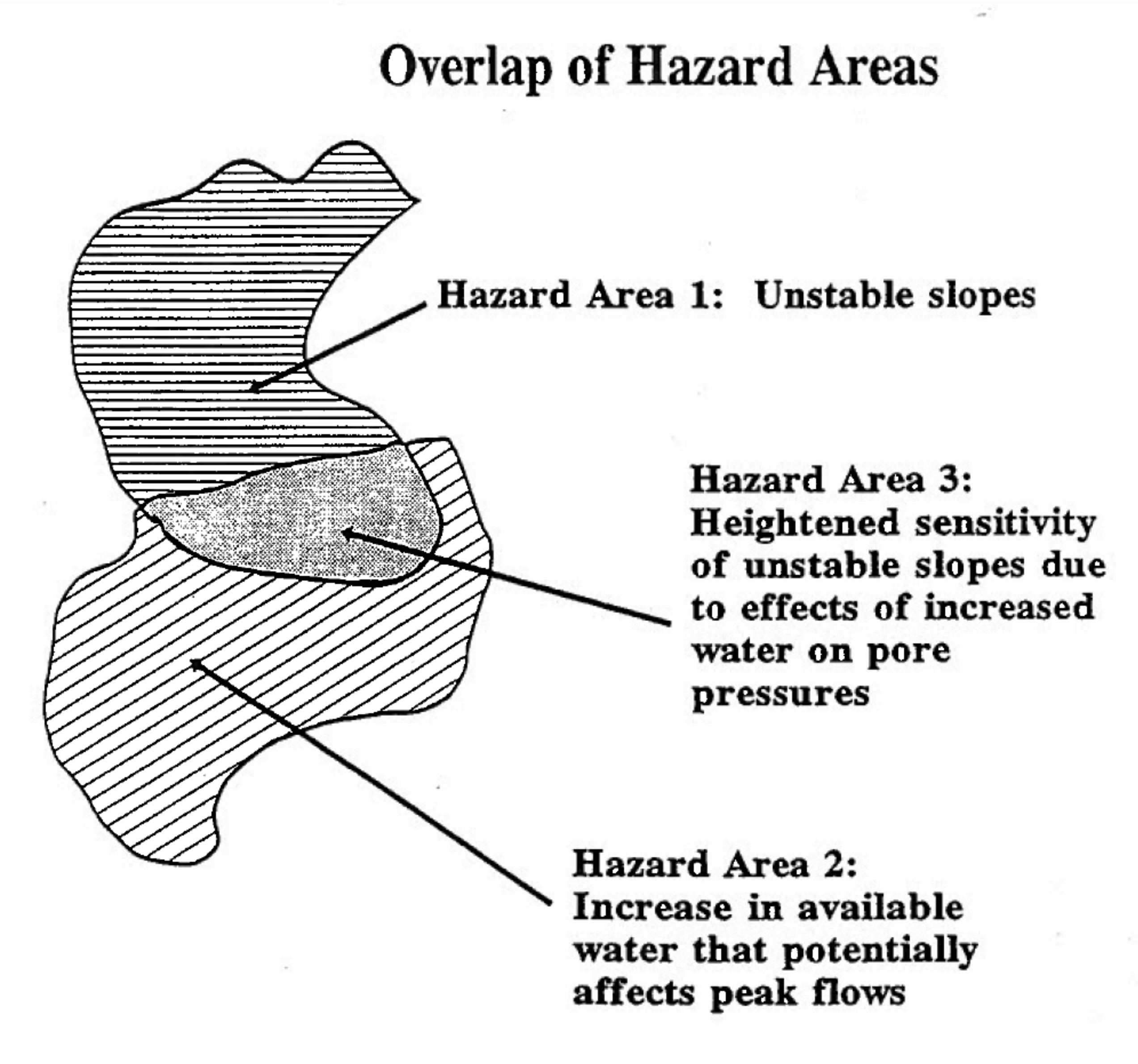


Figure 6. Overlap of Hazard Areas

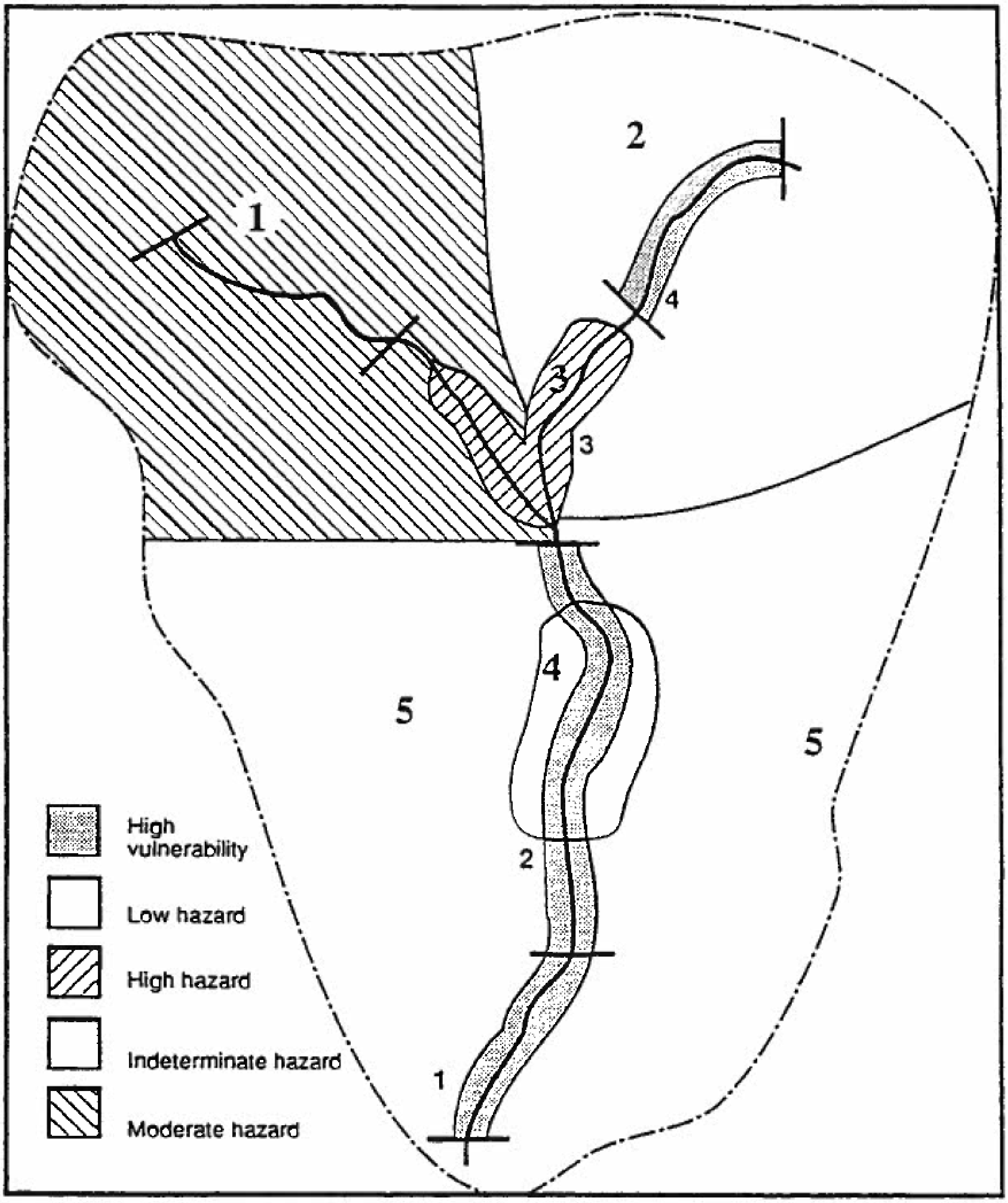


Figure 7. Example of high habitat vulnerability to coarse sediment map (from Appendix Fig. F-3) superimposed on mass wasting impact potential map (from Appendix Fig. A-4)

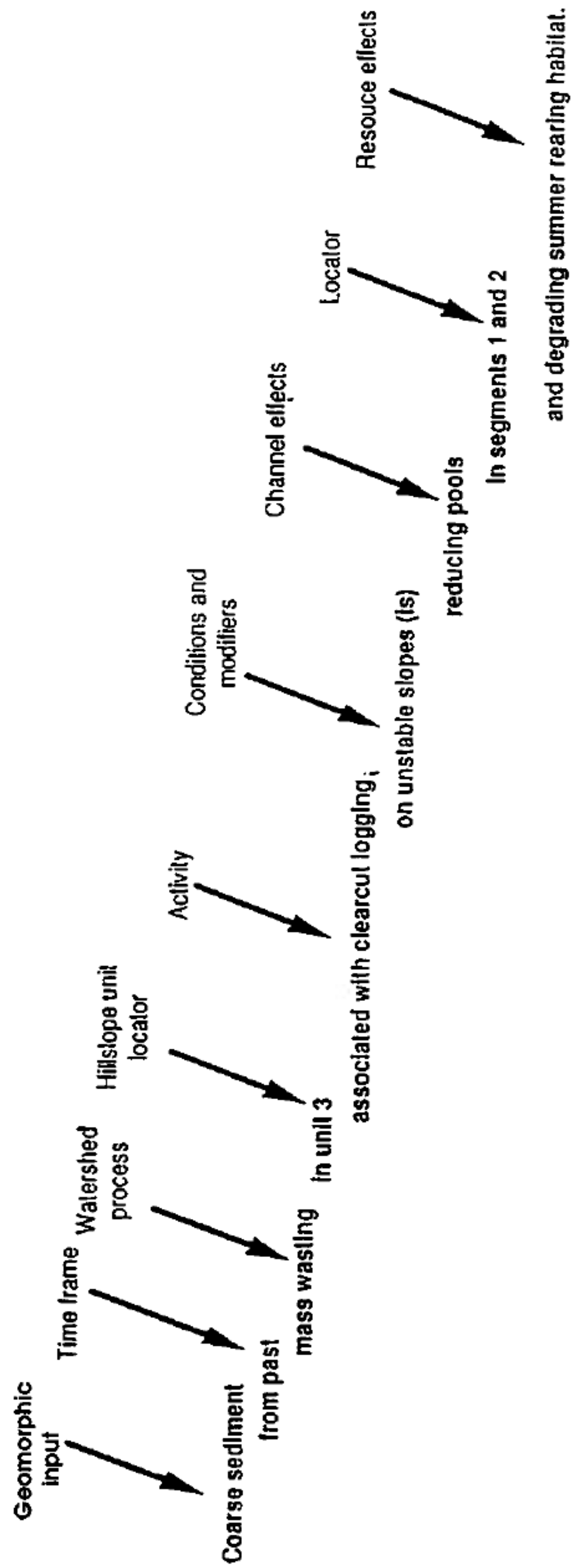


Figure 8. Situation Sentence Syntax

For example, the resource, fish habitat, can be divided into rearing habitat and reproduction habitat. Good spawning habitat demands high quality spawning gravels. A risk to the resource is present when spawning gravels are degraded (or placed at risk) because of fine sediment loading associated with forest practices. A rearing sensitivity or risk arises when forest practices result in (or heighten the potential for) pool filling and reduction in summer rearing habitat.

The team should also consider the overlap of hazard areas to determine whether changes in more than one watershed process in that geographic area may heighten the potential hazard. Figure 6 illustrates this point. For example, if a change in available water in the rain-on-snow zone (hydrology unit 1) heightens the probability of shallow debris flow on unstable slopes (mass wasting unit 2) then a new area (3) enveloping the overlap in triggering mechanisms should be identified as a separate resource sensitivity. If the two hazards do not directly interact, then no additional differentiation is needed; they remain and are treated as separate hazards.

Resource Sensitive Areas

If a mapped area can produce delivered changes in coarse or fine sediment, water, wood or energy resulting in significant adverse impacts on stream and habitat conditions, then the mapped area is termed a "resource sensitive area." Some hazard areas identified in the inventory modules may not become resource sensitive areas if significant impacts cannot be delivered. It is important to note that the resource sensitive area is designated relative to the hazard area rather than to the stream segments with which it is associated.

As depicted in Figure 7, a resource effect may arise when a change in hillslope process (e.g., a road failure) generated material (e.g., coarse sediment) that can affect channels or otherwise impair resource function. The evaluation of effect must include an assessment of delivery to a stream and the responsiveness or vulnerability of resources to the input. Various stream segments will respond differently to each of the inputs. The method must recognize this by defining conditions under which responses are registered.

To provide accountability, the team compiles key summarized information for each resource sensitivity; each such sensitivity must have demonstrated that the linkages between sources, routing, channels, and habitat or water quality have been evaluated. These linkages and their rationale are accounted for in the Resource Condition report.

Although this background information is useful for accounting for how the resource sensitive area was identified, the information needed by the field managers team to address the sensitivity must be focused on the processes and mechanisms by which forest practices can influence the area. This information is provided in a Causal Mechanism Report, which briefly states the problem and elaborates more fully on its potential causes.

The problem statement for each resource sensitive area is termed a "situation sentence." The team confirms each of the key elements of the sentence with reasonable certainty based on the evidence (Figure 8 Situation sentence syntax). Each sentence is constructed based on the empirical or process theory evidence used to justify the linkages; the linkages are clearly documented in the routing, watershed process, and resource modules. The completion of all of the elements of the sentence represents a confirmed hypothesis of hazard linked to a vulnerable resource. Therefore, the existence of the situation sentence signals that the team has compiled enough evidence to identify a resource sensitivity and the content of the sentence expresses the nature of the problem. If one of the key sentence elements is not present, or of insufficient magnitude to be of concern, then that situation component is not confirmed; here, the linkage of hazard to vulnerable resources is not established, the sentence is not completed, and a problem is not found to exist for the purposes of the watershed analysis rules. In this case, the identified hazard area is not considered a resource sensitivity.

The key information developed by the scientists that will help the field managers team to develop appropriate prescriptions is the triggering mechanism. This is as good a description as possible of what the analyst believes is the factor that contributes to the potential to change a watershed process sufficiently to create the sensitivity. The analyst is encouraged to be as specific and detailed as possible. Simply saying that logging causes problems is incomplete. A clear articulation of what aspects of logging (e.g., soil displacement associated with high lead logging), is important in the development of appropriate prescriptions.

Rule Calls

For decision making within the rule, the resource assessment team also makes a rule call that determines the standard of performance for prescriptions based on the risk to resources. In the synthesis stage, the team has the relevant information with which to establish with reasonable certainty the relative likelihood of an adverse change in watershed processes associated with particular practices and the relative vulnerability of the public resources to changes in those processes. This qualitative determination sets the performance standard for prescriptions according to Figure 9.

The Washington Forest Practices Rules (WAC 222-22-050) specify that data from the assessments determines the appropriate management response, the rule call. The rule call, the management response, is defined by the rule matrix in Figure 9. To correctly use the rule matrix, potential hazards must be capable of being routed to a vulnerable resource. This is the question of deliverability. Deliverability is defined in the rules as the likelihood that a material amount of wood, sediment, or energy will be delivered to fish, water, or capital improvements of the state. This definition of deliverability has three conditions that must all be satisfied before an impact is delivered: (1) an impact is likely to occur, (2) the magnitude or size of the impact is sufficient to have a significant adverse effect on the resource characteristic, and (3) the impact is likely to be delivered to a stream segment with a vulnerable resource.

Each hillslope impact identified by the situation sentences must be evaluated for deliverability. Information needed to assess deliverability is derived from the data supporting the situation sentences. The likelihood of the event and its magnitude are elements of the module impact ratings. The likelihood of impacts reaching vulnerable resources is derived from the routing assessment. Because riparian impacts are not likely to be routed downstream and are directly adjacent to the stream, these impacts are assumed to be delivered and no further analysis is required. For sediment and peak flow impacts, the linkages between impacts and vulnerable resources must be established to determine deliverability.

Deliverability is determined for each input variable by examining linkages between the hillslope and the indicator areas. Beginning with the indicator areas closest to the potential impact, the team determines deliverability. This is repeated for each successive indicator area, for each impact area, and for each input variable. Impacts that are delivered to indicator areas are recorded by unit, map number, and rating on Worksheet 1.

Cumulative Effects Rule Matrix

RESOURCE VULNERABILITY	Likelihood of Adverse Change and Deliverability: L	M	H
L	Standard	Standard	Prevent
M	Standard	Minimize	Prevent
H	Standard	Prevent	Prevent

Figure 9. Matrix Used to Produce Management Response Call for a Given Basin Problem Statement (from WAC 222-22-050)

Delivered potential impact and vulnerability determinations are combined to produce prescribed management responses (Figure 9). The X axis refers to potential impact from changes in watershed processes delivered to resources, and the Y axis refers to resource vulnerability.

The rule matrix produces three possible management responses:
1. Standard rules
2. Minimize
3. Prevent or avoid

The causal mechanism report is a compilation of the synthesis results. To condense this information into a readily usable format, the situation sentence products and supporting data are summarized on the causal mechanism report Summary (number it Form xx) using the format suggested in Figure 4. This form is prepared for each resource sensitivity that was developed in the synthesis phase. A causal mechanism report should be completed for each resource sensitive area, although parts of it may be completed by the resource assessment teams prior to synthesis.

This format is designed to assist the team to develop an understandable report without extensive written documentation; the team is encouraged to include observations or discussions in an appropriate level of detail, that increase clarity or justification of the conclusions.

Form 4. Suggested Format of the Causal Mechanism Reports.

Causal Mechanism Report Summary

WAU:____

Resource Sensitivity Number:____

Situation Sentence:____

____

____

____

____

Triggering Mechanism(s) (Be as precise as possible):____________________

____

____

____

____

Rule Call for Management Response:___________________________________

Additional Comments: ____

____

____

____

An Example from the Tolt River - Causal Mechanism Report

Form 4. Causal Mechanism Report Summary

WAU: TOLT

Resource Sensitivity Number:
Mass Wasting Hazard Unit #1

Situation Sentence:
Coarse and fine sediment from past landslides in Unit #1 associated with roads and timber harvest within inner gorges has reduced pools and degraded cutthroat (and possibly dolly varden and bull trout) spawning, and summer and winter rearing habitat in the North Fork braided reaches (Segments 13, 15, and 17). Sediment from this unit is also routed downstream and can affect depositional areas such as segments 1, 2, 3 and 5.

Triggering Mechanism(s) (Be as precise as possible):
Failures are mainly associated with roads, both side cast failures and fill failures. Stream crossing failures are the result of the active transport of wood debris and bedload down these channels, causing plugged culverts. Harvest of the very steep slopes adjacent to streams has accelerated mass wasting. This is due to root strength deterioration and changes in groundwater hydrology. The larger melt rates and volumes due to clearcut harvest may lead to an increase in saturated thickness causing failure. Given the elevation and rock type, root strength is the more important of the two.

Rule Call for Management Response:
Prevent or Avoid

Additional Comments:
Dolly varden and rainbow may be present. Unit #1 is a naturally unstable area. Delivery associated with Segments 13, 15 and 17.

Resource Assessment Report

The majority of the Watershed Analysis Report for the WAU will consist of the resource assessment products. It is recognized that producing a full written report for the watershed would be a very time consuming effort for the team and is not possible within the time constraints of the watershed analysis regulation. The report consists of a compilation of key products produced during the course of the assessment. Once the prescriptions are completed by the field managers team, they can be added to report to complete the watershed analysis products. It may be most useful for review purposes to append each prescription to the appropriate causal mechanism report.

Watershed Characteristics

The watershed characteristics information is recorded on Form 5. Most of the information for this form will be derived from the startup phase.

Resource Condition Reports

These reports provide the watershed interpretations for each of the geomorphic units of the watershed. They convey in narrative form findings of the team including public resource condition, contributing hazards, and routing assumptions. They also record the resource vulnerability calls with supporting evidence.

Causal Mechanism Reports

The situation sentence is recorded along with the triggering mechanism and rule call. In addition, the specific supporting information (e.g., input variable and the resource affected) and source of the information (e.g., map or source data) are recorded. The actual maps, data, and worksheets are included as appendices.

The contents and format of this report are listed in Figure 11. Because landowners, agencies, and other interested parties will be using and reviewing watershed information for more than one WAU, a common report format is necessary to facilitate easy reference.

Resource Assessment Report

A. Watershed Characteristics (Label Form 5)
Team Personnel (Form 1)

B. Resource Condition Report - one for each indicator area (Form 3)

C. Causal Mechanism Report - one for each resource sensitive area (Form 4)
Situation Sentence
Rule Call
Trigger Mechanism
Confidence Discussion
Supporting Data

D. Module Summary Reports (see each module)

E. Maps

Appendices

A. Assessment Module Products

B. Synthesis Products

Figure 11. Suggested format for the Resource Assessment Report

Hand-off

Although the field managers team is encouraged to attend in the Synthesis stage of Resource Assessment, and therefore may be familiar with the scientific findings, it is important for the resource assessment team to formally hand off their product to the field managers team. This should be accomplished in a meeting setting with the focus on explaining the causal mechanism reports. This will ensure that the field managers fully understand their contents. It may also be useful for resource analysts to consult with the field managers during prescription writing.

An Example from the Tolt River Resource Condition Report

Indicator Area: Lynch Creek

Watershed Location Information:
Major tributary to the South Fork Tolt River below the dam.

Streams Observed:
Lynch Creek and Crazy Creek (Segments 119, 122, 124) were visited by the Channel and Fish Teams.

Applicable to other streams:
Entire Lynch Creek. (Segments 112-117); Crazy Creek (118-124); and Segment 125, a tributary to Lynch Creek.

Macro Story

Public Resources Situation:
Lynch Creek is presently inhabited by resident cutthroat trout. Anadromous species are prevented from moving into Lynch Creek by perched culverts at the pipeline road. An old stringer bridge downstream of the pipeline road was apparently a blockage in the past but is not a barrier today. A shotgun culvert in Segment 116 may become a barrier if not maintained. Beaver dams at several locations in the system may also form barriers.

The channel gradients and confinements characteristic of the system create good spawning and rearing potential. Current conditions are rated as at or near potential in most locations. The spawning habitat is sensitive to fine sediment contamination. Free-flowing reaches are sensitive to wood loss because LOD is an important pool forming agent in these areas. The abundance of beaver ponds in some segments of this system are probably warmer than free flowing reaches in the system. This may heighten sensitivity to temperature increases in these areas.

Crazy Creek is notably different than Lynch Creek. Large slides in headwater segments (122-124) dominate stream characteristics now and will into the future. Fish habitat in Segments 119-124 is off potential due to (1) high levels of fines in gravels and pools, (2) continuously turbid water from exposed clays in slide areas, (3) extremely low pool to riffle ratio (4-10% pools) due to filling by sediments, (4) continuous channel shifts in Segment 120, and (5) a potential fish migration barrier at the upstream end of Segment 118.

An Example from the Tolt River Resource Condition Report

Overall Interpretation:
A number of landslide hazards throughout the sub basin chronically contribute both coarse and fine sediment to Crazy Creek. Elsewhere in the Lynch Creek basin is relatively benign except in incised portions of the channels where bank erosion is (Segment 112) or may become (Segment 116) problematic. Active mass wasting processes include road and non-road related shallow debris flows and ancient deep-seated landslides. The contact between hard rock walls and glacial till deposits are the location of significant mass wasting concerns is not a problem. The roads have a few problem erosion locations but generally are in good condition. Channels in active landslide locations of Crazy Creek are active and destabilized. Beaver ponds occur in the lower alluvial channels providing storage for sediment. Target shade conditions are generally reached except for some locations.

Fish habitat conditions for spawning and rearing are good in the basin, although access for anadromous species is currently blocked by a culvert barrier at the lower end of the basin. The main pipeline culverts are perched, preventing fish movement.

Confidence: Confidence in hazard identification and channel condition is good based on the methodology and field observations. It is assumed that removing the migration block would allow steelhead use of available habitat.

Discussion points or Remaining Questions:
- Did sockeye salmon use Lynch Lake at one time? Are they present in the lake now?
- What is the seasonality of the hydraulic connection of Lynch Creek to the South Fork Tolt?

An Example from the Tolt River Resource Condition Report

Coarse Sediment

Channel Condition:

- Crazy Creek Segments 121 and 122 of Crazy Creek flow across the earth flow area. The channel there is characterized by loose boulder stair steps and appears to be very active and destabilized.
- Upper reaches are zones of transport bringing coarse and fine sediments down to the alluvial reaches.
- Headwaters shifting, unstable, milky color during high flow events. Non-cohesive banks.
- Where streams leave the slide area and flow only the glacial tills, the channel is initially lost and then re-emerges and flows into beaver pond channels.
- Lower Lynch Creek cuts down through sheer vertical walls of clean sand.

Public Resource Effects and Sensitivity:

There are some good spawning gravels available in the system. No evidence of coarse sediment problems relative to fish habitat.

Habitat n Segments 119-124 of Crazy Creek are seriously off potential due to:

- High incidence of fines in gravels and pools.
- Continuously turbid water due to input from exposed clays in slide areas.
- Extremely low pool to riffle ratio (4 to 10% pools) in most segments. Pool filling with both coarse and fine material.
- Recent and continued shifts in Segment 120.
- Fish migration barrier at Old Stringer Bridge/Beaver Dam at upstream end of Segment 118.

Barriers:

- Stringer bridge downstream of Pipeline Road did in the past and may in the future be a barrier, but it currently is not a passage barrier.
- Culverts at Pipeline Road are a barrier.
- Beaver dam at Lynch Lake outlet is probably a barrier.
- Beaver dam on Lynch bank tributary and Lynch proper may form barrier.
- Shotgun culvert in Segment 116 is partially plugged causing water to flow down roadway during min or high flow events.
- Beaver dam at Stringer Bridge in 118 and 119 may be a barrier.

An Example from the Tolt River Resource Condition Report

Coarse Sediment *Continued*

Vulnerability Rating:
MODERATE: good potential and good existing habitat conditions in Lynch Creek proper. High vulnerability in Crazy Creek. It currently has good habitat potential in its alluvial reach and currently has poor habitat condition.

Contributing Hazards:
General
- Edge of continental glaciation.
- There is a problem area associated with a precipitous rock wall. Ancient landslide mixed between rock and old till is related to ice margin sediments. These slip off the hard rock walls.
- Recent road and non-road related slides related to an ancient landslide. There has been a lot of recent slide activity, especially in upper Crazy Creek.
- The rest of Lynch Creek on the glacial plain is not a problem.
- Roading is tricky.
- Landslides chronically generate both coarse and fine sediments.

Specific Areas
- Mass wasting Units 4-2 and 4-3 (rock slopes) (HIGH).
- Mass wasting Units 20-22 and 20-23 (ancient landslides) (HIGH).
- Mass wasting Unit 3 (fault trace) (HIGH).

Identified Fish passage barriers.
Routing Considerations:
Routing from upstream to downstream low gradient reaches occurs.

Confidence:
Good confidence on hazard identification and channel response based on method and field observations.

An Example from the Tolt River Resource Condition Report

Fine Sediment

Channel Condition:

- Fine sediments from landslides were observed trapped in beaver dam areas of Crazy Creek.
- Very high V* of silts and sands behind beaver dams (40-80% fill with yellow cake sediments). The source appears to relate to mass wasting, based on observations that sediment color matches the geology.

Public Resource Effects and Sensitivity:

- Segment 112 has some spawning gravel but only fair potential according to default call.
- No sediment sampling was conducted, but there appeared to be fine sediments stored in this segment. Elsewhere in Lynch Creek proper, spawning habitat appears to be in good condition.

Vulnerability Rating:

HIGH: based on current deposition of fines and good potential for rearing and spawning habitat.

Contributing Hazards:

- Bank erosion in Segments 112 and 116 are major sources for Lynch Creek proper.
- Landslides a major source of fines in Crazy Creek.
- No evidence of surface erosion from hill slopes related to soil or terrain.
- There were some trouble spots on roads (see map and list).
- Wind throw of riparian vegetation has uprooted trees, creating some erosion exposure in a location in Lynch Creek.
- Beaver dam failures could pose problem -- see catastrophic events section.

Routing Considerations:

Sediments routed from upper watershed to lower watershed and stored in beaver ponds.

Confidence:

Good, based on method and observations by field team.

An Example from the Tolt River Resource Condition Report

Peak Flow

Channel Condition:

- Channels are very unstable in the upper reaches of Crazy Creek and could be affected by flows.
- Wide low gradient sections in the middle reaches are probably not affected by flows.

Public Resource Effects and Sensitivity:

If fall spawning salmon occur in the Crazy Creek now or in the future they will be vulnerable to peak flows. No evidence of past effects.

Vulnerability Rating:

HIGH: based on vulnerability of channels to peak flows

Contributing Hazards:

General

- Most of the basin is in the rain dominated zone.
- Some of the vegetation is in sparse category but most is in small dense and large dense.
- Susceptibility to enhanced flows is inherently low and the vegetation is now in a favorable situation.
- Estimated Q2 increase is 6%.

Specific Areas
None identified.

Routing Considerations:

None

Confidence:

Upper reaches of Crazy Creek could be affected by peak flows, but the channel is so active that it's difficult to determine the influence of peak flows separate from the influence of sediment loading. Peak flows are probably not dominant, however.

An Example from the Tolt River Resource Condition Report

Large Woody Debris

Channel Condition:

- Lynch Creek channels have moderate wood volumes in areas not influenced by beaver dams.
- Crazy Creek channels are generally low in wood. Where present, wood functions in trapping sediment and forming stair steps in the steeper sections.
- Boulders are also functioning in forming pools.
- Moderate levels of LOD functioning to create pools in free flowing segments of Lynch Creek proper.
- Low amounts in Segment 112.
- Sensitive to loss of in channel LOD or interrupted recruitment.
- Low gradient channel nature means most of the wood remains within the system.
- Lack of LOD in Crazy Creek above Segment 118 -- sensitive to further loss where beaver dams don't form pools.

Public Resource Effects and Sensitivity:

- There is good rearing habitat in the beaver dam reaches and elsewhere in Lynch Creek proper.
- There are not many pools and not much LOD in the upper reaches of Crazy Creek but there is a lot of wood in the beaver pond segments.

Vulnerability Rating:

HIGH: based on function in providing pools and trapping sediments.

Contributing Hazards:

General

- Harvest within the last 10 years has left many stands in young conditions. About 70% of the system is rated as situation category RF1 (see maps dd-2 and dd-5).
- Most of the riparian area below Lynch Lake, except along the beaver ponds, are low in recruitment potential.

Routing Considerations:

None

Confidence:

Good based on method and field observations.

An Example from the Tolt River Resource Condition Report

Catastrophic Events

Channel Condition:

- Evidence that the channels in the upper reaches have experienced debris flows entering them in the past.
- Lower reaches are too low in gradient to pass debris flows through them.

Public Resource Effects and Sensitivity:

Immediate effects disastrous, indirectly affect spawning and rearing conditions in downstream areas of Crazy Creek and in Lynch Creek (Segment 112) where materials may be routed.

Vulnerability Rating:

HIGH, if occur.

Contributing Hazards:

- The old Stringer Bridge is now a beaver pond. It could pose erosion hazard and fish migration problems.
- Dam break floods from this or other beaver ponds in Crazy Creek could devastate downstream reaches in Lynch Creek.

Routing Considerations:

Confidence:

Good

An Example from the Tolt River Resource Condition Report

Temperature

Channel Condition:
Shade in beaver pond areas is achieved through alder, vine maple and willows covering most wetted areas, even when overstory shade is below target.

Public Resource Effects and Sensitivity:
May exceed water quality standards in reaches with low shade. Beaver ponds may be particularly susceptible to increased temperatures.

Vulnerability Rating:
HIGH

Contributing Hazards:
- There is adequate shade along much of the stream.
- Target shade is not being met in some locations (see map d-4).
- Depending on temperatures in Lynch Lake and its associated wetlands, the influence of this lake on downstream temperatures may be positive or negative.

Routing Considerations:
Inflow from Lynch Lake and associated wetlands may increase water temperature in segments below.

Confidence:

MODERATE. Based on TFW temperature method. Offsite influences could affect temperature not considered in method. Temperature monitoring would improve confidence

Form 5. Watershed Characteristics Format

Watershed Administrative Unit:

Drainage System:____

Location:____

Basin Area (acres):____

Climate:________________ Mean Annual Precipitation:________________

Elevation Range: ____

Geology: ____

Stream Density (mi/mi^2):_____________Road Density (mi/mi^2):_________

Vegetation (dominant): ____

Vegetation (sub-dominant): ______________________________________

Land Use: ____

Major Land Owners: ____

Water Supplies: ____

Major Capital Improvements: _____________________________________

____

Fisheries Resources: ____

____

____

____

Part 6 Prescription Writing Process

6.1 Watershed Analysis Management Response

The watershed analysis management response follows watershed assessment by using its products as the basis for writing prescriptions. Prescriptions are appropriate solutions to the issues or problems identified during the assessment processes and documented within the causal mechanism report(s) for individual watershed administrative units. Characteristics of the system include:

- Performed by a team of qualified field managers with appropriate expertise and training;
- Considers the assessment maps and causal mechanism reports from the Level 1 analysts or the Level 2 specialists plus the management response calls from the rule matrix;
- Provides flexibility for land owners in the form of options designed for specific situations;
- Provides protection for public resources through prescriptions for regulatory application;
- Provides opportunities for resource enhancement or restoration through actions that may be used voluntarily outside of regulations;
- Identifies problems or events not regulated by forest practices and forwards them in the report.

6.2 Basic Features

Prescription writing takes the products of watershed assessment and develops management solutions for use on the ground. The basic goal of watershed analysis is to protect and restore specific public resources, i.e., fish, water and capital improvements of the state or its political subdivisions, and the productive capacity of fish habitat, while maintaining a viable forest products industry. The role of prescriptions is to protect and allow the recovery of these resources. In areas of resource sensitivity as set forth in the rule, prescriptions must minimize, or prevent or avoid, the problems identified by the assessment. Since assessment is done on individual watersheds, prescriptions will address individual watershed problems generally on a resource specific basis.

Regulatory use of prescriptions in areas of resource sensitivity will be required for selected forest practices activities and situations identified by each watershed assessment (WAC 222-22-070(3)). Ideally, a number of prescriptions will be developed for each area of resource sensitivity, and landowners may select from a list of options, including alternate plans (WAC 222-12-040). Each prescription will appropriately address the stated problem(s).

Voluntary mitigation measures, initiated by landowners, are encouraged for resource enhancement or restoration. Voluntary actions may be used by the landowner to improve or restore resource conditions. Such voluntary actions may provide the foundation for cooperative projects.

Level 1 prescriptions and Level 2 prescriptions should be similar and the process should be the same. However, a Level 1 analysis with "indeterminate" findings leads to interim prescriptions, whereas a Level 2 (or a Level 1 that does not need Level 2) will lead to final prescriptions. Level 2 should provide for more site and sensitivity-specific prescriptions. The greater detail and understanding resulting from a Level 2 assessment will provide additional information that is transferred to the prescription process. In some cases, this information will require additional detail in the prescription process as well. Different prescriptions for each situation may be possible at Level 2 due to more specific assessment products.

Watershed analysis and the prescriptions process are based on the concept of adaptive management. Experience will help improve the process. A flow chart of the process is provided in Figure 12.

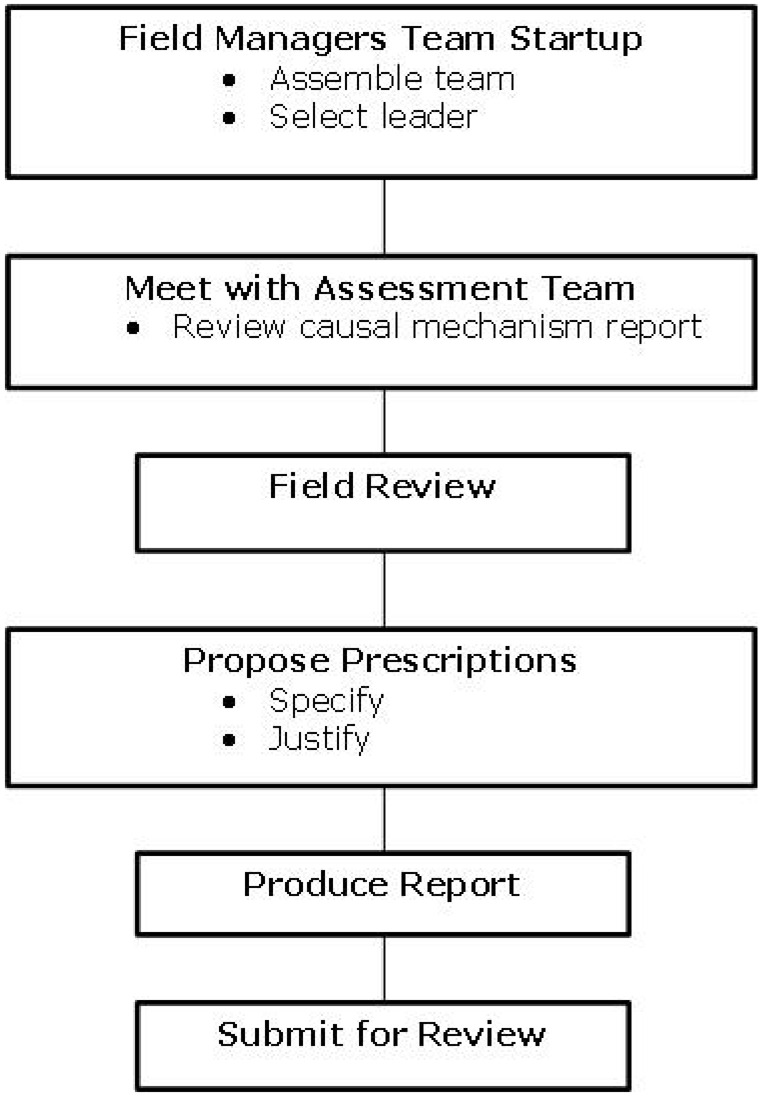


Figure 12. Field Manager's Team's Prescription Writing Process

6.3 Prescription Writing

1. ***Assemble the field managers team.*** Tentative assignments to the field managers team can be made when the assessment team is being formed. The final field managers team composition should reflect issues brought out in the causal mechanism reports from the assessment. The team composition should generally include expertise in forest management, engineering, hydrology, and fisheries science. Composition may vary depending on resource conditions and the watershed processes identified in the analysis. Individuals from a cross-section of qualified TFW or other participants, with local knowledge, are preferred as team members. Assessment files and information should be gathered and available to the prescription team. Photos, maps and field notes should be included.

2. ***Select a team leader.*** The team leader should be responsible for setting work schedules and completing the prescription package.

3. ***Meet with the assessment team.*** It is beneficial for members of the field managers team to observe the synthesis sessions of the assessment team. This helps the field managers understand how the various modules work together to identify problems contained in the causal mechanism reports. In addition, when the assessment phase is complete, it is essential for the assessment team to meet with the field managers team for a complete face-to-face hand-off of the assessment products. This provides a complete overview of all modules, and ensures that all reports are understood. Information gathered and developed during the assessment will be the basis for prescription writing. The watershed analysis team may have recommendations for prescriptions to be reviewed by the field managers. The involvement of the assessment team is to ensure the development of prescriptions that adequately address the areas of resource sensitivity.

4. ***Clarification of the causal mechanism reports, as needed.*** In some cases, the reports may have multiple underlying causal mechanisms which could be separated; prescriptions for the multiple mechanisms would be developed. Mapping may also provide some opportunity for refinements. Where the assessment identifies impacts caused by nonforestry related activities, the prescription team must take these into account and develop prescriptions only for those contributions related to forest practices. This is especially important in areas of mixed use. The management team should include those nonforestry related impacts in the final report for notification to the proper jurisdictional authorities.

5. ***Field review.*** Field review of resource sensitive areas may be necessary. Appropriate members of the field team should be on site for this review. The team should identify whether areas are resource specific (limited to identifiable sites) or basin wide.

6. ***Propose prescriptions.*** Each previously identified area of resource sensitivity will have causal mechanism reports. For each, there will be an assigned management response call from the rule matrix (Figure 13) and WAC 222-22-070(3). The team's task is to determine if and how specific forest practices and activities can be conducted consistent with the standard of protection required in the rule. Prescriptions must address the issues and processes identified in the causal mechanism reports and meet the rule standard.
   Where a proposed voluntary action would lead to a different set of prescriptions than those that would be necessary without the voluntary action, the team should describe, if possible, two (or more) alternative

series of actions: a prescription that is necessary if the voluntary action is not taken, and another prescription that is made possible by taking the voluntary action.

Prescriptions must be reasonably designed to meet the standard set forth in the rules (WAC 222-22-050(2)(d) or WAC 222-22-070(3)); they must either minimize or prevent or avoid as specified in the causal mechanism report based on the resource assessment, the likelihood of adverse change and deliverability that has the potential to cause a material, adverse effect to resource characteristics. In other words, prescriptions are to work on the "hazard" side of the equation. They are designed to minimize, or prevent or avoid, additional contributions to an existing problem or new contributions where a problem does not currently exist, but has the potential to exist; such potential needs to have been identified during the assessments. It is important to note, however, that the prescriptions are not required to minimize, or prevent or avoid, any further or potential contribution, but only those that have the potential to cause a material, adverse effect to a resource characteristic (e.g., damage to spawning habitat). These prescriptions are intended to create conditions in which these resources are allowed an opportunity to recover.

Where the matrix requires "minimize," the intent is to minimize the likelihood of those events or chronic circumstances identified in the causal mechanism report that have a potential for material, adverse impacts to resource characteristics; the intent is not to minimize the adverse impacts to the resource characteristics.

Cumulative Effects Rule Matrix

RESOURCE VULNERABILITY	Likelihood of Adverse Change and Deliverability: L	M	H
L	Standard	Standard	Prevent
M	Standard	Minimize	Prevent
H	Standard	Prevent	Prevent

Figure 13. Matrix used to produce management response calls for a given problem statement within a causal mechanism report (same as Figure 9 in Resource Assessment).

Where the matrix requires "prevent or avoid," the intent is to prevent or avoid events or chronic circumstances identified in the causal mechanism report that have the potential for material, adverse effects. One of the solutions may be to avoid or defer activities such as harvesting, road construction or use, salvage, that may contribute to the problems identified in the causal mechanism report. Other solutions could include technological solutions that prevent or avoid the effects of the forest practices identified as potential problems in the causal mechanism report.

The team's responsibility is to develop various ways to address the processes and issues identified in the causal mechanism report. Consideration should be given to all relevant factors. The team is encouraged to develop more than one prescription for each causal mechanism report. This allows landowners to select from a variety of options.

Each landowner in the watershed is entitled to submit draft prescriptions for its lands to the team. A landowner need not be qualified under WAC 222-22-030 to submit draft prescriptions for its lands. The team should compile all those prescriptions and discard those that are not reasonably expected to work. The team can use the various proposed prescriptions to prepare alternatives for each situation. Prescriptions will generally be resource specific, but may include broad responses such as road maintenance and abandonment plans. If the causal mechanism report requires, prescriptions might include a verification step, such as determination if an identified field condition actually exists on the site of the proposed forest practice. They should also include a mechanism for applying prescriptions to recognized land features identified in the WAU as areas of resource sensitivity but not fully mapped.

Currently utilized practices that are successful, versus standard forest practices as defined by rule or past practices, should be encouraged. Prescriptions might include an operational monitoring component or landowner plan to verify compliance. Staged operations are a possibility when there are appropriate prescriptions implemented consistent with the staging. Creative problem solving is essential for prescription writing and the inherent variation of assessment products.

Time frames for implementation of the prescriptions will be required where appropriate. For example, time frames with expected start and completion dates for road maintenance plans should be required.

7. ***Potential subjects.*** For issues identified in the causal mechanism report, the follow issues may need to be addressed:

I. Harvest

A. Method of harvest

1. even age or uneven age

2. yarding method (linked to roads)

3. designated skid trails

B. Harvest size limitation, if any, for rain-on-snow or other purposes

C. Timing of harvest activities (e.g., summer v. winter)

D. Wet-weather restrictions

E. Buffers

1. stream type

2. stream reach

3. wetland type

F. Hydrologic maturity

G. Possibility of no harvest

II. Road construction, maintenance, abandonment, and use

A. Construction

1. Location (including avoidance)

2. **Grade**
3. **Sidecast/endhaul**
4. **Drainage structures-design for 50- or l00-year storms**
    a) **Bridges, fords**
    b) **Culvert size, spacing, intake, outfall, skew**
    c) **Waterbars**
    d) **Outsloping**
    e) **Ditch size, depth, gradient, shape**
    f) **Vegetative protection or buffers**
5. **Road width control**
6. **Compaction**
7. **Rip-rap anchoring toe, retaining walls**
8. **Revegetating cuts and fills**
9. **Berms, dikes, debris racks, overflow channel**
10. **Surface material**
11. **Water management-gullies, natural drainage, cross-drains, wetland protection**
12. **Abandonment as a design standard**

B. Maintenance
1. **Frequency and timing**
2. **Drainage structures**
3. **Surface-crowned, insloped, outsloped**
4. **Emergency maintenance (e.g., storm events)**
5. **Monitoring, sampling**

C. Abandonment
1. **Water management**
    a) **natural drainage**
    b) **culverts**
    c) **bridges, fords**
    d) **cross-ditch size, location, spacing**
    e) **water bars**
2. **Surface treatment**
    a) **outslope**
    b) **inslope**
3. **Fill and sidecast**
4. **Revegetation**

5. Landing

D. Road Use

1. Timing

2. Activities

8. ***Support for prescriptions.*** Prescriptions must be expected to work. Sufficient rationale, based on local operational expertise or information from appropriate scientific literature, should be provided. This is not a literature review exercise but rather a reasonable demonstration that the proposed prescription will adequately address the specific processes and issues identified by the causal mechanism report. The explanation of the proposed prescriptions can be in several forms. Logic and reasoning relative to the causal report may be sufficient justification. Science and research reports that support the proposed prescription, or examples of successful prescriptions from past operations rather than avoidance as a prescription should be provided. The team shall document their technical rationale for selecting prescriptions.

9. ***Voluntary actions.*** The watershed analysis rules do not require restoration projects; however, there may be opportunities to identify such projects for voluntary implementation. The team should look for these restoration and enhancement opportunities and report on their scope and feasibility. Identification of these opportunities will be helpful to landowners and other resource managers in forming cooperative projects for specific watersheds. If used to justify alternative prescriptions, proposed restoration and enhancement projects must be proven to be successful (see previous section).

10. ***Report.*** The team should compile the prescriptions in an interim final draft report for the watershed. The format shall be consistent with the assessment report and products, with linkage between the products and prescriptions as needed. For each area of resource sensitivity, prescriptions should be clearly stated and complete. Maps and drawings may be helpful. Include appropriate definitions or explanations as needed.

11. ***Timing.*** Upon departmental acceptance of the assessments, the field managers team shall submit the prescriptions to the department within 21 days for Level 1 Analysis or 30 days for Level 2 Analysis (see WAC 222-22-070(4)).

12. ***Agency, tribal and public review of prescriptions.***
    a. *Final Watershed Analysis, Level 1 or Level 2*. The field managers team shall submit the final draft watershed analysis report to the

department (DNR). The department shall circulate the draft to appropriate divisions in the departments of fisheries, wildlife, and ecology, affected Indian tribes, local governments, affected landowners in the WAU and the public for their review and comments (see WAC 222-22-080(1)). This is a 30-day circulation period.

b. *Interim Watershed Analysis, Level 1 Only*. Before submitting recommended interim prescriptions to the department, the field managers team shall review the recommended prescriptions with available representatives of the jurisdictional management authorities of the fish, water, and capital improvements of the state. This includes, but is not limited to the departments of fisheries, ecology, and affected Indian tribes. The team shall provide for a reasonable period of time for comments; such comments must occur within the 21 days required by rule. See number 11 (Timing) above.

A copy of the draft report should also be provided to the relevant watershed analysis team. The team may, when consistent with existing laws, rules and methods, incorporate agency and tribal input for the development of an interim/final report.

13. ***Interim/Final Watershed Analysis Report.*** The field managers team attaches the prescriptions for each identified resource sensitivity (recorded on Form 6) to the Causal Mechanism Report. This combined report is termed the Watershed Analysis Report for the WAU. The report will be considered interim if there are indeterminates within the resource assessment (Level 1). The report will be considered final when the indeterminates have been resolved by Level 2 analysis and prescriptions. Include non-forest practice related contributing activities.

14. ***The interim or final report will be submitted to the department.***

a. *In WAUs* that contain no areas of resource sensitivity or no indeterminate ratings, Level 1 Analysis is considered final after approval by the department.

b. *In WAUs* that contain indeterminate ratings, Level 1 Analysis is considered interim after approval by the department. It is anticipated that such WAUs will receive Level 2 Analysis, converting the interim into final.

c. *Level 2 Analysis* is considered final after approval by the department.

Review Process

1. ***Review of watershed analysis.***
   a. *Final Watershed Analysis.*
   The department shall circulate copies of the final watershed analysis (assessments plus prescriptions, if any) to other relevant state and federal resource management agencies, affected Indian tribes and local governments, forest landowners, and the public for their review and comment according to the rules. The department shall review the comments and revise the watershed analysis as appropriate, and approve or disapprove the analysis within 30 days of the receipt of the watershed analysis report (WAC 222-22-080(1)).
   b. *Interim Watershed Analysis.*
   Interim Level 1 watershed analysis products are not circulated (see WAC 222-22-080(1)) but comments to the department are encouraged, subject to the timing mandates established by WAC 222-22-050(5) and WAC 222-22-070(4). Copies will be available for review at the regional office.

2. ***State Environmental Policy Act.*** The Forest Practices Board has directed the department to consider the approval of a watershed analysis as a governmental action subject to SEPA. The responsible official is the RP&S Assistant Regional Manager, DNR.
   a. *The field managers team* for any watershed analysis shall prepare an environmental checklist. Parties conducting watershed analysis shall prepare the SEPA documents at their sole expense.
   b. *The responsible official* shall review the checklist for adequacy and make a draft threshold determination.
   c. 15-day SEPA Comment Period.
      i. Final Watershed Analysis. The determination shall be circulated for a 15-day commentary period during the same time period that it circulates the draft watershed analysis under WAC 222-22-080(1).
      ii. Interim Watershed Analysis. There is no 30 day circulation period required under the forest practice rules (WAC 222-22-050(5)). The department shall circulate the interim watershed analysis environmental checklist threshold determination for a 15-day SEPA review.
   d. *Subsequent to the evaluation* of the comments, the responsible official may approve, modify or deny the watershed analysis. In some circumstances, an EIS may be required.

Form 6. Suggested Format for Prescription Writing

WAU:____

Resource Sensitivity Number:____

Situation Sentence for the Area (from causal mechanism report):

____

____

____

Triggering Mechanism (from causal mechanism report):_________________

____

____

____

Rule Call for Management Prescriptions (from causal mechanism report):___

Field Observations:____

____

____

Prescriptions:____

____

____

____

____

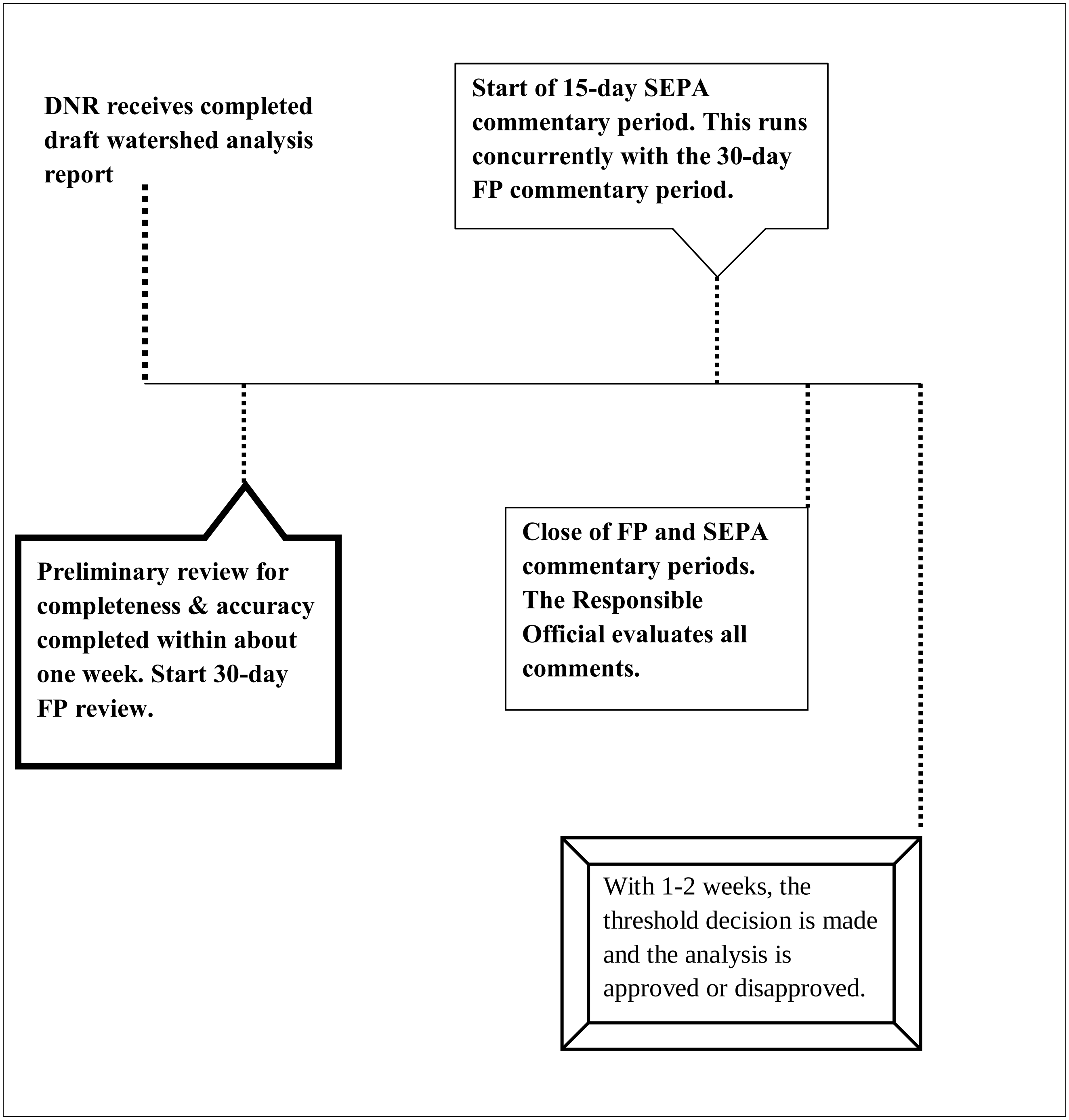
Justification for Prescriptions:_______________________________________

____

____

____

Review of Watershed Analysis by the Department of Natural Resources



Part 7 Monitoring Program Identification Process

7.1 Introduction

After completion of the assessment and prescription process, management practices developed by the prescription team will be applied in the sensitive areas identified. The managers of the forest, fish and water resources need to know whether these prescriptions are working and if resource goals are being achieved. Monitoring information can play an important role in evaluating the effectiveness of watershed analysis, determining trends in the conditions of resources and providing direction for future resource management. (See Figure I-1 in the Introduction to Watershed Analysis section).

The purpose of the monitoring module is to provide guidance for monitoring programs to evaluate the effectiveness of watershed analysis in achieving watershed-specific objectives. Monitoring must answer two questions in order to be useful in the context of watershed analysis: 1) are the prescriptions effective in preventing cumulative effects; and 2) how are the resources of concern responding to the protection provided by watershed analysis?

The effectiveness of forest practices prescriptions can be determined by monitoring the response of triggering mechanisms and input processes. Monitoring the status of stream channel, fish habitat and water quality conditions can determine if the resource objectives of the watershed analysis are being met.

The formal mechanism for using monitoring information in evaluation of watershed analysis and adaptive management is provided by WAC 222-22-090 *(4) of the forest practices rules. This section requires DNR to evaluate the effectiveness of prescriptions in providing for protection and recovery of resources in cases where the condition of resource characteristics or indices of resource conditions is fair or poor. If resource conditions are found to be fair or poor, information gathered through monitoring will be critical for evaluating whether the trend in resource condition is improving consistent with the intentions of the WAC.

In addition, monitoring information can be used to guide local management decisions and cooperative efforts for additional resource benefits. Monitoring can provide adaptive management feedback to help refine and improve the analysis over time.

The monitoring module is based on several underlying principles. Watershed analysis monitoring uses a watershed-based approach that examines the relationships between prescriptions, triggering mechanisms, input processes and associated channel, habitat and water quality effects. These linkages provide a context for interpretation of monitoring results. Monitoring plans are developed and implemented locally (for each watershed) and cooperative monitoring efforts are encouraged to reduce costs and share responsibilities. Monitoring parameters are chosen to be consistent with local conditions, processes, and resources based on watershed-specific information from the causal mechanism, resource assessment, and prescription reports and the knowledge of people familiar with the watershed. Standard methods will be available.

This module provides guidance so people with different backgrounds and skills can develop monitoring plans that will produce consistent and useful monitoring information.

7.2 Critical Questions

Watershed analysis monitoring is designed to answer two fundamental questions:

Are the prescriptions effective in controlling identified trigger mechanisms and maintaining related input processes within acceptable ranges?

Are the conditions of the channel, fish habitat, water quality, water supply or public works responding as expected?

7.3 Assumptions

Watershed analysis monitoring is based on the following assumptions:

1. Cause and effect linkages exist between forest practices (prescriptions), triggering mechanisms, input processes and channel, fish habitat, water quality, water supply and public works conditions.

2. The Causal Mechanism Reports identify the key linkages and provide testable hypotheses that can be used to test the effectiveness of watershed analysis.

3. Changes in the condition of stream channels, fish habitat and water quality, water supply and public works can be detected and measured.

4. Trends in resource conditions over space and time can be distinguished from natural variability.

7.4 Overview of Procedure and Products

The following is a listing of when the major steps occur in the watershed analysis process for preparing a monitoring plan and implementing a cooperative monitoring program. The product produced is a Monitoring Plan Report for filing with DNR and for use during cooperative implementation efforts.

Start-up

- Project manager instructs each resource assessment team leader and prescription team leader to identify potential monitoring objectives.

Resource Assessment

- Assessment teams identify potential monitoring objectives.

Synthesis

- Assessment team leaders discuss potential monitoring objectives during the module report presentations.

Prescription

- Prescription teams identify potential monitoring objectives.

Wrap-up

- Wrap-up team discusses potential monitoring objectives.
- Team selects final monitoring objectives for inclusion in the monitoring plan.
- Prepare the monitoring plan report for filing with DNR.

Voluntary Implementation

- Project manager convenes stakeholders to discuss monitoring plan report.
- Identify participants volunteering for monitoring implementation.
- Select a coordinator from volunteering participants.
- Develop a cooperative monitoring implementation workplan.
- Implement the workplan.

7.5 Qualifications

Participating resource analysts, managers, and members of assessment and prescription teams are qualified to participate in the development of a monitoring plan.

7.6 Background Information

Much of the information needed to prepare a watershed analysis monitoring plan is found in the watershed analysis documents. The team will need a copy of the resource assessment, causal mechanism, and prescription reports. Maps showing areas of resource sensitivity and channel response segments will be needed. Other useful information includes past monitoring data and sources of standard methods, such as the TFW Ambient Monitoring Program Manual.

7.7 Procedure

The procedure for the Watershed Analysis Monitoring Module is presented in two sections. The first section describes how to develop a monitoring plan. The second section discusses cooperative implementation of the plan and procedures for collecting, interpreting and using monitoring data.

Section 1. Developing a Watershed Analysis Monitoring Plan

Each monitoring plan is developed during the wrap-up phase by representatives of the resource assessment and prescription teams. The plans are tailored to watershed-specific conditions and concerns documented in the resource assessment, causal mechanism, and prescription reports. The monitoring module does not generate the local information needed to develop a monitoring plan. Instead, it provides guidance for using information gathered during watershed analysis along with other local sources to develop an effective monitoring plan.

Step 1: Initial Discussion

During the start-up phase of watershed analysis the project manager should discuss the issue of monitoring with participating organizations and stakeholders, informing them that a monitoring plan will be developed during wrap-up and that a decision on whether to cooperatively implement the monitoring plan will need to be made following the completion of watershed analysis.

The project leader should also remind leaders of the assessment teams and the prescription team that they should document information on situations that would benefit from monitoring and record that information in module write-ups. At synthesis, the assessment module team leaders should discuss potential monitoring ideas as part of the assessment module presentations.

Step 2: Identifying Watershed-Specific Monitoring Objectives

One of the most important tasks is to clearly identify specific monitoring goals to provide the focus needed for a successful monitoring plan.

The primary goal of watershed analysis monitoring is to determine if watershed analysis has been effective in achieving resource management objectives. This section provides guidance for translating this general goal into specific monitoring objectives for each watershed.

Developing specific monitoring objectives is a critically important step in putting together an effective monitoring program. Specific monitoring objectives will keep the monitoring program focused and efficient, and help ensure that the information collected serves a useful purpose. The procedure in this section provides a means of identifying, evaluating and prioritizing potential watershed-specific monitoring objectives.

Identifying potential monitoring objectives

The causal mechanism reports are the main tools used to identify monitoring objectives relating to effectiveness of watershed analysis. Each causal mechanism report identifies a cause and effect relationship between forest practices, input processes and resource effects that can be evaluated with monitoring data. The resource assessment reports and prescriptions are additional sources of useful information for identifying monitoring objectives when used in conjunction with the causal mechanism reports.

Using the monitoring objective work sheet

Form M-1 provides a suggested format to assist in the process of identifying and evaluating potential monitoring objectives, and organizing information useful in evaluating each monitoring objective. As you examine the information discussed above and identify potential monitoring issues or situations, use the suggested format to develop a narrative discussion of each potential monitoring objective. The following section describes the information that should be included in each narrative. However, feel free to include additional applicable information not specified below.

Monitoring objective. There are several potentially useful alternative approaches for identifying monitoring objectives. One approach is to base the monitoring objectives on the cause and effect relationships between input processes and resource conditions described in the causal mechanism reports.

In these cases the monitoring objective will often be to evaluate the effect of the prescriptions on triggering mechanisms, input processes and resource conditions over time. Monitoring to achieve this objective is recommended in cases where the condition of the resource characteristics is determined to be fair or poor as measured by indices of resource condition in the resource assessment reports. An example of a monitoring objective derived from a causal mechanism report (and the relevant prescriptions) might read:

"To evaluate the effectiveness of the road maintenance prescription for Surface Erosion Mapping Unit (SEMU) 2 in reducing fine sediment levels in spawning and incubation habitat in Channel Segment 6."

Another approach used to identify monitoring objectives (which may be faster) begins with identifying a critical resource objective(s). Then the resource assessments and causal mechanism reports are used to identify what input processes are affecting the resource. Work through the relevant cause-effect pathways to identify potential parameters related to the resource of concern. This type of monitoring objective may capture the effect of multiple input processes on a critical resource. A monitoring objective of this type may state:

"To monitor the status of older age-classes of resident cutthroat trout in Segment 10 as a means of evaluating whether the combination of prescriptions affecting LWD recruitment, coarse sediment input and catastrophic events are improving rearing habitat for those age-classes."

Finally, monitoring of the biological resource itself, such as fish populations, may provide a means of truly understanding the biological response to input processes and channel conditions.

Source. List the source of information that each monitoring objective is based on, such as a specific causal mechanism report, resource assessment report, assessment or prescription team suggestion, etc.

Monitoring hypothesis. The next question requires formulation of a hypothesis for each monitoring objective. Where the monitoring objective is based on a causal mechanism or resource assessment report, the cause and effect relationship needed to develop a monitoring hypothesis has already been identified. For example, a hypothesis based on a causal mechanism report might state:

"The road maintenance prescription for SEMU 2 will reduce sediment delivery to the stream system, reducing fine sediment levels in spawning and incubation habitat in Channel Segment 6."

Current status. Describe the current situation using information in the causal mechanism and resource assessment reports, and the knowledge of team members. Discuss the past effects of natural events, forest practices and other activities that have contributed to current conditions. An example of a description of current status may state:

"Surface erosion from roads in SEMU 2 has been delivering moderate amounts of fine sediment to the stream system for the last ten years. A large storm event in 1989 deposited large amounts of fine sediment from upstream bank erosion and mass wasting. Spawning gravel fine sediment levels in channel segment 6 are elevated (mean of 16.1% <0.85 mm)."

Future prognosis. The future prognosis should be developed by assessment team members based on the current situation, the expected response to future management, and natural disturbance/recovery cycles. Watersheds are dynamic physical systems subject to natural or management-induced disturbances that create cycles of disturbance and recovery over time so a variety of future outcomes are possible. The time-frame required for recovery from disturbance depends upon factors such as the magnitude of disturbance, the frequency of disturbance, distribution of the disturbance over the stream network, the type of process involved, and inter-relationships with other processes. To determine if a system is responding as predicted in the monitoring hypothesis, it is important to know the time-frame over which changes, such as recovery from past disturbance, are expected to occur. It is also important to identify other factors that could affect the rate or direction of change over time. This information will help in the evaluation of resource recovery in WAC 222-22-090 *(4) by establishing realistic expectations for resource response. An example of a future prognosis might read:

"Implementation of the road maintenance prescription in SEMU 2 is expected to result in a decrease in fine sediment delivery to the stream channel. Reduction in the spawning gravel fine sediment levels in Segment 6 is expected to occur over the next 5-10 years, at which time levels should stabilize at a mean of less than 12% <0.85mm. Mass wasting and/or bank erosion associated with a large peak flow event could temporarily reverse or slow the recovery process."

This is also a place to capture critical uncertainties which arise due to the fact that we may not have a thorough knowledge of a watershed process, or we cannot accurately predict the probability of disturbance or the rate of recovery.

Potential monitoring parameters and their feasibility. The next part of the work sheet provides spaces to record potential monitoring parameters and comments about their feasibility and applicability to the monitoring objective. This is an identification of the basic "how to's" for possible monitoring. Detailed plans will be developed during cooperative implementation for selected objectives.

A parameter is defined as a variable used as an indicator to gage in a quantitative manner whether there has been a change to part of a system. Be specific when identifying parameters, keeping in mind what data needs to be generated and how it will be analyzed and used. For example, pool habitat is too general to be a useful monitoring parameter. More specific parameters are used to measure pool habitat depending on the linkage to input processes that are being monitored. Examples of parameters to measure pool habitat include: pool surface area as a percentage of total surface area, channel widths per pool, and residual pool depth.

Spaces are provided for parameters related to input processes, triggering mechanisms, channel effects, habitat effects and water quality effects. All types of parameters will not be relevant in each case so fill out only the appropriate ones for each monitoring objective.

Use the comment section to record factors such as relevance or feasibility that make certain parameters better choices than others for inclusion in the monitoring plan. For example, measuring changes in stream flow may be very expensive and require a long period in order to produce a meaningful data set.

Appendix A shows a variety of possible parameters for triggering mechanisms, channel, and fish habitat effects and the input processes that they are associated with. See MacDonald et al. (199I) and the TFW Ambient Monitoring Program Manual for additional information on monitoring parameters related to forest practices and their effects.

Step 3: Determining monitoring objectives
The next step is to finalize and prioritize the potential monitoring objectives. This step involves winnowing through the possible objectives and narrowing the field to those which will be most efficient, useful and informative, and eliminating those not meeting these criteria.

Selection of final monitoring objectives is a judgment of the team about the relative importance of the objectives and their ability to answer the key questions. The worksheet information is useful for evaluating and comparing potential monitoring objectives, but does not provide a formula for final selection among objectives. Use Form M-3 to document the selected objectives. If priorities are determined among final monitoring objectives, note relative importance as a comment.

Step 4: Prepare a Monitoring Plan Report
Once the final monitoring objectives have been identified and prioritized, the team assembles this information in written form. The monitoring plan is not part of the final Watershed Analysis Report submitted to DNR for approval, however it should be filed with DNR as a separate report for future reference. The monitoring report should include the selected monitoring objectives and document the process used to identify and select these parameters.

Section 2. Cooperative Implementation of Watershed Analysis Monitoring

Implementation of the monitoring plan is done through cooperative efforts by stakeholders. As such, the actual monitoring done depends on resources available through various stakeholders and their commitment of those resources to a monitoring program. There will be cases where no monitoring is done, cases where some of the plan is done and cases where the plan is done as designed.

Step 1: Determine the amount of cooperative commitment for implementation of monitoring

The project manager for the watershed analysis convenes a meeting of interested stakeholders to discuss the monitoring plan report and determine the level of interest in cooperative implementation of a monitoring program. The monitoring plan report provides guidance for monitoring to answer the key questions. Additional monitoring goals may be discussed. Stakeholders should be encouraged to help implement the developed plan first, before adding additional objectives.

Determine the commitment of cooperative resources to a monitoring program. Determine any specific commitments to individually identified objectives. Based on the level of cooperative commitment of resources, decide whether to proceed with detailed development of a monitoring program.

Select a coordinator from volunteering cooperators to manage the development of a monitoring workplan and coordinate its implementation. The coordinator works with cooperators, ensuring that monitoring is carried out on schedule and according to plan. A feedback loop is recommended to provide for review and revision of the monitoring workplan to ensure that program objectives are being met. The coordinator structures meetings as needed to share results, review progress and distribute data. The coordinator should be experienced in project management with some knowledge in operational monitoring and quality assurance.

Step 2: Develop a cooperative monitoring workplan

The actual design of monitoring activities needs to be done with utmost care. The goal is credible data that answers the key questions. Use standard methods, such as those developed by the TFW Ambient Monitoring Steering Committee or other recognized available methods, to provide the needed consistent quality of data. Poorly designed monitoring will not provide answers to the questions being asked. It is recommended that special expertise be recruited to assist in this effort. Experience in natural resources monitoring and statistical design of sampling programs is recommended. The TFW Ambient

Monitoring Steering Committee has experience and knowledge in this area and could be called on for assistance and advice.

Based on the commitments made in Step 1, develop a detailed workplan for the selected objectives. For each selected objective, the details for parameters to sample are defined. Sampling design should include such factors as sampling location, sampling intensity, sampling methods, sampling schedule and quality control/quality assurance. Data analysis needs should be considered. Completion of the module includes a report developed cooperatively by the participants that summarizes results. Form M-4 provides a possible format for organizing the elements of the monitoring workplan.

Step 3: Implement the workplan

The actual implementation of the monitoring workplan is done by participating cooperators as agreed on during the development of the monitoring program. Each cooperator assumes the operational responsibility for their respective portion of the program. It is essential that all cooperators follow through with their commitment, ensuring that procedures, schedules and quality controls are carried out as designed. Individuals taking the samples should be adequately trained in the field procedures assigned. The TFW Ambient Monitoring Steering Committee provides training in proper field procedures for many parameters and additional methods are being developed. Cooperators will work with the coordinator during implementation of the workplan.

Table M-2. Monitoring Module Task Checklist

Review	Task	Schedule	Complete
	Project manager instructs each resource assessment team leader and prescription team leader to identify potential monitoring objectives.		
	Assessment teams identify potential monitoring objectives.		
X	Assessment team leaders discuss potential monitoring objectives during the module report presentations.		
	Prescription teams identify potential monitoring objectives.		
	Wrap-up team discusses potential monitoring objectives.		
	Wrap-up team selects final monitoring objectives for inclusion in the monitoring plan.		
X	Prepare the monitoring plan report for filing with DNR.		

7.8 Acknowledgments

The Watershed Analysis Monitoring Module is the product of a concerted effort by the Ambient Monitoring Steering Committee and the TFW Ambient Monitoring Program. This version of the module was written by Dave Schuett-Hames, with revisions by Bob Gustavson and Blake Rowe. It incorporates many concepts and suggestions from the Ambient Monitoring Steering Committee and other reviewers including Stan Donda, Hans Ehlert, Mark Hunter, Jeff Light, Randy MacIntosh, George Pess, Allen Pleus, Ed Rashin, Ed Salminen, and Julie Thompson. Dennis McDonald assisted in editing this document.

The Northwest Indian Fisheries Commission and the Washington Forest Protection Association provided funding for development of this version of the monitoring module.

7.9 References

MacDonald, L.H., A.W. **Smart** and R.C. **Wissmar**. 1991. Monitoring guidelines to evaluate the effects of forestry activities on streams in the Pacific Northwest. EPA/910/9-91-001. Environmental Protection Agency. Seattle.

Schuett-Hames, D., A. **Pleus**, L. **Bullchild** and S. **Hall**. 1993. TFW Ambient Monitoring Program Manual. Northwest Indian Fisheries Commission. Olympia.

Schuett-Hames, D. and G. **Pess**. 1994. A strategy to implement watershed analysis monitoring. Northwest Indian Fisheries Commission. Olympia.

Form M-1. Outline for Cooperative Monitoring and Objective Worksheet

WAU____

Date____

Potential Monitoring Objective

Source

Monitoring Hypothesis

Current Status

Future Prognosis

Potential Monitoring Parameters

Input Process

Triggering Mechanisms

Channel Effects

Habitat Effects

Water Quality Effects

Form M-2. Prioritizing Cooperative Monitoring Objectives Worksheet

Priority Number/ Objective Number	Monitoring Objective	Reasoning/Comments

Form M-3. Outline for Watershed Analysis Cooperative Monitoring Objective Description

WAU__________________________________ Date______________________

Monitoring Objective Priority Number _____

Monitoring Objective

Source

Monitoring Hypothesis

Current Status

Future Prognosis

Monitoring Parameters Selected

Form M-4. Outline for Watershed Analysis Cooperative Monitoring Workplan Parameter Description

WAU___________________________________ Date_____________________

Monitoring Objective Priority Number _____

Parameter

Type of Parameter

Sampling Location

Data Collection Methods

Sampling Design and Procedures

Data Analysis Procedures

Quality Assurance Plan

Products

Roles and Responsibilities of Participants

Lead Organization:

Project Leader:

Phone:

Address:

7.10 Possible Parameters for Watershed Analysis Cooperative Monitoring

The following parameters have been identified from existing Watershed Analysis Causal Mechanism Reports. Currently the only CMER approved standard methods are in the TFW Ambient Monitoring Program Manual (July 1993). Additional parameters will be added to the list as identified in the future. When developing standard methods for each parameter it is desirable to consider both high and low methods for stakeholders to be able to choose from. Development and adoption of additional standard methods for other parameters is dependent upon future efforts and/or funding. (A Strategy to Implement Watershed Analysis Monitoring 1994)

Triggering mechanisms

- Aerial photo landslide inventory
- Slope stability analysis
- Deep-seated landslides
- Road assessment procedure
- Surface erosion survey
- Fine sediment delivery
- Aerial photo survey of riparian vegetation
- LWD recruitment
- Aerial photo survey of rain-on-snow (ROS) zone vegetation
- Site-specific peak flow runoff monitoring

Channel effects

- Channel substrate size (fining or coarsening)
- Channel aggradation or degradation
- Channel widening, braiding, lateral migration and bank erosion
  - Aerial photo method
  - Field methods
- Sediment storage features

Fish habitat effects

- Spawning gravel scour
- Redd de-watering
- Spawning gravel sedimentation and redd entombment **(TFW AM Manual)**
- Spawning gravel availability
- Water temperature **(TFW AM Manual)**
- De-watered habitat (sub-surface flow) **(TFW AM Manual)**
- Macro-invertebrates
- Pool rearing habitat

(TFW AM Manual)

- Overhead/instream cover
- Pool refuge habitat
- Interstitial refuge habitat
- Large woody debris (LWD) refuge cover
- Off-channel refuge habitat
- Adult holding pools
- Passage blockage

Part 8 Review and Reanalysis of Watershed Analysis

Flooding and landslides associated with the 2007 storm events in western Washington led the Forest Practices Board (Board) to request a review of watershed analysis rules . The Board questioned the effectiveness of watershed analyses (WAS) prescriptions associated with approved watershed analyses (WSA) and their ability to provide necessary protection to public resources. Consequently, the Board directed the Adaptive Management Program to develop recommendations for change if needed. This led to the Department of Natural Resources (DNR) developing a watershed analysis review and a revised WSA mass wasting prescription reanalysis process (see Appendix K).

This part of the Watershed Analysis Board Manual contains guidance for completing a review and reanalysis on an approved watershed analysis. The guidance supplements chapter 222-22 WAC, which regulate forest practices on forest lands with approved watershed analyses.

8.1 Review Overview

DNR will perform a review on approved watershed analyses (WSA) to determine if a reanalysis is necessary in order to maintain current prescriptions. The WSA reviews occur when specific criteria are met and specific steps must be followed during performance of the reviews. The criteria and steps are outlined below.

1. Periodic WSA review is required and is based on WAC 222-22-090 which provides the following criteria:
   - A review will take place five years after the date the watershed analysis is final, and every five years thereafter; or
   - The occurrence of a natural disaster; or
   - Deterioration in the condition or no improvement of a resource characteristic in the watershed administrative unit (WAU).

2. DNR will notify forest landowner(s) in the WAU when a review is conducted on their approved watershed analysis and DNR has determined that reanalysis is necessary.

3. For any approved watershed analysis, the DNR will determine which WSA prescriptions and modules will be reanalyzed, if applicable.
   - DNR will provide opportunities for stakeholder input regarding prescriptions for reanalyzed WSAs.

4. Forest landowners must either accept the reanalysis or give up existing WAU prescriptions.

5. If the landowner chooses not to conduct a reanalysis DNR will initiate a nonproject State Environmental Policy Act (SEPA) checklist to eliminate the identified WSA prescriptions.

Forest landowners with habitat conservation plans (HCP) are exempt from DNR watershed analysis reviews per WAC 222-12-041, if watershed analysis prescriptions have been incorporated into their HCP. Reviews of privately-sponsored watershed analysis associated with an approved federal HCP are on schedules established through their HCP agreement. All reanalysis of WSA prescriptions on HCP covered lands will continue to be reviewed in cooperation with DNR.

8.2 Reanalysis Overview

When a DNR review determines that a reanalysis is necessary and landowners in the WAU decide they would like to retain their approved watershed analysis prescriptions the subsequent steps will be followed:

1. DNR will solicit forest landowners with 10% or greater forest land ownership within a WSA area to determine who may be willing to sponsor, co-sponsor, or assist in a reanalysis. A schedule for reanalysis will be established once the landowner(s) responds. This schedule will incorporate input from the forest landowners regarding their level of participation.

2. Once the landowner commits their resources to completing a reanalysis, DNR in consultation with the departments of ecology and fish and wildlife, affected Indian tribes, forest landowners, and the public shall establish a timeline for the reanalysis. DNR will work with individual forest landowners who are sponsoring or participating in reanalyses to consider appropriate schedules.

3. DNR may request a meeting to gather new information and concerns from interested parties pertaining to the specific module(s) included within the reanalysis.

4. DNR will notify the forest landowner(s) they have the following options:
   a. Sponsor or co-sponsor a reanalysis, or
   b. At any time during the reanalysis process, DNR, in consultation with the forest landowner(s), can rescind the WSA prescriptions and use the applicable forest practices rules for the module being reanalyzed (i.e., target module).

8.3 Reanalysis Start-up

1. DNR notifies the landowner, the departments of ecology and fish and wildlife, affected Indian tribes, relevant federal agencies and local governmental entities, and the public that a reanalysis is necessary.

2. DNR will provide the specific prescription(s) and target module(s) needing reanalysis.

3. DNR will determine the degree of expertise required to conduct the reanalysis.

4. DNR will provide necessary training for module(s) being reanalyzed.

5. DNR will determine the geographic area(s) being reanalyzed.

6. DNR in consultation with the departments of ecology and fish and wildlife, affected Indian tribes, forest landowners, and the public will develop a reanalysis timeline.

7. Supportive Documentation
   DNR with the landowner's assistance will provide the required start-up maps and supportive documentation. Reference Table 2 located in Start-up, Appendix A located at http://www.dnr.wa.gov/Publications/fp_wsa_manual_section02.pdf.
   - Map of previous years forest activities prior to initial watershed analysis.
   - Map of Forest Practices Applications (FPAs) completed in the WAU in the past five years - include all applicable FPA numbers.
   - Map of known restoration projects completed in the WAU in the past five years.
   - Any reports about the area written since the last review.
   - Any monitoring data collected since the last review.
   - There are established maps, tables, and report requirements that are

- standard WSA products, and many of these should be included in a reanalysis document.
- Aerial photos, LiDAR, and other appropriate tools are encouraged to be
- used.

8. Critical Questions

The objective of each watershed analysis module is to guide development of information necessary to address questions critical to understanding the natural and anthropogenic processes in a watershed.

- DNR in consultation with stakeholders will develop critical questions for the reanalysis based on an assessment of the questions from the current approved watershed analysis, taking into account any changes that have occurred in the watershed. Pertinent involvement by stakeholder groups will be encouraged while developing these critical questions.
- Mass Wasting Reanalysis Critical Questions (Appendix K).

9. Assumptions

- A number of fundamental assumptions are outlined in each current
- approved watershed analysis module. It is important to review these assumptions and determine if they remain valid in relation to current scientific knowledge, new rules that may render them obsolete, and/or innovative field or assessment methods.
- New assumptions can be established by the landowner if they are supported by new data and/or science, documented and shared with stakeholders, and approved by DNR before the reanalysis begins.

10. Qualifications

- DNR, per WAC 222-22-030, will determine the qualifications for participation in both the resource assessments and prescription teams for reanalyses. DNR will provide training to explain the resource assessment and reanalysis process to prescription teams.
- The State of Washington requires an Engineering Geologist license for assessing and making recommendations for forest practices activities associated with potential unstable slopes and landforms (Appendices A and K). DNR established that Qualified Experts for FPA review of unstable slopes requires 3 years of experience evaluating unstable slopes in the forested environment (WAC 222-10-030(5)).
- Modules other than mass wasting may require different qualifications. DNR will determine the qualifications for participants in reanalysis of these modules and prescriptions for these modules.

8.4 Reanalysis Process

1. Flow chart for the reanalysis process

   - The sponsors of the reanalysis are encouraged to create a flow chart of the assessment process and assign tasks. DNR in consultation with forest landowner(s), and analysts will determine timelines and milestones such as field work and report writing. DNR will identify reviewers and a schedule for the completion of the reanalysis will be outlined.

2. Maps
   - DNR will provide background maps for the reanalysis of the target module(s). Many of these resources are available to download from DNR's spatial GIS layers at http://www.dnr.wa.gov.
   - Forest landowner(s) assessment maps will follow map standards provided by DNR. Reanalysis maps pertinent to each target module(s) and resource assessment(s) will maintain the current approved watershed analysis maps' naming conventions and include new dates.

3. Resource Inventory
   - The target module(s) will drive the assessment requirements for the reanalysis. Maps or tables from the current approved analyses will be updated by the sponsor(s). Attribute requirements should follow the current approved WSA in order to be comparable and show changes in the condition of the watershed. Use the same numbering, classifying, and protocols outlined in the current approved analyses. DNR recommends using the current approved WSA mapping standards for reanalysis maps. Modern techniques such as LiDAR or higher resolution aerial photography, if available, should be used.

4. Field reconnaissance
   - The current board manual process for the target module(s) in Parts 2 and 3 will guide the appropriate level of field and or office review. Procedures and field protocols should be comparable with the current approved WSA and current version of the WSA Board Manual.

5. Review of historic and present conditions
   - The reanalysis should include a thorough review of the background information in the current approved module data. This data should inform the analyst on how to supplement that information for the period of time since the last current approved watershed analysis was completed. Analysts should review the entire WSA Report to gain an understanding of the watershed overall.

6. Tables and Matrices to update
   - The reanalysis of a module will update existing data sheets, attribute and summary tables, and any other scientific monitoring or collection records used in the current approved module assessments.
   -
7. New Scientific Considerations
   - Generally use literature published since the approval date of the current
   - approved watershed analysis (DNR has the approval date of all of the approved watersheds). The reference sections for each current approved module are a starting point for literature searches.
   - Consider pertinent literature relevant to critical questions.
   - Consider relationships to other Resource Modules (see causal mechanism reports within each current approved WSA).

8.5 Synthesis

Evaluate and compare the approved watershed analysis causal mechanism reports to the reanalysis modules to determine the reanalysis prescription's relationship to other modules.

1. Hazards, Resources, and "Triggers"
   a. Triggers, in the context of watershed analysis, are the cause for resource degradation. Look at the relationships between the new hazard assessments, resource sensitivities and triggers (i.e. synthesis report).
   b. Within the target module, complete the necessary reanalysis products (e.g., for mass wasting reanalysis, complete an updated landslide inventory; for riparian conditions, complete an updated shade hazard report using current stream typing information, etc.)
   c. For each necessary resource sensitivity reanalysis, compare current conditions to previous conditions (e.g., has fish habitat changed or have public works changed?).

2. Results
   a. Answer key questions pertaining to resource conditions, forest practices, and synthesis per Part 4 *Synthesis* within the current watershed analysis board manual.
   b. Map Products used during assessment (i.e. current landslide inventory, Mass Wasting Map Units, Riparian Shade Units, RMAP accomplishments, monitoring station locations, updated Timber Age Classes, etc.) should be consistent with the current approved WSA products for comparison.

8.6 Evaluate and Compare

Evaluate and compare the current approved watershed analysis prescriptions. Ask what worked and what did not work within the WSA.

1. Does the assessment incorporate the current science and methods?
   - Would new methods substantially change results of the assessment?
   - Would the new results likely affect prescriptions?

2. Was the resource assessment sound?
   - Did the assessment correctly identify and map problems related to forest practices, agricultural practices, and other human influences?
   - Did the assessment correctly identify cause-and-effect linkages related to identified problems?
   - Did the module correctly interpret effects of the situations identified?
   - Was there a cause-and-effect relationship between extreme natural events and observed resource affects?

3. Causal Mechanisms
   - Should causal mechanism reports (CMRs) be created or significantly altered as a result of this new assessment?

4. Have there been FPAs within the current approved WSA mapped units?
   - Were prescriptions or standard rules implemented?
   - Were prescriptions or standard rules effective at protecting public resources?

5. Prescription Modifications Needed?
   - Do prescriptions incorporate current science?
   - Is there new information challenging the adequacy of prescriptions?
   - Are there new causal mechanisms that result in new prescriptions or can they be incorporated into existing prescriptions?
   - Do the resource sensitivity maps need to be updated?

8.7 Reanalysis Prescription Modifications

If prescription amendments or new prescriptions are needed, a prescription team will be convened. Prescriptions will be written and submitted to DNR for review. DNR will approve or disapprove the prescriptions to include in the final report.

1. Completion of Final Report
   a. Watershed analysis for the WAU is completed when the team produces the watershed analysis report, including associated causal mechanism reports, and prescriptions, if applicable.
   b. Prescriptions are attached to each target module(s) assessment.
   c. The final reanalysis report will require the sponsors to complete a SEPA nonproject environmental checklist and submit it to DNR.
   d. The proposed monitoring plan (if required) will also be attached.

2. Criteria for determining the completeness of reanalysis are:
    a. All critical questions were answered.
    b. Causal mechanism reports and statements on triggering mechanisms have been completed, if applicable.
    c. Final prescriptions were developed for each area of resource sensitivity, if applicable.
        - If final prescriptions were not developed, an explanatory statement discussing this decision will be added to the final report.
    d. Required maps have been finalized.
    e. Completion of the target module report.

3. SEPA and Approval Process
    a. When DNR determines that the reanalysis is complete, they will accept or disapprove the watershed analysis within thirty days of receipt.
    b. DNR makes a threshold determination of the nonproject SEPA checklist, submits it to the SEPA center, and the SEPA checklist will be distributed for stakeholder review.
    c. SEPA comments will be accepted and evaluated for 30 days. DNR will issue a final threshold determination.
    d. The final watershed analysis will be distributed to landowners and implemented per WAC 222-22-090.

Glossary

Note: Although an attempt has been made to conform to proper usage of technical terms, many of the words and phrases defined below are terms of art with meanings specific to the watershed analysis process. Sources of the definitions are not cited, except for terms defined in the Forest Practices Rules, Title 222 WAC: Chapter 222-16 WAC, General Definitions, and Chapter 222-22 WAC, Watershed Analysis.

channel-forming discharge. Stream flow of magnitude sufficient to mobilize significant amounts of bed sediments.

channel indicator. Characteristic of streambed, banks, and floodplains used to interpret the effects of changes in sediment, water, or wood.

channel sensitivity. Capacity to respond to physical disturbance.

CMER. Cooperative, Monitoring, Evaluation and Research Committee established by the Timber/Fish/Wildlife Agreement.

critical question. Fundamental question, based on scientific process considerations, addressed in one of the modules of this manual.

cumulative effects. Changes to the environment caused by the interaction of natural ecosystem processes with the effect(s) of two or more forest practices (WAC 222-16-010).

dam-break flood. Downstream surge of water caused by the sudden breaching of an impoundment in a stream channel; a form of debris torrent. The rapid failure of the dam(formed by a landslide , the deposit of a debris flow, or a debris jam) can cause a flood up to two orders of magnitude larger than normal storm-run off floods. These extreme hyperconcentrated (water>sediment) floods can occur in 1^{st}- through 6^{th}-order valleys, in both natural and managed landscapes.

debris flow. Highly mobile slurry of soil, rock, vegetation, and water that can travel many miles down steep (>5°) confined mountain channels; a form of debris torrent. While generally occurring in colluvium-filled 1^{st}- and 2^{nd}-order streams, debris flows can deposit sediment in streams of any order, typically at tributary junctions.

debris torrent. Debris flow or dam-break (or other hyperconcentrated) flood, undifferentiated. The effects of debris flows and dam-break floods can appear superficially similar (particularly on air-photos), although the two processes differ in initiation, composition, and travel characteristics. This term is used when it is not possible to distinguish between the two, either because of poor resolution on air-photos or inconclusive evidence in the field.

deep-seated failure. Landslide involving deep regolith, weathered rock, and/or bedrock, as well as surficial (pedogenic) soil. As used here, deep-seated landslides commonly include large (acres to hundreds of acres) slope features, associated with geologic materials and structures. ***In watershed analysis, they are divided into***:

large-persistent deep-seated failures, commonly slump-earthflows involving large areas of hillside; found in natural and managed landscapes, recognizable over long periods of time, and almost without exception predate land use;
small-sporadic deep-seated failures, commonly smaller slumps that can be triggered at irregular time intervals (by storms or earth movement), and can decay to the point where they are indiscernible.

Because movement of deep-seated failures is hydrologically controlled (at least in part), land use can influence movement insuitable situations.

deliverability. Likelihood that, as a result of one or more forest practices or by cumulative effects, a material amount of wood, water, sediment, or energy will be delivered to fish habitat, streams, or capital improvements; three conditions must all be satisfied: 1) an impact is likely to occur; 2) the magnitude or size of the impact is sufficient to have a significant effect on the resource characteristic(s); and 3) the impact is likely to be delivered to a stream segment with a vulnerable resource.

delivered hazard, or potential impact. Adverse change in the amount or location of wood, water, sediment, or energy being delivered to fish, water quality, or capital improvements.

dry ravel. Down slope movement of dry, non cohesive soil or rock particles under the influence of gravity; a form of soil creep.

earthflow. Deep-seated landslide of broken soil and rock, dominantly by slow flow; produces linear areas of hummocky, disjointed terrain. Earth flow activity is favored in deep, cohesive soil, clay-rich bedrock, or slumped material, and is largely controlled by seasonal (or longer) fluctuations of pore-water pressure.

erosion. The removal of rock and soil from the land surface, by a variety of processes: by gravitational stress, through mass wasting; or by the movement of a medium (e.g. water, in solution or by overland or channel flow).

flood-frequency curve. Graph showing the relationship between recurrence interval(or exceedance probability)and peak discharge (volume flux of water per unit time).

geomorphic processes. Landscape-modifying processes such as erosion, mass wasting, and stream flow.

GIS. A computerized geographic information system.

gully erosion, gullying. Advanced stage of surface erosion in which rills, carved by channelization of overland flow, coalesce into larger channels in soil or soft rock.

habitat value. Characteristic of the environment in which an organism (e.g., fish) lives.

hydrologic maturity. Condition of a forest stand in which hydrologic processes operate as they do in a mature or old-growth forest. In particular, snow accumulation is typically lower in thick, dense forest (at middle and lower elevations) than in openings, due to interstorm melt of snow caught in the canopy; and snow melt is slower, due to decreased wind-aided flux of sensible and latent heat.

indicator area. Particular area or stream reach, adopted as representative of a response segment.

input variable. Amount of sediment (coarse and fine), water, wood, and/or energy delivered to a stream segment.

landslide. Any mass-movement process characterized by downslope transport of soil and rock, under gravitational stress, by sliding over a discrete failure surface; or the resultant landform. In common usage, can also include other forms of mass wasting not involving sliding (rockfall, etc.)

LWD recruitment. Large woody debris delivered by the fall of streamside trees, or delivery from upstream sources by stream transport.

mass wasting. General term for the dislodgement and downslope transport of soil and rock under the direct application of gravitational stress (i.e., without major action of water, wind, or ice); mass movement. In watershed analysis, this class of erosion processes is divided into three categories: shallow-rapid landslides, deep-seated failures, and debris torrents (see definitions).

mass-wasting map unit (MWMU). Landscape element for application of hazard ratings, defined in the mass-wasting assessment module. MWMUs are delineated on the basis of physical (geologic, climatic, etc.) characteristics, susceptibility to mass-erosion processes, sensitivity to forest practices, and potential for delivery of sediment to public resources.

peak flow event. Maximum instantaneous stream discharge during runoff, commonly caused by an individual rainstorm, rain-on-snow, or spring snow-melt.

rain-on-snow zone. Area (generally defined as an elevation zone) where it is common for snowpacks to be partially or completely melted during rainstorms several times during the winter.

resource characteristic. specific, measurable characteristic of fish, water, and capital improvements of the state or its political subdivisions:

For fish and water -
physical fish habitat, including temperature and turbidity;
turbidity in hatchery water supplies;
turbidity and volume for areas of water supply;
For [public] capital improvements:
Physical or structural integrity.
(From WAC 222-16-010.)

resource vulnerability. Likelihood of material adverse effects on resource characteristics. Criteria may include (but are not limited to) current resource conditions.

response segment. Location (segment) of the stream channel that is susceptible to changes in inputs of wood, water, energy, and/or sediment.

rill erosion. Development of many closely-spaced channels, caused by the removal of soil by concentrated overland flow; a form of surface erosion, intermediate between sheet erosion and gullying.

riparian function. Activity relating to the LOD-recruitment and stream-shading functions provided by riparian vegetation.

riparian zone. Area surroundinga stream, in which ecosystem processes are within the influence of stream processes.

sediment budget. Accounting of the sources, movement, storage, and disposition of sediment produced by a variety of erosion processes, from its origin to its exit from a basin; includes sediment types, amounts, and routing to specific locations of analysis.

shallow-rapid landslide. Landslide produced by failure of the soil mantle (typically to a depth of one or two meters, sometimes including glacial till and some weathered bedrock), on a steep slope; includes debris slides, soil slips, and failures of road cut-slopes and sidecast. The debris moves quickly (commonly breaking up and developing into a debris flow), leaving an elongate, spoon-shaped scar.

sheet erosion. Removal (more or less evenly) of surface material from sloping land, by the action of broad sheets of overland flow; a form of surface erosion.

slump. Deep, rotation all and slide, generally producing coherent movement (back-rotation) of blocks over a concave failure surface. Typically, slumps are triggered by the build up of pore-water pressure in mechanically weak materials (deep soil or clay-rich rock).

slump-earthflow. Landslide exhibiting characteristics of both slumps and earth-flows: typically the upper part moves by slump (rotation of blocks), while the lower portion moves by flow (hummocky terrain). For purposes of hazard assessment, discrimination between slumps and earthflows is preferred, if possible and appropriate.

snow-water equivalent (SWE). Amount of liquid water (expressed as depth) derived by melting a snowpack.

surface erosion. Movement of soil particles down or across a slope, as a result of exposure to gravity and a moving medium such as rain or wind. The transport of sediment depends on the steepness of the slope, the texture and cohesion of the soil particles, the activity of rainsplash, sheetwash, gullying, and dry ravel processes, and the presence of buffers.

transport capacity. Ability of the flow to carry the sediment delivered to the stream; indicated by the stream power.

watershed administrative unit (WAU). Basic geographic unit for watershed analysis. An area shown on the map specified in WAC 222-22-020(1) (WAC 222-16-010).

watershed analysis. For a given WAU, the assessment completed under WAC 222-22-050 or 222-22-060, together with the prescription selected under WAC 222-22-070, including assessments completed under WAC 222-22-050 where there are no areas of resource sensitivity(WAC 222-16-010).

APPENDIX A
Mass Wasting Module

Table of Contents

Introduction

Mass wasting is a natural process that occurs to some extent in most forested basins in the Pacific Northwest. Certain forest management activities can accelerate mass wasting processes. Because the various slope processes generate widely variable amounts of sediment under different sets of conditions, analysts and specialists must identify specific trigger mechanisms and distinguish among the types and rates of processes active in a basin to accurately evaluate the mass wasting hazard potential. Evaluation of forest management activities in the context of terrain characteristics provides the best guidance in developing appropriate management prescriptions for reducing mass wasting.

Four types of mass wasting commonly occur on forested slopes: shallow-rapid landslides, debris torrents, large-persistent deep-seated failures, and small-sporadic deep-seated failures. Shallow-rapid landslides (also known as, debris slides, debris avalanches, or planar failures) commonly occur on steep slopes where soil overlies a more cohesive material (for example, bedrock or glacial till). Soil thickness is typically small compared to slope length or the length of the landslide. Debris in the slide moves quickly downslope and commonly breaks apart to form a debris avalanche. Shallow-rapid landslides typically occur in convergent areas where topography concentrates subsurface drainage (Sidle and others, 1985), and may deliver sediment to streams and damage roads. Susceptibility of an area to shallow-rapid failures is affected by steepness of slope, saturation of soil, and loss of root strength. Forest management activities can increase the occurrence of shallow-rapid landslides by altering these conditions; however, only a small portion (typically a few percent or less) of the landscape actually fails following timber harvest (Ice, 1985).

A debris torrent contains 70-80% solids as a highly mobile slurry of soil, rock, vegetation and water that can travel kilometers from its point of initiation, typically in steep (>5^{o}), confined mountain channels. Debris torrents form when landslide material liquefies concurrently with, or immediately after the initial failure. As the debris torrent moves through first- and second-order channels, the volume of material may be increased by several orders of magnitude over initial slide volume, enabling debris torrents to become more destructive the further they travel. Debris torrent initiation is generally confined to steep, colluvium-filled first- and second-order channels; debris torrents can, however, deposit large volumes of unsorted sediment and organic debris in streams of any order, typically at tributary junctions. (Benda 1990) or on alluvial debris fans. Hence, debris torrents can contribute sediment locally at the site of deposition and also downstream, increasing fine sediments in spawning gravels, causing secondary erosion of valley walls, and damaging structures and fish habitat at considerable distances from their points of initiation (Eisbacher and Clague 1984).

Landslides and debris torrents that are deposited in narrow valley floors can create temporary dams that quickly impound water, creating small lakes. Failure of these dams can lead to extreme floods, referred to as landslide dam-break floods that can be up to two orders of magnitude greater in peak discharge than normal runoff floods. Such floods have caused extensive downstream erosion and sedimentation along entire stream segments throughout the mountainous regions of the state. Dam-break floods may also be triggered by the build-up and failure of logging slash in steep, first- and second-order streams (Type 5 and 4 waters) in managed forests. Similar to debris torrents, dam-break floods may cause erosion of valley walls (landsliding), damage to structures, and/or destroy or affect fish habitat considerable distance from their point of initiation.

Deep-seated landsliding occurs in response to strong seismic shaking, geologic weakness, or channel incision. Climatic changes, ranging from major (such as glacial-interglacial transitions), to intermediate (runs of several wet years), to short-term (extreme storm precipitation) can also trigger or accelerate deep-seated failures. The failure plane is below the colluvial layer and commonly cuts through two or more strata. These slides may persist in the landscape for a few years or centuries; in any case, debris is typically supplied from the margins of the features to a channel. The stream itself can be the cause of chronic movement, if it periodically excavates the toe of a large slide mass.

Small-sporadic deep-seated landslides are slumps that can be triggered at irregular time intervals (by storms or earth movement), and can decay to the point where they are indiscernible in the landscape. Because movement of deep-seated failures is hydrologically controlled (at least in part), land use can influence movement in certain situations.

The time scale (relative or absolute) of mass wasting in a basin is important to an understanding of the sediment mass balance of a watershed. Mass wasting events may occur on a return interval of one or two years, decades, centuries, or even millennia. While the smaller, more frequent events may cause the fresh scars seen on the landscape, the larger, infrequent events are probably the real shapers of the landscape. Both types of landslides are influential in their impact on physical resources. In a natural, unmanaged forested basin, the dynamic replenishment of material to the channels by mass wasting is essential to the diversity and health of the ecosystem.

Not all landslides deposit sediment directly in streams; sediments may be deposited on flood plains, glacial or alluvial terraces, or foot slopes, without reaching a stream. However, as basin area increases, the cumulative probability of either one small landslide entering a stream or one small failure triggering a debris torrent with catastrophic impact on habitat conditions increases.

In this module, analysts develop information (maps and text) leading to ratings of the potential for delivery of debris and sediment to streams by mass wasting for geographic zones of the basin. These ratings are applied to the "likelihood of adverse change and deliverability" axis of the cumulative effects rule matrix. Mass wasting processes occur naturally. We attempt to isolate human activities (specifically forest practices) that contribute to "non-natural" mass wasting events and processes. Altering these activities can prevent such occurrences.

Critical Questions

The purpose of the mass wasting module is to guide development of information necessary to address several questions critical to understanding the mass wasting processes in a watershed:

What are the potential sediment sources in the basin?

Is there evidence of, or potential for mass wasting in the watershed?

What mass wasting processes are active?

How are mass wasting features distributed throughout the landscape?

What physical characteristics are associated with these features?

Do landslides deliver sediment to stream channels or other waters?

Do forest management activities create or contribute to instability?

What areas of the landscape are susceptible to slope instability?

What is the relative contribution of sediment from mass wasting compared with other sources?

Assumptions

A number of fundamental assumptions underlie the approach developed here. The most fundamental requirement is that the analysis is based on the best available scientific information and techniques. Thus, the module analysis methods themselves are designed to change as newer methods are developed. The underlying assumptions and analysis framework, on the other hand, are not. Rather, these assumptions dictate a rigorous, yet flexible, framework for analysis. Our primary assumptions include:

- Aerial photographs can be used to interpret and document the history of land use and mass movement in a basin. Although some features are obscured by vegetation, most landslides of significant size can be identified on aerial photos, as can the tracks of debris torrents and dam-break floods.
- Identification of existing mass-movement features can be used to predict the likelihood of future instability. Areas prone to these processes can be mapped based on physical characteristics, as interpreted from aerial photographs, topographic maps, and geologic and soils maps.
- Although most landslides are at least partly caused by natural processes or events, in most cases, the initiation or acceleration of mass movement can be attributed either to natural conditions or to forest practices. Mass-movement features associated in time and space with logging or roading activities are assumed in Level 1 to be caused by forest practices.
- It is feasible to extrapolate from one sub-basin to another having similar characteristics, based on information obtained from maps and aerial photos.

Overview of Approach

Mass wasting is one of several sediment sources in a watershed. In order to understand the relative importance and contribution of sediment from mass wasting, a sediment budget approach is suggested.

A sediment budget is defined as a quantitative description of sediment production rates, transport, storage, and output by the different processes in a drainage system (Dietrich and Dunne, 1978). (See Swanson and others (1982) for a description of the sediment budget approach.) This discussion focuses on the supply aspect of a sediment budget since routing of delivered sediment is addressed in the channel module. For Washington state watershed analysis, quantification and analysis is concentrated on sediment production and delivery from mass wasting, road erosion, sheetwash and gully erosion from hillslopes, and surface erosion from landslide scars. Other processes include stream bank erosion, dry ravel, tree throw, and animal burrowing in addition to non-forest management sources such as cattle or agricultural and urban development. Although these processes are not specifically named in watershed analysis, if they are determined to be a significant source of erosion, they should be addressed.

Prior to data collection, team members need to identify and discuss the major sediment sources in the watershed administrative unit (WAU). Sediment sources can be identified with the use of aerial photographs and field reconnaissance, and by communication with land managers who are familiar with the WAU. Based on discussions, team members must decide who will assess the processes associated with sediment sources. For example, mass wasting is generally not a major process in east-side forests, while surface erosion from roads, hillslopes, or agricultural practices is more common. In this case, team members may focus on surface erosion processes by dividing the tasks among available qualified team members. The result is a more thorough quantification of sediment inputs from each source. Simply stated, the team must decide how best to use available analysts and time. Another example may be in surface erosion of landslide scars until ground cover is established. In west-side forests, mass wasting is commonly a dominant process, but after the initial mass wasting event, landslide scars may continue to produce sediment through surface erosion. Depending on the work load, analysis of the sediment source may be included in the mass wasting module or the surface erosion module. Once the dominant sediment sources have been identified and division of labor has been determined, the methodology for assessing mass wasting is conducted. When comparing the relative sources of sediment in a basin, attention should be given to the time scale at which various processes are contributing and to compare sources or rates in the same units.

The mass wasting assessment is conducted using aerial photographs, maps and field observations. Based on this information, the analyst interprets mass wasting processes relative to the critical questions. Watershed analysis requires the mass wasting analyst to develop information to address each critical question. The method developed in this manual describes the standard mass wasting assessment.

A series of exercises designed to either confidently answer the key questions, or to identify more detailed information necessary to do so, is developed in the module (Figure A-1). The objective of these exercises is to generate information sufficient to establish:

1. The mass wasting features and processes (shallow-rapid landslides, debris torrents, and deep-seated failures) active in the basin.

2. Portions of the landscape having similar inherent physical characteristics relative to mass-movement behavior.

3. The relative potential for mass wasting impacts associated with the landscape units.

The analyst first conducts an inventory of landslides in the watershed. The assumption underlying this approach is that many of the activities potentially triggering mass wasting have been conducted in the past in some or all of the areas sharing similar erosive characteristics. These prior "experiments" can be used to infer future erosion response.

An interpretation of the mass wasting potential is made by associating the occurrence of landslides with terrain or geologic features. These associations form the basis for the mapping of mass wasting map units in the watershed. Mass wasting map units are drawn for each area with similar mass wasting characteristics and triggering mechanisms. These mechanisms are the specific geomorphic processes that appear to contribute to mass wasting (i.e., increased groundwater and pore pressure, over-steepened or over-loaded slopes, excess water drainage, etc.). Unique units are described if the mass wasting processes are similar (i.e., shallow debris flow), but the triggering mechanisms are different (i.e., roads versus loss of root strength on hillslopes).

The mass wasting potential for the units are qualitatively rated guided by criteria based on the watershed information according to likelihood of occurrence. These ratings determine the level of "potential hazard" for use in the rule call at later stages of the assessment.

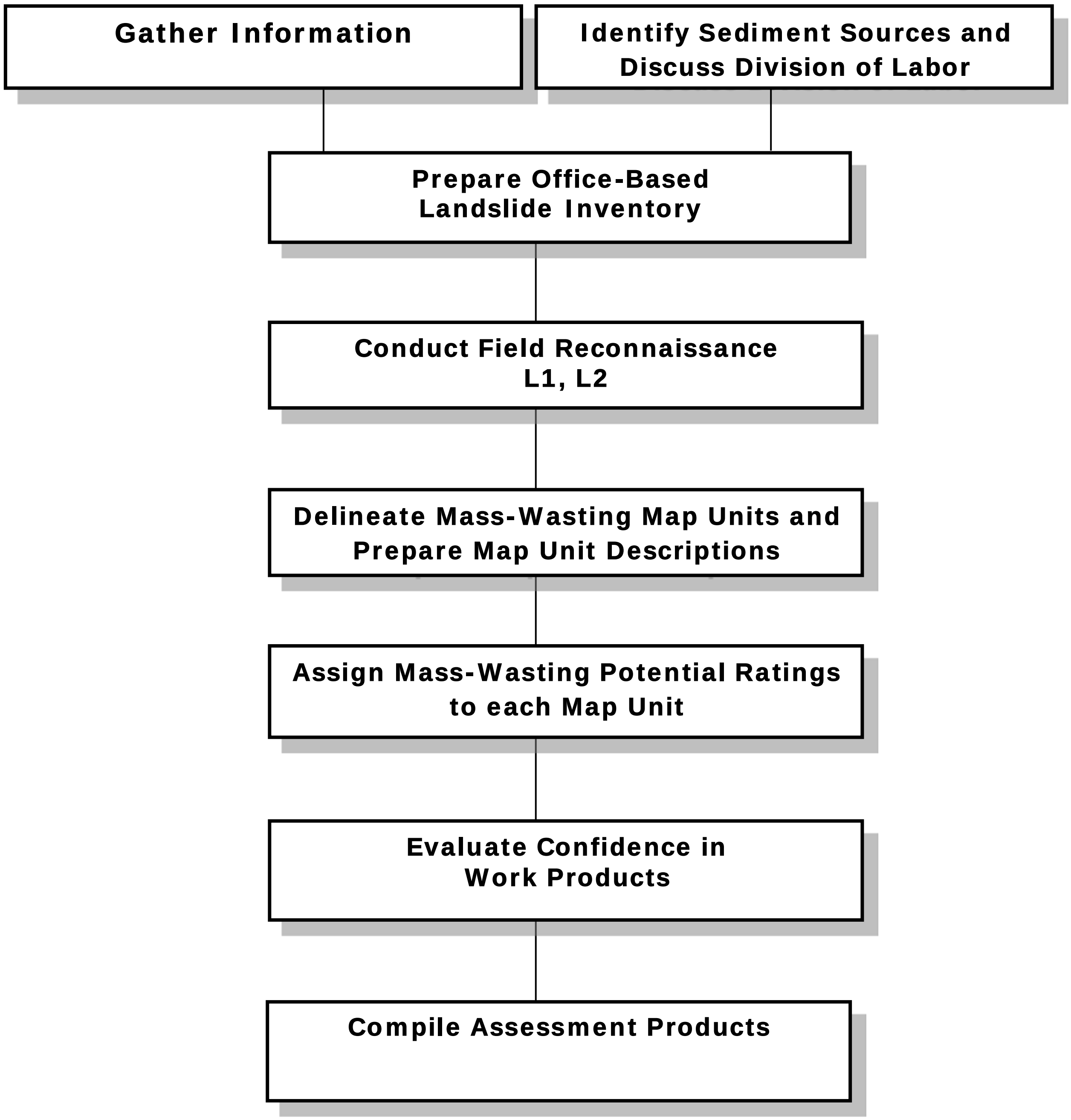


Figure A-1: Mass Wasting Module Flow Chart

Qualifications

Analysts conducting the Level 1 mass wasting assessment should possess a knowledge of hillslope processes (including erosion, transport, and deposition) and their relationship to forest management activities. Skill in aerial photo interpretation, landform analysis, and recognition of mass-movement features (including shallow-rapid landslides, debris torrents, and deep-seated failures) in a variety of geomorphic settings is necessary.

The education associated with these qualifications includes a college degree (preferably post-graduate) in geology or geomorphology; or in a related field, such as geotechnical engineering, soil science, geophysics, or forest engineering, with a significant amount of course work or other training in geomorphology and/or mass-movement processes.

In addition to the qualifications for Level 1, Level 2 specialists should be familiar with the methods of sediment budgeting, routing of mobile mass-movements, and slope stability modeling.

Table A-1. Mass Wasting Assessment Checklist

Below is the mass wasting assessment checklist, which helps guide the mass wasting team leader through the watershed analysis.

Task	Scheduled	Completed	Reviewed
Assemble startup materials:			
• official WAU base map			
• aerial photographs			
• orthophotos			
• geology maps			
• soils maps			
• topographic maps			
Team coordination meeting - discuss sediment sources and division of labor; schedule approx. field days with other module participants.			
Landslide Inventory:			
• aerial photo inventory			
• complete Form A-1			
• record on to Map A-1			
Formulate tentative mass wasting map units			
Field reconnaissance			
MWMU designation:			
• MWMU descriptions (Form A-2)			
• Mass Wasting Summary Table (Form A-3)			
• Delineate MWMU polygons on Map A-2			
Summary report			

Background Information

Maps

Official WAU base map

Topographic maps of the assessment area

U.S. Geological Survey 7.5-minute series (or largest scale available). See USGS index to topographic map coverage for Washington (USGS, 1992). Maps are available from commercial dealers, DNR Photo & Map Sales (Olympia (360) 902-1000), and USGS (Denver).

Geologic maps
USGS or DNR Division of Geology & Earth Resources (DGER) maps at 1:100,000 (or larger) scale. See DGER indices to geologic mapping (Manson 1984, 1994, 1995 or county bibliographies); or contact

DNR - Division of Geology and Earth Resources
Olympia: *(360) 902-1000*
USGS - Maps 1-888-275-8747

a. For areas administered by the U.S. Forest Service, maps of geologic resources and conditions (GRC) might be available; contact the appropriate forest supervisor's office, zone engineering office, or district ranger station.

Soil maps
There are a variety of sources for soil maps:

a. State soil survey (for nonfederal forest lands) or in township plots from GIS data; text volumes available for purchase or examination at DGER.

b. Soil surveys published by the U.S. Natural Resources Conservation Service (formerly Soil Conservation Service) (particularly after about 1980) typically utilize the same map units as the state survey, and contain additional information; contact local NRCS office.

c. For national forests, soil resource inventory (SRI) maps and information might be available; contact local USFS office.

Other maps that may be helpful if available:

a. Landslide maps have been published covering some parts of the state. Consult the WDGER indices for availability. For national forests, consult the GRC maps.

b. Mass-wasting hazard maps have been produced for a few regions, mostly in urban areas. Consult the DGER indices.

c. GIS models of slope form and stability, based on digital elevation data, are becoming available. The DNR slope-morphology model, based on slope gradient and shape (convergent-straight-divergent), can be reproduced using the information in Shaw and Johnson, (1995); the GIS-AML (ARC Macro Language) program is available from DNR. The model addresses debris avalanches (e.g. shallow-rapid landslides) only. Other similar models are also being developed (Montgomery and Dietrich, 1994; Wu and others, 1993).

d. The DNR GIS also contains digital data on precipitation zones, forest roads and canopy/core density of vegetation from Landsat. Contact DNR

Information Technology Division for availability. (Analysis teams working through the DNR basin priority list will have preference in getting DNR GIS products and assistance.)

e. Maps of land use, vegetation cover, etc., might be available from the USGS, local planning agencies and/or landowners. Check with hydrology module analysts who also use precipitation and vegetation information.

Photographs

The mass wasting assessment is built around the examination of aerial photographs. Although it is preferable to examine a complete series of air photos spanning decades, time constraints in Level 1 may necessitate using a more limited number of photo sets. Analysts should examine as many photographs as necessary to obtain an adequate basic understanding of the mass wasting behavior of the basin.

a. Indices of most aerial photo flights over Washington can be obtained at DNR Photo & Map Sales. Prints of photos available through DNR can be ordered there; prints for some areas and times must be obtained from the USFS, USGS, Agricultural Stabilization and Conservation Service (USDA), the National Archives, commercial firms, or other sources.

   Photographs at about 1:12,000 to 1:16,000 scale are best for detection of small features; scales of 1:24,000, 1:40,000, and 1:62,500 cover more area with fewer photographs, and are better for terrain evaluation, but provide reduced resolution. Color photographs are preferred, because they allow detection of subtle differences in tone of soil, vegetation, etc.; however, they are more expensive and produced less often.

b. Orthographic aerial photographs (orthophotos) of townships and quarter-townships are available for most of Washington; contact DNR Photo & Map Sales.

Equipment

- A mirror stereoscope is necessary for efficient mapping from aerial photographs.
- Mylar (or other material) overlay sheets for individual photos (9" x 9") are useful for initial mapping.
- Two mylar sheets, for base map overlays, are required.

Other information

- Environmental and land use history: Information on the incidence of forest fires, recent major storms, and human activities may be helpful in interpreting apparent mass-movement features (particularly in Level 2 analysis). Such information can be obtained from geologic and geomorphic studies (see DGER bibliographies listed in Manson, 1984, 1994, 1995); vegetation studies (e.g., the USFS guides to plant associations for the national forests); and compilations of climatic data (from the National Weather Service) and streamflow data (USGS), both available in paper and CD-ROM formats. Local landowners, residents, technical personnel, etc., may also provide some information.

Analysis Procedure

Standard Methods

The following procedures constitute the standard methodology. Level 1 analysts may rely solely on the methods provided here. Additional methods for resolving uncertainties are provided.

The purpose of the landslide inventory is to collect information that will aid in understanding the distribution, timing, and relative size of mass wasting processes in the basin, and thus be useful in creating mass wasting map units. The primary intent of this module is to evaluate and map the potential for delivery of mass wasting hazards, for use in the synthesis and prescriptions modules; therefore, do not spend an inordinate amount of time on the inventory.

More time is allowed in Level 2 and the methods are more flexible, so that detailed analysis can address the specific problems identified in a WAU. In particular, the relationships between land use activities and landslide processes are to be identified more accurately and precisely and with greater spatial resolution. The result is a higher level of certainty in the information and mass wasting potential hazard ratings.

If the analysis is beginning at Level 2, the maps, tables, and summaries normally prepared in Level 1 must be produced. If a Level 1 analysis has already been conducted, the Level 2 assessment builds upon the information already gathered, especially the mass wasting mapping. Then, Level 2 is intended to answer the important questions that were not resolved by the Level 1 investigation, and to further isolate and identify mass wasting problem areas and trigger mechanisms.

1. Landslide Inventory

a. Identify the parts of the watershed in which landslides are most likely, based on slope gradient, unstable soils, and storm-water input. Focus attention on sub-areas having mass wasting problems in forest lands.

b. Select appropriate set(s) of aerial photographs:
- The most recent set (small- to medium-scale) available;
- Sets that depict pre-logging conditions (if possible);
- Sets taken at time intervals (8 to 12 years) that allow appraisal of changes in slope instability (photos taken a few years after major logging operations or big storms are helpful).

c. Examine the aerial photographs in stereo (begin with earliest years to most recent) to identify landslides, debris torrents, and other erosion features; map the mass wasting features. Initial mapping may be on photo-overlay (9" x 9") sheets, or directly onto a topographic base map. Transfer the features onto a mylar overlay (*Map A-1: Landslide Inventory*) placed on the WAU base map.

d. Assign an identification number to each feature. The identification system must provide a distinctive geographic identifier to each landslide in the inventory, so that readers can correlate features between maps, inventory lists, and text. The system explained below is strongly recommended, but other identification schemes that provide equal or better utility are allowed. UTM and latitude/longitude coordinates have particular usefulness to GPS and GIS applications for data management and display.
- Landslide Identification Number Example: 13/05E-26L278(_______) See explanation below:
- Township: (e.g., from example, **13/**)
- Range (E or W of Willamette meridian): (e.g., from example, **05E**)
- Section: (e.g., from example, **-26**)
- A letter representing the initiation location of the feature by each 1/16 (40 acres) section (see diagram; e.g., D, G, R, ...): e.g., from example, **L**

D	C	B	A
E	F	G	H
M	L	K	J
N	P	Q	R

- Number of the feature (within the 1/16 section) (in consecutive numbers; e.g., from example, **L2**).
- Year of the photograph on which the feature first appears: from example, **78** or;
- (Optional) Actual date of the slide if known (e.g., year/month, 82/02).

e. Complete the mass wasting assessment data form (Form A-1:

Mass wasting Inventory Data), found at the end of this appendix. On the form, arrange the observations by smaller sub-basins, beginning at the upstream end of the watershed. Organization of the inventory in this manner, combined with recording the appearance and size of features by photo dates (see below), allows the analyst to appreciate the cumulative distribution and timing of mass wasting downstream through the basin.

For each feature, fill in as much of the following information as possible. Less important items, or those with a level of detail not practical for a Level 1 assessment, are marked "optional."

- Sub-basin
- Landslide Identification Number
- Mass Wasting Map Unit **-**To be filled in after delineation of map units.
- Landslide Processes and Certainty of Identification **-**record the following information:

Process:

SR Shallow-rapid landslides

DT Debris torrent

LPD Large-persistent deep-seated failure

SSD Small-sporadic deep-seated failure

Other descriptor(s), as appropriate

Certainty of identification (optional) -Based on the number and expression of slide-related features, these designations can be modified following field reconnaissance:

d definite

p probable

q questionable

For example, a debris slide that is clearly recognized would be identified as SR/d; a questionable, large slump-earthflow might be LPD/q. (See Wieczorek, 1984).

- Year of initiation and size of failure - Note the date (or flight number) of the aerial photograph set in the column heading on Form A-1; arrange the flights from oldest (left column) to most recent (right), preserving the last column for features initiated after the latest photos (i.e., identified in the field).

- Record the approximate area of the slide in the column corresponding to the photo set being examined. For landslides, find the size by measuring directly off the photograph, or use the categories below. A template of size categories, calibrated to the average photo scale, will be useful in basins with many landslides.

<500 yd^2	=	small
500-2000 yd^2	=	medium
2000-5000 yd^2	=	large
>5000 yd^2	=	very large

- For debris torrents, indicate the type and length of stream affected. If multiple photo sets are examined, note changes between photograph dates.

- Note the area of any obvious enlargement of features in the appropriate columns.

- For older features not active during the photo-documented history, note approximate age and probability of future movement in the first column, using the following codes:

  a ancient, ~ 10^2 to ~ 10^6 years old

  d dormant, suggests it has been or might be rejuvenated

- Sediment delivery to streams or other waters **-**note if sediment is delivered to a stream, and the type of receiving water(s):

  N no sediment delivered

  Y sediment delivered - add water-type number of nearest receiving water

  I indeterminate

- Surface erosion of scar - estimate of percent of landslide scar unvegetated and presumed to contribute fines to stream system.

- Land use activity associated with the feature - Record information on associated activities:

  Harvest activities:

  CC Clear-Cut

  PC Partial Cut (crown opening reduced by 50% or less)

  Approximate stand age at time of failure:

  0-20 years = younger than age of root-strength recovery

  20-50 years = younger than the age of hydrologic recovery

  >50 years = hydrologic and root recovery

  Yarding method: tractor, high lead, other

  Forest roads: note type, stream crossing, landings, etc.

  Other forest practices associated with slope failure

  No associated forest land use

  Wildfire: note time since most recent fire

  Other (non-forest) land use(s) associated with failure

- Geomorphic characteristics of the slope around the feature - Include: *Gradient* (or range)

  Form (concave, convex, planar, headwall, inner gorge, flow topography, etc.)

- Soil type *(optional)* - Record the general soil type (residual, colluvial, glacial, etc.), and texture (coarse, fine, mixed)

- Bedrock *(optional)* - Record the type of rock or regolith underlying the landslide; if possible, note the formation name
- Elevation *(optional)* - Record the initiation elevation or precipitation zone of the feature; note whether the feature might be affected by conditions related to elevation or climate (rain-on-snow events, etc.)
- Comments - Note additional information as appropriate or other effects such as any effects on streams, structures, roads, utilities, populated areas, etc.

2. Field Reconnaissance

The analysts should conduct a brief inspection of the basin to evaluate whatever can't be seen on or interpreted from the maps and photographs, or to help resolve major uncertainties regarding:

a. The physical conditions associated with landsliding, and the particular characteristics that should be used in establishing the mass wasting map units;

b. Land use trigger mechanisms associated with slope instability (e.g., road sidecast failure, undersized culverts);

c. Delivery of sediment to streams, public works, etc.;

d. Extrapolation of map units to lesser-known areas.

3. Mass Wasting Map Units

In this step, the basin landscape is partitioned into map units, based on physical characteristics contributing to slope instability and the potential for landslide sediment to enter streams or affect other public resources.

a. Inspect the landslide inventory data and map, noting the geologic and geomorphic factors associated with each mass wasting feature. What mass wasting features are present in the basin, and how are they distributed?

b. Define the mass wasting map units (MWMUs) as areas of terrain having similar physical characteristics and mass-movement behavior. (Do not differentiate map units based on the presence or absence of management activities at this point; landscape sensitivity to management practices is evaluated in the hazard ratings.) When designating MWMUs, consider the following characteristics related to slope instability:

- Landslide processes and densities
- Slope gradients and landforms
- Bedrock types and structures
- Soil materials
- Potential for sediment entry into streams or lakes (high, remote, NO)
- Slope hydrology
- Natural vegetation types
- Climatic zones, storm-water input rates
- Other appropriate factors (hollow spatial scale, hollow density)

In addition, each MWMU should be unique with respect to at least one of the following: process, density, delivery.

The number and nature of map units designated in a WAU will depend on the geomorphic complexity of the basin. Although the analyst is free to design map units appropriate to the area being examined, some consistency in units (particularly among adjacent basins) would be useful and practical. (For guidance, see Rib and Liang (1978); Fiksdal and Brunengo, (1981); Varnes (1984); Sidle and others (1985); Howes and Kenk (1988); Chatwin and others (1991).)

c. Outline the map units on a second overlay (Map A-2 Mass Wasting Potential). Label the MWMUs by number; for units with multiple polygons, include a polygon number for each (e.g., 3-1, 3-2, ...).

d. Summarize information on each MWMU into a concise summary form (see Form A-2, Mass Wasting Map Unit Description Form). Write a brief description of the physical characteristics, mass-movement history and behavior, sediment-delivery characteristics, and associations with forest practices, for each map unit. Descriptions should be as quantitative as possible. Refer to the example on Figure A-2.

   Distributions and types of existing landslides are important in designating the MWMUs. If many slides were located adjacent to the main stream channel in an inner gorge, the gorge could be identified as a separate map unit. In many places, shallow landslides are associated with the toes or headscarps of large slump-earthflows; thus, deep-seated slides (or specific parts of them) could be defined as map units. Note whether mass wasting features are persistent sources of coarse or fine sediment, either from continued enlargement, active earthflow, or surface erosion of landslide scars.

e. Tabulate, for each MWMU, the number of features (by type) associated with various land use activities (on Form A-3 Mass Wasting Summary Table) (Figure A-3).

f. Extrapolate map units and descriptions to other areas. When appropriate, the analyst can extend the mass wasting map units to areas having no photographic record, or areas that have not been intensely affected by harvesting or roading. This allows extrapolation of the predictive mass wasting potential ratings as well.

Form A-2 Mass Wasting Map Unit Description Form

MWMU Number:	1
Description:	Steep (>65%) relatively straight slopes adjacent to stream channels
Materials:	Shallow permeable soils, containing both colluvium and glacial sediments, mantling competent, but fractured, andesitic bedrock
Landform:	Inner gorge: a narrow inset V-shaped valley characterized by steepening of slope gradient above stream channels, with a more-or-less distinct break in gradient between the relatively planar inner-gorge slope and the lower gradient hillslope above. Relief of the inner gorges (measured from the slope break) varies between about 30 to 150 feet (10 to 30 meters). The inner gorge slope typically runs directly to the active stream channel (that portion inundated during high flows) with little or no intervening low-gradient flood plain or terrace.
Slope:	> 65% (33%) measured on site
Elevation:	1,600 ft. - 3,800 ft. (490 to 1160 meters)
Total Area:	269 ac. (optional) (109 hectares); 0.5% of the total WAU area
MW Processes:	*10 road-related shallow rapid landslides* • 5 side-cast failures • 3 fill failures, all at stream crossing, 2 of which developed into debris torrents discharge from roads *6 non-road related shallow rapid landslides* • *5 in clearcut harvest units (each of which was less than 20 years old)* • 1 in mature forest with no previous forest practices
Non Road-related Landslide Density:	(optional) 1 landslide per 269 acres observed over the 30-year record (0.08 landslides per square mile per year)
Forest Practices Sensitivity:	• High sensitivity to roading • High to moderate sensitivity to clearcut harvesting (sensitivity to other harvest techniques unknown)
Mass Wasting Potential:	High; there is both a potential for landsliding under unmanaged conditions and a high sensitivity to forest practices
Delivery Potential:	High

Figure A-2: Example of MWMU Description Form

Delivery Criteria Used:	Steep slopes adjacent to stream channels (no intervening low-gradient area for deposition); historical delivery observed
Hazard-Potential Rating:	High
Trigger Mechanism(s):	*Roads:* • Failure of sidecast material placed on slopes of gradient > 65% • Fill failures at stream crossings. Road washouts at stream crossings may result from plugged culverts. Culverts may become blocked by woody debris and bedload transported down the steep inner-gorge channels during storms. • Discharge of surface water on to steep slopes. Two shallow rapid landslides occurred below ditch-relief culverts draining on to steep slopes. *Harvest:* • Increased landslide rates are associated with clearcut harvests within inner gorges. This increase is probably the result of reduced soil strength caused by loss of root mass.
Confidence:	• High confidence that the potential hazard rating for this MWMU is high: landslides occur naturally in unmanaged areas within this MWMU and there is an increase in landslide activity in those areas affected by past forest practices. • Low confidence, however, that the entire area mapped as MWMU 1 is unstable. Inner gorges are often very narrow and may be obscured on aerial photos by full forest canopy. For that reason, many inner gorges cannot be confidently delineated from contour lines on a topographic map. For most cases, identification of inner gorges relied on interpretation of aerial photographs and field identification. MWMU 1 polygons are mapped conservatively in an effort to include all inner-gorge slopes; for that reason some stable areas are undoubtedly included within the MWMU area. Likewise, it is likely that some inner gorges were missed. The final determination as to whether or not any particular slope falls within MWMU 1 depends upon actual field conditions and should be based upon the description given above.
Comments:	Timber harvest may also affect slope hydrology in a manner that could increase the potential for mass wasting. For example, snow accumulations (and water equivalent) in clear-cuts are commonly deeper than under forest canopy. Melting of the snowpack can result in greater inputs of moisture to the soil within a clearcut than within a mature forest (e.g., during a rain-on-snow event). Larger moisture inputs result in more extensive saturation of the soil and greater likelihood of shallow-rapid landsliding. The spatial distribution of this effect is difficult to predict in this area because of the extremely variable permeability of the underlying bedrock (fractured andesite).

Figure A-2: Example of MWMU Description Form (Continued)

MASS WASTING FEATURE

ACTIVITY	Shallow Rapid LS	Large Persistent Deep-Seated Failures	Small Sporadic Deep-Seated Failures	Debris Torrent	Totals
Clear Cut 0-20 years	2	0	1	1	**4**
Clear Cut 20-50 years	1	2	0	1	**4**
Partial Cut	0	1	0	0	**1**
Road	6	0	0	3	**9**
Stream Crossing	1	0	0	1	**2**
Landing	1	0	0	0	**1**
Other Forest Practices	0	0	0	0	**0**
Wildfire	0	0	0	0	**0**
Mature Forest	0	0	0	0	**0**
Non-Forest Land Use	2	0	0	0	**2**
Totals	**13**	**3**	**1**	**6**	**23**

Figure A-3. Example of Mass Wasting Summary Table (Form A-3)

For an inference to be valid, the known area and the unmapped area must be comparable in materials, landforms, and (to the extent known) erosion processes. Important characteristics that should be similar include all of those used to define the known MWMU (see b. above), especially:

- Slope form and gradient
- Bedrock and soil types
- Elevation, climatic zone
- Vegetation type

The greater the similarity of these characteristics between the known and unknown areas, the greater the confidence will be in the extrapolation of hazard ratings. If there are large differences between the areas, extrapolation should not be attempted, and indeterminate ratings should be assigned to the unmapped or unknown area.

4. Mass Wasting Hazard Potential Ratings

Ratings of the potential hazard of mass wasting debris or sediment to be delivered to streams and other public resources are assigned to the mass wasting map units. The ratings are determined on the basis of occurrence of landslides in the past (recognized in the landslide inventory and Form A-3), the relationships among forest practices and instability processes, and the likelihood that debris or sediment will be delivered to sensitive locations or waters (mass-wasting map unit descriptions Form A-2). Each element is part of the rating.

a. Consider the following factors, in combination, when making hazard ratings:
   - What is the natural potential for mass wasting processes?
   - Are the mass wasting processes associated with forest practices?
   - What is the potential for sediment to be delivered to streams or other waters?

The specific criteria used to evaluate delivery potential and predict the length of landslide tracks should be explicitly stated. A method to predict debris torrent run out is in Benda and Cundy, 1990, and channel characteristics associated with landslide dam-break floods are described in Coho and Burges, 1994. A synthesis of runout path length methods for shallow-rapid landslides, debris flows, and dam-break floods is in Kennard, 1994.

Because of regional variability in mass-erosion rates across the state, and the limitations inherent to Level 1 methods, it is not possible to define specific quantitative criteria for hazard rankings. Rather, they are assigned to map units within the WAU relative to the rest of the basin (and considering adjacent basins, if that information is available). The ratings address the most likely sediment sources in the watersheds; some basins may not contain a MWMU with a high hazard rating, while others may not include any low ratings.

The objectives of Level 1 are to identify with high confidence areas with low mass wasting hazard potential, and approximately differentiate the areas with moderate, high, and indeterminate levels of hazard, the criteria are applied in the order given below:

1. *Low:* Mass-movement features are rare to nonexistent; factors contributing to slope instability are practically absent; and there is little or no sediment delivery to water from mass wasting. This rating should be applied so as to minimize the possibility of masking small high-hazard areas within larger areas with low potential ratings (false negatives).

2. *High:* Landslides are common and there has been a debris torrent, or there is significant potential for either; mass wasting is associated with forest practices; and debris and sediment are typically delivered to streams or other waters.

3. *Indeterminate:* Landslide density in the map unit is unknown; the future behavior of slopes is unpredictable; the sensitivity to forest practices is unknown or unpredictable; or the likelihood of sediment delivery is unknown.

4. *Moderate:* All other combinations of landslide density, probability, sensitivity to forest practices, and sediment deliverability are rated moderate in Level 1.

b. Hazard-potential ratings for mass wasting are derived from both mass wasting potential and delivery potential. (See Table A-2.) Both components of the rating should be included on the MWMU description form with appropriate justification, evidence, and confidence addressed (see example Form A-2). A summary table of mass wasting and delivery potential and hazard-potential ratings (Figure A-4) is helpful, but not required.

   Indicate the ratings for hazard potential assigned to the mass-wasting map units (using the shading patterns indicated) on the MWMU overlay (Map A-2) and note and justify ratings in the descriptions of the mass-wasting map units (Form A-2). Figure A-5 shows an example of a hazard-potential map. It may be desirable to designate mass-wasting map units on the original 1:24,000 map overlay in color for use by the assessment and prescription teams; however, maps need to be reproducible in black and white, and all polygons should be clearly labeled with the unit number, optional polygon number, and hazard shading.

Table A-2. Ratings for Potential Hazard of Delivery of Debris and Sediment to Streams by Mass Wasting

		Mass Wasting Potential		
		Low	Medium	High
Delivery Potential	Low	L	L	M
	Medium	L	M	H
	High	L	M	H

Form A-4: Summary of Mass Wasting and Delivery Potential

MWMU	Mass Wasting Potential	Delivery Potential	Potential Hazard Rating
1	High	High	High
2a	Moderate	Moderate	Moderate
2b	Moderate	Low	Low
3	Low	Low	Low
4	High	Moderate	High
5	High	Low	Moderate
6	Low	Moderate	Low
7	Low	High	Moderate

Figure A-4: Example of Mass Wasting and Delivery Potential Summary Table (Form A-4)

c. Prepare a concise statement, to be included in the description for each mass-wasting map unit, describing the basis for the assignment of the hazard-potential rating, including the sensitivity to specific forest practices and likelihood of delivery of debris and sediment. Justify your calls with specific references pertinent to your analysis.

These ratings of potential mass wasting hazard are taken to the routing and synthesis modules, and applied to the "likelihood of adverse change and deliverability" axis of the cumulative-effects rules matrix.

d. Write a statement on Form A-2 linking mass wasting events to trigger mechanisms. Specific details are necessary to set appropriate prescriptions (e.g., landsliding caused by road sidecast failures, debris torrent initiated by failure of fill at stream crossing).

Analysts should evaluate the potential for continued occurrence of mass wasting due to outdated or substandard forest practices (e.g, yarding across streams, orphaned roads), because they may continue to contribute to landsliding and stream sedimentation.

e. Prepare a statement on Form A-2 on the confidence in the analysis. If this has been a Level 1 analysis, include recommendations or guidance on the appropriateness or necessity of Level 2 analysis, including the specific questions or uncertainties that should be addressed. A brief summary evaluating the certainty level of the assessment and the work products must also be included in he final mass wasting assessment report.

   Consider the following factors that can influence confidence in the mass wasting assessment:

   - Complexity of the basin
   - Extent of field-checking and accessibility to basin
   - Scale and range of aerial photograph coverage and length of record
   - Quality and quantity of other information
   - Additions to or deviations from standard methods
   - Skill level of the analyst

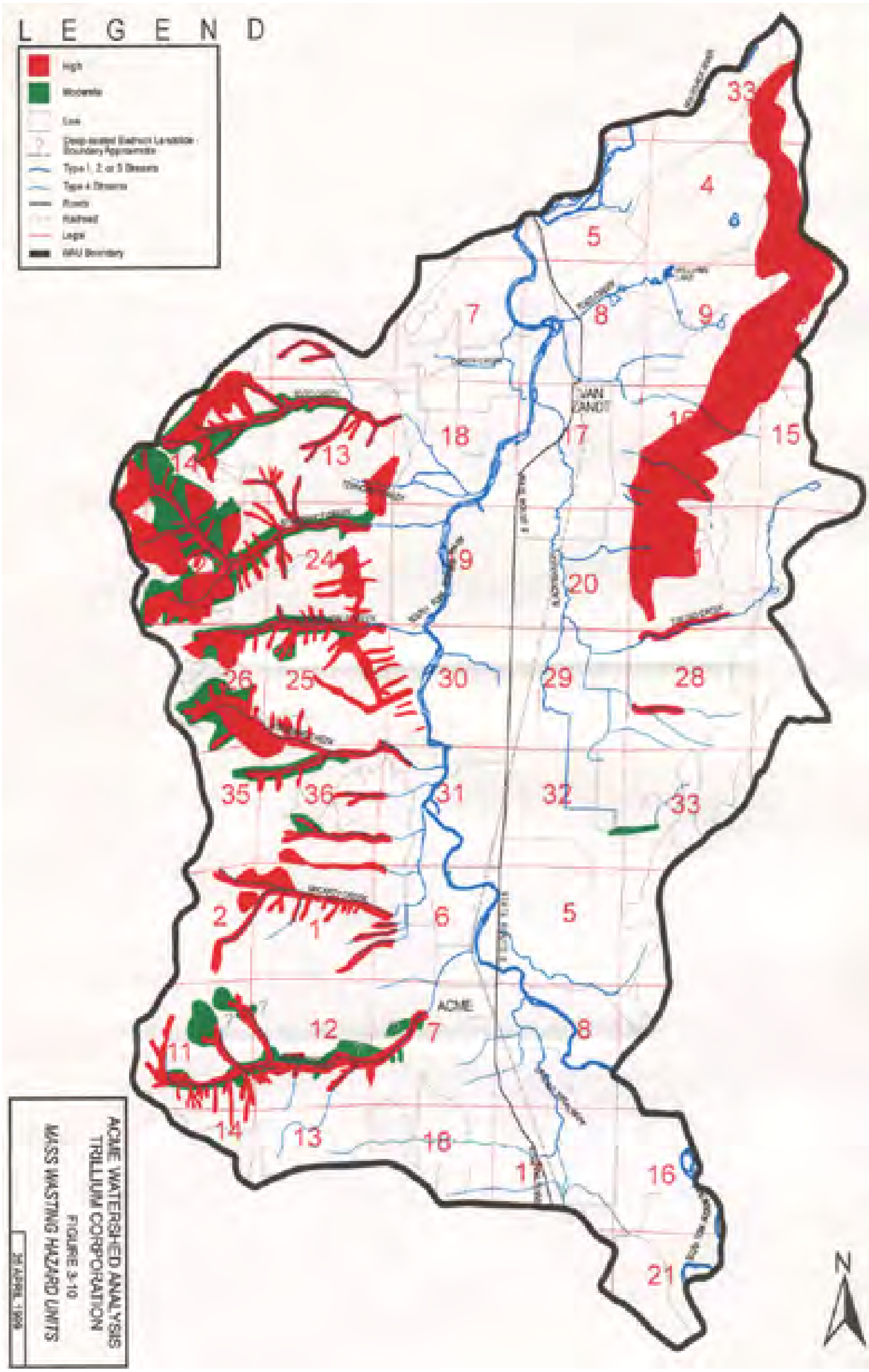


Figure A-5: Example of mass wasting hazard potential map

Suggested Methods for Use in Level 2 Assessments

There are a number of ways to improve the analysis to better address the critical questions or resolve uncertainties that Level 2 analysts could employ. Some of these are described below:

1. Expand and improve the landslide inventory mapping. In many cases, the Level 2 work will include additional aerial photo interpretation (more area, or more sets of photographs), supplemented with more extensive field verification. Increase the level of certainty in the contributing physiographic factors (geologic, climatic, etc.), trigger mechanisms, the linkages between forest practices and landsliding (these links are important in developing forest management prescriptions), delivery of sediment to streams, and the effects on stream function, habitat, and capital improvements.

2. Identify the mass wasting potential from the existing forest roads. Analyze the road network for potential to fail, for the landslide to impact identified downstream resources, and rank unstable sites relative to each other by the potential to impact resources.

   A field-based method to assess and rank risks to watershed resources from forest road landslides (Kennard, 1994) is available from the Weyerhaeuser Company, Tacoma, WA.

3. Obtain a better understanding of deep-seated failures. Analyze time-series of aerial photographs, precipitation records, and other information to establish chronic or event timing, and to detect any relationships between land use and the initiation or movement of deep slumps, slides, and earthflows. Field-check those features that seem to be affecting streams, structures, etc., to determine specific causes and consequences.

4. Further differentiate debris torrents, and try to understand their behavior. Although the indicators of debris flows and dam-break (or other hyperconcentrated) floods can seem similar on aerial photos, there are differences in the ways they begin and act, the parts of the stream systems they affect, the deposits they leave, and the kinds of hazards they pose (Pierson and Costa, 1987; Costa and Schuster, 1988; Johnson, 1990; Coho and Burges, 1991). Thus, it is desirable to discriminate between them; in particular, note the relationships between initiating events and land use activities, and the run-out behavior that might threaten stream habitat, structures, or public safety.

5. Improve the quality and resolution of the map of mass wasting units. This could be done by increasing the number of factors included in the delineation of the MWMUs, or by adapting and using an existing method of

landform classification (such as the system of Howes and Kenk, 1988). This will increase the precision of the material-process-landform associations for the basin, and the connections between mass-movement and land use activities.

6. Compute landslide rates (number/area/time) or material transfer rates (volume/area/time), using a sequence of historical aerial photographs supplemented by field inspection. Determine the effects of particular forest practices (or other land uses) on mass-erosion rates over time. See Howes (1987) for an example of quantitative methods of rating and extrapolation of post-logging landslide-hazards; and Sidle and others (1985), Ice (1985), and Pentec Environmental (1991) for comparisons of rates derived from other studies.

7. If other Level 2 assessment methods do not resolve the outstanding issues, the specialist team could construct a partial sediment budget for appropriate areas of the basin (Swanson and others, 1982). This might be done to:

    a. Tie sediment problems recognized in streams to specific hillslope sources or activities, if none can be identified otherwise;
    b. Discriminate among the rates, effects, and hazards of various mass wasting and surface-erosion processes, in basins where both are significant sediment sources;
    c. Document the relative contributions of chronic and intermittent processes (e.g., related to great storms); or
    d. Calculate rates of erosion, sediment transport, and storage when those are required (for example, if stream enhancement is contemplated).

Level 2 specialists may modify decision criteria for hazard ratings as additional information is obtained. The report must document the results of the analysis, and provide sufficient information to support the decision criteria and potential-impact ratings.

Mass Wasting Assessment Report

All information generated by an assessment becomes part of the record; that produced in Level 1 will be available for the Level 2 analysis and/or any later assessments. The following mass wasting assessment products are forwarded for use in the routing, synthesis, and prescription modules:

I. **Title page** with name of watershed analysis, name of module, level of analysis, signature of qualified analyst(s), and date

II. **Table of contents**

III. **Maps**
- Mass wasting landslide inventory (map A-1)
- Mass wasting map units and hazard potential ratings (map A-2)

IV. **Summary Data**
- Mass wasting inventory data (form A-1)
- Mass wasting map unit description form (form A-2)
- Mass wasting summary table (form A-3)
- Summary of mass wasting and delivery potential (form A-4) -- **optional**

V. **Summary Text**
- Summary geologic and physiographic setting pertinent to mass wasting interpretations
- Study methods
- Summaries of analysis and results
- Descriptions of mass wasting map units
- Description and explanation of mass wasting potential ratings
- Statement on trigger mechanisms
- Recommendations for Level 2 (at Level 1 only)
- Statement of the author's confidence level in the analysis and results
- Does module report address all critical questions?

VI. **Other Information (optional)**
- Monitoring strategies and design and implementation suggestions
- Learning resources (a.k.a., references, bibliography) section
- Acknowledgments section

Confidence

Include in the report a consideration of the confidence in the assessment and work products.

Example of confidence statement
The Hemlock Creek watershed was very complex, containing broad alluvial valleys, deeply and freshly incised tributaries, and rolling upland plateaus. A mixture of volcanic bedrock and glacial deposits complicates the geologic story.

The road network was well established and passable in the northern half of the watershed (Fern, Gneiss, and Alabaster sub-basins), but road washouts and a sparse network in Lodgepole and Cobble Creeks precluded much field checking there. Watershed-wide, 53 percent of the landslides were observed in the field; however, only 15 percent were checked in the Lodgepole Creek and Cobble Creek sub-basins.

The aerial photo coverage went back to 1943 for the entire basin, although those photos had poor resolution. Starting in 1964, photos were available every five to seven years; however, the Cobble Creek sub-basin was not photographed consistently.

The owner provided excellent records regarding harvest history and fires; however, only anecdotal information was provided for road maintenance (i.e., washouts, erosion, landslide blockage).

Confidence in assessing natural potential for mass wasting under unmanaged conditions:
There were good opportunities for observing naturally occurring landslides. Both Lodgepole and Cobble Creek sub-basins had large areas of forest with no previous forest practices. These areas included all the mass wasting map units defined for this WAU except for MWMU 7. In addition, the 30-year period of aerial photo coverage included two large storm events (1973 and 1985, with photos available for 1975 and 1988), so the conditions under which landsliding is likely to occur were included in the historic record. Field verification of landslide sites identified on aerial photos indicated high accuracy in aerial photo interpretations.

Assessment of the natural mass wasting potential also relied on field interpretations: examples of all MWMUs were visited.

Confidence in assessing sensitivity to forest practices:
Opportunities for observing the effects of forest practices on mass wasting activity varied widely between MWMUs. Road building and clearcut harvesting have occurred extensively in low-gradient valley bottom and upland areas (MWMUs 4 and 5); moderate activity occurred in the higher-elevation areas underlain by ultramafic bedrock (MWMU 3). Two large storms occurring over the course of the aerial photo record provided conditions conducive to landsliding; unfortunately, much of the valleyside harvesting was done after 1985, thus

reducing the likelihood of observing any effects of forest-practice activities. Additionally, forest practice techniques have changed over the course of the aerial photo record, so some inferences of sensitivity to forest practices may be based on techniques no longer in use.

Confidence in mapping accuracy:
MWMU polygons were delineated on the map using characteristics discerned from 1:24,000-scale topographic maps, 1:100,000-scale geologic maps, 1:24,000-scale soil-type maps, and 1:12,000-scale aerial photos. Mapping accuracy was field-checked at only a limited number of sites (in Fern, Gneiss, and Alabaster sub-basins). Overall, a high level of confidence in mapping accuracy can be applied to Fern, Gneiss, and Alabaster sub-basins; a moderate degree of confidence in Lodgepole Creek, and a low level of confidence in Cobble Creek (because of both limited photographic coverage and restricted access to the basin for field checking).

Map resolution:
Map polygons are drawn in an effort to include all areas matching the particular MWMU description. At a 1:24,000 map scale, areas having linear extent less than about 250 feet may not be resolved. Forest canopy further increases the minimum size of landscape features that can be discerned. It is probable, therefore, that within any MWMU polygon there are small areas that belong to a different MWMU, e.g., there may be areas of low hazard contained within mapped high-hazard polygons, and vice-versa. In all cases, the ultimate determination as to which MWMU any particular site belongs must rely on field conditions.

Skill of the analyst:
The mass-wasting module analyst, Ms. Crystal Peneplain, has performed three mass-wasting modules, one in eastern Washington and two in western Washington. She has been working on forest geomorphological problems since 1984.

Acknowledgments

This module has benefited from the work of many individuals. The current version was revised by Mary Raines, Dan Miller, Periann Russell, Jim Ward, Matt Brunengo, Venice Goetz, Bill LaPrade, Jeff Kirkland, and Gary Ketcheson based in part on earlier drafts developed by Lee Benda, Matt Brunengo, Mary Raines, Paul Kennard, Bill LaPrade, and Lynne Miller.

References

Benda, L., and T. W. **Cundy.** 1990. Predicting deposition of debris flows in mountain channels. Canadian Geotechnical Journal. v. 27, pp. 409-417.

Chatwin, S. C., D. E. **Howes,** J. W. **Schwab,** and D. N. **Swanson,** 1991, A guide for management of landslide-prone terrain in the Pacific Northwest. British Columbia Ministry of Forests, Land Management Handbook 18, 212 p.

Coho, C., and S. J. **Burges,** 1994, Dam-Break Floods in Low Order Mountain Channels of the Pacific Northwest, Water Resources Series Technical Report No. 138, Dept. of Civil Engineering, Univ. of Washington, Seattle, TFW-SH9-91-001, 23 p.

Costa, J. E., and R. L. **Schuster,** 1988, The formation and failure of natural dams. Geol. Society of America Bulletin, v. 100.7, pp. 1054-68.

Dietrich, W. E. and **Dunne,** T., 1978, Sediment budget for a small catchment in mountainous terrain: Z. Geomorphology Supplement 29, pp. 191-206.

Eisbacher, G. H., and J. J. **Clague.** 1984. Destructive mass movements in high mountains: hazards and management. Geologic Survey of Canada, pp. 8-16, 230 p.

Fiksdal, A. J., and M. J. **Brunengo,** 1981, Forest slope stability project, phase II. Wash. Dept. of Ecology, Technical Report 81-14, 62 p.

Howes, D. E., 1987, A terrain evaluation method for predicting terrain susceptible to post-logging landslide activity - a case study from the Coast Mountains of British Columbia. British Columbia Ministry of Environment and Parks (MOEP), Technical Report 28, 38 p.

Howes, D.E., and E. **Kenk,** 1988, Terrain classification system for British Columbia (rev'd ed). British Columbia Ministry of Environment (MOE), Manual 10, 90 p.

Ice, G. G., 1985, Catalog of landslide inventories for the Northwest. National Council of the Paper Industry for Air and Stream Improvement (NCASI), Technical Bulletin 456, 78 p plus appendices.

Johnson, A. C., 1990, The effects of landslide dam-break floods on the morphology of channels. [Unpubl master's thesis], College of Forest Resources, Univ. of Washington; TFW-SH17-91-001, 90 p.

Kennard, P., 1994 Road Assessment Procedure (RAP), consultant report to the Weyerhaeuser Company, Tacoma, WA.

Manson, C. J., 1984, Index to geologic and geophysical mapping of Washington, 1899-1983. Wash. Division of Geology & Earth Resources (WDGER), Information Circular 77, 56 p.

Manson, C. J., 1994, Preliminary bibliography and index of the geology and mineral resources of Washington, 1993. WDGER, Open File Report 94-15, 102 p.

Manson, C. J., 1995, Geologic and geophysical mapping of Washington, 1984-1994; and Theses on the geology of Washington 1986-1994; WDGER, Open File Report 95-2, 41 p.

Montgomery, D. R., and W. E. Dietrich, 1994, A physically-based model for the topographic control on shallow landsliding: Water Resources Research, v. 30.4, pp. 1153-1171.

Pentec Environmental, Inc., 1991, Methods for testing effectiveness of Washington forest practices rules and regulations with regard to sediment production and transport to streams: report submitted to Wash. Dept. of Natural Resources, TFW-WQ8-91-008, 100 p.

Pierson, T. C., and J. E. **Costa,** 1987, A rheologic classification of subaerial sediment-water flows: in Costa, J. E., Wieczorek, G. F., eds., Debris flows/ avalanches - process, recognition, and mitigation: Geol. Society of America, Reviews in Engineering Geology, v.7, pp. 1-12.

Rib, H. T., and **Ta Liang,** 1978, Chapter 3, Recognition and identification; in R. L. Schuster and R. J. Krizek, editors, Landslides: analysis and control. National Academy of Sciences, Transportation Research Board Special Report 176, pp. 34-80.

Shaw, S. C., and D. **Johnson,** 1995, Slope morphology model derived from digital elevation (DEM) data: Wash. Dept. of Natural Resources - Forest Practices Division OFR 94-1.

Sidle, R. C., A. J. **Pearce,** and C. L. **O'Loughlin,** 1985, Hillslope stability and land use. American Geophysical Union, Water Resources Monograph 11, 140 p.

Swanson, F.J., and R. J. **Janda,** T. Dunne, D. N. Swanston, 1982, Sediment budgets and routing in forested drainage basins: USDA Forest Service General Technical Report PNW-141, 165 p.

U. S. Geological Survey, 1992, Washington Index to topographic and other map coverage [catalogue]. U.S.G.S. National Mapping Program, 48 p.

Varnes, D. J., 1984, Landslide hazard zonation: a review of principles and practice. UNESCO Natural Hazards series n. 3, 63 p.

Wieczorek, G. F., 1984, Preparing a detailed landslide-inventory map for hazard evaluation and reduction. Assoc. of Engineering Geologists Bulletin, V. XXI.3., pp. 337-342.

Wu, T. H., C. J. **Merry,** M. Abdel-Latif, C. P. Benasly, 1993, Landslide hazard mapping - 1. Estimating piezometric levels: report submitted to Wash. Dept. of Natural Resources, TFW-SH15-93-001, 100 p.

Suggested Reading

Benda, L., G. W. **Thorsen** and S. **Bernath,** Report of the I.D. team investigation of the Hazel landslide of the North Fork of the Stillaguamish River: Wash. Dept. of Natural Resources.

Benda, L., and W. **Hang,** 1990. Accounting for the stochastic occurrence of landslides when predicting sediment yields: In: International Symposium on Tropical Erosion, Suva, Fiji: IAHS Publication 192.

Eide, J., 1990, a 48-year sediment budget (1942-1989) for Deer Creek basin, Washington [Unpubl. master's thesis]: Bellingham, Western Washington University, 122 p.

Hammond, C., S. M. **Miller** and R. W. **Prellwitz,** 1988, Estimating the probability of landslide failure using Monte Carlo simulations: In: Proceedings of the 24th Engineering Geologists and Soils Symposium, Moscow, Idaho: University of Idaho. pp. 319-331.

Hammond, C., and D. **Hall,** S. **Miller,** P. **Swetik,** 1992, Level I Stability Analysis (LISA), documentation for Version 2.0: Intermountain Research Station USDA Forest Service, Moscow, Idaho, General Technical Report INT-285, 190 p.

Kelsey, H. M., 1980, A sediment budget and an analysis of geomorphic process in the Van Huzen River basin, north coastal California, 1941-1975: Geological Society of America Bulletin, Part II, v. 91, pp. 1119-1216.

Pacific Watershed Institute, 1991, Prototype watershed analysis: report submitted to Wash. Dept. of Natural Resources, TFW-CEI-92-001, 113 p. plus appendices.

Reid, L., and T. **Dunne,** 1992 [draft], Rapid evaluation of sediment budgets: Pacific Southwest Research Station, USDA Forest Service, Albany, Calif., draft technical report.

Form A-1 Mass Wasting Inventory Data

Sub-basin	Landslide I.D. No.	MWMU	Landslide Process and Certainty	Landslide Size (by date of appearance on aerial photograph)						Sed. Del. to nearest stream (y/n, type)	Surface erosion of scar (percent)	Assoc. land use activity	Geomorphic character (gradient) (slope form)	Soil type & texture	Bedrock or parent material	Initiation elevation	Comments
				Photo yr	Photo yr	Photo yr	Photo yr	Photo yr	New slides								

Form A-2 Mass Wasting Map Unit Description

MWMU Number:

Description:

Materials:

Landform:

Slope:

Elevation:

Total Area:

MW Processes:

Non-road-related Landslide Density: (optional)

Forest Practice Sensitivity:

MW Potential:

Delivery Potential:

Delivery Criteria Used:

Hazard Potential Rating:

Trigger Mechanism(s):

Confidence:

Comments:

Form A-3 Mass Wasting Summary Table

ACTIVITY	MASS WASTING FEATURE Shallow Rapid LS	Large Persistent Deep-Seated Failures	Small Sporadic Deep-Seated Failures	Debris Torrent	**Totals**
Clear Cut 0-20 years					
Clear Cut 20-50 years					
Partial Cut					
Road					
Stream Crossing					
Landing					
Other Forest Practices					
Wildfire					
Mature Forest					
Non-Forest Land Use					
Totals					

Form A-4: Summary of Mass Wasting and Delivery Potential

MWMU	Mass Wasting Potential	Delivery Potential	Potential Hazard Rating

APPENDIX B
Surface Erosion Module

Table of Contents

Introduction

Surface erosion occurs when detachable soils on sufficiently steep slopes are exposed to overland flow and/or the impact of rainfall. Sediments introduced to streams from surface erosion processes are generally fine-grained and can influence water quality and aquatic habitat. Watershed analysis is primarily concerned about identifying locations and activities that deliver sediments to these public resources.

Raindrop splash, freeze/thaw, dry ravel, and biogenic processes such as wind throw and animal burrowing are natural causes of soil detachment. Gravity and overland flow of water are natural transport mechanisms of the detached soil particles. Overland flow of water rarely occurs under natural forest conditions because the soil is usually protected by an absorbent, protective layer of organic material resulting from residue of the forest plants. Soil compaction can lead to overland flow and serious erosion consequences. Hillslope angle, soil texture as it affects how well the soil holds itself together, and climate are important influences on the inherent erosion hazard of the site.

Any activity that strips the protective duff layer to the bare mineral surface may allow surface erosion. Surface erosion can also occur on compacted surfaces where the capacity of the soil to quickly absorb free water is diminished. The result is that water is readily channelized into surface flows. Among the activities most likely to cause surface erosion are roads, silvicultural practices involving high intensity broadcast burns or mechanical scarification, poor yarding practices, and natural processes such as wildfire.

Forest management activities that accelerate soil detachment and transport include:

Those that expose bare mineral soil to the weather:

- Road construction and maintenance
- Yarding techniques that disturb the duff layer such as skidder/tractor yarding, no suspension and one end suspension cable yarding
- Site preparation techniques such as burning or scarification

Those that compact soil and/or intercept subsurface flow zones, encouraging overland flow include:

- Skid trails
- Road and landing construction

If water bars and other water control measures are neglected, runoff from roads, cut- and fill-slopes, skid trails, etc. can contribute to hillslope erosion. These features actively produce sediment in most watersheds, with construction practices and drainage design influencing how much sediment is delivered to streams.

How far material can be transported on slopes, and how it behaves once it enters the stream, are largely determined by the nature of the slope and the texture of the sediment.

Factors that influence delivery to the stream system include:

Hillslope Erosion
- Proximity of erosion to the stream system
- Slope angle
- Soil texture, reflecting differences in the distance that various particle sizes will travel
- Areas where overland flow occurs

Road erosion
- Amount and condition of road prism area that drains directly into the stream system
- Traffic levels on the direct entry area of the road surface
- Material used for road surfacing

Some of the natural conditions that limit delivery of eroded soil to the stream include vegetated areas along streams that can filter out soil particles, and topographic conditions that prevent eroded material from entering the stream. Management practices that can limit delivery of eroded soil from hillslopes to the stream system include minimizing duff disturbance, water-barring and/or grass-seeding exposed areas near streams, and avoiding compacting the soil. Minimizing the road surface area that delivers directly into the stream, maintaining it according to the traffic levels, and limiting traffic during wet weather are management techniques that may help control the entry of erosion material into streams.

Critical Questions

The purpose of the surface erosion assessment module is to guide development of information necessary to address key questions critical to understanding erosion processes in a watershed context. Two types of erosion processes are addressed in the module, with the same critical questions for each source:

Hillslope Erosion

- What is the hillslope erosion potential?
- Are contributing activities present?
- Is sediment delivered to streams?
- What areas are sensitive to forest practices?

Roads Erosion

- What are the roads' erosion potentials?
- Are contributing activities present?
- Is sediment delivered to streams?
- What roads are sensitive to forest practices?
- What is the potential effect of sediment on public resources?
- What is the baseline sediment level?
- What are the amounts and types of sediment contributions from forest practices?

Answering these key questions relies on a combination of maps, aerial photos, and field observations. A series of exercises designed to answer the critical questions, or identify more information necessary to do so, are provided in the module. The module is designed to generate the level of information necessary to introduce sound information into land use decision-making.

Assumptions

A number of fundamental assumptions underlie the approach developed here. These assumptions dictate a rigorous, yet flexible, framework for the analysis. Our primary assumptions include:

Hillslope Erosion Assessment

- Sheet erosion of hillslopes is influenced primarily by soil type, hillslope gradient, protective cover, precipitation intensity and human activity (USDA, ARS in press).

- Certain soils (easily detachable) and slope conditions (steeper) are conducive to surface erosion (USDA, ARS, in press).

- On potentially erodible soils, the primary factors determining whether surface erosion occurs are exposure and compaction of mineral soil. Surface erosion tends to increase with exposure and/or compaction (Packer 1951).

- Certain forest practices can expose and/or compact surface mineral soil and significantly increase surface erosion. High-intensity burns, such as those used in site preparation, can expose large areas of mineral soil (Tiedemann et al. 1979). Both ground-based and cable yarding harvest activities have the potential to expose and compact surface mineral soil. The extent of soil disruption tends to be higher on ground-based harvest sites due to the skid trails (Megahan 198). Harvest activities that do not expose or disrupt the surface mineral soil are unlikely to increase surface erosion (Bennett 1982).

- Rainfall intensity and amount influence whether soils erode; however, since all places in the state of Washington have some probability of intense rainstorms, they also have some probability of surface erosion.

- If gullying occurs and the gullies connect to the channel network, then all sediment carried through them will be delivered to the stream system.

- Surface erosion may be delivered anywhere in the stream system by dry ravel or overland flow, but is fairly easily disrupted by buffers of slash, duff and other protective soil cover. Therefore, sediment is generally not delivered to the stream system if adequate buffers exist on the hillslopes (Comerford et al. 1992).

- Visible evidence of surface erosion is present where surface erosion has occurred in recent years.

- Dry ravel is primarily a function of slope gradient, hillslope storage potential, and soil erodibility (Mercereau and Dyrness, 1972).

- Most surface erosion occurs within five years of a contributing activity (Mercereau and Dyrness, 1972).

- The Forest Practices Rules of the State of Washington (Title 222 WAC) are followed, unless evidence suggests otherwise, and the rules are effective at preventing excessive surface erosion, unless the soils are especially erosive.

Roads Erosion

- Surface erosion occurs from nearly all roads. However, excluding special problem sites, sediment delivery to channels only occurs:
  1. When ditches or culverts drain near the channel (within 200 ft). Within this zone, the sediment delivery ratio is 100% (Burroughs and King 1989).
  2. Within a 200-foot buffer distance from the stream at other locations, delivery is based on the probability of downslope sediment transport. Outside the buffer zone, sediment supply to streams is assumed to be inconsequential because of the low probability of delivery (Ketcheson and Megahan unpublished report; Burroughs and King 1989). The buffer zone can be adjusted based on field evidence. The justification for such an adjustment should be explicitly included in the summary report.

- During wet weather, heavily trafficked roads produce substantially more sediment than do abandoned or low-use roads (Reid and Dunne 1984; Sullivan and Duncan unpublished report).

- Roads meet current Forest Practices Rules specifications, unless observed otherwise.

- Most road construction sediment is produced within the first two years of life of the road, but may continue at a reduced rate for long periods (Megahan 1974; Burroughs and King 1989).

- Ridge-top roads not draining to defined channels are considered to be non-contributing and not included in the assessment unless field evidence suggests otherwise.

Background Sediment Calculation

- A rough calculation of the baseline sediment supply to the stream can be made from estimates of stream channel length, soil depth, and creep rate.

- Comparing sediment yield from forest practices to the baseline can provide a means of rating the sediment hazard to streams posed by forest practices.

- There may be confounding conditions where the baseline comparison is not appropriate, such as basins where mass wasting is particularly active.

Overview of Assessment and Products

Before reading this section, the analysts should review the first three paragraphs under "Overview of Approach" in the Mass Wasting module.

The objective of the surface erosion assessment is to generate key information that addresses the critical questions for the watershed. During the course of the assessment, the analyst will establish:

- The relative potential for surface erosion from hillslopes,
- Contributing land use practices influencing surface erosion from hillslopes and delivery to streams,
- The relative potential for surface erosion from road surfaces based on road construction and drainage design,
- Effects of contributing activities of traffic on road sediment production, and delivery to streams,
- Background sediment yield from the watershed (excluding mass wasting processes), and
- The magnitude of effect on sediment supply from mapped sources.

Each of these objectives is an integral component of the surface erosion assessment. To determine background sediment yield, the watershed is divided into sub-basins (on Map B-1) usually of the Type 3 streams, and a background sediment yield is calculated as a function of soil depth, creep rate, and stream length.

Using an erosion potential mapping process, based on terrain (steep slopes erode more) and erodibility of the soil (soil K factor), the analyst develops a Preliminary Soil Erosion Potential Map (Map B-2). This can be done from soils, geology, or the DNR Soil Erosion Potential maps. These maps represent an initial hypothesis of potential surface erosion, producing ratings of high, moderate, and low.

To validate the initial hypothesis, the analyst uses aerial photography and field observations to determine whether erosion is actually occurring. To do so, they evaluate sites with recent management activities. Landowners supply information during Start-up on their forest activities in the past 5 years. These are compiled on the Past 5 Years Activities Map (Map B-3). The analyst uses aerial photos and field visits to determine what level of impact these forest practices have had on causing erosion in representative sites or each of the rated areas. Observations relevant to erosion from recent forest practices are recorded on the Hillslope Field/Photo Assessment Form (Form B-1).

When surface erosion is observed, the analyst estimates the likelihood of delivery to the stream system. Sediments not delivered to streams, wetlands, or lakes are not considered to have an effect on public resources. When delivery is established, a surface erosion unit is identified.

To determine these units, the analyst revises the soil erodibility map to more accurately reflect where surface erosion occurs and is delivered to a stream system as a result of forest practices. (Final Soil Erosion Potential Map, Map B-4). The High, Moderate, and Low ratings on this map are the hazard ratings used in the Rule Matrix to determine whether special prescriptions need to be written for these areas. The amount of surface erosion contributed to streams is not required unless dramatic or important surface erosion sites are contributing to a stream system. This reflects the assumption that surface erosion resulting from today's forest practices tend to occur sporadically.

Roads are also assessed for erosion potential. Landowners, during the start-up phase, supply the preliminary information on road use and surfacing materials, which is compiled on Map B-5, Landowners Roads Information Map. Roads are divided into segments based on parent material, surfacing material, and road use. Similar road segments are grouped and these groups are analyzed for sediment delivery to streams. Sediment production is predicted (using Form B-3) based on field observations (recorded on Form B-2) of road condition, drainage system design, and assumed truck traffic use rates. The analyst will not be able to inventory the entire road system in most cases, but will sub-sample various road categories. These results are extrapolated to the remainder of the basin. A Road Sediment Delivery Map, Map B-6, is produced that shows the rates of sediment delivery predicted for roads of each type in each sub-basin.

Since road sediments are a persistent and widespread source of fine sediments, the predicted amounts of sediment from roads for each sub-basin are compared to the background rate for the sub-basin. These estimates help determine a hazard rating for road sediment. These ratings are used in the Rule Matrix to determine if special prescriptions are needed to protect public resources

Qualifications

The Surface Erosion Module provides a structured approach to assessing surface erosion hazards on a watershed basis. The module is not a cookbook, and some expertise in recognizing and evaluating surface erosion is required to effectively complete the surface erosion assessment. In addition to completing the Watershed Analysis Training provided by DNR, the surface erosion analyst must possess the following skills, education, and experience at a minimum.

Skills: Level I
Knowledge of soil science, hillslope processes (including erosion, transport and deposition), and their relationship to forest management activities.

Skill in use of soil maps, air photo interpretation, and recognition of surface erosion features in a variety of geomorphic settings.

Working knowledge of Universal Soil Loss Equation.

Familiarity with forest management activities potentially affecting surface erosion in a region.

Additional Skills: Level 2
Familiarity with methods of sediment budgeting.

Education and Training: Level I
Bachelor's degree in soil science or geomorphology, or in a related field such as forestry, forest engineering, geotechnical engineering, geology, geophysics, etc.

With a significant amount of course work or other training in geomorphology and/or surface erosion processes.

Additional Education and Training: Level 2
Master's degree in soil science or geomorphology, or in a related field.

With a significant amount of course or thesis work or other training in geomorphology and/or erosion processes.

Experience: Level 1
At least 2 years of field experience in assessment, scientific management, or research on erosion in forest lands or mountainous areas.

Additional Experience: Level 2
At least 2 years of field experience in assessment, scientific management, or research on erosion in forest lands or mountainous areas, including substantial experience with field interpretation.

Two additional years of relevant experience may be substituted for the Master's degree. No years of field experience are required with a PhD in a closely relevant field.

Background Information

All of the information necessary to complete the module, with the exception of field information, must be gathered prior to starting an assessment to ensure that the analyst will be able to complete the analysis in a timely manner.

Base Maps

The final products of the Hillslopes and Roads portions of the module will be plotted at 1:24,000 scale, compatible with DNR's Geographic Information System (GIS), on mylar. These maps may be plotted by hand or by GIS, but they must be on the official base map. Two copies of the base map on mylar showing the watershed analysis unit (WAU) boundary, section lines, hydrology and roads will be needed to plot the final products, if plotted by hand. These base maps can be obtained from the DNR regional office. If a GIS system is to be used to produce final products, it must be compatible with DNR's GIS system, using the same projections, etc. Consult the GIS person at the DNR regional office for more information on fitting GIS information to DNR's system.

It may be useful to have two additional copies of the base map plotted on mylar for use in producing intermediate products - one to be used to compile all landowners information on activities of the past 5 years, and another to be used to compile all landowners roads information.

Where possible, the entire analysis team should decide on the sub-basins to be used early during the process. The boundaries for these should be digitized at the DNR regional office, or on a landowner's compatible GIS, so that they can be included on plots of the base map. The sub-basins boundaries must otherwise be plotted by hand onto all maps.

Other Maps

For the Hillslope portion of the module, the analyst will use topographic maps, geology maps and descriptions, soil maps and descriptions, maps of activities of the past 5 years as provided by the landowners, and the DNR GIS layer "Soil Erosion Potential". Soil maps can usually be acquired from the local USDA Soil Conservation Service (SCS) Office for the counties involved. The USDA Forest Service usually has Soil Resource Inventory (SRI) maps and descriptions available at the local Ranger District Offices. DNR has soil maps of DNR managed lands, and often include adjacent land as well. Some private forest land owners have their own soils maps which may be useful.

Where possible, digitize the compiled landowners' past 5 years activities map. This will ease producing information on amounts of various activities on various erosion potentials. In addition, for the Roads portion of the module, landowners' maps of road use and surfacing will be needed.

Aerial Photographs
Access to a recent set of 1:12,000 scale aerial photographs will be necessary. The Mass Wasting analyst will be using a series of older photos, which may be consulted.

Other Information
Reports on various aspects of surface erosion may have been produced in the past for various landowners in the basin. For example, the Forest Service may have done some analyses or reports on portions of their ownership that coincide with the WAU. Inquiring of each ownership for any relevant reports may provide some useful background and supporting material for the analyst. Likewise, important water bodies may have been studied in the past, and information relevant to surface erosion may be available on them. Local Counties and citizens groups may have carried out studies which resulted in reports, maps, etc.

All of the information, maps, photos should be *in hand* before the analysis begins. There is often a month or more involved between requesting information from various sources and receiving it. With the limited time frame of Watershed Analysis, the analyst will need to ensure background information is already assembled at Startup when the assessment is initiated.

Analysis Procedure
There is a certain level of information necessary to analyze surface erosion processes in a watershed context. The following procedure defines a standard methodology appropriate for watershed analysis and must be completed regardless of the qualifications of the analysis team.

Level 1 and Level 2 watershed analysis levels specify the qualified individuals and time frame available for the assessment. Limitations of time and resources for performing the assessment, and the analyst's qualifications, will also determine the degree of resolution and confidence in assessment interpretations.

It is expected that Level 1 assessments produce the standard products, but greater uncertainty of results and indeterminate interpretations are expected. It is important that uncertainties be noted so that decisions based on this information can account for them. Where resolving uncertainties is considered important for improving interpretations and decision-making, a Level 2 assessment may be appropriate. Level 2 teams are expected to produce the standard assessment products augmented by additional information on specific situations. Level 2 analysis can be invoked when analysts are not satisfied with their ability to answer one or more critical questions based on the standard analyses. Level 2 assessment requirements are flexible, allowing the analyst to invest his or her effort in gathering data and observations as warranted by the nature of the question to be answered and the watershed situation to be resolved. This may include more defined analyses of particular processes or sub-areas within the watershed.

The surface erosion assessment is divided into two parts:

The Hillslopes section accounts for surface erosion occurrences, or potential for surface erosion, on hillslopes.

The Roads section assesses the amount of erosion that can be expected from the roads in the basin. Roads can be chronic sources of surface erosion that can contribute sediment for the life of the road.

Surface Erosion Links

Following is a summary of points for which the surface erosion analyst will need to touch base with others during an analysis. Initial contact during Start-Up (SU) is important for many of these items. Some of these items suggest preliminary synthesis discussions (SYN).

Landowner/DNR - sources of information
- road surfacing/traffic (SU)
- road problems (SU)
- areas harvested in past 5 years (SU)
- harvest methods, site prep methods (SU)
- wildfire history (SU)
- availability of a guide/helper

Mass Wasting Analyst
- agree on who is covering road failures (SU)
- agree on who is covering orphan roads (SU)
- agree on who is estimating landslide scar erosion (SU)
- discuss relative importance of various sediment sources (SYN)

Hydrologic Change Analyst
- agree on sub-basins (SU)
- source of rainfall information for roads analysis

Riparian Analyst
- may see evidence of sediment reaching streams across riparian areas
- in conjunction with the channel analyst, discuss role of woody debris in Type 4 & 5 streams (SYN)

Stream Channel
- agree on who is covering stream bank erosion (SU)
- along with Mass Wasting analyst, discuss relative importance of various sediment sources (SYN)
- along with Riparian Analyst, discuss role of woody debris in Type 4 & 5 streams (SYN)

Fish Habitat
- discuss sediment sources in relation to presence of fine sediment in fish habitat (SYN)

Water Supply/Public Works
- discuss sediment sources in relation to presence of fine sediment in water supplies (SYN)

Watershed Partitioning

Sub-division of the WAU into sub-basins will allow tracking the effects of sediment on public resources on a more localized basis assuming that the relative influence may not be uniform throughout a watershed the size of a WAU. Although the analyst will not use the sub-basin divisions until later in the assessment, early identification of these in conjunction with the hydrology assessment team will facilitate compiling data and results in a manner conducive to later steps.

The WAU may be sub-divided into Type 3 stream basins. The surface erosion analyst should consult with the hydrology analyst on the identified units, since the hydrologist also uses Type 3 basins as one criteria for hydrologic analysis units. The sub-basin units are placed on the base map of the watershed. The sub-basin boundaries will be transferred to the hillslope erosion maps and the roads erosion maps. Later steps in the assessment will estimate sediment yield from surface erosion sources throughout the WAU. The sediment rates will be estimated at the mouth of each sub-basin based on soils, road characteristics and hillslope conditions in the sub-basin based on results from the assessment.

Surface Erosion From Hillslopes Assessment

The potential for surface erosion from hillslopes is primarily a function of the characteristics of the soil, the steepness of the terrain, and the vegetation cover. The Washington Forest Practices Rules contain standard rules intended to protect public resources from the effects of excessive erosion from timber harvest (Chapter 222-30 WAC). Experience with operations performed under these rules is that forest activities *generally* do not result in widespread increased surface erosion. However, it is also possible to improperly conduct activities so that significant amounts of sediment from surface erosion are delivered to streams. It is important to note that erosion problems from improperly conducted activities can occur anywhere on the landscape. However, erosion damage is most likely in the more erosive areas.

The focus of the hillslope portion of the module is to locate the potentially erosive slopes in order to map areas sensitive to forest practices conducted according to the standard rules as applied in that area. Because of the importance of the interaction between inherent site erodibility and the manner in which a forest practice is applied, determining the sensitivity of an area to hillslope surface erosion requires consideration of both. Erosion potential is estimated by mapping soil properties and slope. Sensitivity is determined when potential is confirmed because actual erosion problems are found in the field. The analyst will have to sort out from field observations whether surface erosion appears to result from standard rules on sensitive soils or slopes, or lack of compliance with standard rules.

For these sensitive areas, the Rule Matrix will show whether prescriptions will be needed from the field managers team to provide protection of public resources. Standard rules will remain in place in all areas where prescriptions are not required.

In the Hillslopes portion of the module, the analyst examines the *potential for erosion*, the effects of *forest activities* on the different erosion potentials, and the *delivery* of erosion products to the stream system. The analyst then provides information on *areas sensitive to forest practices*.

Surface Erosion Potential

Different parts of the basin landscape have different inherent rates of surface erosion. Some soils are composed of easily detached material that is mobilized with minimal disturbance. Other soils require considerable disturbance or compaction to cause soil particles to be detached and displaced. In addition to the inherent soil properties, the slope on which the soil lies affects how easily it is eroded. A soil on a steep slope is more likely to erode than the same soil on a gentle slope because of the effects of gravity. The first step in evaluating the potential for erosion on hillslopes is to develop a map of the soils with greater and lesser likelihoods of erosion. A soil erosion potential map will be developed that includes effects of slopes and soil erodibility. There are a variety of ways to obtain or develop an appropriate soil erosion potential map.

DNR Soil Erosion Potential Map

The simplest way is to obtain the DNR Surface Erosion Potential Map from DNR's GIS. On these maps, soil types are already rated for erosion potential using principles similar to those on which this module is premised. However, this map should be viewed as a preliminary estimate, since the soil surveys on which they were based were conducted based on silvicultural rather than engineering specifications. These maps need to be field verified, and difference in actual erosion from the rated erosion potential will not be unusual. The DNR maps are available for most forested lands in Washington through the local DNR Region office.

Other Erosion Mapping Methods

An alternative soil map may be produced by using the K factor assigned to each soil unit from SCS soil surveys, or assigning a K factor using the soil erodibility nomograph from the Revised Universal Soil Loss Equation (RUSLE) combined with slope. The analyst would need to provide justification for any assigned K values since K values are based on percent silt and sand fractions, soil structure, and permeability. The K factor indicates the influences of soil properties on the effects of rainfall, runoff, and infiltration. Erodibility ratings and slope categories have been grouped into three classes as potential erosion ratings (Table B-1). SCS maps are often available on forest lands in Washington. The K factor for a soil can be usually be found in the tables in the SCS county soil survey, in a table in the back of the survey document, titled "Physical and Chemical Properties of Soils".

Table B-1: Erodibility Ratings Based on K and Slope

Slope Class (Percent)	**K < 0.25 Not easily detached**	**0.25 < K > 0.40 Moderately detachable**	**K > 0.40 Easily detached**
< 30	Low	Low	Moderate
30 – 65	Low	High	High
> 65	Moderate	High	High

The USDA Forest Service has soil maps and descriptions, called the Soil Resource Inventory (SRI), which contain adequate information to produce a soil erosion potential map for Forest Service lands in the WAU. This information is usually available at the local Forest Service Ranger District office.

If there is an area in the basin for which there are not soil maps, a good soil erosion potential map can be constructed from geologic and topographic maps of the area. A geologic map can be used to identify the general nature for the soils developing on dominant parent material relative to erosivity and the nature of the sediment produced. A rating of erosion potential can be made by using the combination of geology and topography maps, according to Table B-1 above, qualitatively estimating the K factor range from parent material.

Geology, topography, and soils maps will also be useful to interpret and define the DNR Soil Erosion Potential Map units. This initial map is a work tool, not a final product. This "Preliminary Soil Erosion Map", Map B-2, will be reviewed in light of field evaluations of sites where forest management activities have been carried out in the past 5 years. Field evidence will be used by the analyst to draw a final map of surface erosion sensitive areas.

Contributing Activities

Field evidence of erosion is the primary means of determining the hazards within the watershed for hillslope erosion. Unlike mass-wasting features, surface erosion is difficult to detect with remote sensing techniques and may require field inventories to discover or confirm its occurrence. The primary evidence of surface erosion on hillslopes is gullying, some of which may be visible in aerial photographs.

Observations from local sites are extrapolated to other locations in the watershed through the erosion potential map. The analyst must visit the field, and, based on observations in the field and on photos, modify the preliminary soil erosion potential map to reflect the likelihood of high, moderate, or low occurrence of erosion and sediment delivery to streams from standard forest practices. Field visits focus on sites with activities conducted in the past 5 years, both to identify erosion before it is masked by revegetation, and to reflect current practices.

As part of the Startup information, the analyst has a map or other information on the land management activities of the past 5 years that would affect surface erosion. These activities include area and type of timber harvest with type of yarding system; area and type of site preparation activities and intensity; location of grazing allotments and rules or improvements required of lessee; areas where off-road vehicle use commonly occurs. The analyst plots all activities on a mylar base map (or more than one map if activity patterns make one map confusing). These activities will be rated for expected erosion impact (see Table B-2). All will be examined on aerial photos, and a field sampling scheme will be developed to visit a variety of activities of different intensities on a variety of terrain.

With the Preliminary Surface Erosion Potential Map (Map B-2), the compiled landowners' Past 5 Years Activities Map (Map B-3), and a recent set of 1:12,000 aerial photos in hand, the analyst can develop a field sampling scheme. All sites from the past 5 years are rated for expected erosion and examined on aerial photos. A subset of these sites are field checked to compare intensity of erosion expected with that existing on the site. The analyst must consider whether the activity was carried out in general compliance with the Forest Practices Rules and whether sediment was delivered to streams. Information generated from the photo and field examinations is recorded on the Hillslope Field/Photo Assessment Form (Form B-1).

Table B-2: Rating Guidance for Contributing Activities

Activity	Low	Moderate	High
Burns	Discontinuous Low intensity Light duff burn	Spotty intense	High intensity 3" deep or more Continuous over a large area
Tractor Logging	Waterbars intact	Spotty evidence of occasional gullying	Skid trails on steep (>10%) slopes Heavy, widespread compaction Waterbars non-functional
Highlead (cable) yarding	Fully suspended logs	SOME deeply gouged haul-back corridors	NUMEROUS, deep gouges from half-suspended logs
Scarification for site preparation	Shovel scarification on gentle slopes	Cat scarification on gentle slopes	Cat scarification on steep (>10%) slopes
Grazing	Animals fenced away from riparian, springs, minimal evidence	Some impact from animals delivered to streams	Springs, riparian areas unprotected, extensive evidence of trampling
Off-road vehicles	Little access to streams, streambanks by vehicles	Some vehicle access to streams	Evidence of running up and down streams, streambanks

Figure B-1 provides a schematic for the hillslope assessment.

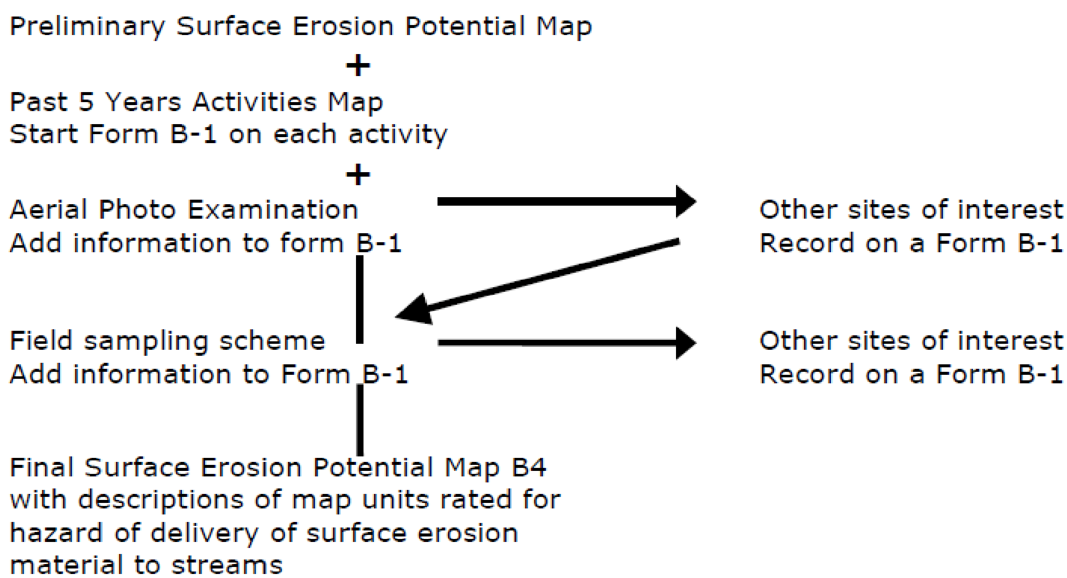


Figure B-1: Hillslope Assessment Overview

During the photo and field assessment, other sites may come to light that were not part of activities of the past 5 years, but appear to be eroding and delivering sediment to streams. These sites will also be recorded on a B-1 form and receive the same examination. All sites may be useful in determining trends in amount of surface erosion, in determining recovery rates, or in demonstrating the sensitivity of the soils involved to surface erosion. The analyst must always consider if the forest activities causing the erosion at these sites were carried out according to standard rules for forest practices.

Field Site Selection

Due to time limitations, field site selection must allow efficient visits to as many types of activities and terrain as possible. Field visits for both the hillslopes and roads portions of the module can be carried out together, so consideration of roads to be visited can influence field sampling.

Field visits should include all or most levels of potential erosion and types of activities. Visits should also cover the range of soil erosion potentials. Additional site selection criteria may include varying geology and terrain. The rationale for site selection should be described in the final report.

Delivery

The analyst needs to note not only that erosion is occurring or has the potential to occur, but that erosion products are likely to be delivered to a stream. The final hazard map units are rated for delivered hazard. Eroded soil that deposits on-site or where it cannot reach a stream is not of importance to this assessment. Factors that influence delivery include proximity of erosion to the stream system, and the existence of buffering factors such as well vegetated slopes between the erosion and the stream, or a break in topography such as a flat stretch between the eroded site and the stream of sufficient length to prevent erosion materials from reaching the stream. Figure B-2, provides some guidance on the circumstances influencing delivery of sediment to streams. If evidence contrary to the assumed delivery exists, rate delivery according to observed evidence.

The delivered hazard map units may be drawn as a broad area, but in their description be more closely defined. For example, an area may be delineated on the map with an accompanying map unit description that defines the actual hazard areas to be "those areas within 100 feet of a stream channel" within that map unit. Or, a map unit may be drawn, and the accompanying map unit description defining the hazard area as the "steep (>50%) convex slopes" within the mapped unit.

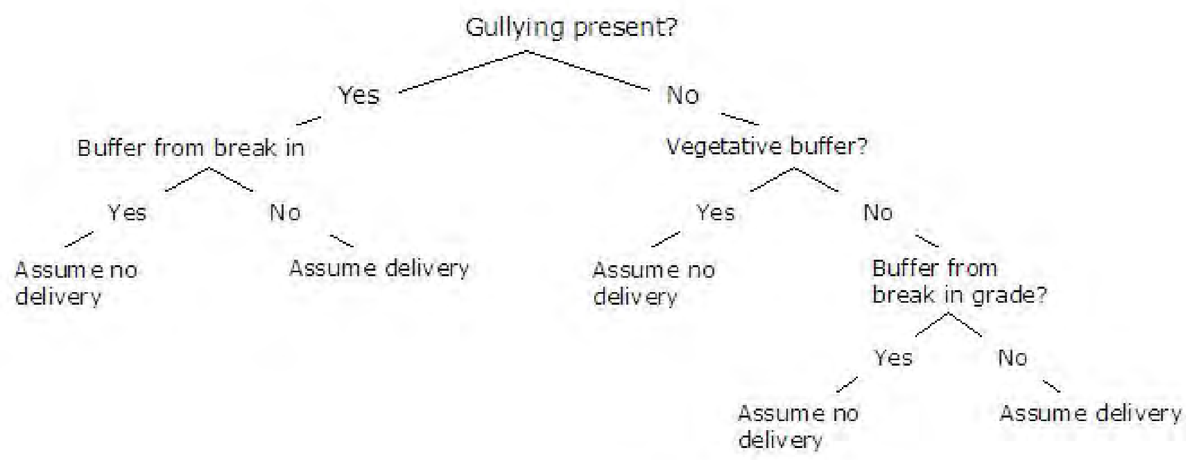


Figure B-2: Surface Erosion Delivery to Streams

Field Form. For each site, the analyst will record observations on a form labeled "*Form B-1*, Hillslope Field/Photo Assessment Form". The exact format of the form is left to the analyst, but must include the following information, at a *minimum*:

___ WAU
___ Sub-basin
___ Site location
___ Preliminary Soil Erosion Potential rating
___ Type of activity, year
___ Activity rating from Table B-2
___ Whether field or photo observation
___ Observations, including descriptions of:
  ___amount of area affected by erosion
  ___erosion type and degree
  ___particle sizes of eroding material
  ___compaction, if present
  ___evidence of overland flow
  ___slopes where erosion is occurring
  ___apparent causes
  ___delivery to stream system

To allow flexibility, the specific layout of the form is left to the analyst. The field forms will be included in the final report as an appendix.

Hillslope Areas Sensitive To Forest Practices

The evidence gathered in the field is used to modify the initial soil erosion potential maps to produce the surface erosion units. The analyst uses all available information from maps, photos, and field visits to determine if areas identified on the Preliminary Surface Erosion Potential Map as high, moderate, or low erosion potential are correct representations of the delivered hazard from surface erosion. This determination is made based on professional judgment of the evidence generated during the assessment. The spatial extent, frequency of occurrence or severity of erosion would tend to suggest a rating of "High". Localized, occasional or mild levels of erosion would tend to suggest a rating of "Moderate". Erosion problems resulting from poorly conducted practices should be noted, but not necessarily considered representative of erosion potential under management conducted according to standard rules. The delivered hazard ratings from the final map are used in the Rule Matrix to determine the need for special prescriptions to protect public resources.

Some guiding questions to assist the analyst are provided below:

Are past activities or practices contributing to active erosion? How much area? What is the nature of the sediment?

Did some practice consistently result in erosion on all or certain soil / slope categories?

Did some practices occasionally result in erosion on all or certain soil / slope categories?

Did the field reconnaissance yield any insight as to precise problems?

For example, if a unit was logged in the past 5 years with standard practices and a few problem areas, the analyst would rate the activity as likely having a moderate impact. If the analyst then viewed the site on photos or in the field and found excessive erosion, then either the activity was not carried out according to the standard rules, or the soil is especially erodible, and something beyond the standard rules may be needed to protect public resources, depending on the resources' vulnerabilities. The analyst will have to distinguish between activities carried out according to the standard Forest Practices Rules, and activities which were not, so familiarity with the standard rules on timber harvesting (chapter 222-030 WAC) is essential.

The analyst revises the initial soil erosion potential map to reflect observed conditions, producing the Final Surface Erosion Potential Map B-4. Each map unit on the final map will have an accompanying description that describes the location and reasons for delineation of the map unit, the delivered hazard rating and reasons for the rating, and the specific activities that trigger erosion and delivery of sediment. The unit number and triggering mechanism can be placed on a Causal Mechanism Report (Form 4) at this time.

Surface Erosion from Roads Assessment

Unlike surface erosion from exposed hillslopes where revegetation usually occurs within a few years, road surfaces can continue to erode as long as the road is used. The road cutslope and fillslopes tend to revegetate, reducing erosion from those sources over time. However, road running surfaces continue to provide fine-grained sediments over the life of the road, especially when used by log trucks (Reid and Dunne 1984). The focus of this part of the module is to identify roads producing a significant amount of sediment that affects public resources including water quality and fish habitat. This analysis develops an understanding of the overall effects of the road system on sediment yield by roughly quantifying the amount of sediment delivered to streams from roads in a sub-basin, and comparing that amount to the estimated background sediment rate.

The amount of sediment produced from the running surface of a forest road is determined by the amount and type of traffic (Reid and Dunne 1984; Sullivan and Duncan 1980), construction materials and methods (Burroughs and King 1989), and the design of the drainage system (Reid 1981). Sufficient research has been conducted on the factors that influence road erosion on different parent materials that the sediment rate for a given road segment can be estimated according to these factors. Erosion rates from forest roads commonly having the range of traffic rates, surfacing materials, and drainage design can vary by as much as two orders of magnitude. Therefore, to appropriately estimate the potential for adverse effects from roads on public resources in a watershed, roads should be examined in some detail according to factors that influence sediment generation.

The approach for estimating sediment production is to examine road segments for characteristics of the road prism, drainage system design, and traffic, as they influence the delivery of sediment to the stream system, and calculate sediment yield based on them. Factors are applied for differing conditions of the road tread, cut and fill slopes, and traffic use that increase or decrease the estimated sediment yield of that segment as compared to the "Reference Road"(a compilation from the literature). The result is an estimate of sediment yield for each road segment for its expected traffic use rate. The estimate is further modified according to the average delivery of sediment to streams along that segment. The reference road is described as:

Reference Road
An insloped road with a ditch; native surface road tread and ditch; general use traffic (mostly pick-ups and sedans); cutslope gradient 1:1 (horizontal to vertical) and fillslope gradient 1.5:1; initial ground cover density of zero on cut and fill slopes; sustained grade of 5-7 percent; and an average cross-drain spacing of 500 feet. The proportions of the total long-term average road erosion rates attributed to the components of the standard road prism are:

Road Tread	40%
Cutslope and Ditch	40%
Fillslope	20%

(**Swift**, 1984; **Burroughs** and **King**, 1989; **Sullivan** and **Duncan**, 1980; **Megahan**, unpublished data)

Since it is usually not possible to visit every road segment in the WAU, the road system must be stratified, enabling sampling of portions of the system. Each road "type" can be characterized, and sediment yields determined and extrapolated to other roads of the same type. Road "types" consist of segments of similar use and construction standards. Once sediment yield has been estimated for each road type in the sub-basin, the relative effect of the entire road system on water quality and sedimentation can be evaluated.

Localized Road Problems
During the course of this assessment, the analyst may discover portions of the road system or local problem spots that contribute adverse levels of sediment to streams. These sites may or may not occur along a generally high sediment yield road segment type, or may or may not occur in a sub-basin with a generally high sediment load. In any case, these site situations are recorded on a site form so that these sites can be addressed according to standard rules where they are not addressed by prescriptions. The analyst cannot be expected to uncover every site problem during watershed analysis, but any site problems that are encountered can be addressed outside of watershed analysis through standard rules, no matter where they occur in the basin.

Table B-3, below, provides a general overview of the types of forest road situations, and their expected relative ratings for producing sediment that is delivered to streams. This table is not used in the analysis, but rather is provided to give the reader a general view of the types of road segments that produce High, Moderate, and Low ratings.

Table B-3: General Criteria for Sediment Production from Roads

Low	Moderate	High
Few roads	Moderate amount	Lots of roads
Ridgetop roads	Roads _|_ to streams	Roads paralleling streams
Cohesive soils	Moderately cohesive soils	Non-cohesive soils
CONSTRUCTION PRACTICES: Resistant surfacing (Good lift)	Surfacing less thick	Little or no surfacing or non-resistant materials
CUT SLOPES: Low-angle Surface protected cohesive materials	Higher angle Somewhat exposed Prone to ravel	High angle Exposed Highly susceptible to ravel
FILLSLOPES: Protected around streams especially	Partially exposed and of erodible soils	Exposed and of erodible soils and near streams
SURFACE DRAINAGE: Uniform, well-spaced culverts Insloped roads	Moderately spaced culverts Outsloped roads	Widely spaced culverts Berms on roads Rutting
TRAFFIC PATTERNS: Occasional traffic by log trucks	Occasional traffic, but occurring each year	Continual log-truck traffic
USE: Roads closed (put to bed)	Roads in non-use status	Roads open and used

Erosion Potential

The basis of this procedure is to examine representative segments of road to determine their condition relative to sediment-production factors. These characteristics are used to adjust the reference sediment yield up or down and produce a modified estimate of annual sediment yield from the road segment type.

Identifying Road Segments

Roads will be grouped into road segment types within the WAU, according to parent material, surfacing material, and traffic use. These groups represent the potential erosion road units. Road lengths with generally similar characteristics within that length are called road segments. A road segment is defined as a mile or more of road crossing similar topography and parent material, with similar construction and use. Criteria that distinguish road types are parent material, surfacing material, traffic use, and similar topographic positions.

Each forest landowner usually builds and maintains roads to a consistent standard based on anticipated use by log trucks, so there will often be obvious groups of road segments that share many characteristics of construction, maintenance, and use. Start-up materials include maps provided by the landowners in the WAU displaying road surfacing and use. Use of this information, along with parent material and topography, will allow the analyst to break out road segments. Further grouping may occur where road prism geometry varies significantly from the Reference Road, or where sediment delivery percentages vary within the cluster.

During the Start-up phase, each landowner in the WAU is asked to provide a map of his/her roads, coded according to the type of surfacing and traffic use that occurs. The traffic use should reflect an average of use expected over the next 5 years. If the future road use is not known, the analyst may assume that the past 5-years use rate is a good representation.

The analyst produces a map of road use and surfacing coded according to Table B-4 below, for all roads in the WAU, labelling it Map B-5, "Road Traffic and Surfacing.

Table B-4: Surfacing / Road Use Coding

	Abandoned	Inactive	Active Secondary	Active Mainline
Asphalt	AA	AI	AS	AM
Dust-oil	DA	DI	DS	DM
>6" Gravel	6A	6I	6S	6M
2 - <6" Gravel	2A	2I	2S	2M
Native	NA	NI	NS	NM

NOTE: For a description of road categories, see Table B-9.

Analysis of Road Segment Groups

Road segment groups will be analyzed to produce estimates of rates of sediment delivery for each road segment type, and that rate will be applied to the segments of that type in each sub-basin, resulting in an estimate of sediment delivery from roads for each sub-basin. The amount of sediment delivered to the stream from each road segment type is estimated by apportioning the inherent erosion rate among the road prism components. Each component rate is modified by cover and contributing activities, and then the percentage of the road delivering sediment into the stream system is applied. The calculated number is the rate of sediment delivered to streams from road segment types. The rate multiplied by the amount of each segment type in each sub-basin will provide an amount of sediment from roads for each sub-basin.

Roads differ in the inherent erodibility, or erosion potential, due to the geology, or parent material on which they are constructed. In addition, factors that affect erodibility included in this analysis, are: road age, road surfacing material, and vegetative cover on cut and fill slopes. The key contributing forest activity is log truck traffic on roads.

The delivery of road erosion products to the stream system is key to understanding the influence of roads erosion on the stream system. Delivery is affected by the road drainage system design including road prism shape, proximity of the road to the stream system, and length of road draining directly into a stream channel at crossings. The characteristics of the road that affect delivery are part of the standard to which the road was built, and will be generally consistent across a groups of road segments. Where there are different delivery scenarios, the road segments can be regrouped to represent that.

Road Erosion Potential

For forest roads, the erosion potential is determined from three attributes:
The relative areas of the road in each prism component

The inherent erodibility of the parent material on which the road is constructed
The protection provided by cover materials (i.e. vegetation, woody material, surfacing rock, etc.) which reduce the exposure of soil to rainfall and traffic wear

Road Dimensions

The proportion of the road area for each road prism component must be determined. The dimensions of the Reference Road described previously are assumed. If field visits indicate that the dimensions of the prism components for a group of road segments do not resemble the Reference Road, the standard dimensions can be adjusted according to field estimates. Doing so will require the analyst to track the erosion rates by component, and adjust them accordingly.

Basic Erosion Rate

Various researchers have established inherent erodibility rates for roads built in different geologic materials, and these rates are displayed as the "Basic Erosion Rates" for "Old" and "New" roads in Table B-5. The rates represent erosion from bare road prism surfaces of the Reference Road built on each parent material type. The different rates associated with "old" and "new" roads reflect the tendency for recently exposed soils to "armor", as the finer soil particles are washed from the surface.

The analyst determines which group of parent materials is most similar to the parent material of each road segment, or road segment type. The analyst may wish to consult with the Mass Wasting analyst for assistance in choosing the appropriate basic erosion rate.

The Basic Erosion Rate is apportioned to the cutslope/ditch, fillslope, and tread, according to the percentages given for the Reference Road.

For example, sediment production from one acre of a 2-year old road built on Coarse-grained granite material would be, for the various prism components:

Tread	**40% of 110 = 44**
Cutslope/Ditch	**40% of 110 = 44**
Fillslope	**20% of 110 = 22**

Table B-5: Basic Erosion Rates

Numbers represent erosion rates in Tons/acre of road prism/year.

		Road Age	
General Category	**Parent Material**	**New 0-2 Years**	**Old > 2 Years**
High	Mica schist Volcanic ash Highly weathered sedimentary	110	60
High/Moderate	Quartzite Course-grained granite	110	30
Moderate	Fine-grained granite Moderately weathered rock Sedimentary rocks	60	30
Low	Competent granite Basalt Metamorphic rocks Relatively unweathered rocks	20	10

(Kochendorfer, J. N. and J. D. Helvey 1984; Hayden et al. 1991; Megahan and Kidd 1972; Reid and Dunne 1984; Sullivan and Duncan, US Forest Service unpublished data)

Cover Factors for Cut and Fill Slopes (Erosion Potential)

Erosion rate from cutslope and fillslope parts of the road prism are altered according to the amount of cover on these surfaces. "Cover" refers to all surfaces other than soil, and could typically include vegetation, rock, slash, or erosion control materials. The Reference Road has unvegetated cut and

fill-slopes, so cover protecting these slopes will reduce the basic erosion rate. Specific reduction factors for erosion control materials can be found in Burroughs and King (1989) or
other sources. Table B-6 provides factors for adjusting erosion rates for cover density.

Table B-6: Correction Factors for Cut and Fill Slopes

Ground Cover Density	Factor
>80%	0.18
50%	0.37
30%	0.53
20%	0.63
10%	77%
0%	1.00

(Megahan 1991; Burroughs and King 1989; Megahan unpublished data)

***For example,* for the cutslope and fillslope in the previous example, with a basic erosion rate of 44 Tons/year, and a vegetative cover of 50% on the cutslope and a basic erosion rate of 22 Tons /year and 80% vegetative cover on the fill slope, the adjusted basic erosion rates will be:**

Cutslope: 44 X 0.37 = 16.28 Tons/year
Fillslope: 22 X 0.18 = 3.96 Tons/year

Surfacing Factor for Road Tread (Erosion Potential)

Road surfacing material and construction determine the erodibility of the surface tread with log truck and other types of traffic. Road surfacing material and history can be determined by information from landowners and field observations. Road prism factors are provided in Table B-7, Factors for Road Tread Surfacing, to be used to adjust the erosion rate for surfacing. The Refer ence Road is native surface, so any surfacing material will reduce the erosion from the road surface.

Table B-7: Factors for Road Tread Surfacing

Surfacing Material	Factor
Paved	0.03
Dust-oil	0.15
Gravel, > 6" deep	0.2
Gravel, 2" - 6" deep	0.5
Native soil/rock	1.00

***For example,* In the previous example, with the road tread basic erosion rate of 44 Tons/year, and a thick gravel surface, the adjusted erosion rate would be:**

22 X .20 = 4.4 Tons/year

We now have adjusted rates for all the prism components, based on the amount of cover:
Tread: 4.4
Cutslope/Ditch 16.28
Fillslope 3.96

This erosion rate can be thought of as the "erosion potential" for the road. Traffic will be analyzed next as the "contributing activity".

Traffic Characteristics - “Contributing Activities”
Perhaps the single greatest factor affecting generation of sediment from road surfaces is the amount of traffic (Reid and Dunne 1984; Sullivan and Duncan unpublished). Although forest road surfaces are generally constructed of resistant materials such as gravels, traffic can grind the road surface into smaller particles that can be transported by rainfall runoff into ditches and potentially into streams. Traffic rate determines the quantity of sediment available for transport, while the rainfall determines the transport capacity.

Table B-8 correlates traffic rate with mean annual rainfall to provide a road tread erosion factor. One source for determining the mean annual rainfall for the WAU is the precipitation frequency atlas published by the National Oceanic and Atmospheric Administration (NOAA) (Miller et al. 1973). Consultation with the Hydrology analysis team can also help in providing this information.

Table B-8: Traffic/Precipitation

The traffic and road categories are described in more detail in Table B-8, Traffic Definitions.

Annual Precipitation			
Traffic Use/Road Category	**<1200 mm**	**1200 mm - 3000 mm**	**>3000 mm**
Heavy Traffic/Active Mainline	20	50	120
Moderate Traffic/Active Secondary	2	4	10
Light Traffic/Not Active	1	1	1
No Traffic/Abandoned	0.02	0.05	0.1

(Reid and Dunne 1984; Sullivan and Duncan unpublished)

Table B-9: Traffic/Road Category Definitions

Traffic Category	**Road Category**	**Estimate of Long-Term Average Use**
Heavy	Active Mainline	Road is actively used and maintained for log haul traffic. Receives log haul traffic more than 50% of the time during the year.
Moderate	Active Secondary	Road receives log haul traffic up to 50% of the time. These are typically well-maintained major spur roads that provide access to larger areas.
Light	Non Active	Traffic limited to pick-up traffic the majority of the time, with occasional log truck traffic. This will usually be a spur road accessing areas that rarely have log haul.
None	Non-used	Roads that are rarely used and are typically blocked to 4-wheel drive highway vehicles. This category includes both roads where drainage structures are left in a condition to minimize erosion in the absence of maintenance and those without erosion control, or orphaned roads.

***For example,* the tread erosion rate in the previous example was calculated at 4.4 Tons/year. If that road is an active secondary road with moderate traffic in a basin with 1500 mm precipitation per year, the erosion rate is:**

4.4 X 4 = 17.6 Tons/year

A *Level 2* assessment may refine the traffic factor for particular roads based on more detailed traffic information. More detailed information may include seasonal closures, hauling restrictions, and variable traffic rates. Document the reasons for any change in road use factors.

The factors shown in Table B-8 are adjusted for the amount of time the road receives the use indicated on a long-term average basis, but they can also be applied on an annual basis.

For example, the previous example road, in a basin with l500 mm annual precipitation, but has heavy truck traffic for 3 months (25%), moderate traffic for 6 month (50%), and light traffic for 3 months (25%), would have a factor of 14.75: (.25 X 50) + (.50 X 4) + (.25 X 1) = 14.75

This factor is then multiplied by the basic erosion rate for the road segment:
14.75 X 4.4 = 64.9

The above level of detail is usually associated with a Level 2 analysis.

Sediment delivery from roads to streams

Sediment from road surfaces is routed from the road prism through flowing water, which occurs in roadside ditches, gullies, culverts, or in some cases as overland flow. Although all roads generate erosion, only a portion of the road system drains into the stream system. Road runoff from parts of the system drains onto permeable soils where the sediment is deposited as the runoff infiltrates. The percentage of road length with stream entry varies between individual roads and watersheds, due to stream and road densities, road drainage design, topography and other factors (Sullivan and Duncan unpublished). It is important to determine what proportion of the sediment from a road system is delivered to streams in order to evaluate the contribution of road surface erosion to downstream resources.

Delivery from Prism Components

The drainage design of a road strongly influences the amount of sediment delivered to streams. Two aspects of the drainage are important: (1) the ditching and drainage system as it connects to stream channels, and (2) the cross-sectional design of a road dictates the flow of water from the road prism either toward or away from the ditch. Both aspects are used to determine the road sediment delivery.

Where runoff from fillslopes is dispersed onto permeable soils below, infiltration may prevent sediment delivery to a stream located downslope. On the other hand, if fillslope runoff continues downslope as overland flow or reaches an active gully, sediment may be routed to a stream. The orientation of the tread (i.e., insloped, crowned, or outsloped) determines whether runoff from the tread drains into the ditch or over the fillslope. Crowns and outslope must be maintained, or they may function more like an insloped road. Field observations can determine the correct call for the road segment type.

Delivery can be adjusted by determining the portion of the road surface draining to the ditch according to the prism configuration. Road prisms can be divided into four cross-sectional designs, as illustrated in Figure B-3, Road Prism Cross sectional Design.

Although the flow paths of road surface drainage could be mapped at a very fine scale, the analyst will use a generalized characterization of the prism configuration to determine pathways for a road segment or group of similar segments.

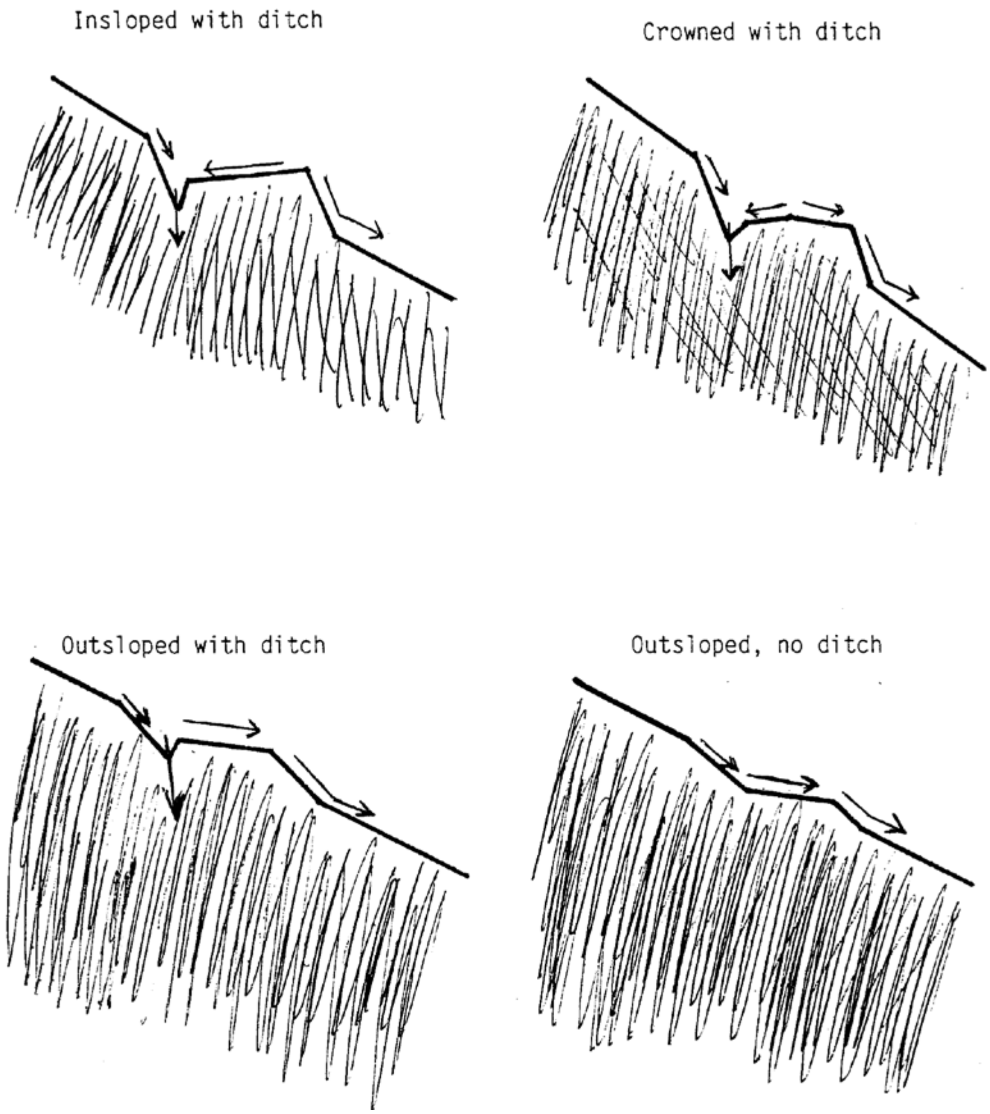


Figure B-3: Road Prism Cross-Sectional Design

Drainage to Streams by Ditches

For an individual road segment, the length would be divided into the sections that drain into each drainage site, i.e., the place where water is directed away from the road prism, often a culvert, ditch-out or bridge. At each drainage site, the potential for sediment delivery to the stream is determined. The delivery percentage for each drainage section is based on three rules:

1. If the road drains directly to a stream channel* via a ditch or gully: Assume 100% delivery from the parts of the road that drain directly to the stream. The fill slope does not drain down the road ditch, and delivery from the fill slope should be considered separately.
2. If the road drains onto a hillslope within 200 feet of a stream: Assume 10% delivery from that section.

3. If the road drains onto a hillslope more than 200 feet from a stream: Assume 0% delivery from that section.

* A **"channel"** is defined as any drainage depression containing a defined bed and banks, extending continuously below the drainage site. The flow regime can be ephemeral, intermittent, or perennial.

Rule #2 above was developed from Idaho research (Ketcheson and Megahan unpublished) that showed that sediment flow from most cross drains extends less than 200 feet, and that 90% of the sediment volume was deposited within the first 40% of the maximum length. If the analyst observes evidence that this rule of thumb is not appropriate for a group of segments, then the analysis should reflect the more accurate rates of delivery, with explanation for rates used.

For Example:
If field visits to road segment type from the previous example showed that about 30% of the length of the segments drained directly into a stream channel, about 30% drained to within 200 feet of the stream, and the remainder did not drain to a stream, the following calculation would give the delivery percent:

Adjusted Tread Rate (Mod Traff):	**17.6**	**Tons/year Adjusted**
Cutslope/Ditch Rate:	**16.28**	**Tons/year Adjusted**
Fillslope Rate:	**3.96**	**Tons/year**
	37.84	**Tons/year/Acre of Road prism**

((.30 x 1.00) + (.30 x .10) + (.40 x 0)) x 37.84 = 12.49 T/yr/Acre of road prism

This 12.49 is the erosion rate for these segment types. The units are still Tons/acre of road prism/year, the same as the Basic Erosion Rate. All adjustments were by dimensionless factors.

The result is in **U.S. Tons.** Convert to **Metric Tonnes** for comparison with background sediment calculations by multiplying the road sediment figures by 1.1. The delivered sediment rate calculated at this point is applied to all segments in the group. The length and average width of each segment type is used to calculate the acres of road prism of each segment type in each sub-basin. Delivered sediment is calculated for each sub-basin.

For example, **assume the following segment types and lengths for these sub-basins:**

Sub-basin A	**Length**	**Avg. Width**	**Rate**	
1. Active mainline	**1 mile**	**30'**	**35**	**Tons/acre of road prism/year**
2. Secondary road	**3 miles**	**25'**	**12**	**Tons/acre of prism/year**
3. Not active road	**13 miles**	**18**	**4**	**Tons/acre of prism/year**

Segment Type 1
(5,280' x 30')/43,560 sq ft/acre = 3.6 acres of road
3.64 acres x 35 Tons/acre road prism/year = 127.4 T/yr
Segment Type 2: ((3 x 5,280 x 25)/43,560) x I2 = 109.09
Segment Type 3: ((I3 x 5,280 x 18)/43,560) x 4 = 113.45
Sub-basin Road Sediment Total: 349.94 T/yr

The analyst is encouraged to develop an electronic spreadsheet to calculate estimated road-generated sediment rates and amounts. Whether electronic or hand-made, a calculation form, labeled *Form B-2*, "Roads Calculation Sheet", will be included in the final report, as an appendix, and will include at a *minimum*, the following information:

- WAU
- sub-basin
- road segment type
- length of the road segment type in sub-basin
- basic erosion rate
- % area of each prism component if other than Ref Road
- cover factors for cut and fill slopes
- surface factor for road tread
- traffic factor
- rate of erosion for each prism component
- delivery percentage
- sediment delivery rate and amount for segment type
- total amount of sediment from roads for sub-basin

Exact format of the calculation sheet is left to the analyst.

Field Sampling for Roads

The analyst develops a field sampling scheme to visit sufficient samples of each type of road segment to be able to estimate sediment with reasonable confidence. It is expected that these will be more sampling of the segment groups with the most miles, and those likely to be high contributors of sediment.

These field visits are used to verify traffic and surfacing information provided by landowners, to verify segment types and grouping, to check average road width and percentages of prism components, to collect information on cover percents on cut and fill slopes, to locate localized problem areas, and to check delivery percents.

The analyst can use any field data collection methodology and form that they choose. However, field data is expected to be included in the module products. Appropriate materials should be labeled *Form B-3*, "Road Field Form," that will include at a minimum:

- WAU
- Sub-basin
- road identifier
- road type (landowner information)
- agreement/reasons for disagreement with road type
- % area of each prism component if other than Ref Road
- cover percentages for cut
- cover percentages for fill slopes
- delivery percentages

The field forms will be included with the final report as an appendix.
A final roads map, labelled *Map B-6*, "Road Segment Delivery", will be developed showing various segment types and rates of delivery as they occur in each sub-basin. This map will be useful in determining "triggering mechanisms" for basins rated Moderate or High (see "Determining Sensitivity" in the "Potential Effects of Land Use Activities on Sediment Yield" section).

Summary Table
A summary table, labelled *Form B-4*, "Surface Erosion Summary", of information from calculations of road sediment should be prepared that will include, at a minimum:

- WAU
- Sub-basin
- Each Segment Type
- Total sediment rate
- Contributions from
  - Cut slope
  - Fill slope
  - Tread and traffic
  - Delivery percentage

Comparative rankings of segment types for sediment delivery

The amounts and comparative rankings will be useful in describing the triggering mechanisms for the Causal Mechanism Reports.

Effect on Public Resources

All managed watersheds are likely to have some increase in sediment yield over pristine conditions. The purpose of this assessment is to locate areas in the watershed likely to experience significant changes in sediment that result in chronic changes in turbidity or deposition of fines in stream beds affecting aquatic life. Sediment yield in a watershed is highly variable from year to year reflecting climate pattern (Beschta 1978). Sometimes varying as much as an order of magnitude annually, differences in sediment yield can be difficult to detect statistically. Some evidence has shown that sediment yields increased by 50% or more of the long-term average are detectable with water sampling procedures (Sullivan pers com). To develop a relative indication of the increase in fine sediment yield from roads and hillslope erosion, an estimate of sediment production must be developed to provide a means for comparison.
The analyst should determine the sub-divisions of the WAU most relevant comparing background and management-related sediment input, preferably following consultation with fish and channel analysts. Useful sub-divisions for comparison could be fish-bearing sub-watersheds, or the entire upslope area contributing to a stream location sensitive to fine sediment, due to fish habitat or water quality concerns.

Some helpful conversion factors:

1 U.S. ton (2,000 lb) = 0.907 metric tonne (also megagram, Mg)
1 metric tonne or megagram (Mg) = 1.10 U.S. ton
1 metric tonne or megagram (Mg) = 1,000 kilograms
1 gram/cubic centimeter (g/cc) = 1 tonne/cubic meter

Bulk density of soil

Bulk density may be given in kg/cubic meter and ranges from around 1200 kg/cubic meters to 1700 kg/cubic meters (Soil Conservation Service 1986).

Bulk density may also be given in tonnes/cubic meter. Bulk densities given in grams/cubic centimeter also range from 1.2 to 1.7 g/cc.

Background Sediment Yield

Rates of fine sediment production can be estimated using several approaches. One approach would be to determine sediment input rates from each of the significant input processes operating in the watershed, creating a partial sediment budget. This "Sediment Budget" approach could utilize field observations, aerial photos and maps and be relatively elaborate or simple, depending on the importance of sediment input issues within the basin. The Soil Creep Model, explained below, is a relatively simple form of the Sediment Budget approach.

A second approach would be to utilize sediment yield data from a river or stream comparable to the study watershed, which would reflect the net output of sediment from all upstream sources. Under this "Sediment Yield Data" approach, data from comparable watersheds would be used to estimate background output rates for the study watershed. The analyst can determine which approaches are most appropriate, depending on local watershed conditions, available information and the confidence level required for the issues specific to the study watershed. Table B-9 provides some general guidance for the selecting between two standard approaches for estimating background sediment.

Table B-9. Sub-watershed and responses reach conditions that support the use of the Soil Creep Model vs. Sediment Yield Data methods for estimating background sediment production.

Prevalent Conditions	**Preferred Method**	
Sub-watershed or response reach attribute	**Soil Creep Model**	**Sediment Yield Data**
Location of response reach	Headwaters (order 1-3)	Lower basin (order 3+)
Prevalent valley morphology	Channels confined by valley walls	Alluvial reaches located upstream
Magnitude of inputs from mass wasting and/or alluvial bank cutting	Low	High[1]
Quality of information on soil depths & drainage density	Good	Poor
Availability of sediment yield data from comparable watersheds[2]	Poor	Good

[1] In some cases, this can be resolved by supplementing soil creep inputs with estimated input rates for other processes.

[2] Watersheds should be somewhat comparable in terms of geology, topography, land use, etc.

Sediment Budget Approach
Because sediment derived from surface erosion processes activated by land use practices generally consists of finer-grained particles, the estimate of background input or output rates should be confined to the proportion of fine particle sizes. In mountainous watersheds, soil creep, mass wasting, and alluvial bank cutting are often the major input processes.

In many basins, the dominant natural source of fine-grained weathered sediments is soil creep. The classical definition of soil creep is the slow downslope movement of the soil mantle under the influence of gravity, although other soil displacing processes, such as tree wind-throw and animal burrowing are generally reflected in estimated rates of soil creep as well. Back-calculations from sediment yields suggest that soil creep provides sediment at a rate equivalent to between 1 and 2 mm/year along the entire channel length. For basins where creep dominates, the soil creep model described below may be adequate.

In basins where mass wasting or alluvial bank cutting processes are major sources of fine sediment, an alternate approach may be necessary. Where inputs rates from non-creep processes can be identified, evaluation using field or aerial photo investigation can be used to supplement the sediment input budget. Alternatively, the Sediment Yield approach may be useful for some situations (Table B-9)

The factors used to calculate annual soil creep erosion rates are length of the stream channel in the basin, average soil depth, and the creep rate as a length per year. If this assumption is grossly in error in a given watershed, then results of this portion of the assessment may have low confidence.

Stream Channel Length (L)
For this assessment the amount of sediment introduced to the stream system is estimated as the total of hillslope volume delivered to Type 5 and larger streams. Estimate the length of Type 1-5 streams in the sub-basin in meters which can generally be easily determined using a GIS or topographic maps. However, different maps provide varying levels of accuracy in identifying small streams, which may constitute a large proportion of the total stream length. Some spotchecking of the upslope extent of incised channels is justified in many watersheds to adjust for systematic mapping errors. The total stream length is multiplied by two to account for both sides of the stream.

Soil Depth (D)
Soil depth can be generalized over the sub-basin using soil maps and field reconnaissance for verification. Rough approximations are sufficient for this crude sediment budgeting approach. Road cut banks and stream banks offer

point for observation of soil depth sufficient for this assessment. If soil depth is significantly deeper than 2 meters, estimate the depth as accurately as possible. Soil surveys usually provide sufficient information to estimate average soil depth over a sub-basin.

Soil Creep Rate (C)
Relatively little research has been conducted on rates of soil creep, especially in typical forested mountain watersheds. Creep may be influenced by soil and rock material, hillslope hydrology, and slope angle. For simplicity, we use only slope gradient as the primary estimator of creep rate: If average slope is less than 30%, then use a creep rate of 0.001 meters/year. If average slope is 30% or greater, use 0.002 meters/year. If the analyst has a better estimate of creep rate, they are encouraged to use it.

Calculation of Background Rate:

$$\text{Annual Erosion Volume } (m^3/yr) = L\ (m) * 2 * D\ (m) * C(m/yr)$$

Sediment yield in metric tonnes per year is approximately equal to 1.5 times erosion volume, assuming bulk density of the soil to be about 1.5. This assumption may be modified if better information is available.

Sediment yield = (1.5 X Erosion Volume) You should correct total volume to delete the coarse sediment particles. The proportion of coarse particles can often be determined using soil survey information.

The Background Rate has been calculated in metric Tonnes. The road sediment was calculated in US Tons, so conversion to a common format is needed for comparison. Field managers are generally more familiar with US Tons and acres, as opposed to metric Tonnes and hectares. Provide information in both formats to facilitate comparison with other scientific literature in metric measures, and to meet the needs of field managers in US measures.

Sediment Yield Data Approach
Where available, sediment yield data can provide an empirically-based means of estimating of background sediment production. Much of the published sediment yield data is compiled in the Erosion and Sedimentation Catalog of the Pacific Northwest (Larsen and Sidle 1980), but other data may be available from the USGS or other agencies. However, data from sampling that did not cover an extended time period and range of flow levels is unlikely to provide a valid long-term average. Sediment yields that refer specifically to suspended sediment particles is the most relevant for comparison to inputs generated from surface erosion. In many cases, fine sediment yield data can be estimated from data for total sediment yield by converting using a reasonable bedload proportion.

Interpretation of measured sediment yield is complicated by the fact that rates incorporate sediment input from both land-use and natural erosion processes in the entire basin above, which may differ from the sub-watershed being analyzed. The analyst should recognize that yield data from many basins do not represent pristine conditions for comparison. For these reasons, it is important to consider the location where sediment samples were collected to determine the similarity to the sub-watershed you wish to extrapolate data toward. Geology, topography, the extent of forestry and other land uses all may be important factors that affect the suitability for extrapolation.

For example, sediment yield could be estimated from a 5,000 acre sub-watershed in the Chehalis River Basin using published yield data (Larsen and Sidle 1980):

Average annual suspended sediment yield - Chehalis River:

136 tons/mi^2 X 0.35 (conversion factor) = 47.6 tonnes/km^2

Sub-watershed area: 5,000 acres 247 acres/km^2 (conversion factor)

= 20.2 km^2

Annual Sub-watershed sediment yield:

47.6 tonnes/km^2 x 20.2 km^2 = 962 tonnes.

Potential Effects of Land Use Activities on Sediment Yield

Hillslope Erosion

Based on the findings of the Hillslope Erosion Analysis, the analyst should estimate the rate of sediment input from hillslope surface erosion processes. If evidence of surface erosion was either absent or thought to be minimal (i.e. 2 or more orders of magnitude less than input from roads), then inputs can be ignored. If the analyst did discover significant areas actively contributing surface erosion, they should estimate an erosion rate due to surface erosion and multiply by the area of the watershed affected.

Roads

Sediment delivery rates for each road segment have been determined in previous steps of the assessment. The road erosion rate is multiplied by the length of the road segment type in the sub-basin to determine the road sediment yield.

Determining Sensitivity

The total amount of sediment is determined by summing the land-use related sources. The relative importance of land use related sediment is determined by comparison with the baseline sediment yield. If sediment is increased by 50%-100%, the effect of the sediment may be small, but chronically detectable.

If the increase in total yield is more than 100%, the change in annual sediment yield is likely to be large enough to exceed water quality standards. In this case, the hazard rating for surface erosion is rated as Moderate (or High).

The analyst should interpret results with caution however. This sediment budget technique is crude in that neither natural or land use erosion processes are documented very thoroughly with field observations. The estimate of baseline sediment yield is likely to be in the neighborhood of reality, even at this gross scale of generalization. For example, if soil depth estimates of 0.5 meters to 2 meters are used, the baseline erosion estimate will usually calculate to be 6 to 50 tons/km^2 .These are close to measured values from Pacific Northwest mountain streams (between 6 to 100 tons/km^2). (Larsen and Sidle 1980). However, calculated road erosion rates can vary by an order of magnitude depending on the assigned traffic use rate, construction conditions or delivery features. Once the crude sediment budget is constructed, the analyst should first weigh whether the estimates in either land use or baseline erosion rates make sense before interpreting the severity of sensitivity to surface erosion. The conclusion may also be cross-checked with observations of impacts of fine sediment to stream channels were observed by the fish or channel analysts (i.e., V* values or particle size samples) for confirmation during synthesis.

If moderate or high sediment yields are determined for the roads, the analyst should determine which roads are contributing significantly and what factors are driving the rates up. These can be identified as road erosion units, and the factors leading to high sediment yield are identified as the triggering mechanism.

Surface Erosion Assessment Report

The Surface Erosion Assessment Report organizes and presents results of the surface erosion assessment. The report is a compilation of key work products, maps and narrative summarizing interpretations. Narrative may be on the order of several pages long and provide a concise discussion summarizing results of each section of the analysis module. While the Surface Erosion Assessment Report should be concise, it should be complete enough so that, together with the other module products, it provides the input necessary for the synthesis and prescription phases of Watershed Analysis where the information developed in the analysis modules is incorporated into land use decision making.

Realistically, there will not always be the type of data or information available that the analyst would desire for high confidence in the analyses and interpretations. Assessment of the confidence level possible based on available information thus may be important for decision-making based on these analyses. The degree of confidence that can be assigned to the products of this analysis depends upon a number of factors. Considering the amount, type, and quality of available information, analysts should determine their relative confidence in the interpretation based on each work product. Other factors to consider in this evaluation may include, but are not limited to, extent of field work, experience of the analyst, complexity of the geology and terrain, aerial photographs and map quality, and multiple lines of evidence for inferred changes.

Surface Erosion Assessment Report

I. Title page with name of watershed analysis, name of module, level of analysis, signature of qualified analyst(s), and date

II. Table of contents

III. Maps
- Hydrologic Analysis Unit (HAU) map (map B-1)
- Preliminary soil erosion potential map (map B-2)
- Past 5 years activities map (map B-3)
- Final soil erosion potential map (map B-4) with map unit descriptions
- Road traffic and surfacing (map B-5)
- Road segment delivery (map B-6)

IV. Summary Data
- Hillslope field/photo information (form B-1)
- Roads calculations worksheet (form B-2)
- Roads field forms (form B-3)
- Surface erosion summary (form B-4)

V. Summary Text
- Description of networkwide influences on surface erosion
- Study methods, including parameters used in background calculations
- Hillslope erosion conditions and activity situations
- Methods and rationale for developing Map B-4
- Narrative describing road conditions in the landscape
- Narrative providing interpretation of results in assessing surface erosion effects on public resources
- Descriptions of any deviations from the standard methods and why the changes were necessary
- Statement of the author's confidence level in the analysis and results
- Does module report address all critical questions?

VI. Other Information (optional)
- Monitoring strategies and design and implementation suggestion

- Learning resources (a.k.a., references, bibliography) section
- Acknowledgments

If Level 2 analyses have been performed, the report should include a description of methods and results. All module work products should be archived for use during the Synthesis of this assessment and in future years.

Checklist for Project Management

Below is the Surface Erosion Module checklist, provided to guide the surface erosion analyst through the administrative steps of resource assessment. It will be especially useful if there is a team conducting the assessment. Note: The hillslope and roads preliminary work can proceed concurrently, review of preliminary products can be done concurrently, and the field work can be done concurrently. The order of listing below is not meant to imply the order of occurrence. Steps are included for review among members of the surface erosion team to aid in keeping the team updated and together as steps are completed.

Analysis materials in place

Start-up meeting for module team
- brief team on process and intent
- develop schedule

Develop Map B-1, subdividing the basin
- work with Hydrology team on this

***Hillslopes* Preliminary Work**

Develop Map B-2, Preliminary Surface Erosion Potential Map

Develop Map B-3, Past 5 Years Activities for the basin

Examine aerial photos, begin filling in Form B-1

Develop field sampling scheme and for hillslope sites

Review preliminary hillslope products and sampling scheme with members of the surface erosion team

***Roads* Preliminary Work**

Develop Map B-5, Road Traffic and Surfacing for the basin

Begin Roads Calculation Spreadsheets, Forms B-2

Develop Roads Field Form, Form B-3

Develop field sampling scheme for roads

Review preliminary roads information and sampling scheme with member of the surface erosion team

Field Work
Carry out hillslopes and roads field sampling scheme, filling in Form B-1 for hillslope sites and Form B-2 for roads.

Review results of field work, plan/design final products with the surface erosion team

Prepare Draft Final Products - to be used in Synthesis
Prepare Draft Final Surface Erosion Potential Map, Map B-4, with narrative description of surface erosion map units

Prepare narrative report explaining how information was used to produce final map, and describing systematic hillslope erosion problems and activity situations

Complete roads spreadsheets

Prepare narrative report interpreting roads information

Review final products with the surface erosion team

After synthesis:
Finalize maps

Prepare Final Surface Erosion Assessment Report, including field forms and spreadsheets

Acknowledgments

This module represents the results of many people over the course of several years. This version was written by Nancy Sturhan, Walt Megahan, Kate Sullivan, Curt Veldhuisen, and Steven Toth. Lynne Miller drafted the first version of this module. Development of surface erosion module benefited from discussions with Mary Raines and Ken Schlichte.

References

Beschta, R. L. 1978. Long-term patterns of sediment production following road construction and logging in the Oregon Coast Range. Water Resources Research. 14:1011-1016.

Bilby, R. E.1985. Contributions of road surface sediment to a western Washington stream. Forest Science. 31:827-838.

Bilby, R. E., K. **Sullivan**, and S. H. **Duncan**. 1989. The generation and fate of road-surface sediment in forested watersheds in Southwestern Washington. Forest Science 35(2): 453-468.

Larsen, K.R. and R.C. **Sidle**. 1980. Erosion and Sedimentation Catalog of the Pacific Northwest. USDA Forest Service, R6-WM-050-1981.

Megahan, W. F., and W. J. **Kidd**. 1972. Effects of logging and logging roads on erosion and sediment deposition from steep terrain. Journal of Forestry. 70:136-141.

Megahan, W. F. 1974. Erosion over time on severely disturbed granitic soils: a model. USDA Forest Service. Research Paper INT-156.

Megahan, W. F. 1978. Erosion processes on steep granitic road fills in central Idaho. Proceedings of the Soil Science Society of America. 42:350-357.

Megahan, W. F, K. A. **Seyedbagheri**, T. L. **Mosko**, and G. L. **Ketcheson**. 1986. Construction phase sediment budget for forest roads on granitic slopes in Idaho. In: Drainage Basin Sediment Delivery. ed: R. F. Hadley. International Institute of Hydrologic Science, Publication 159 p 31-39.

Megahan, W. F, K. A. **Seyedbagheri**, and P. C. **Dodson**. 1983. Long-term erosion on granitic roadcuts based on exposed tree roots. Earth Surface Processes and Landforms 8:19-28.

Reid, Leslie M. 1981. Sediment production from gravel-surfaced forest roads, Clearwater Basin, Washington. M.S. Thesis, University of Washington. 247 pp.

Reid, Leslie M., and Thomas **Dunne**. 1984. Sediment production from forest road surfaces. Wat. Resources Research 20(11):1753-1761.

Sullivan, K. O., and S. H. **Duncan**. 1980. Sediment yield from road surfaces in response to truck traffic and rainfall. Weyerhaeuser Technical Report 042--4402/80. Weyerhaeuser Company, Technical Center, Tacoma, WA. 98477.

Swift, L. W., Jr. 1984. Gravel and grass surfacing reduces soil loss from mountain roads. Forestry Science 30:657-670.

USDA Soil Conservation Service, Methods of Soil Analysis, Part 1, Physical and Mineralogical Methods, Second Edition, 1986, page 364.

APPENDIX C Hydrologic Change Module

Table of Contents

Introduction

The hydrologic performance of forested watersheds is affected by three broad classes of processes:

1. Delivery of water to the forest is determined by rates of condensation and precipitation (rain and snow), largely controlled by climate;

2. Delivery of water to the forest floor is determined by interception and snowmelt, which in turn are largely controlled by vegetation;

3. Delivery of water to streams is determined by the balance between precipitation, evapotranspiration, and runoff-generating processes, the latter involving several surface and subsurface pathways.

Forest practices can alter each of these processes in several ways. Opening of the canopy by timber harvest can cause greater snow accumulation in winter (because snow on the ground is less affected by interstorm melt than is snow in the canopy) or increased snowmelt in spring (by removal of overstory shade); openings also allow accelerated melt rates, due to increased radiation and wind-assisted flux of sensible and latent heat to the snowpack. Maximum accumulations are found in openings on the order of three to four tree heights in width; at widths greater than 10-20 tree heights, snow accumulation may be less than that under a canopy, owing to wind redistribution of snow (Troendle 1983). The loss of vegetative cover may reduce rates of interception and evapotranspiration, leaving more water to enter the ground. In some cases, loss of forest canopy may actually decrease soil-water input, through reduction in the amount of fog drip. Compaction of the soil on roads and skid trails reduces local infiltration, increasing the likelihood of overland flow at the expense of slower subsurface pathways. The magnitude or timing of streamflows may be altered because of the augmentation of storm-runoff volume due to enhanced soil moisture or snowmelt, because of reduced detention storage on the hillslope, or because road construction or other surface disruption makes the drainage network more efficient in conveying runoff.

Thus, forest practices can change the magnitude and timing of streamflows. Whether or not any of these changes combine into cumulative effects depends on the precise character of the hydrologic changes in a specific basin. The methods described herein assume that the greatest likelihood for causing significant, long-term cumulative effects on public resources via alteration of forest hydrologic processes is through the influence of timber harvest on snow accumulation and melt during rain-on-snow (ROS) storm events (Harr 1981, 1986; Coffin and Harr 1992). Cumulative effects caused by forestry-induced changes in seasonal snowmelt, low flows, water yield, and flow routing are generally less likely, but may be important in certain watersheds.

These are briefly discussed at the end of the analysis procedure section, but no formal procedures for addressing them are included at this time.

Critical Questions

The purpose of the hydrologic change module is to address the following key questions:

What are the current watershed conditions influencing hydrologic response?

What is the history of floods and disturbances of hydrologic significance in the watershed?

What is the influence of land use on runoff during storm events which generate peak flows?

What are the effects of changes in runoff on flood peaks?

What are the effects of changes in peak flows on public resources?

The procedures for answering these key questions rely on a variety of tools, including maps, remote sensing (Landsat) imagery, climate and streamflow information, and hydrologic models. These tools are used to calculate the effects of changes in forest cover on snow accumulation, snowmelt, and runoff during a simulated storm event.

Assumptions

A number of assumptions underlie the approach developed here. The most fundamental assumption is:

- ***The greatest likelihood for causing significant, long-term cumulative effects on public resources via alteration of forest hydrologic processes is through increases in peak flows attributable to the influence of timber harvest on winter snow accumulation and melt rates during rain-on-snow events.***

Other assumptions include:

- Regional flood-frequency regression equations, including their explicit estimates of confidence, provide a reasonable framework for evaluating the effects of forest harvest on peak flows over basin-scale areas.

- The effects of historically changing forest characteristics on the regional regression equations cannot be evaluated. The equations were based on data collected under a variety of land uses and forest patterns, including undisturbed, disturbed, and mixed conditions. However, for the purposes of this analysis, it is assumed that the regression equations predict flows under hydrologically mature (pre-disturbance) conditions.

- Although they do not necessarily occur together, it is appropriate to relate storms and flows having the same recurrence intervals (e.g. the 2-year storm and the 2-year flow, each having a 50% probability of exceedance).
- Snow measurements (recorded by the Cooperative Snow Survey and the National Weather Service) are made under a variety of forest stands; we do not know the conditions at most stations. In addition, snow accumulation is not a function of elevation alone, and the relationship is quite variable. We assume here that the snow regression equations derived from the measurements represent hydrologically mature conditions.
- The U.S. Army Corps of Engineers' snowmelt equation is appropriate for estimation of melt under ROS conditions.

Overview of Assessment and Products

The objective of the hydrologic assessment is to evaluate how forest practices may critically alter the hydrology of the WAU. This is accomplished by addressing the critical questions presented above. During the course of the assessment, the analyst will attempt to establish:

- The hydrologic conditions and characteristics of the watershed influencing peak flow response to land use;
- The historic patterns of peak flows and other disttrbances of hydrologic significance in the watershed;
- The change in water available for rtnoff with changes in forest vegetative cover;
- The change in flood peaks associated with changes in runoff;
- The potential effects on ptblic resotrces of changes in flood peaks.

Each of these objectives is an integral component of the hydrologic assessment. Together, this information provides a means for evaluating potential peak flow response to changes in vegetative cover conditions in the watershed.

The analyst evaluates the hydrologic condition of the watershed by identifying the general watershed characteristics that are likely to significantly affect storm runoff, including climate, physiography, and land use. For purposes of the assessment described in this manual, land uses other than managed forest are considered to have potentially important effects on peak flows, but these effects are assumed not to change over time. Operations occurring in managed forests may also affect storm peaks, but these effects are likely to change in response to harvest and regrowth of forest stands.

The analyst utilizes precipitation zones which spatially define the likelihood and magnitude of hydrologic response to forest practices at any point in the watershed. Considering both land use and climatic factors, the analyst stratifies the hydrologic analysis units within the watershed representing sub-basins similar in responsiveness to forest management effects. These are mapped as the hydrologic analysis units, and the areal distribution of land use/cover types and precipitation zones is summarized on Form C-1: Basin Acreage by Precipitation Zone and Land-use/Cover Type. These hydrologic analysis units are subsequently evaluated for sensitivity to forest practice effects using the ROS analysis. The analyst also identifies the public works which may affect or be affected by changes in flood peaks in the watershed and places them on the map.

The analyst attempts to establish the historic patterns of peak flows and upslope disturbances which may affect hydrologic response, including changes in land use. From this information, the analyst may be able to identify changes in hydrologic response attributable to individual or cumulative disturbances.

The next steps involve using a series of calculations to estimate the potential for changes in peak flows during ROS events due to harvest-related enhancement of snowmelt runoff. These calculations are performed for the outlets of sub-basins identified as hydrologic analysis units.

The standard hydrologic assessment described in this manual uses local climatic and hydrologic data and/or regional empirical relationships to estimate values for the processes which generate the water available for runoff (WAR), including: (1) storm rainfall, (2) snow accumulation, (3) snowmelt. WAR estimates are then used to estimate peak flows.

Assessment of water available for runoff begins with establishing the baseline precipitation amounts associated with storm events having recurrence intervals of two to 100 years. The analyst determines the current vegetative condition of the watershed using data available from landowners, aerial photographs, or Landsat imagery. Using vegetative cover scenarios of "maximum hydrologic maturity" (hydrologically mature), "current condition", and "minimum hydrologic maturity" (hydrologically immature), the analyst determines the snow accumulation as a function of elevation and forest cover, and snow-melt as a function of wind speed, temperature, and precipitation. These meteorological variables are estimated for assumed "average" rain-on-snow conditions, as well as for "unusual" (deeper snowpack, warmer and windier weather) conditions. The snowmelt water equivalent (a function of forest cover) is added to the baseline estimates of precipitation to determine the WAR in each hydrologic analysis unit for each combination of storm intensity, vegetative cover condition, and recurrence interval. Results of this portion of the assessment are summarized on Form C-2: Summary of Water Available for Runoff.

Storm peak flows are determined using a regression equation correlating 24-hour precipitation with estimated or measured values of peak discharge. Applying WAR estimates to this equation will produce an estimate of peak flow for each scenario under consideration. Results of this assessment are summarized on Form C-3: Summary of Peak Discharge Estimates.

Once the increases in peak flows are estimated, the analyst must weigh the probability of significant hydrologic change under different land-use scenarios. This is done by evaluating potential effects on public resources attributable to flood peaks. Response ratings may be based solely on predicted increases, or may be augmented by further analysis of the direct impacts to specific resources (such as water depth for large floods relative to public works, or implications for bed scour frequency for fish habitat). These assessments will better address uncertainties, since little is known regarding the effects of changes in peak flows on fish habitat, and are recommended for a level 2 analysis. A narrative describing the implications of peak flow changes from managed forest zones (and recognizing the effects from other land use in the watershed) is the product of this portion of the assessment.

Qualifications

Expertise in applying hydrologic and hydraulic principles is required to effectively complete this assessment. In addition to completing the watershed analysis training provided by DNR, those conducting the hydrologic assessment must possess, at a minimum, the following skills, education, and experience.

Skills

- Understand the components (relevant processes and magnitudes) of the hydrologic cycle, as they pertain to forested areas;
- Understand principles of probability and statistics, as they apply to the frequency analysis of hydrologic processes.
- Be familiar with computer-based methods (spreadsheets, GIS, and computer models) for estimation of runoff;
- Be familiar with basic channel surveying techniques including determination of channel cross-sections, slope gradient, bankfull flow levels, flow resistance, and streambed particle size distribution;

- Understand basic principles of sediment transport.

Education and Training

Level 1:
Bachelor's degree in hydrology (or a related field such as civil engineering, geology, forestry, forest engineering, soils, etc.), with a significant amount of course work or other training (academic or commercial short courses, etc.) in hydrology (particularly hillslope hydrology in forested basins).

Level 2:
Level 1 qualifications, plus:
Graduate level course work in hydrology, fluvial geomorphology, river mechanics, or some closely aligned field that includes hydraulics of open channel flow, channel form and process, and sediment transport.

Experience
Level 1:
Two years of field experience in assessment or research regarding hillslope hydrology of forested and/or mountainous areas.

Level 2:
At least two years of field experience in assessment, scientific management, or research regarding hillslope hydrology, particularly the estimation of runoff from forested and/or mountainous areas and sediment transport in natural channels.

Background Information

The following materials are necessary to start the hydrologic change module.

Maps

- Official WAU base map;

- Topographic maps of the area (**U.S. Geological Survey 7.5-minute series**, 1:24,000 scale; available from commercial dealers, **DNR Geology and Earth Resource (Olympia, (360) 902-1000)**, and **USGS Western Mapping Center (Denver)** at http://geography.wr.usgs.gov/;

- **Maps of vegetation age and type** might be available from **landowners**; the **USGS** publishes some digital maps of land use and land cover.

Aerial photography
Recent air-photos may be useful in detecting changes in vegetation patterns since the Landsat imagery (upon which GIS interpretations are based) was

acquired (mostly in 1988). These can be used directly to map the vegetative cover for the watershed.

Climate and streamflow data
Summaries of climatic data, including maps of mean annual precipitation, can be found in reports on the climate of Washington counties (see references for listing). Compilations of climatic data from stations reporting to the National Weather Service are available in paper format (monthly "Climatological Data for Washington" for all stations, and "Local Climatological Data" for first-order stations), and on CD-ROM (from private vendors). Data from snow courses and snow pillows, compiled by the Natural Resources Conservation Service (NRCS) are available in annual data summaries or on-line from the NRCS/WNTC computer (contact **NRCS at (509) 353-2341** for more information).

Flow data are available in USGS water-supply papers and open-file reports (summarized in Williams and Pearson 1985a,b; Williams and others 1985a,b), and on CD-ROM (from private vendors).

Analysis Procedure - Level 1

The standard hydrology assessment is described below. Information and products consistent with the standard assessment must be completed for each watershed analysis performed (including Level 2 assessments).

A Level 1 assessment will produce the standard products, and may result in indeterminate hazard calls. A Level 2 assessment is expected to address uncertainties identified in the Level 1 assessment; indeterminate hazard calls must be resolved at this level. It is important that both the nature and magnitude of uncertainties be identified so that subsequent decisions in the synthesis and prescription phases may account for them.

A Level 2 analysis should be invoked when analysts are not satisfied with their ability to answer one or more critical questions based on the standard methods. This may include more refined analyses of particular processes or sub-areas within the watershed. Level 2 assessment requirements are flexible, allowing the analyst to tailor the approach to best address unresolved issues. A Level 2 assessment is expected to produce the standard products augmented by additional information as required.

Products from the analysis consist of maps, forms, and narrative as identified in the "Hydrologic Assessment Report" section of this module. The maps provide a graphical depiction of the factors influencing the hydrologic condition of the WAU, while the forms provide an accounting trail of the information and observations used by the analyst in developing interpretations. These products facilitate the review process, and provide the necessary means to reevaluate hypotheses over time. It is important that narrative sections be concise; the focus should be upon summarizing results and explaining deviations from or additions to the standard methods.

Hydrologic Condition and Characterization of the Watershed

It is important to establish the hydrologic condition of the watershed to provide a context for potential changes in hydrology due to forest practices. The hydrologic condition is the integration of those general watershed characteristics that are likely to significantly affect storm runoff, including land use patterns, structural features disturbance history, and climate. Forest land use is considered explicitly in the module, while other land uses are noted but not specifically addressed.

Within the forest zone, the hydrologic response is likely to vary with precipitation/elevation (climate) zone and vegetative cover. Rain-on-snow conditions can occur at almost any elevation, depending upon the right combination of climatic variables. The highest probability of rain-on-snow conditions occurs in the mid-elevation rain-on-snow zone; the next highest probabilities occur within the adjacent rain-dominated and snow-dominated zones. The lowest probabilities occur within the lowland and highland zones. Based on these probabilities, the analyst can screen out portions of the WAU with a low potential for rain-on-snow enhancement of peak flows, and focus the analysis on the remaining portions.

Hydrologic Characterization

An initial characterization of the hydrologic regime is an important first step. A brief summary of amounts and seasonal distribution of precipitation, average daily flows, and peak flows can assist the analyst in determining which processes (rain, snowmelt, rain-on-snow) are most important in generating peak flows. A hydrologic summary will help the analysis team identify the land use effects potentially influencing hydrologic response, and determine whether the standard rain-on-snow peak flow methodology is appropriate. For instance, the standard model may be of little use in a basin where major peak flows are generated by spring snowmelt processes. Another example is where extensive impermeable surfaces produced by residential development are the major land-use influence to peak flows (Booth 1989). In these cases, the use of an alternative method of analysis (if available) would be justified.

The hydrologic characterization should contain the following basic information:

Precipitation

1. **Annual total**, forms (i.e., rain, snow, fog drip) and seasonal distribution.

   Sources: Isohyetal maps (NOAA), climate data.

Streamflow Regime

2. Seasonal distribution of daily and peak flows.

3. Peak flow-generating processes. This refers to annual and larger peakflows. Three categories - rain only, rain-on-snow or spring snowmelt -apply to most forested area. In many basins, the dominant process generating annual peaks varies between years. In some cases it is hard to distinguish between ROS and primarily rain peaks; in such cases you may need to investigate weather records immediately prior to known peak flow events.

4. Peak flow history. Collect all streamflow data for the WAU, or nearby watersheds if the WAU has no gages or a limited period of record. If a sufficient period of record exists for a gage within the WAU, generate an annual series to identify when major flooding events occurred. Regression analysis utilizing a nearby gage may be used to extend an incomplete record; if the WAU is ungaged, the annual series of a nearby gage may be used to estimate the temporal distribution and relative magnitude of historic floods.

Determine the baseline flood-frequency curves for the hydrologic analysis unit of interest, using the USGS regional regression equations (Cummans and others 1975) to calculate flows:

$$Q_R = a \times A^{b1} \times P_a^{b2} \times F^{b3}$$

where Q_R is the peak flow for recurrence interval R (R = 2, 5, 10, 25, 50 and 100 years), A is area of the hydrologic analysis unit (mi^2), P_a is the average annual precipitation (in.) for the basin, and F is the percentage of the unit normally covered by forest vegetation (50% = 50). The values of a, b_1, b_2, and b_3 are reproduced in Table C-2; they are arranged by the 12 regions shown in Figure C-4. (Note that for all of the regions in western Washington, F is insignificant in the regression, so b_3 is not given.)

If sufficient data are available, perform a log-Pearson type III frequency analysis on the annual series to estimate the 2, 5, 10, 25, 50, and 100 year floods. Flood frequency analysis results are recorded on *Form C-3 - Summary of Peak Discharge Estimates*.

Flood frequency and history information should be conveyed to the channel condition analyst, and retained for use later in this assessment.

Sources (#2-4): USGS (major source) or other flow data (Bureau of Reclamation, municipal data at water supplies, small hydro data).

Land Use Patterns

Divide the WAU into land use/cover types as defined in Table C-1. Use the DNR GIS coverage of vegetation size and density, local stand information, and aerial photographs. Use recent photos (if available) to identify changes made since the maps or coverage were created. Delineate the types on a map of the WAU to create *Map C-1 - Current Land Use and Vegetative Cover* (see example, Figure C-1). If less than 5% of the total area is in non-forest types, it may be delineated collectively as "non-forest".

Structural Features

Identify any dams, levees, irrigation diversions, or other public works that may affect or be affected by flow in the stream channel (you may wish to confer with the public works analyst). Show these features on a base map of the WAU. Consider how these structures may exacerbate or mitigate problems associated with peak flows, and briefly discuss those effects in the narrative.

Table C-1. Land Use/Cover Types and Description.

Land Use/Cover Type	Description
Forested (1):	
Hydrologically Mature	Maximum Hydrological Maturity >70% total crown closure AND <75% of the crown in hardwoods or shrubs
Intermediate Hydrologic Maturity	Intermediate Hydrologic Maturity 10%-70% total crown closure AND <75% of the crown in hardwoods or shrubs
Hydrologically Immature	Minimum Hydrologic Maturity <10% total crown closure AND/OR >75% of the crown in hardwoods or shrubs
Non-Forested (2):	
Urban	Residential/Commercial/Industrial
Agricultural	Cultivated and Grazing Lands
Open Water	Lakes, Ponds, Reservoirs Inundated Wetlands
Other	Naturally occurring open areas (e.g. talus slopes, meadows, barrens)

(1) Unmanaged or managed lands currently occupied by, or capable of growing, stands of trees of commercial size.

(2) Lands permanently converted from forest, or incapable of growing stands of trees of commercial size.

Hydrologic Analysis Units

Delineate precipitation zones (as defined by the DNR Forest Practices Division) on the base map of the WAU. Using a topographic map at the same scale as the base map, delineate the sub-basin draining to the outlet of each DNR Type 3 stream. Overlay these two maps and determine the proportion of each sub-basin in each precipitation zone. Sub-basins with greater than 75% of their area in either the lowland or highland zones are initially assigned a low hazard rating for rain-on-snow and may be excluded from the remaining portion of this assessment (Note: This rating may be modified if physical or anecdotal evidence suggests that rain-on-snow enhancement of peak flows is a significant factor in a particular sub-basin). The remaining Type 3 sub-basins are identified as *hydrologic analysis units*.

Additional hydrologic analysis units include:

1. the entire WAU;

2. at the location of any stream gage with a useful period of record (generally 10+ years);

3. at the location of any structural features identified by the public works analyst as having moderate or high vulnerability to peak flow changes;

4. at additional locations of interest, in consultation with channel and fish habitat analysts. To properly consider scale, there should be one hydrologic analysis unit defined for each increase in stream order above that represented by the Type 3 streams.

Note that it is possible for hydrologic analysis units to overlap; analyses and interpretations for overlapping units should be conducted independently of each other.

Hydrologic analysis units, stream gages, vulnerable structural features, and identified locations of interest should be identified on *Map C-2 - Hydrology Base Map* (see example, Figure C-2). Multiple base maps may be required to properly depict all the items properly. Within each hydrologic analysis unit, calculate the percent area for each combination of land use/cover type and precipitation zone. Summarize the information on *Form C-1 - Basin Acreage by Precipitation Zone and Cover Type* (see example, Figure C-3).

In the narrative section, discuss which areas of the watershed have a large percentage of forested land, especially in rain-dominated, rain-on-snow, and snow-dominated areas. Also, discuss how other land uses such as urban and agricultural land may affect the hydrologic behavior of the watershed.

Disturbance History
From aerial photographs or anecdotal information, identify the time and location of major upslope disturbances in the WAU, including extensive fire, insect and disease outbreaks (where they may affect hydrologic maturity through defoliation), and mass wasting events which contributed substantial amounts of sediment (confer with the mass wasting analyst). Look for obvious correlations between these disturbances and changes in temporal flooding patterns (note: it may be necessary to obtain a partial duration series to conduct this portion of the analysis). Disturbance information is summarized in narrative form and conveyed to other module analysts (mass wasting, channel, surface erosion).

Water Available for Runoff

The primary mechanism by which forest practices can affect peak flows is assumed to be alteration of snow accumulation and melt rate in response to changes in forest canopy density (Harr 1981, 1986; Coffin and Harr 1992). This phenomenon may occur at any elevation from sea level to mountain peaks, but it most commonly occurs between approximately 1200 and 4000 feet elevation (the "rain-on-snow" zone). At these elevations, and especially on the west side of the Cascade Mountains, shallow snowpacks that accumulate during the winter may entirely melt under the relatively warm and windy conditions associated with large frontal storms.

This portion of the analysis uses an empirical approach to estimate rain-plus-snowmelt inputs to the soil surface of each hydrologic analysis unit. The process described below must be repeated for every analysis unit defined. Estimation of the WAR requires determination of a baseline 24-hour precipitation amount for a given return interval. To this is added an estimated snowmelt, which is obtained by subjecting a model snow accumulation to a simulated 24-hour storm. The model snow accumulation and simulated storm parameters (air temperature, wind speed, and precipitation amount) are obtained from regional equations and graphs provided in the module, or are derived by the analyst from local data. Values for these parameters are modified across the landscape with respect to elevation and vegetative cover.

The credibility of the WAR calculations are based largely on the validity of the weather conditions used in their calculation. Among completed applications of this peakflow method to date, local data have been used to develop input data for each of the follow inputs: temperature, windspeed, snowpack and baseline streamflows. Although substantial weather data were used to derive the regional relationships for temperature, wind and snowpack provided in the module, these values do not account for the substantial variability within regions. For this reason, it is important to use local data, either to verify the reasonableness of values obtained from the regional relationships, or to replace them, if data is sufficient. Weather data need not have been collected within the WAU to be valid, as long as conditions at the collection station (elevation, topography, etc.) were similar, and the rationale for their use is clearly documented in the report. Sources of data include U.S. Weather Service publications, NRCS snow survey publications and research plot data (e.g., Coffin and Harr 1992).

To properly evaluate the range of conditions under which rain-on-snow generated WAR may occur, a number of scenarios are considered. Each scenario represents a particular combination of three factors: precipitation amount, storm type, and hydrologic maturity of the WAU.

Precipitation amounts used in this assessment are 24-hour totals for the 2-, 5-, 10-, 25-, 50-, and 100-year recurrence intervals.

Two storm intensities are considered:
- an **"average"** storm, representing a typical rain-on-snow event, and using mean values of storm temperature, wind speed, and snow accumulation;

- an **"unusual"** storm, representing a less frequent, more intense event, and using the mean value plus one standard deviation for storm temperature, wind speed, and snow accumulation;

Three vegetative cover conditions are considered:
- **"maximum hydrologic maturity"** classifies all forested lands (i.e. lands not classified as urban, agricultural, or open) as hydrologically mature (as defined in Table C-1);

- **"current condition"** represents the current distribution of land-use/ cover types;

- **"minimum hydrologic maturity"** classifies all "forested" lands as hydrologically immature (as defined in Table C-1).

An estimate for WAR is generated for each of the 36 scenarios (6 precipitation events x 2 storm intensities x 3 vegetative cover conditions). It is recommended that the analysis procedure be performed on a spreadsheet or within a GIS, especially if there are many hydrologic analysis units.

Note: If two or more hydrologic analysis units are expected to have similar peak flow responses, (by virtue of having similar proportions of area in each land use/cover type and precipitation zone), then one unit may be selected as an "indicator"; analysis results for this unit will apply to the remaining units.

Baseline Precipitation
For each of the designated recurrence intervals, determine the average values of the 24-hour precipitation ($P_{24/R}$, where R is the recurrence interval) using the

NOAA Atlas (Miller and others 1973) or DNR GIS coverage. If estimating visually from the atlas, use precipitation amounts at the high end of apparent averages for the hydrologic analysis units; if using GIS, more exact area-weighted averages can be calculated. Convert the values for $P_{24/R}$ to centimeters.

Snow Accumulation

Snow accumulation and melt are determined by considering the effects of forest cover on wind speed, storm temperature and snow accumulation (Coffin and Harr 1992).

Estimate an average snow accumulation for each precipitation zone in the basin, using the relationship between average January 1 (nominal) snow-water equivalent and elevation (Brunengo unpublished):

$$SWE_{z1} = d_1 + (d_2 \times E_z) + (d_3 \times E_z^2)$$

where SWE_{z1} is the snow-water equivalent (cm), E_z is the mean elevation of the precipitation zone (m), and d_1 and d_2 are regional coefficients given in Table C-3; regional boundaries are shown in Figure C-5. If local data are available (SNOTEL data from NRCS, Summary-of-the-Day data from NWS), a more basin-specific relationship can be developed, especially if the equation results seem unreasonable. The result is the basis for an "average" snow accumulation, to be modified for vegetative cover conditions in a later step.

Using the appropriate standard error of the estimate (SEE) from Table C-3, estimate the basis for an "unusual" snow accumulation:

$$SWE_{z2} = SWE_{z1} + SEE$$

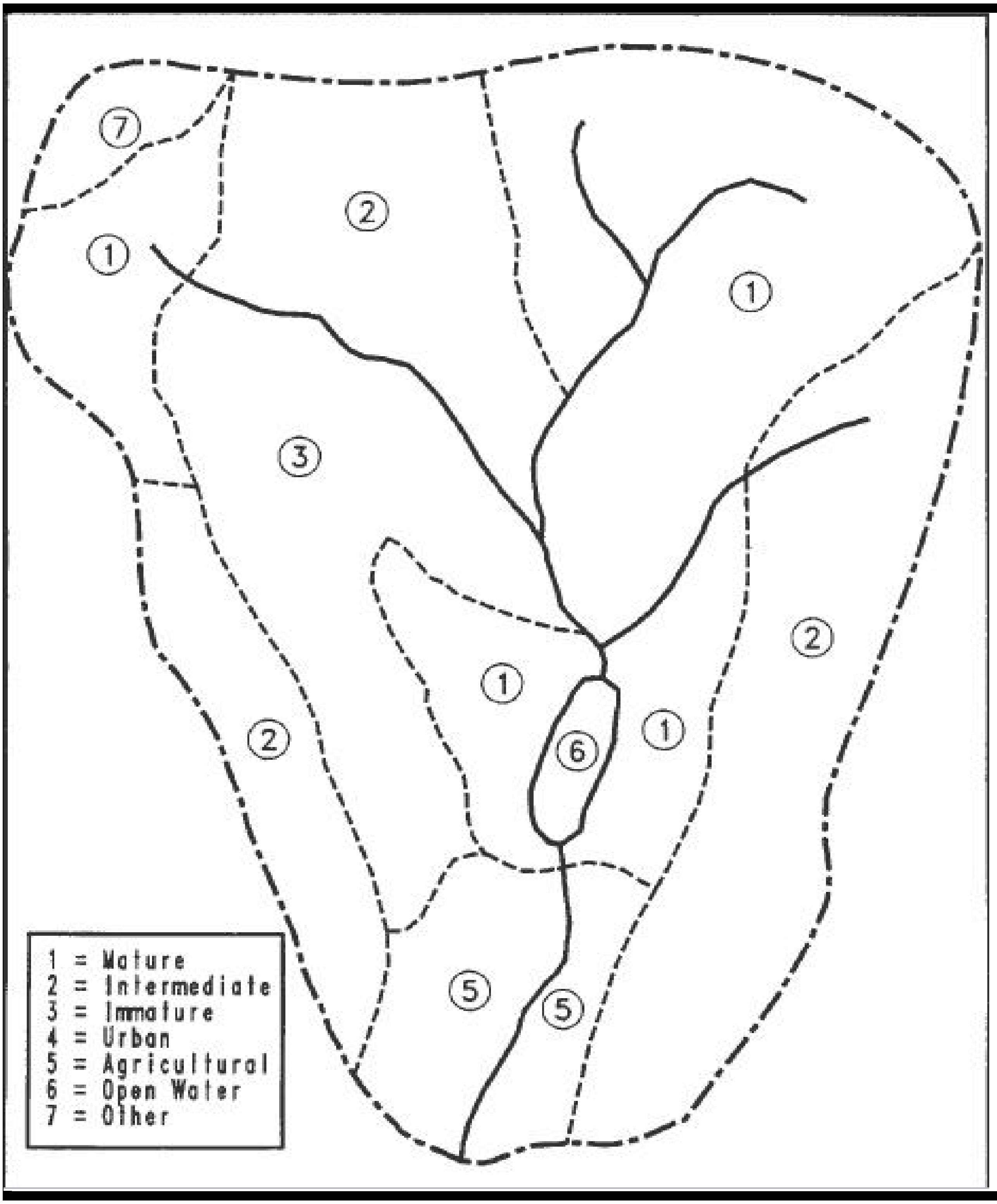


Figure C-1. Example: Map C1-Current Land Use and Vegetative Cover.

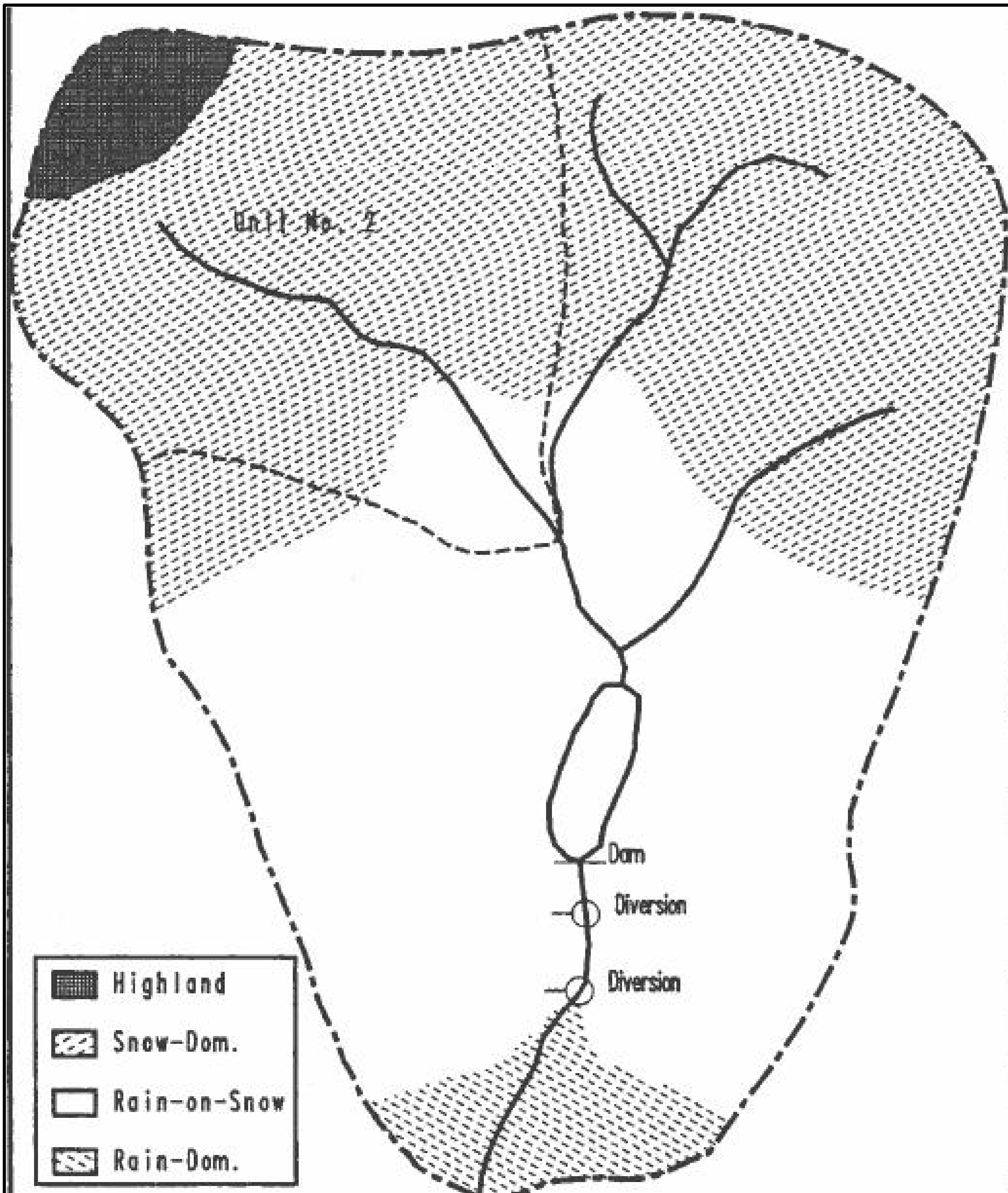


Figure C-2. Example: Map C-2-Hydrology Base Map Showing Hydrology Analysis Unit 2.

Hydrologic Analysis Unit: Entire WAU

	Lowland	Rain-dominate	Rain on Snow	Snow Dominate	Highland	Total
Hydrolog. Mature	0	0	2323	4479	85	6887
Intermediate Maturity	0	224	3035	3272	0	6531
Hydrolog. Immature	0	0	1694	1128	0	2822
Total Forested	**0**	**224**	**7052**	**8879**	**85**	**16240**
Non-Forested: Urban	0	0	0	0	0	0
Non-Forested: Agriculture	0	591	880	0	0	1471
Non-Forested: Open Water	0	0	216	0	0	216
Non-Forested: Other	0	0	0	1	382	383
Total Non-Forested	**0**	**591**	**1096**	**1**	**382**	**2070**
Total	**0**	**815**	**8148**	**8880**	**467**	**18310**

Figure C-3. Example: Form C-1 - Basin Acreage by Precipitation Zone and Land Use/Cover Type

SWE_z values calculated above are assumed to represent snow accumulation in hydrologically mature forests; these must be modified to account for variations in accumulation between different land use/cover types. For each polygon (representing a combination of precipitation zone and land-use/cover type), multiply SWE_z by the appropriate ratio given in Table C-4:

$$SWE_{v1} = SWE_{z1} \times R_{zv}$$

$$SWE_{v2} = SWE_{z2} \times R_{zv}$$

Snowmelt

Now that an estimate of snow depth for the design storm event has been established, the snow must be melted. This assessment uses the U.S. Army Corps of Engineers (1956) snowmelt equation, which requires estimates of storm temperature, wind speed, and storm precipitation to melt the accumulated snowpack.

Storm temperature varies primarily with elevation. Determine the "average" storm temperature (T_{z1}, ^{o}C) for each precipitation zone based on generalized regional lapse-rate equations:

Western Washington	T = 10 - (0.006 x E)
Eastern Cascades and Blue Mountains	T = 8.5 - (0.006 x E)
Northeast Washington	T = 8.0 - (0.006 x E)

where E_z is the average elevation (m) of the precipitation zone; the boundary between the eastern Cascades and northeast Washington is considered to lie along the Okanogan River.

These equations are based on the average maximum temperatures in fall and winter months; temperatures during ROS storms are generally near these seasonal highs. The analyst may attempt to improve estimates by using local data to generate lapse rates.

To estimate a temperature for warmer conditions representing the "unusual storm", add one standard error; if no other data are available, assume standard error = $2^{o}C$

$$T_{z2} = T_{z1} + SEE$$

Local wind speed is primarily dependent on the vegetative cover, with mature forest canopies significantly reducing the wind speed at the interface between the snowpack and the air. Using representative frequency curves for wind speed during storms (Figure C-6), select the value that is exceeded 50% of the time for the "average" storm (U_{o1}), and 16% of the time for the "unusual" storm (U_{02}). Local data may be used, if available.

For each polygon in the hydrologic analysis unit, modify the wind speed estimates to reflect the influence of land use/cover types, using the equation (Dunne and Leopold 1978):

$$U_{v1} = U_{o1}[1 - (0.8 \times F)]$$

$$U_{v2} = U_{o2}[1 - (0.8 \times F)]$$

where U_{v1} and U_{v2} are the modified estimates and F is the canopy closure (fractional form; 100% = 1.0). Use direct measurements or estimates of the canopy density for each polygon if time permits and they are readily available. Alternatively, use the canopy closure values given for each land use cover type in Table C-4.

Calculate snowmelt in each polygon using the equation (U.S. Army Corps of Engineers 1956; Harr, 1981):

$$SM_{24/R} = T_z\,[0.133 + (0.086 \times U_v) + (0.0126 \times P_{24/R})] + 0.23$$

The calculation is performed for each scenario (combination of precipitation amount, storm type, and vegetative cover condition). If the calculated $SM_{24/R}$ for a given scenario exceeds the estimated snow accumulation (SWE_z), set $SM_{24/R} = SWE_z$; also, if $T_z \leq 0.23$, $SM_{24/R} = 0$.

Determine water available for runoff for each polygon (in cm) by adding calculated snowmelt to precipitation amount:

$$WAR_p = P_{24/R} + SM_{24/R}$$

(**Note:** If Tz ≤ 0 ^{o}C for a precipitation zone, it is assumed that no snowmelt occurs and all precipitation occurs as snow; therefore, WAR = 0.)

Convert this result to inches.

Multiply the WAR from each polygon by its area (A_p, in ac or mi^2, measured off the map or in GIS); sum the values for all polygons in the hydrologic analysis unit, and divide the sum by the total unit area (A_u), to calculate a unit-averaged WAR:

$$WAR_u = [\Sigma (WAR_p \times A_p)] / A_u$$

Results of this analysis are summarized on a form labeled *Form C-2 - Summary of Water Available for Runoff* (see example - Figure C-7).

Peak Flow Estimation

This portion of the assessment converts the WAR estimates calculated above into estimates of peak flows at the outlet of the hydrologic analysis units under consideration. The products are flood-frequency curves for the range of return intervals used for the WAR estimate, under each of the assumed storm types and vegetative cover conditions. Peak flow sensitivity is evaluated by comparing flow estimates for different levels of hydrologic maturity. Results of this comparison are used to develop a peak flow sensitivity rating, in consultation with the analysts of channel condition, fish habitat, and public works. The sensitivity rating is delivered to the routing and synthesis modules, where it is used to evaluate whether any hydrologic changes may have significant impacts on public resources.

Storm runoff can be related to discharge with an appropriate model for the watershed. Ideally, the relationship could be established for each watershed based on measured precipitation and streamflow data. It would be of interest to generate the entire flood hydrograph; however, time limitations and data availability may preclude this (especially for level 1 assessments). The standard methods, therefore relies on regression equations for estimating peak discharge, in the absence of more local information. However, more sophisticated models may be used, especially those that generate an entire hydrograph, and are prescribed for use in forested watersheds.

Estimate baseline flood frequency curves
Use estimates obtained earlier in the assessment using the USGS peak flow equations.

Table C-2. Summary of Peak Flow Regression Coefficients, for Regions Shown in Figure C-4

Recurrence Interval, T	Regression Coefficients				Standard Error of Estimate (percent)
	Regression Constant A	Drainage Area b_1	Annual Precipitation b_2	Forest Cover B_3	
Region I					
2	0.191	0.86	1.51	__	24.9
5	.257	.86	1.53	__	24.6
10	.288	.85	1.54	__	26.9
25	.317	.85	1.56	__	31.5
50	.332	.86	1.58	__	35.7
100	.343	.86	1.60	__	40.3
Region II					
2	0.104	0.86	1.51	__	39.8
5	.140	.86	1.53	__	37.3
10	.158	.85	1.54	__	37.1
25	.176	.85	1.56	__	38.5
50	.186	.86	1.58	__	40.7
100	.194	.86	1.60	__	43.5
Region III					
2	0.054	0.86	1.51	__	41.6
5	.073	.86	1.53	__	42.8
10	.082	.85	1.54	__	45.4
25	.092	.85	1.56	__	50.3
50	.098	.86	1.58	__	55.1
100	.102	.86	1.60	__	60.7
Region IV					
2	0.059	0.86	1.51	__	39.3
5	.081	.86	1.53	__	38.5
10	.092	.85	1.54	__	36.9
25	.105	.85	1.56	__	39.9
50	.112	.86	1.58	__	42.4
100	.119	.86	1.60	__	46.0
Region V					
5	0.982	0.90	1.35	-0.21	65.1
10	2.87	.88	1.16	-.23	73.9
25	7.51	.87	1.03	-.25	91.1
50	13.6	.86	.95	-.27	105
100	23.4	.85	.89	-.29	121

Table C-2. Summary of Peak Flow Regression Coefficients, for Regions Shown in Figure C-4 (Continued)

Recurrence Interval, T	Regression Coefficients				Standard Error of Estimate (percent)
	Regression Constant A	Drainage Area b_1	Annual Precipitation b_2	Forest Cover B_3	
Region VI					
5	.260	.90	1.35	-0.21	50.2
10	.741	.88	1.16	-.23	45.2
25	1.77	.87	1.03	-.25	48.3
50	2.97	.86	.95	-.27	55.7
100	4.70	.85	.89	-.29	66.2
Region VII					
5	0.263	0.90	1.35	-0.21	75.8
10	.850	.88	1.16	-.23	50.0
25	2.07	.87	1.03	-.25	54.7
50	3.46	.86	.95	-.27	57.1
100	5.45	.85	.89	-.29	59.4
Region VIII					
5	0.508	0.90	1.35	-0.21	41.7
10	1.32	.88	1.16	-.23	44.1
25	2.95	.87	1.03	-.25	47.4
50	4.78	.86	.95	-.27	51.3
100	7.36	.85	.89	-.29	55.9
Region IX					
5	0.186	0.90	1.35	-0.21	62.9
10	.525	.88	1.16	-.23	64.4
25	1.29	.87	1.03	-.25	72.2
50	2.22	.86	.95	-.27	81.0
100	3.60	.85	.89	-.29	91.7
Region X					
5	0.449	0.90	1.35	-0.21	90.1
10	1.16	.88	1.16	-.23	93.1
25	2.54	.87	1.03	-.25	104
50	4.03	.86	.95	-.27	115
100	6.05	.85	.89	-.29	129

Table C-2. Summary of Peak Flow Regression Coefficients, for Regions Shown in Figure C-4 (Continued)

Recurrence Interval, T	Regression Coefficients				
	Regression Constant A	Drainage Area b_1	Annual Precipitation b_2	Forest Cover B_3	Standard Error of Estimate (percent)
Region XI					
5	0.450	0.90	1.35	-0.21	66.6
10	1.36	.88	1.16	-.23	62.2
25	3.59	.87	1.03	-.25	63.3
50	6.61	.86	.95	-.27	72.1
100	11.5	.85	.89	-.29	88.0
Region XII					
5	0.157	0.90	1.35	-0.21	93.6
10	.629	.88	1.16	-.23	54.0
25	1.76	.87	1.03	-.25	56.6
50	3.05	.86	.95	-.27	67.0
100	4.83	.85	.89	-.29	81.8

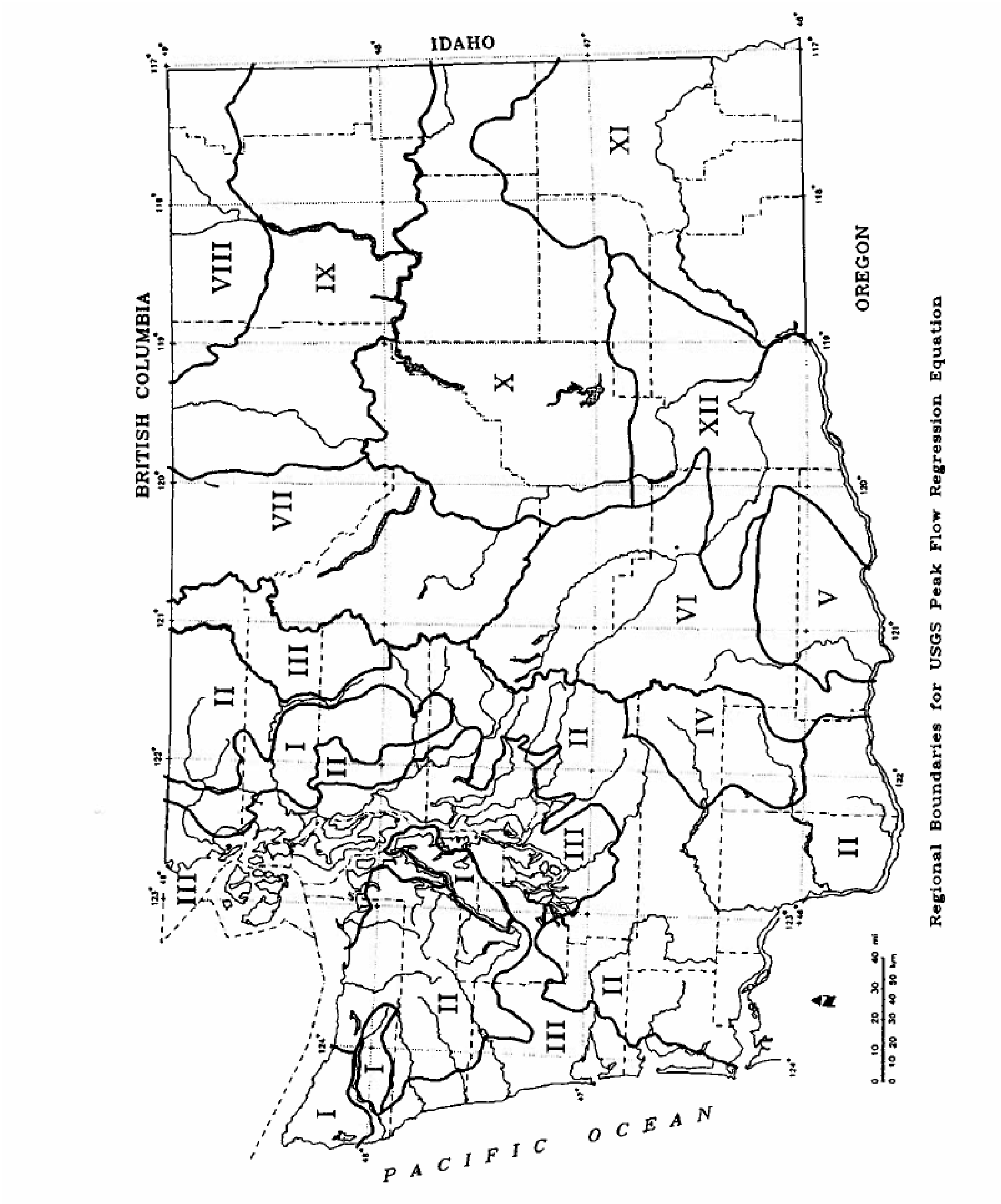


Figure C-4. Regional Boundaries for USGS Peak Flow Regression Equation (see Table C-2).

Table C-3. Regression of Snow-Water Equivalent vs. Elevation for Regions Shown in Figure C-5

Region	n	Constant (d_1)	1st-order coeff (d_2) x 10^{-3}	2nd-order coeff (d_3) x 10^{-5}	R^2	Std Error of Est.	Notes
Coastal	22	0.6218	-10.56	2.710	.9280	1.693	
Rain Shadow	20	0.3029	-1.291	2.874	.8347	12.170	
North Cascades	45	-2.098	39.84		.8126	12.656	1
Cedar-Skykomish	34	-1.707	7.741	2.201	.9263	5.935	
Green-Nisqually	49	-5.487	18.08	1.074	.7747	11.647	
Lewis-Cowlitz	53	-2.131	5.533	2.1775	.8186	10.956	4
Lower Yakima-Klickitat	46	-4.683	11.341	1.077	.7067	10.792	2
Naneum-Umtanum	19	-3.492	14.71		.8682	3.170	1, 2
Upper Yakima-Naches	33	-14.615	36.10		.5386	13.086	1, 2
Entiat-Wenatchee	33	-9.859	38.87		.8505	7.762	1
Methow-Chelan	20	-0.1508	4.982	1.316	.8091	9.701	
Okanogan-Sanpoil	29	2.318	-0.4536	0.4589	.7269	2.186	
Columbia-Pend Oreille	32	6.393	-18.575	2.121	.8830	3.979	4
Blue Mountains	19	0	-11.775	1.754	.9093	3.362	3, 4
Columbia Basin	55	0	-2.657	0.8589	.7926	2.001	3, 4

Notes: Regions are as shown in figure C-5; regional boundaries are approximate. Regression factors are calculated from data collated in Brunengo (1995); n = number of stations used in each region; elevations measured in meters, SWE (and the standard error) in centimeters.

1. In some regions, a second-order regression is small improvement, so the first order equation is given. In most cases, however, the first order equations tend to over-estimate the snow depths in the lower (especially the rain-dominated) zones. A segmented (two-line) relationship may be a better fit to the data.

2. In many of the eastern regions, particularly those on the east side of the Cascades, there is typically a wide spread in average snowpacks between high-elevation stations near the crest as opposed to those farther east. Be aware of local conditions in these regions.

3. Some regressions were forced through the origin (0 elevation and 0 snow) to better fit the data.

4. Regressions for some regions included data from adjacent areas of Oregon, Idaho, and/or British Columbia. Information from the rest of the region has not yet been utilized to full potential. In particular, there are >50 snow survey sites in BC below 50^0N lat (most not included in these calculations) that could be used in analyses for northern Washington basins.

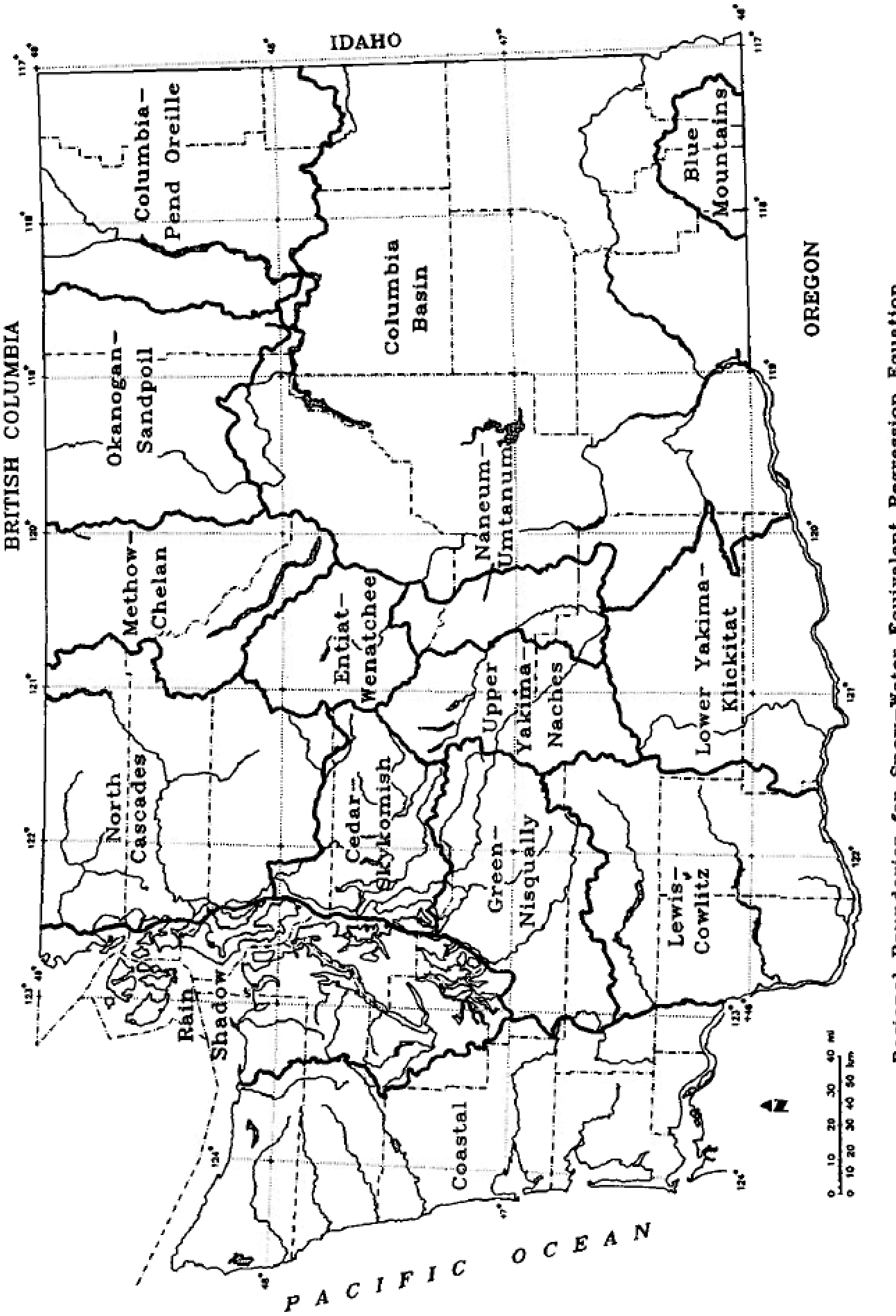


Figure C-5. Regional Boundaries for Snow-Water Equivalent Regression Equation (see Table C-3).

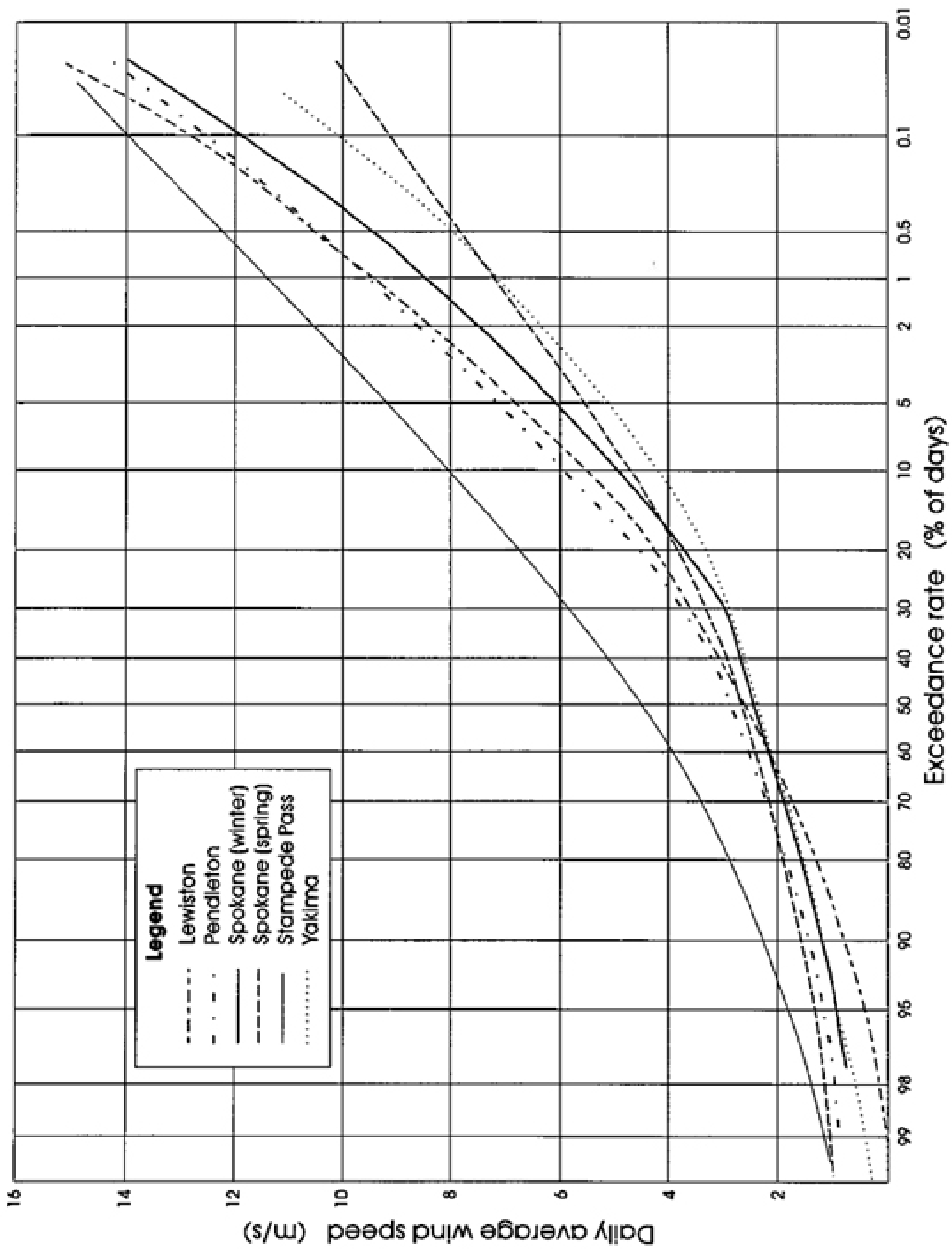


Figure C-6a. Frequency Curves for Wind Speed (Eastside)

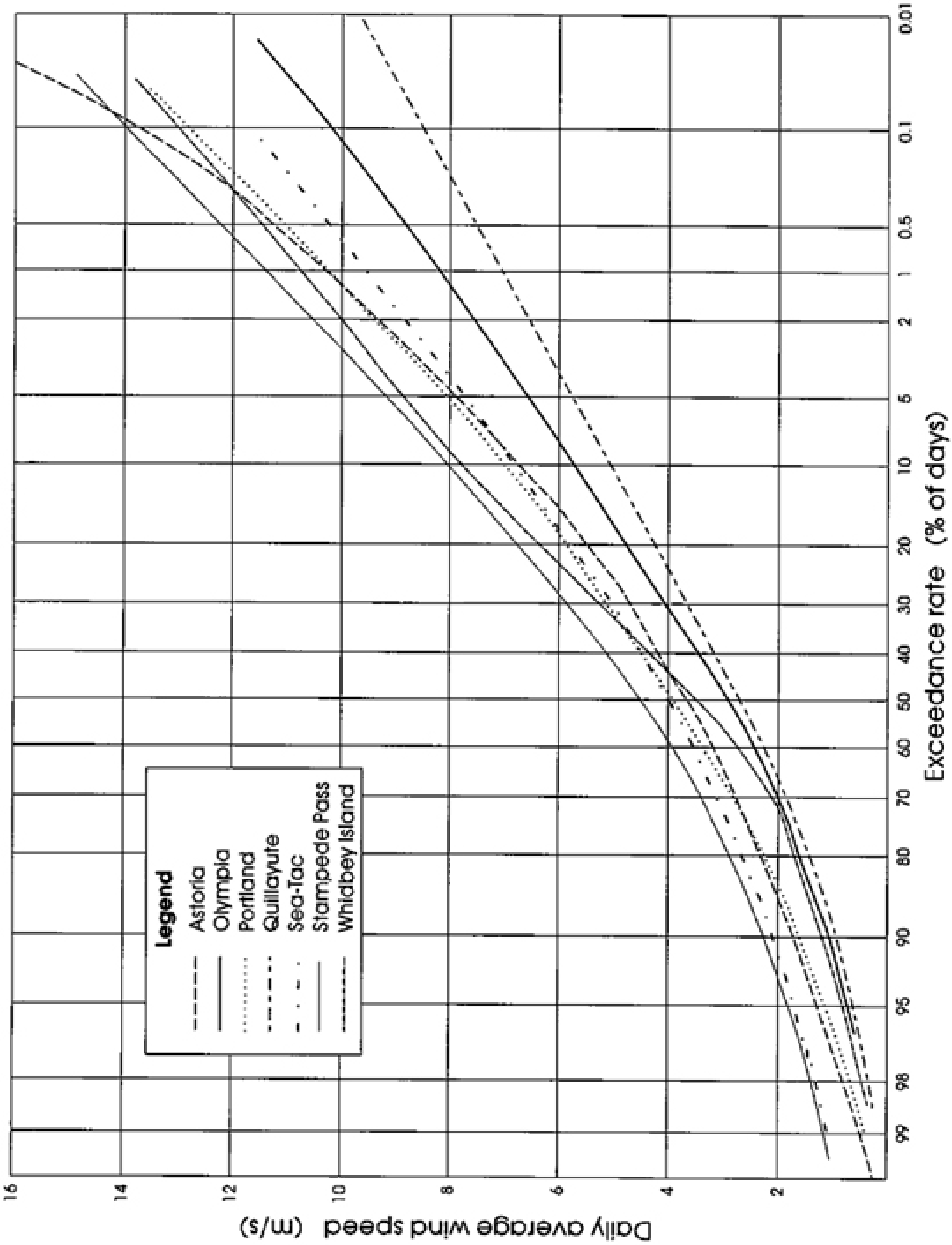


Figure C-6b. Frequency Curves for Wind Speed (Westside)

Table C-4. Coefficients for use in snow accumulation and melt calculations.

Land Use / Cover Type	R (Snow Water Equivalent Ratio)					Canopy Density
	Lowlands	Rain-Dominated	Rain-on-Snow	Snow-Dominated	Highlands	Fc
Forested						
Mature	1	1	1	1	1	0.85
Intermediate	2	1.75	1.5	1.25	1	0.4
Immature	3	2.5	2	1.5	1	0.05
Non-Forested						
Urban	3	2.5	2	1.5	1	0
Agricultural	3	2.5	2	1.5	1	0
Open Water	0	0	0	1.5	1	0
Other	3	2.5	2	1.5	1	0

Vegetation class and description adapted from Pacific Meridian Resources, Inc. 1993.

Snow-water equivalent ratios from Brunengo et al. 1992.

Relate precipitation inputs to flow outputs

The basic hydrologic approach is to predict the discharge associated with various rainfall events. Ideally, both the instantaneous peak flows and hydrographs could be determined. Although several such models exist, they are beyond the scope of the standard assessment. Instead, a simple empirical approach relating rainfall amount and runoff amounts for corresponding recurrence intervals is used.

Although they do not necessarily occur together, we assume that it is appropriate to relate precipitation amounts and discharges having the same recurrence intervals (e.g. the 2-year rainfall and the 2-year flow, each having 50% probability of exceedance; that is, $P_{24/RR}$ yields Q_R).

Regress baseline peak flow estimates (dependent variable) against baseline precipitation estimates (independent variable):

$$Q_{R(pred)} = f\,[P_{24/R}] \qquad (Q_R \text{ in cfs; } P_{24/R} \text{ in inches})$$

Linear regression should provide a function with a reasonably high coefficient of determination ($r^2 > 0.7$).

Estimate Modified Peak Flows
Estimate peak flows for each hydrologic analysis unit by substituting WAR values for each scenario into the regression equation:

$$Q_R(\text{pred}) = f\ [\text{WAR}]$$

The results from this step are summarized on *Form 3 - Stmmary of Peak Discharge Estimates* (see example - Figure C-8). The results may also be used to generate modified flood-frequency curves for each combination of storm type and vegetative cover condition.

The output is an estimate of likely changes in peak discharges, under rain-on-snow conditions, for different levels of hydrologic maturity within the hydrologic analysis unit. Write a brief summary of the findings, including any insights obtained from evaluation and comparison of the assessment scenarios.

Interpretation of Results

The relative differences in peak flow discharge at various storm frequencies are the primary interpretative tool for this assessment. The calculations for average and unusual storm events under "maximum hydrologic maturity" conditions assist the analyst to understand the range of possible natural conditions that the watershed may experience. The relative change in discharge at similar storm frequencies with level of hydrologic maturity is the primary means of determining the hydrologic effects of forest management. There may be more water available for the a given rainfall event from a hydrologically less mature watershed, and therefore greater discharge. This would tend to shift the flood-frequency curves to produce more frequent recurrences of a given flood magnitude.

The flood magnitude of greatest concern is usually influenced by the public resources of concern in the watershed. Downstream flooding will focus attention upon the larger storms (Q_{25}, Q_{50}, and Q_{100}), while fish habitat concerns may be more focused on increasing the frequency of the channel-forming discharge (thought to be approximately Q_5 in most steep mountain streams; see Lisle 1981).

For scenarios combining "average" storms and "maximum hydrologic maturity" vegetative cover condition, the resulting peak discharge estimates (depicted graphically as a flood frequency curve) are considered the typical response of an undisturbed, fully stocked forest to storm precipitation amounts at a range of recurrence intervals, and approximately mean ROS-storm temperature and wind, all acting on an average seasonal snowpack. These represent the baseline condition against which increases in peak flows for other scenarios are determined. Scenarios considering "unusual" storms provide an indication of the sensitivity to inputs in warmer and windier storm conditions, acting on a deeper snowpack. Scenarios considering "current conditions" and "minimum hydrologic maturity" represent the responsiveness of the hydrologic analysis unit to the spectrum of land use changes associated with forest practices and other types of disturbances.

Effects of Peak Flow Changes on Public Resources

The significance of the estimated change in peak flows must be related to the likelihood of delivering adverse impacts to public resources. Interpreting the effects of changes in peak flows from land use is confounded by the reality that peak flows are naturally highly variable from year to year. Stream channel dimensions and characteristics are adjusted to accommodate the bankfull (2-year) event in lower gradient self-formed rivers (Wolman and Miller 1960), and the 5-year event in steeper mountain streams (Lisle 1981). However, it is not unusual for stream channels to experience larger but more infrequent events, and they usually do so without significant observable damage.

Hydrologic Analysis Unit: Entire WAU

Recurrence Interval	**Storm Intensity**	**WAR [in]**		
		Fully Forested	**Current Condition**	**Fully Stocked Young Forest**
2 years	Average	12.2	13.4	29.2
2 years	Unusual	12.7	14	29.8
5 years	Average	14.3	15.7	31.8
5 years	Unusual	14.9	16.4	32.5
10 years	Average	16.3	17.9	34.2
10 years	Unusual	17	18.7	35
25 years	Average	18.4	20.2	36.7
25 years	Unusual	19	20.9	37.4
50 years	Average	20.4	22.4	39.1
50 years	Unusual	21.1	23.2	39.9
100 years	Average	22.4	24.6	41.5
100 years	Unusual	23.1	25.4	42.3

Figure C-7. Example: Form C-2 - Summary of Water Available for Runoff

Flood control strategies involve managing human development within the 50- or 100-year floodplain, accommodating the natural occurrence of over-bank flooding. Interpreting the effects of changes in peak flows on public resources requires a framework for translating some characteristic(s) of flows directly to the affected resources. For example, flood damage potential depends on the amount of increase in water surface elevation, whereas potential for scour of salmon redds depends on the amount of decrease in streambed elevation.

Fish Habitat

A rationale for conceptualizing the effects of peak flows on fish habitat is based on the mobilization and scour of streambed sediments and the resulting disruption of the egg incubation environment (redds). Stream gravels are mobilized and move as bedload during large peak flow events occurring, on the average, every two to five years (a 20 to 50% probability of exceedance in any year). The depth of the mobile bed layer during the channel-forming discharge is not well documented. Lisle (1989) measured the mobile bed thickness in three California streams with depths ranging from 6 to 15 cm in what appeared to be more stable streams; streams appeared to be unstable when scour depths exceeded 25 to 50 cm.

Salmonids generally bury most of their eggs at depths of between 10 and 45 cm, depending on species (Peterson et al. 1992). Evolutionary strategy would suggest an advantage to burying eggs below the bed layer mobilized by a natural 2-year peak flow event, since scour frequency at shallower depths could affect populations on a nearly annual basis. Larger floods with greater volumes and duration of flow may cause deeper scour of the gravels. Since these storms occur less frequently, they have a lower probability of affecting the entire population, but could have significant effects on the brood in the years in which they do occur.

From a fisheries view, the question is--what flow will mobilize the bed to a depth at which redds are found? Bed load mobilization and transport is reasonably well understood and its occurrence can be related to shear stress associated with depth and velocity of flow (see Leopold et al. 1964). However, our understanding of factors contributing to depth of scour (as opposed to bed mobilization) are not well understood at this time. The shear stress associated with various stormflow discharges relates to the size and volume of sediment mobilized (Richards 1982), although those relationships are not fully established. Hypothetically, a significant increase in shear stress relative to the streambed sediments would result in increased depth and volume of scour. Some geomorphologists have argued that the 5-year flow is the important channel-forming event in mountain streams, implying sufficient scour of the bed and banks.

Unless better evidence is available, we make the assumption that the 5-year event is sufficient to cause deep bed scour in forest stream channels where fish typically spawn. Fish habitat is considered to be significantly affected when either (1) the shear stress increases significantly, or (2) the discharge associated with the 5-year event occurs significantly more often. Although the volume increase necessary to move from a 2-year to a 5-year event varies with channel cross-section, an increase of 20% can be used as a rule-of-thumb to index the difference.

Overbank Flooding and Channel Erosion
Increases in peak flows affect public works primarily by increasing the depth of water on the floodplain or by increasing erosion of channels or levees. Changes in flow depth can be estimated using normal hydraulic routing techniques (see Dunne and Leopold 1978). Overbank flooding is considered significant when the storm flow increases significantly according to accepted planning standards of local, state, or federal agencies.

Channel and levy erosion is more difficult to quantify, although the same rationale for fish habitat changes may also be appropriate for generally predicting channel erosion response to peak flows.

Peak Flow Sensitivity Ratings
Since the effects of changes in peak flows and channel processes associated with forest land use are poorly established, the peak flow sensitivity ratings should be developed directly for each hydrologic analysis unit, utilizing the standards presented above. If the analyst can develop suitable data and rationale for specific locations, the ratings will be better grounded.

The hydrology specialist should consult with the stream channel and fish habitat analysts while performing this analysis. While Level 2 specialists may have the time and capability to perform such assessments, Level 1 analysts are not expected to use this approach. Instead, use relative ratings that provide generalized evaluations of likely channel response based on the geomorphic conceptual model discussed above. These ratings are as follows:

It is assumed that there are no adverse effects for peak flow increases of up to 10%, given the inherent error in the prediction method, and the fact that changes in peak flows of up to 10% are typically below detection limits using standard stream gauging methods. Hydrologic analysis units meeting this criterion are assigned a **LOW** sensitivity rating.

Hydrologic Analysis Unit: Entire WAU

	Discharge and % Increase for Given Recurrence Intervals											
	2-Year		5-Year		10-Year		25-Year		50-Year		100-Year	
	Disch.	%Incr	Disch.	%Incr	Disch.	%Incr	Disch.	%Incr	Disch	%Incr	Disch.	%Incr
USGS Eqn	3950		4720		5280		6370		7640		8630	
+1 Std. Err.	4900		5850		6550		7900		9475		10700	
Log Pearson Estimate												
+1 Std. Err.												
Fully Forested												
+ Avg. Storm	4345		5115		5675		6765		8035		9025	
+ Unus. Storm	4523		5293		5853		6943		8213		9203	
Current Condition												
+ Avg. Storm	4797	10.4	5567	8.8	6127	8.0	7217	6.7	8487	5.6	9420	4.4
+ Unus. Storm	4994	14.9	5764	12.7	6324	11.4	7414	9.6	8684	8.1	9598	6.4
FullyStocked/Young For												
+ Avg. Storm	5085	17.0	5855	14.5	6494	14.4	7505	10.9	8882	10.5	9815	8.8
+ Unus. Storm	5293	21.8	6033	17.9	6703	18.1	7683	13.6	9079	13.0	9993	10.7

Figure C-8. Example: Form C-3 - Summary of Peak Discharge Estimates.

Peak flow increases of more than 10% offer the possibility for adverse effects, and require a level 2 analysis if there is an identifiable potential for down-stream flood damages or scour damage to fish spawning areas. Hydrologic analysis units meeting these criteria are assigned an **INDETERMINATE** sensitivity rating.

Level 2: Analysis of Sensitivity to Peak Flows

Sensitivity analysis is used to estimate the risk of increased flood damage and bed scour caused by increases in peak flows. Both evaluations require estimates of the flood stage for alternative flows. Flood flow values used are those representing fully stocked forest sites and those generated for either current or potential future forest conditions (whichever is higher). The peak flow recurrence interval to be used for calculating the percentage change in flow is the 2-year event for evaluation of bed mobility potential, and the 50-year event for flood damage.

Peak flow sensitivity analyses are site-specific, in that they depend on channel slope and cross-sectional shape, and evaluation of flow resistance, and the particle-size distribution of the bed. The intensive field data requirements make it difficult to conduct analyses at many locations or to extrapolate results to other locations so it is necessary to work closely with the public works, fish habitat, and channel condition analysts to assure that sites selected for analysis are representative of key potential problem areas.

Flood Damage Potential

Flood damage is directly related to increased flood stages. Analysis of channel cross sections is used to estimate change in flood stage for different flow rates. Grant et al. (1992) provide background information and a computer program that simplifies such assessments based on the analysis of a single cross section. Single cross section assessments of this type assume uniform flow conditions. If non-uniform flow conditions exist, methods which utilize multiple cross sections (e.g. HEC-2 or Shearman 1976) are required. Once the analysis is completed for the different flood flows, the cross sections can be used to estimate flood damage by comparing the change in flood stage and area inundated for the sites in question. **MODERATE** or **HIGH** sensitivity ratings are assigned on the basis of the change in estimated flood damage.

Bed Mobility Analysis

Bed mobility analysis is used to determine whether the larger particles in the streambed (usually represented by D_{84}) are likely to be transported at a given flow. Bedload transport equations appropriate for the existing field conditions are used to make the assessment. The predicted bed particle size is then compared to the measured particle size to assess whether or not the bed material is likely to be mobilized for the flow level in question. As an example, if the predicted flow is estimated to move D_{84} particles of 10 cm size and the actual D_{84} for the bed is 5 cm, the potential for bed mobility is high. In contrast, the potential for bed mobility is low if the actual D_{84} for the bed is 30 cm. Thus, the ratio of D predicted (D_p) to actual (D_a) provides a measure of bed mobility potential. The mobility potential is high if $D_p/D_a >> 1$ and low if $D_p/D_a << 1$.

Channel cross-section analysis is also necessary for evaluating bed mobility potential; the reference by Grant et al. (1992) is recommended. In addition, bed-load transport equations are needed to estimate bed particle size movement potential. Not all bed-load transport equations are suited to the large streambed particles found in channels draining forested lands in Washington.

Uncertainty associated with the use of bedload transport equations is relatively high and commonly results in a range in sizes in the value of D_p if different transport equations are used. Thus, it is critical to select the equation that is best suited to the field situation. Even if the best equation is used, there is still considerable margin for error. Thus a range of D_p/D_a values is appropriate for assigning sensitivity ratings of **MODERATE** or **HIGH** for bed mobility. As an example, ratings might be set up using ratio values of 1.8 or greater for **HIGH**, 0.8 to 1.8 for **MODERATE** and <0.8 for **LOW**.

Bed mobility tends to be directly proportional to scour, and thus provides an index of scour potential. However, it is impossible to predict the amount of scour because it is not possible to account for sediment supply from upstream sources without more detailed procedures for routing sediment (such as HEC-6). Bed mobility also tends to be directly proportional to sediment supply, and may reflect large supplies of sediments supplied either naturally or from accelerated erosion on the watershed. Low bed mobility may indicate that the channel system is inherently stable and not subject to scour; on the other hand, it can also mean that the channel has already been scoured of finer materials by large natural floods or by increased flooding induced by land management activities. Considering the potential for interactions between bed mobility, watershed sediment supply and present channel conditions, it is essential that sensitivity ratings of moderate and high be interpreted in conjunction with the assessments made in the channel module.

Other Hydrologic Issues

The focus of this module is on estimating land-use induced changes to peak flows associated with rain-on-snow storms. While it is assumed that this phenomenon is most likely to have cumulative effects upon public resources, evaluation of other hydrologic issues may be warranted in certain WAUs.

Seasonal and Annual Water Yield

There is a large body of knowledge on the effects of forest management on water yield (e.g. Helvey 1980; Bosch and Hewlett 1982; Harr 1983; Kattelmann et al. 1983; Troendle 1983). These studies show that for several years after logging, water yield increases throughout the year, with the most pronounced effect occurring during the summer and early fall months. However, some observed decreases in summer water yields have been attributed to harvesting in areas where fog-drip is an important precipitation component (Harr 1982), and in response to establishment of phreatophytic hardwoods in the riparian zone (Hicks et al. 1991). In the former case, measured decreases occurred immediately after harvest and approached pretreatment levels after five to six years (Ingwersen 1985); in the latter case, small decreases in summer water yield occurred after five years and have persisted nearly 20 years after treatment.

In general, increases in water yield attributable to forest harvest are perceived to be a net benefit; consequently, no watershed analysis methods have been developed to formally address this issue. In addition, there are insufficient data on the extent and magnitude of fog-drip to develop a method for evaluating this phenomenon. In the event the analyst believes there is justification to perform an evaluation, it is recommended that the case studies mentioned above be carefully applied and the procedures fully explained.

Spring Snowmelt

Where a persistent snowpack contributes large amounts of spring runoff and rain-on-snow events are less common (e.g. higher elevation watersheds east of the Cascade crest), peak flows generated by snowmelt only (little or no rain) may account for most of the 2- to 10-year flows. Strict application of the ROS analysis in these areas events may give erroneous results, because the snowmelt equation used in the analysis was developed for ROS conditions, where advective heat transfer is the dominant form of energy provided. If the analyst suspects that the WAU is in an area where snowmelt-only peak flows are generated, consideration should be made to applying a more appropriate snowmelt model.

Timing of snowmelt runoff is important in many eastern Washington watersheds because this runoff is vital for irrigation supplies and fish outmigration. Changes in the timing of snowmelt runoff due to timber harvest are not well understood. A number of studies in the Rocky Mountains region have indicated that clearcut timber harvesting causes the stream hydrograph to rise more quickly, but has little effect on recession flows (Troendle and Leaf 1981; Troendle 1983; Swanson and Hillman 1977). Peak discharges are generally increased by substantial harvesting within a basin, but depending on the patterning and schedule of harvest, timing of flow may be desynchronized such that increases in peak discharges are not detectable (Troendle and Leaf 1981).

Road Drainage

Forest road networks (including haul roads, skid trails, and landings) and their associated drainage systems can influence hydrologic response by altering the way water is routed through the watershed. Roads and skid trails are the chief contributors to soil compaction; these surfaces are much less permeable, and more likely to generate overland flow. Road ditches collect surface runoff from compacted road surfaces, in some cases augmented by subsurface flow intercepted by the road cut (Megahan 1972). During storm events, this surface runoff is routed more quickly through the watershed; this, in turn, may serve to increase storm peaks if the road network is well connected to the stream channel network.

In watershed studies involving small basins (0.3 to 5 km^2), road drainage has been linked to statistically significant increases in peak flows where roads and skid trails occupied a high percentage (12%-15%) of the drainage area (Harr et al. 1979; Harr et al. 1975). Other studies have indicated no change or even a significant decrease in peak flows attributable to road construction (King and Tennyson 1984; Cheng et al. 1975). It should be noted that these experimental basins are generally smaller then the hydrologic analysis units evaluated in Watershed analysis; in addition, almost all the peak flows measured in these studies were less then the mean annual peak (2.33 year recurrence interval). In studies involving large forested basins (50-600 km^2), no significant increases in peak flow was detected (Duncan 1986; Toth 1990).

Simple generalizations regarding peak flow response relative to the area occupied by the road network may be tenuous, as additional factors (such as the proximity and connectivity of the road network to the stream channel network) may need to be considered. In addition, the response of many small sub-basins comprising the WAU may be attenuated by desynchronization of sub-basin peaks. Identification of a cumulative effect due to road drainage may only be possible if local effects are large and extensive enough. Evidence of local effects may be evaluated by field inspection of road drainage systems upstream from observed gullying or channel enlargement.

Mixed Land Use

As rural areas undergo conversion, namely a permanent change of land use from forestry to residential or other non-forest land-use, natural hydrologic pathways can be permanently altered. Landscaping and agricultural activities remove stumps and compact soils, radically reducing soil porosity, the effective soil water storage, and the macropore network in the soil, all of which diminish soil infiltration rates. Soils disturbed in this way produce surface flows more often and in greater quantities than forested soils because the soils are saturated more frequently as the precipitation rate exceeds the infiltration rate more often. Storm flow peaks from these soils are typically double those of forest soils (Booth 1989). The annual flow volume also significantly increases because of increased storm flow volumes and reduced total evapotranspiration.

Hydrology Assessment Report

The hydrology assessment report organizes and presents results of the hydrologic assessment. The report is a compilation of key work products, maps and narrative summarizing interpretations. Narrative may be on the order of only several pages in length, and should provide a concise discussion of results of each section of the analysis module. While the hydrologic assessment report should be concise, it should be complete enough so that, together with other module products, it provides the input necessary for the synthesis and prescription phases of watershed analysis where the information developed in the analysis modules is incorporated into land use decision making.

Realistically, there will not always be the type of data or information available that the analyst would desire for high confidence in the analyses and interpretations. Assessment of the confidence level possible based on available information is important for decision-making based on these analyses. The degree of confidence that can be assigned to the products of this assessment depends upon a number of factors. Considering the amount, type, and quality of available information, analysts should determine their relative confidence in the interpretations based on each work product. Other factors to consider may include (but are not limited to) extent of field work, experience of the analyst, and multiple lines of evidence for inferred changes.

Hydrology Assessment Report

I. **Title page** with name of watershed analysis, name of module, level of analysis, signature of qualified analyst(s), and date

II. **Table of contents**

III. **Maps**
- Current land use and vegetation cover (map C-1)
- Hydrologic Analysis Unit (HAUs) maps (map C-2)

IV. **Summary Data**
- Basin acreage by precipitation zone & land use cover for each hydrologic unit (form C-1)
- Summary of water available for runoff for each analysis unit (form C-2)

- Summary of peak discharge estimate for each analysis unit (form C-3)

V. Summary Text

- Narrative describing current watershed land use patterns, structural features, and flood and disturbance history
- Summary of methods, analysis, and results for peak flow analysis
- Summary of methods, analysis, and results for runoff analysis
- Descriptions of any deviations from the standard methods and why the changes were necessary
- Summary and justification for peak flow sensitivity ratings
- Recommendations for Level 2 (at Level 1 only)
- Statement of the author's confidence level in the analysis and results
- Does module report address all critical questions?

VI. Other Information (optional)

- Monitoring strategies and design and implementation suggestions
- Learning resources (a.k.a., references, bibliography) section
- Acknowledgments section

Module Project Management

The module project management checklist is provided to assist the module leader and team members to schedule tasks and review interim and final module products. It is not a requirement of watershed analysis.

Table C-6: Hydrology Project Task Checklist

Review	Task	Schedule	Complete
	Analysis materials in place		
	Startup meeting—brief team on process and intent. Schedule module tasks.		
	Map Hydrologic Units—Complete Hydrologic Unit worksheet (Form C-1).		
	Produce Hydrology Unit map on mylar overlay (Maps C-1 and C-2).		
	Provide hydrologic map to channel analyst.		
	Meet with fish and channel analysts for input on analysis sites and select analysis sites.		
	Perform historic trend analysis; complete the annual peak flow worksheet (form C-2).		
	Review products and checkoff with team:		
	Perform hydrologic modeling: Water-available for runoff and peak flows; complete forms C-2 and C-3.		
	Level 1 teams make sensitivity calls based on estimated change in discharge; complete narrative assessment. Level 2 teams continue with channel cross-section analysis.		
	Level 2 teams calculate changes in flood depths or bed shear stress at selected channel locations to evaluate potential effects of changes in discharge. (Complete narrative assessment).		
	Team meeting: review results and interpretations.		
	Produce module report.		
	Review module report.		

Acknowledgments

This module represents the results of many people over the course of several years. The individuals that contributed to the scientific content of this module include Matt Brunengo, Terry Cundy, Walt Megahan, Kate Sullivan, Kevin Lautz, Todd Bohle, Steven Toth and Curt Veldhuisen. Lynne Miller drafted the first version. Cartographic support was provided by Lori Adkins and Nancy Eberle.

References

Booth, D. B., 1989. Runoff and stream channel changes following urbanization in King County, Washington. In: Engineering Geology in Washington, R. Gallster (Editor). Washington Division of Geology and Earth Resources Bulletin 78(II);639-650.

Bosch, J. M. and J. D. **Hewlett**, 1982. A review of catchment experiments to determine the effect of vegetation changes on water yield and evapotranspiration. Journal of Hydrology 55: 3-23.

Brunengo, M. J. unpubl. Estimation of snow available for melting during model rain-on-snow events: DNR Forest Practices Division, Olympia, Washington 46p.

__________ , S. D. **Smith**, and S. C. **Bernath**. 1992. Screening for watershed analysis, a GIS-based method for modeling the water input from rain-on-snow storms, for management and regulation of clearcut forest harvest. Unpubl report, Wash. Dept. of Natural Resources, Forest Practices Division. 22 pp.

Cheng, J. D., T. A. **Black**, J. **DeVries**, R. P. **Willington** and B. C. **Goodell**. 1975. The evaluation of initial changes in peak streamflow following logging of a watershed on the west coast of Canada. In: Proc. IASH. Publ. 117. Tokyo, Japan. pp. 475-486.

Coffin, B. A. and R. D. **Harr**. 1992. Effects of forest cover on volume of water delivery to soil during rain-on-snow. Timber/Fish/Wildlife Report No. SH1-92-001. Washington Dept. of Natural Resources. 118 pp.

Cummans, J. E., M. R. **Collins**, and E. G. **Nassar**. 1975. Magnitude and frequency of floods in Washington. U.S. Geol. Survey Open-File Rept 74-336. 46 pp.

Duncan, S. H. 1986. Peak stream discharge during thirty years of sustained yield timber management in two fifth-order watersheds in Washington State. Northwest Science 60 (4): 258-264.

Donaldson, W. R. 1979. Washington climate for these counties - Grant, Kittitas, Klickitat, Yakima. Coop Extension Service, Wash State Univ. EM 4422.

Dunne, T., and L. B. **Leopold**. 1978. Water in environmental planning. San Francisco - W.H. Freeman and Co. 818 pp.

Grant, G. E., J. E. **Duval**, G. J. **Koerper**, and J. L. **Fogg**. 1992. XSPRO: A channel cross-section analyzer. BLM Gen. Tech. Rept. 387, 53 pp.

Harr, R. D. 1981. Some characteristics and consequences of snowmelt during rainfall in Western Oregon. Journal of Hydrology 53: 277-304.

__________. 1982. Fog drip in the Bull Run municipal watershed, Oregon. Water Resources Bulletin. v. 18.5.785-789.

__________. 1983. Potential for augmenting water yield through forest practices in western Washington and western Oregon. Water Resources Bulletin. v. 19.3.383-894.

__________. 1986. Effects of clearcutting on rain-on-snow runoff in western Oregon: A new look at old studies. Water Resources Research 22 (7): 1095-2000.

Harr, R. D., W. C. **Harper**, J. T. **Krygier**, and F. S. **Hsieh**. 1975. Changes in storm hygrographs after roadbuilding and clearcutting in the Oregon Coast Range. Water Resources Research 11 (3): 436-444.

Harr, R. D., R. L. **Fredriksen** and J. **Rothacher**. 1979. Changes in stream-flow following timber harvest in southwestern Oregon. USDA Forest Service Research Paper PNW-249, Pacific Northwest Forest and Range Experiment Station, Portland, Oregon, 22 pp.

Helvey, J. D. 1980. Effects of a north central Washington wildfire on runoff and sediment production. Water Resources Bulletin. v. 16.4.627-634.

Hibbert, A. R. 1983. Water yield improvement potential by vegetation management on western rangelands. Water Resources Bulletin. v. 19.3.375-382.

Hicks, B. J., R. L. **Beschta**, and R. D. **Harr**. 1991. Long-term changes in streamflow following logging in western Oregon and associated fisheries implications. Water Resources Bulletin 27 (2): 217-225.

Ingwersen, J. B. 1985. Fog drip, water yield, and timber harvesting in the Bull Run Municipal Watershed, Oregon. Water Resources Bulletin 21 (3): 469-473.

Kattelmann, R. C., N. H. **Berg**, and J. **Rector**. 1983. The potential for increasing streamflow from Sierra Nevada watersheds. Water Resource Bulletin. v. 19.3.395-402.

King, J. G. and L. C. **Tennyson**. 1984. Alteration of streamflow characteristics following road construction in north central Idaho. Water Resources Research 20 (8): pp. 231-243.

Leopold, L. B., M. G. **Wolman**, and J. P. **Miller**. 1964. Fluvial processes in geomorphology. Freeman, San Francisco.

Lisle, T. E. 1981. The recovery of aggraded stream channels at gauging stations in northern California and southern Oregon. In Erosion and sediment transport in Pacific Rim steep lands. p. 188-211. IAHS Publ. 132. Christchurch, New Zealand.

Lisle, T. E. 1989. Sediment transport and resulting deposition in spawning gravels, North coastal California. Water Resources Research 25(6):1303-1319.

Megahan, W. F. 1972. Subsurface flow interception by a logging road in the mountains of central Idaho. National Symposium on Watersheds in Transition. American Water Resources Association and Colorado State University. pp. 350-356.

Miller, J. F., R. H. **Frederick**, and R. J. **Tracey**. 1973. Precipitation-frequency atlas of the western United States; Volume IX - Washington. Nat'l Oceanic and Atmospheric Admin, NOAA Atlas 2, 43 pp.

Peterson, N. P., A. **Hendry**, and T. P. **Quinn**. 1992. Assessment of cumulative effects on salmonid habitat: Some suggested parameters and target conditions: Report prepared for the Washington Department of Natural Resources, Timber/Fish Wildlife. 74 pp.

Phillips, E. L.. 1964. Washington climate for these counties - Clark, Cowlitz, Lewis, Skamania, and Thurston. Coop Extension Service, Wash State Univ. EM 2462.

__________. 1965. Washington climate for these counties - Adams, Lincoln, Spokane, and Whitman. Coop Extension Service, Wash State Univ. EM 2545.

__________. 1966. Washington climate for these counties - Clallam, Jefferson, Island, San Juan, Skagit, Snohomish, Whatcom. Coop Extension Service, Wash State Univ. EM 2626.

__________. 1968. Washington climate for these counties - King, Kitsap, Mason, and Pierce. Coop Extension Service, Wash State Univ. EM 2734.

__________. 1970. Washington climate for these counties - Asotin, Benton, Franklin, Garfield, and Walla Walla. Coop Extension Service, Wash State Univ, EM 3127.

__________, and W. R. **Donaldson**. 1972. Washington climate for these counties - Clallam, Grays Harbor, Jefferson, Pacific, and Wahkiakum. Coop Extension Service, Wash State Univ. EM 3708.

__________, and D. C. **Durkee**. 1972. Washington climate for these counties - Ferry, Pend Oreille, and Stevens. Coop Extension Service, Wash State Univ. EM 3554.

__________, and C. **Ruscha**. 1975. Washington climate for these counties -Chelan, Douglas, Okanogan. Coop Extension Service, Wash State Univ. EM 3889.

Richards, K. 1982. Rivers -- Form and process in alluvial channels. Methuen and Co. N.Y.,N.Y.

Shearman, J. O. 1976. Computer applications for step-backwater and flood-way analyses. USDI Geological Survey, Open-File Rept. 76-499, 103 pp.

Swanson, R. H. and G. R. **Hillman**. 1977. Predicted increased water yield after clearcutting in west central Alberta. Northern Forest Research Centre. Edmonton, Alberta. Report NOR - x - 198. 40 pp.

Toth, S. E. 1991. An analysis of hydrologic cumulative effects in a large watershed in western Washington. M.S. thesis. University of Washington, Seattle.

Troendle, C. A. and C. F. **Leaf**. 1981. Effects of timber harvest in the snow zone on volume and timing of water yield. Ins Interior West Watershed Management Symposium, Spokane, Washington, April 8-10, 1980. Washington State University Cooperative Extension, Pullman, Washington. pp. 231-243.

Troendle, C. A. 1983. The potential for water yield augmentation from forest management in the Rocky Mountain region. Water Resources Bulletin. v. 19.3.359-374.

U.S. Army Corps of Engineers. 1956. Snow hydrology - summary report of the snow investigations. North Pacific Division, Portland, Oreg. 437 pp.

U.S. Geological Survey. 1992. Washington - Index to topographic and other map coverage [catalogue]. USGS National Mapping Program, 48 pp.

Williams, J. R., and H. E. **Pearson**. 1985a. Streamflow statistics and drainage-basin characteristics for the southwestern and eastern regions, Washington; volume I. Southwestern Washington. U.S. Geol Survey Open-File Rept 84-145-A. 424 pp.

__________. 1985b. Streamflow statistics and drainage-basin characteristics for the southwestern and eastern regions, Washington; volume II. Eastern Washington. U.S. Geol Survey Open-File Rept 84-145-B, 662 pp.

Williams, J. R., H. E. **Pearson**, and J. D. **Wilson**. 1985a. Streamflow statistics and drainage-basin characteristics for the Puget Sound region, Washington; volume I. Western and southern Puget Sound. U.S. Geol Survey Open-File Rept 84-144-A. 330 pp.

__________. 1985b. Streamflow statistics and drainage-basin characteristics for the Puget Sound region, Washington; volume II. Eastern Puget Sound from Seattle to the Canadian border. U. S. Geol Survey Open-File Rept 84-144-B. 420 pp.

Wolman, M. G. and J. P. **Miller**. 1960. Magnitude and frequency of forces in geomorphic processes. J. Geology 68(1): 54-74.

Form C-1 - Basin Acreage by Precipitation Zone and Land Use/Cover Type

Hydrologic Analysis Unit: ____________________________

	Lowland	Rain-dominated	Rain on Snow	Snow-dominated	Highland	Total
Hydrolog. Mature						
Intermediate Maturity						
Hydrolog. Immature						
Total Forested						
Non-Forested: Urban						
Non-Forested: Agriculture						
Non-Forested: Open Water						
Non-Forested: Other						
Total Non-Forested						
Total						

Form C-2 - Summary of Water Available for Runoff

Hydrologic Analysis Unit: ______________________________

Recurrence Interval	Storm Intensity	WAR [in]		
		Fully Forested	**Current Condition**	**Fully Stocked Young Forest**
2 years	Average			
2 years	Unusual			
5 years	Average			
5 years	Unusual			
10 years	Average			
10 years	Unusual			
25 years	Average			
25 years	Unusual			
50 years	Average			
50 years	Unusual			
100 years	Average			
100 years	Unusual			

Form C-3 - Summary of Peak Discharge Estimates.

Hydrologic Analysis Unit: ____________________________

Hydrologic Analysis Unit: ____________

	Discharge and % Increase for Given Recurrence Intervals									
	2-Year		5-Year		10-Year		25-Year		50-Year		100-Year	
	Disch.	%Incr	Disch.	%Incr	Disch.	%Incr	Disch.	%Incr	Disch	%Incr	Disch.	%Incr
USGS Eqn												
+1 Std. Err.												
Log Pearson Estimate												
+1 Std. Err.												
Fully Forested												
+ Avg. Storm												
+ Unus. Storm												
Current Condition												
+ Avg. Storm												
+ Unus. Storm												
FullyStocked/Young For												
+ Avg. Storm												
+ Unus. Storm												

APPENDIX D
Riparian Function Module

Table of Contents

Riparian Function Assessment:

Overview

Riparian function can be defined as the interaction of various hydrologic, geomorphic, and biotic processes across a range of spatial and temporal scales within the riparian environment. As a result, riparian function encompasses a wide variety of processes that determine the character of the riparian zone and exert an influence on the adjacent aquatic and terrestrial environment.

In the context of watershed analysis, riparian function is defined more narrowly, focusing on two specific processes: (1) the recruitment of large woody debris (LWD) to aquatic systems, and (2) the provision of shade to aquatic systems. This assessment is designed to evaluate riparian areas relative to their capability to supply (LWD) and shade to streams, lakes, and wetlands within the WAU. Both functions play an important role in maintaining the integrity of the aquatic ecosystem, and both can be significantly influenced by forest management.

Part 1 of the riparian assessment evaluates LWD recruitment potential in the near term (10-20 years) and in the long term (20-200+ years). Information about the potential for LWD recruitment is gathered in sufficient detail to characterize riparian condition at both site-specific and watershed-wide scales. As a result, prescription teams should have enough information to develop meaningful riparian prescriptions.

Part 2 evaluates current canopy closure relative to target levels established with the TFW temperature screens for western and eastern Washington. Where warranted, the analyst can expand the assessment by more extensive field measurements to refine their understanding of the temperature regime for the watershed. Both parts provide information useful in developing a monitoring program.

Part 1. Large Woody Debris Recruitment

Introduction

The riparian zone is commonly described as the transition zone between upland and aquatic zones (Oakley et al. 1985). The flow of sediment, water, wood, and energy into and out of the riparian zone is controlled by climatic, geologic, topographic, vegetative, and management-related factors. Forest practices may alter the routing of such elements directly through management within the riparian zone or indirectly through management of upland areas.

The riparian zone serves as the primary source area for large woody debris. Large woody debris, including tree boles, root wads, and large branches, has been recognized as an important structural component of stream systems (Harmon et al. 1986; Bisson et al. 1987). In the stream, large woody debris diverts and obstructs streamflow, thereby increasing channel complexity. The formation of pools and backwater eddies, both of which are important components of fish habitat, is strongly influenced by the presence of large, stable woody debris (Andrus et al. 1988; Robison and Beschta 1990a). Large woody debris plays an important role in stream nutrient dynamics by retaining fine organic matter such as needles and leaves (Sedell and Triska 1977; Bilby and Likens 1980), and it also provides cover from predators and refuge during high streamflows.

Large woody debris creates storage sites for inorganic sediment in both fish-bearing streams and non-fish-bearing streams. Sediment deposits upstream from debris accumulations in larger fish-bearing streams form spawning riffles and retain fine sediments (Bisson et al. 1987). In smaller headwater streams, large woody debris has been shown to be the primary factor in controlling the routing of sediment to downstream reaches (Megahan 1982; Potts and Anderson 1990; O'Conner and Harr 1994). Several studies have shown that the loss or removal of woody debris from stream channels can result in significant changes in channel morphology, a loss in sediment storage capacity, and an increase in the rate of sediment transport (Beschta 1979; Bilby 1984; Heede 1985). Bisson et al. (1987) suggest the primary benefit of the sediment storage capacity of woody debris is in buffering downstream reaches against rapid changes in sediment loading that could degrade spawning gravels, fill rearing pools, and reduce invertebrate populations.

Large woody debris is also structurally important in wetlands, lakes, and reservoirs. In these systems, accumulations of woody debris can provide a substrate for the development of macroinvertebrates that serve as a food supply for a variety of fishes. Submerged woody debris also provides a complex physical structure that fish of many different sizes can use for cover. The recruitment of large woody debris occurs by a variety of mechanisms including windthrow, bank undercutting, mass wasting, overstory mortality, and transport from upstream stream reaches. The relative importance of these processes vary within the stream network; in general, windthrow is a more significant factor along smaller streams while the importance of processes such as channel migration and bank undercutting increase with stream size (Keller and Swanson 1979).

There is relatively little information related to source distances for large woody debris in Northwest streams. In one study, McDade et al. (1990) found that approximately 80% of in-channel large woody debris pieces associated with 80+ year old conifer stands in western Washington and Oregon originated within 66 feet of the streambank and 90% originated from within 100 feet. In a separate study conducted in southeast Alaska, Murphy and Koski (1989) found that 95% of in-channel large woody debris pieces associated with old-growth conifer stands originated from within 66 feet of the streambank and 99% originated from within 100 feet. The difference in relative recruitment reflected by these studies indicates that LWD recruitment is a function of the height of native tree species.

Since European settlement of the Pacific Northwest, many land uses, including forest management, have altered the spatial and temporal patterns of large woody debris input in many stream systems. Large woody debris was regularly removed from many streams and rivers during the late 1800s and well into the 1900s to facilitate log transport; similarly, debris jams were removed from smaller streams during the 1940s and 1950s in an effort to “improve” fish passage (Sedell and Luchessa 1982).

Researchers began to understand the ecological importance of large woody debris in the 1970s. They concluded that riparian areas that regenerate to shade-intolerant, early-successional stage forest types such as red alder tend to produce debris that is shorter, smaller diameter, more easily broken, and less well anchored than coniferous debris (Bisson et al. 1987).

The purpose of this portion of the Riparian Function Module is to evaluate existing riparian forests based on their capability to provide a sustainable supply of large woody debris to streams, lakes, and wetlands. Methods for the remote assessment and field validation of existing riparian condition are provided. Guidelines for additional evaluation of the long-term recruitment potential are also given.

Methodology

The standard procedure evaluates current LWD recruitment potential by examining, by remote means, the type (hardwood or conifer), size, and density of riparian overstory vegetation. In-channel LWD levels provided by the channel and/or fish analysts and channel sensitivity ratings provided by the channel analysts are then used to establish the LWD recruitment hazard call. Additional information related to understory vegetation can be gathered to project long-term LWD recruitment conditions. Throughout the assessment, interaction with the channel and fish analysts is very important in order to accurately characterize riparian condition and provide answers to the critical questions.

Critical Questions

What information is available regarding the early character of the riparian zone relative to its ability to supply functional LWD?

What is the current condition of the riparian zone relative to its ability to supply functional LWD in the near term?

What are the dominant processes by which LWD is delivered to streams, lakes, and wetlands in the WAU?

What is the current condition of the riparian zone relative to its ability to supply LWD in the long term?

Assumptions

- Channel morphology is strongly influenced by LWD (Keller and Swanson 1979), particularly in low gradient, unconfined stream reaches (Montgomery and Buffington 1993).
- The majority of functional LWD is recruited from within a distance of 100 feet in western Washington and 75 feet in eastern Washington.
- In the absence of severe disturbance, the composition of a late-successional riparian forest is determined by the tree species mix that was present when the forest was established.
- Well-stocked riparian stands dominated by large conifers will provide adequate and sustainable supplies of LWD.
- Hardwood-dominated riparian stands are not capable of supplying sufficient long-term LWD inputs.

General Approach and Products

The first step in assessing riparian function is to describe what the riparian zones looked like in the past. The riparian analyst uses older aerial photographs or other anecdotal information to reconstruct the early character of riparian areas including the general distribution, type, size, and density of the riparian vegetation. Using this information, the analyst can identify areas that likely had naturally low LWD recruitment, as well as those areas where significant recruitment occurred. The analyst should include a discussion of early land use practices that may have influenced the structure and function of the riparian zone and associated stream channels. Practices such as log drives, splash damming, stream cleanout, salvaging wood from channels, or clearcut harvest of riparian areas that occurred within the WAU should be identified. Agricultural practices, urbanization, and conversion to other land uses may also have significantly altered the riparian areas.

Next, the analyst assesses the current condition of riparian vegetation using information obtained from recent aerial photographs. The assessment area focuses on those channels with less than 20% gradient, unless modified in consultation with the channel and fish analysts. The riparian zones of these channels are divided into unique units referred to as riparian condition units (RCUs). Each RCU is different from adjacent RCUs in its ability to supply functional LWD to the stream channel. The analyst uses aerial photos to evaluate the vegetation type, size, and density of each RCU. Validation of these preliminary photo calls is made by field checking a representative sample of those areas evaluated. Once final calls are made, the analyst generates a working base map (Map D-1: Riparian Vegetation Condition) which describes the current condition of the RCUs relative to their ability to supply LWD in the near term.

Individual RCUs are then classified according to one of three recruitment potential classes which describe the near-term potential for recruiting functional LWD. The recruitment potential classifications are then combined with channel sensitivity ratings and in-channel LWD ratings to assign LWD recruitment hazard calls by channel segment (Map D-2: Near-term LWD Recruitment Hazard). This approach relies not only on the LWD recruitment potential associated with the current riparian vegetation when assigning hazard calls, but also considers existing levels of in-channel LWD as well as the sensitivity of the channel to inputs of LWD.

The standard assessment describes both the past and current conditions of the riparian zone relative to its ability to supply functional LWD. Further assessment may focus on developing a picture of the long-term LWD recruitment situation. This assessment requires more detailed information regarding the species composition of both the understory and overstory riparian vegetation. As a result, the analyst must spend additional time gathering field data in order to predict forest succession. Products from this portion of the assessment include descriptions of how riparian areas are expected to develop over time and Map D-3: Long-Term LWD Recruitment Potential. The analyst should include a discussion of how silvicultural treatments or catastrophic disturbances (e.g., debris torrents, dam-break floods, or fire) might affect riparian forest development and thus, future LWD recruitment.

Confidence in Work Products

Completed watershed analyses have shown that an experienced photo interpreter can accurately determine the current condition of the riparian overstory using recent aerial photography. It is important for the analyst to calibrate his/her eye relative to the condition of the riparian vegetation as it appears on the photo. The analyst should therefore spend one or more days checking a representative sample of RCUs for agreement with photo calls. Field work may also be necessary to update those areas that have been altered substantially since the last photo flight due to logging, blowdown, debris torrents, or other disturbances.

Information related to in-channel LWD levels is another component of the assessment. Although the channel and/or fish analysts will be collecting in-channel LWD data, the riparian analyst can expand the sample size by collecting their own information.

The analyst’s confidence in the near-term assessment of LWD recruitment potential will be influenced by the quantity and quality of information related to both riparian vegetation condition and in-channel LWD levels. It is therefore important to spend as much time as possible field checking photo calls and assisting the channel and/or fish analysts in collecting in-channel LWD information.

Assessment of long-term LWD recruitment potential is dependent on the quality and extent of information related to riparian species composition. Here again, it is important that the analyst inventory a representative sample of riparian areas to increase the level of confidence in the assessment.

Qualifications and Skills

Skills for assessment of near-term recruitment:

- Ability to interpret vegetation type, size, and density from aerial photographs.
- Ability to use a map wheel.

Education and Training

- Associate’s degree in forestry or related field with four years related experience.

Experience

- At least two years of experience in aerial photo interpretation and field work.

Additional skills for long-term recruitment:

- Familiarity with forest inventory methods.
- An understanding of the processes of natural succession within riparian communities under a variety of conditions and how silvicultural practices or other disturbances may alter the successional pathway.

Startup Materials

Maps

- Official WAU base map (1:24,000 scale).
- Stream channel segment map (Map E-1) from channel assessment team.
- USGS 7.5 minute topographic quadrangle maps (1;24,000 scale).

Photographs

- Most recent aerial photographs (stereo pairs). The minimum scale is 1:12,000. Larger scale photographs are preferable, if available.

- Older aerial photographs (stereo pairs, if available) that will provide insight into early riparian conditions. The earliest, highest resolution photographs are preferable.

Other Materials

- Stand information (obtained from landowners) for uplands adjacent to riparian zones or from riparian zones specifically, if available. Note that timber stand data usually applies to uplands and may not be representative of the riparian zone.

- Riparian seral stage and vegetation type inventory data may be available from the TFW Ambient Monitoring Program. Contact Northwest Indian Fisheries Commission at (360) 438-1180.

- Aerial video of streams and riparian zones may be available. Check with landowners, Washington Department of Fish and Wildlife, and the U.S. Forest Service.

Analysis Procedure

Early Riparian Forest Composition

A number of resources may be available to allow the analyst to infer early riparian forest composition. Although the analyst could expend much effort pursuing detailed information, the main objective is to identify riparian areas that naturally supported either hardwood-dominated forests or non-forest vegetation that provided low levels of woody debris and/or shade. In western Washington, most natural non-conifer sites are associated with wet soil conditions resulting from poor soil drainage (including wetlands, beaver ponds and/or frequent flooding). An on-site evaluation will not be necessary for most riparian areas in the WAU, but should be reserved for those riparian areas where the potential for growing conifers is most uncertain.

The following resources have proven useful for watershed analyses and similar projects:

- Older aerial photos provide excellent documentation, especially early, high resolution photos. Although resolution of old photos varies, they are often adequate to determine forest type (conifer vs. hardwood) and tree size. Old photos may be available from landowners, county agencies and/ or libraries (including UW and WSU).

- Field inspection of remaining stumps can provide an on-site indication of species, tree sizes, and densities of preharvest stands. Large conifer stumps, especially Douglas-fir and western red cedar, are quite durable and can be recognizable for up to a century; hardwood stumps remain for several decades. In some cases, tree age can be inferred from stump size, thus providing insight into the frequency of disturbance processes during pre-settlement times. The absence of stumps may not always be definitive of a non-conifer site, due to the potential for other removal processes, such as intentional removal for agriculture or other development activities and various channel disturbances (e.g., channel migration, splash damming) that can remove or bury stumps.

- Descriptions of historical conditions may be available from survey notes, local histories, and recollections of long-time residents (Platts et al. 1987). In some cases, these sources can provide useful information on historic in-channel woody debris loading as well. It is important to evaluate the reliability of information from these sources, since much documentation focuses on exceptional rather than typical conditions. Survey notes are normally available from county agencies.

Near-Term LWD Recruitment
The following guidelines are designed to assist the analyst in evaluating the current condition of the riparian zones relative to their ability to supply functional large woody debris to streams, lakes, and wetlands in the near term:

Define Assessment Area

- The focus of this portion of the riparian assessment is on the function of LWD in stream channels; therefore, the assessment area is based on those channels dominated by fluvial processes. The assessment of LWD recruitment focuses on that portion of the stream network with gradients less than 20%. Deviations from the 20% criterion can be made in consultation with the channel and fish analysts. Prepare an overlay map from the channel map (E-1) that encompasses those channel segments less than 20% gradient. Label this Map D-1: Riparian Vegetation Condition. This will serve as the working base map.

- Determine the width of the riparian evaluation zone on each side of waters on the working base map from above. For western Washington, use an evaluation width of 100 feet horizontal distance; for eastern Washington, use 75 feet horizontal distance. Convert this distance based on the scale of the photos (e.g., 100 feet equals 0.1 inch on a 1:12,000 scale photo). Evaluation width may be modified as necessary for specific site conditions as justified by the analyst. It should be noted that the evaluation width is for assessment purposes only and prescriptions relating to LWD recruitment will be based on the casual mechanism report(s), not assessment width.

Define Riparian Condition Units (RCUs)

- Once the assessment area has been defined, divide the riparian zones into riparian condition units, or RCUs. Each RCU is unique in that it differs from adjacent RCUs in the type, size, and/or density of riparian vegetation. This means that riparian areas on opposite sides of the stream are treated as separate RCUs. The length of each RCU should be a minimum of 2,000 feet (1 inch on 1:24,000 scale overlay map), unless the conditions of smaller areas can be discerned or are warranted (e.g., where the first 1,000 feet contains old-growth conifer and the next 1,000 feet is a recent clearcut). Delineate the boundaries of RCUs using short lines drawn perpendicular to the stream as shown in Figure D-1.

- In addition to defining the standard RCUs described above, work with the channel analyst to delineate channel migration zones or CMZs. The channel migration zone, for the purpose of this module, is defined as the area that streams have recently occupied (in the last few years or less often decades), and would reasonably be expected to occupy again in the near future.

The primary mechanism for channel avulsion or "channel hopping" is the formation of woody debris jams and/or gravel bars during larger floods. If one streambank is substantially higher, then the CMZ is probably associated with the elevation of the lower streambank. A combination of topographic maps, aerial photographs, soil maps, vegetation surveys, and field work can be used to delineate the CMZ. Field evidence that can be used to help define the CMZ includes unvegetated or sparsely vegetated side channels, wetlands, and signs of recent flooding such as wood debris suspended in branches or deposited outside the ordinary high water mark and large amounts of sediment deposition. The zone may have a significant shrub (e.g., vine maple, salmonberry) and/or hardwood (e.g., cottonwood, red alder, big-leaf maple) component, but few conifers. The water table is often near the surface and abandoned or active side channels are abundant.

Because CMZs are areas where the potential for channel migration is relatively high, it is important to assess these areas for their ability to supply functional LWD in the near term. As a result, they will be assessed in the same manner as RCUs and will be bounded by RCUs along their outer margins (Figure D-2).

The riparian analyst should consult with the channel analyst to identify CMZs using a combination of aerial photos and topographic maps. The CMZs that are of interest for this assessment are those where field exam clearly shows they have been migrating in the recent past. Record the preliminary CMZs on Map D-1. The channel analyst can modify the CMZ boundaries if necessary during the field visit. Once the boundaries of all CMZs are finalized, record them on Map D-1.

- Classify the riparian vegetation type (Table D-1), size (Table D-2), and density (Table D-3) for each RCU and CMZ.

Record the riparian condition codes on the map using the following system:

(CMD), where:

C=Vegetation type (Conifer or Hardwood)
M=Tree size (Small, Medium or Large)
D=Stand density (Dense or Sparse)

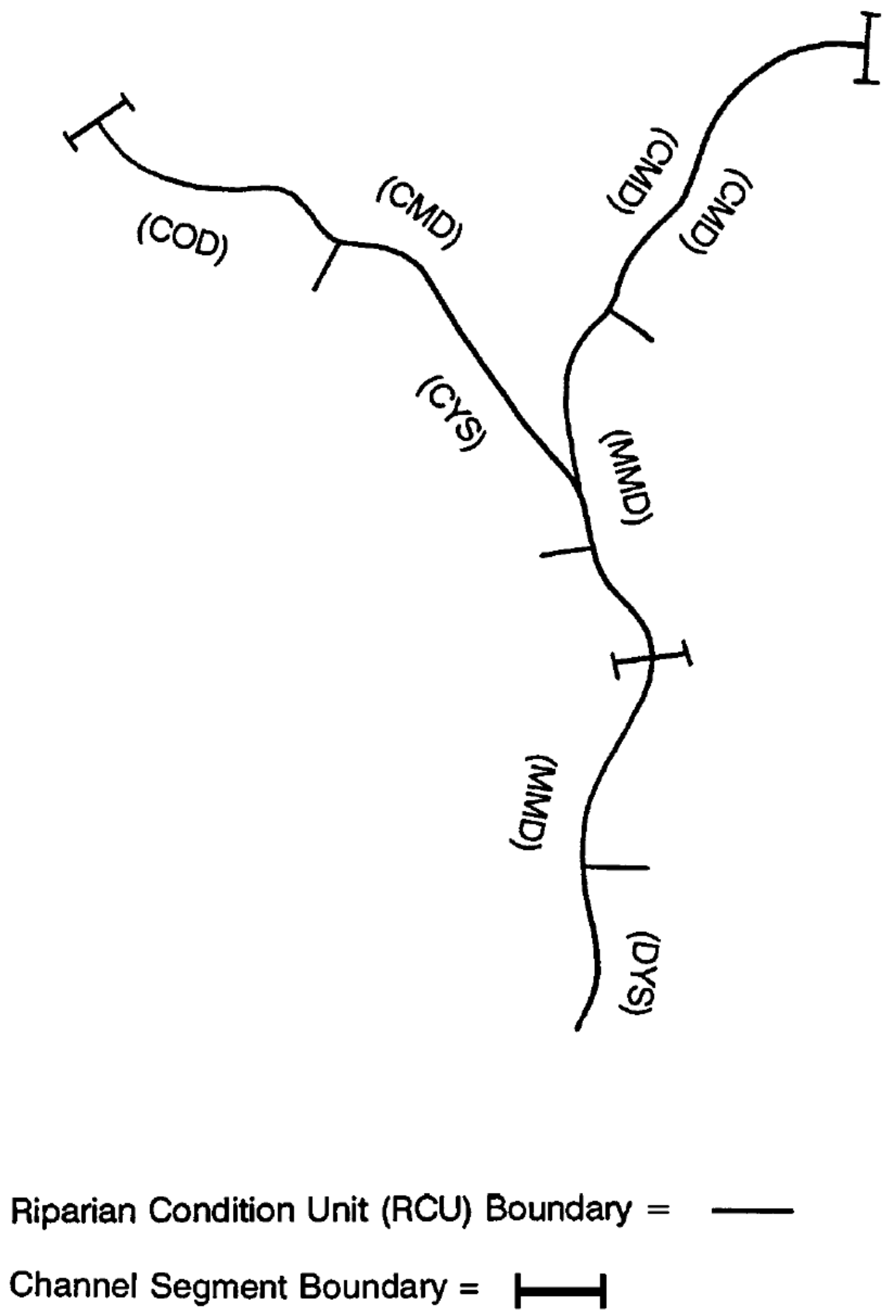


Figure D-1: Example of Map D-1: Riparian Vegetation Condition

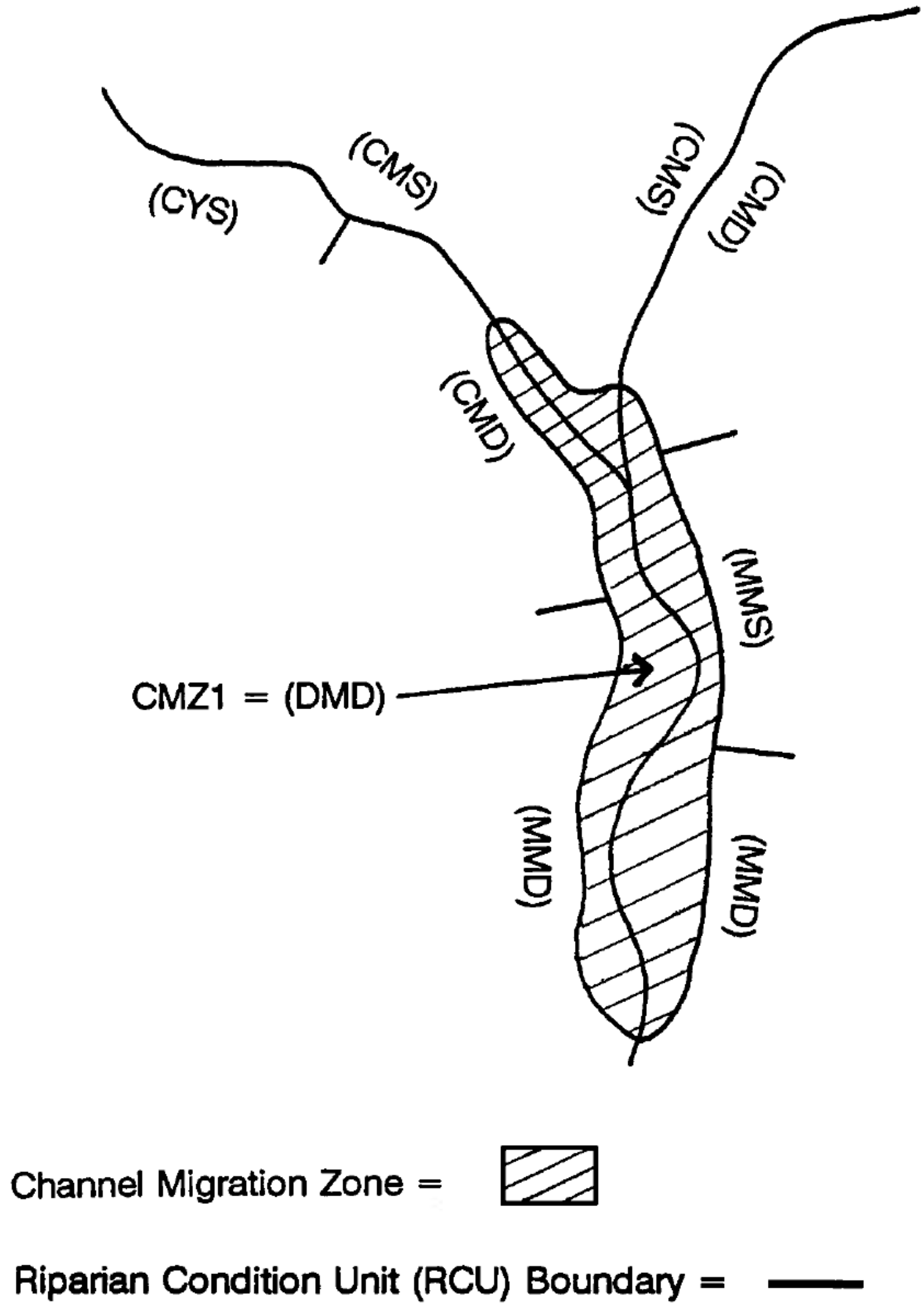


Figure D-2: Example of Map D-1 with Channel Migration Zone

Table D-1: Dominant Vegetation Types

>= 70% Coniferous Species	Conifer Dominated
>= 70% Hardwood Species	Hardwood Dominated
All Other Cases	Mixed

Table D-2: Average Tree Size Classes[1]

Small	<12 inches DBH
Medium	>=12 and < 20 inches DBH
Large	>=20 inches DBH

[1]Under certain circumstances, age may be a reliable indicator of tree diameter; if this is the case, the analyst may obtain forest age class data from landowners and use the information to correlate age and diameter.

Table D-3: Stand Density Classes

Western WA	Density is sparse if more than 1/3 of the ground is exposed. Otherwise, it is dense.
Eastern WA	Density is sparse if more than 1/2 of the ground is exposed. Otherwise, it is dense.

For example, a riparian zone dominated by conifers of medium size and dense spacing would be coded as (CMD). Record the riparian condition codes on the overlay map (Map D-1) and place them off to the side of each RCU and CMZ (Figure D-2).

In some instances, the analyst may discover riparian areas where soil conditions have limited vegetation growth needed to supply LWD. These include talus slopes, bedrock outcrops, wetlands, beaver ponds, and annual floodplains. These areas may be distinguished from those impacted by land use activities by use of historic aerial photos to establish baseline conditions. Other situations unrelated to forest management include road and/or powerline rights-of-way where vegetation is cleared on a regular basis. All of these conditions should be noted and recorded on Worksheet D-2 and Map D-2: Near-Term LWD Recruitment Hazard.

The accuracy of this method is dependent on the analyst's ability to interpret riparian conditions from aerial photography. Confidence in the assessment can be increased by performing field checks of the preliminary photo estimates of riparian conditions. Survey RCUs that represent a range of riparian conditions found in the WAU (i.e., combinations of tree type, size, and density). An easy way to perform the field checks is to transfer the riparian condition code for each RCU and CMZ to a mylar overlay attached to the most recent aerial photograph of the area. This way, photographs can be taken to the field and corrections or comments can be made on the mylar overlay. The analyst should be sure to keep a record of where field checks were made for later evaluation of confidence in the assessment.

Field checks can be expanded by asking members of the fish and channel assessment teams to note riparian conditions while performing their own field work. Provide each assessment team with a smaller scale version of Map D-1 or a marked photocopy of an aerial photo that they can take to the field to record their observations.

- Finalize the riparian condition codes on Map D-1: Riparian Vegetation Condition by making any necessary corrections or adjustments based on the information gained via field checks. Including the RCU and CMZ boundaries and corresponding riparian condition codes will finalize Map D-1.

Tally Information By Channel Segment
Once the riparian condition base map has been finalized, summarize the information by channel segment. By now, the channel assessment team has developed Map E-1: Channel Segment Map (preliminary or field-verified final). Use Map E-1 to transfer channel segment boundaries to the riparian condition base map (Map D-1) or to another overlay.

- With a map wheel, measure the length of each RCU in a given channel segment and record this information on Worksheet D-1. (Partitioning RCU information by channel segment is necessary because LWD recruitment hazard calls will be based on channel segment, not by RCU.)

In some cases, a single channel segment may include several RCUs. When this happens, maintain the channel numbering system established by the channel analyst by dividing the segment into sub-segments. For example, channel segment 37 may contain three RCUs which can be numbered as 37a, 37b, and 37c. By doing this, cross-referencing between RCUs and channel segments is made much easier.

The map wheel measurements will be in centimeters or inches, depending on the type of instrument. At this point it is not necessary to convert the raw data (unit lengths) into kilometers or miles. (This will be done later when the data is summarized for the assessment report.)

- Sum the lengths recorded for each channel segment to obtain a total stream length by channel segment (Worksheet D-1). This number should actually be twice the channel segment length because the riparian zone has been measured on both sides of the stream. Continue completing the worksheet for assessed channels in the WAU.

The next step is to classify each riparian vegetation condition according to its LWD recruitment potential. The recruitment potential rating describes the likelihood that the riparian zone will provide functional LWD to the stream in the near term (e.g., a conifer-dominated riparian zone that contains medium-sized trees and is densely stocked (CMD), will have a HIGH likelihood of providing functional LWD to the stream in the near term).

- Assign a recruitment potential rating to each channel segment based on the segment's riparian condition code and record this information on Worksheet D-2. (See Table D-4.)

Table D-4: Recruitment Potential Ratings

Low	HSS, HSD, MSS, MSD, CSS, CSD, HMS, HLS
Moderate	HMD, MSS, CMS, CLS, HLD, MLS
High	CMD, MMD, MLD, CLD

Incorporate Channel Sensitivity, In-channel LWD Information

The recruitment potential rating is one of three elements used to establish the LWD recruitment hazard call. The other two include (1) the sensitivity of the channel to inputs of LWD and (2) the existing level of LWD in the channel.

Channel Sensitivity Rating—As part of the channel assessment, each geomorphic unit (a group of geomorphically similar channel segments) will be assigned a sensitivity rating for each of five input factors: water (peak flows), coarse sediment, fine sediment, temperature, and LWD. The sensitivity to LWD characterizes the degree to which LWD influences channel form and fluvial processes. LWD tends to function differently in low gradient, unconfined stream reaches as compared to high gradient, confined channels. In general, the capability of LWD to influence flow and channel complexity increases as channel gradient and confinement decrease. Therefore, the sensitivity of a particular channel segment to inputs of LWD is considered when assigning a recruitment hazard. Obtain the LWD channel sensitivity ratings for each channel segment from the channel analyst and record this information on Worksheet D-2.

In-channel LWD Rating—Prior to field checking the riparian condition photo calls, work with the channel and fish analysts to identify channel segments to be inventoried for in-channel LWD. Those channel segments included in the inventory should be representative of the various geomorphic units found within the WAU. Although the channel and/or fish analysts will be collecting most of the in-channel LWD data, the riparian analyst can expand the number of channel segments inventoried by collecting his/her own information. Be sure to work with the channel and fish analysts to establish a standard inventory methodology so that the data is comparable regardless of who collects the information. This may include characteristics such as minimum piece size, influence zone (Robison and Beschta 1990b), and wood type (hardwood or conifer). If a decision is made to inventory LWD, it may be easiest for the analyst to do this in conjunction with field checks of riparian vegetation condition.

The channel and/or fish teams will determine target LWD loadings for channel segments in the WAU. Use this information to determine if existing levels of in-channel LWD meet these target levels (i.e., ON or OFF target) and record this information on Worksheet D-2.

Establish Near-term LWD Recruitment Hazard Calls
Using the matrix illustrated in Table D-5, determine the near-term LWD recruitment hazard call for each channel segment using (1) the LWD recruitment potential rating (Low, Moderate, or High); (2) the channel sensitivity rating (Low, Moderate, or High); and (3) the in-channel LWD rating (On/Off Target) from Worksheet D-2. Record the hazard call for each channel segment (Low, Moderate, or High) on Worksheet D-2.

Transfer the LWD recruitment hazard calls to Map D-2: Near-term LWD Recruitment Hazard using the labeling system described in Table D-6. Remember, each channel segment receives a hazard call so each side of the stream should be coded. Be sure to include areas that are naturally low in LWD recruitment or low due to non-forest land uses such as residential development or agriculture.

Table D-5: LWD Recruitment Hazard Call Channel Sensitivity Rating

Recruitment Potential Rating	LWD On / LWD Off	Low	Mod	High
Low	LWD On	Low	Mod	High
	LWD Off	Low	High	High
Mod	LWD On	Low	Mod	Mod
	LWD Off	Low	High	High
High	LWD On	Low	Mod	Mod
	LWD Off	Low	High	High

Table D-6: Map Labeling Guidelines for LWD Recruitment Potential

Solid Red Line	High Hazard
Solid Blue Line	Moderate Hazard
Solid Green Line	Low Hazard
Solid Black Line	Naturally Low Recruitment
Dotted Black Line	Non-forest Land Use Low Recruitment

Long-Term LWD Recruitment

At this stage in the riparian assessment, there should be a reasonable understanding of the current condition of the riparian zones relative to their ability to supply LWD in the near term. Also, the general distribution of in-channel LWD and the adequacy of in-channel LWD levels have been identified. All this information has been gained through the standard assessment of near-term LWD recruitment potential.

The riparian assessment may be continued by estimating the long-term LWD recruitment potential. This will require a more detailed examination of the age, size, species composition, and density of riparian vegetation. In contrast to the standard assessment which relies on the interpretation of riparian vegetation conditions from aerial photos, the assessment of long-term LWD recruitment is a field-level analysis where both overstory and understory riparian vegetation is inventoried. One use of the long-term assessment information would be to provide managers with information that may be used to guide voluntary active management where the landowner wishes to implement riparian restoration and/or enhancement. This assessment does not result in any hazard calls, but a map is produced showing what the dominant vegetation in the long-term riparian forest will likely be in the absence of disturbance.

There is no sampling protocol for this portion of the assessment. As a result, the analyst must be familiar with standard forest inventory methods and should be able to devise his/her own sampling scheme. In western Washington, the field inventory data will be used in conjunction with the successional charts illustrated in Figure D-3 to predict future riparian vegetation condition, and as a result, LWD recruitment potential. Riparian forest succession is strongly influenced by the composition of the early successional forest. The relative proportions of shade-tolerant to shade-intolerant species within a given stand may strongly influence the composition of the future forest. An underlying assumption associated with these charts is that outside influences such as wind, fire, disease, or logging will not disrupt the successional pathway.

Unless there has been severe disturbance, the tree species mix found in a late-successional riparian forest is likely to be determined by the tree species mix present when the forest was established. The successional charts (Figure D-3) illustrate this for different forest types in western Washington. To use these charts, field observations must be made of the relative proportions of shade-tolerant to shade-intolerant species within each RCU. For example, if shade-intolerant species such as red alder or big-leaf maple comprise 80% of the stems within a given RCU while the remaining 20% consists of shade-tolerant species such as western red cedar, the analyst is able to estimate that the stand will likely persist as a hardwood/conifer mix until it reaches 100 years of age when the hardwood species begin to die off and give way to conifers. Eventually (140+ years), the stand will become conifer dominated even though the early stage successional forest contained only 20% conifer.

Based on predictions of late-successional stage riparian forest conditions, create Map D-3: Long-term LWD Recruitment Potential. Label the segments as hardwood dominated, mixed stand, or conifer dominated. Also include areas that are naturally low in LWD recruitment or low due to non-forest land uses such as residential development or agriculture.

1. STARTING POINT = Pure Hardwood

Height Above Ground (ft)	Column A < 40 years	Column B 40-70 years	Column C 70-100 years	Column D 100-140 years	Column E 140-200 years	Column F 200-250 years
200+						
150-200						
100-150				Occasional Hardwood	Occasional Hardwood	
50-100	Hardwood	Hardwood	Hardwood	Less	Occasional Hardwood	
15-50	Hardwood	Vine Maple	Vine Maple	Vine Maple	Vine Maple	Vine Maple
6-15 (all shrub)	Hardwood Vine Maple Devil's Club	Vine Maple Devil's Club	Vine Maple Devil's Club	Vine Maple Devil's Club	Vine Maple Devil's Club	Vine Maple Devil's Club
3-6 (small shrub)	Salmonberry Thimbleberry	Salmonberry Thimbleberry	Salmonberry Thimbleberry	Salmonberry Thimbleberry	Salmonberry Thimbleberry	Salmonberry Thimbleberry
<3 (ground cover)	Grasses, Sedges, Forbes	Sedges, Forbes	Forbes	Less	Less	Less

2. STARTING POINT = Hardwood + Shade Intolerant Species (Douglas-fir)

Height Above Ground (ft)	Column A < 40 years	Column B 40-70 years	Column C 70-100 years	Column D 100-140 years	Column E 140-200 years	Column F 200-250 years
200+					Douglas-fir	Douglas-fir
150-200				Douglas-fir	Douglas-fir	Douglas-fir
100-150		Douglas-fir	Douglas-fir	Douglas-fir	Douglas-fir	Shade Tolerant Species
50-100	Douglas-fir Hardwood	Douglas-fir Hardwood	Douglas-fir Hardwood	Hardwood	Shade Tolerant Species	Shade Tolerant Species
15-50	Vine Maple Hardwood Douglas-fir	Hardwood Vine Maple	Vine Maple		Shade Tolerant Species	Shade Tolerant Species
6-15 (all shrub)	Vine Maple Devil's Club	Vine Maple Devil's Club	Vine Maple Devil's Club	Less Vine Maple LessDevil's Club STS	Shade Tolerant Species	Shade Tolerant Species
3-6 (small shrub)	Salmonberry Thimbleberry	Salmonberry Thimbleberry	Less Salmonberry LessThimbleberry STS	Less Salmonberry LessThimbleberry STS	Shade Tolerant Species	Shade Tolerant Species
<3 (ground cover)	Grasses, Sedges, Forbes	Grasses, Sedges, Forbes	Grasses, Sedges, Forbes STS	Forbs, Ferns, STS	Shade Tolerant Species	Shade Tolerant Species

Figure D-3: Forest Successional Pathways, Western Washington

3. STARTING POINT = 50% Hardwood, 50% Shade Tolerant Species (STS)

Height Above Ground (ft)	Column A < 40 years	Column B 40-70 years	Column C 70-100 years	Column D 100-140 years	Column E 140-200 years	Column F 200-250 years
200+						Shade Tolerant Species
150-200				Shade Tolerant Species	Shade Tolerant Species	Shade Tolerant Species
100-150		Shade Tolerant Species	STS Hardwood	Hardwood		
50-100	STS Hardwood	Hardwood STS	Hardwood STS			Shade Tolerant Species
15-50	STS Hardwood	Hardwood	Less		Shade Tolerant Species	
6-15 (all shrub)	Vine Maple Devil's Club	Vine Maple Devil's Club	Vine Maple Devil's Club STS	Shade Tolerant Species		Shade Tolerant Species
3-6 (small shrub)	Salmonberry Thimbleberry	Salmonberry Thimbleberry	Salmonberry Thimbleberry	Less	Less Shade Tolerant Species	Less
<3 (ground cover)	Grasses, Sedges, Forbes	Grasses, Sedges, Forbes	Forbes	Forbs, Shade Tolerant Species	Forbs	Less

4. STARTING POINT = Hardwood with a few Shade Tolerant Species

Height Above Ground (ft)	Column A < 40 years	Column B 40-70 years	Column C 70-100 years	Column D 100-140 years	Column E 140-200 years	Column F 200-250 years
200+						Shade Tolerant Species
150-200					Shade Tolerant Species	Shade Tolerant Species
100-150				Shade Tolerant Species	Shade Tolerant Species	Shade Tolerant Species
50-100	Hardwood	Hardwood STS	Hardwood STS	STS Hardwood	Shade Tolerant Species	Shade Tolerant Species
15-50	Hardwood STS	Vine Maple	Vine Maple	Vine Maple	Vine Maple	STS Vine Maple
6-15 (all shrub)	Devil's Club Vine Maple STS	Devil's Club Vine Maple STS	Devil's Club Vine Maple STS	Devil's Club Vine Maple STS	Devil's Club Vine Maple STS	Devil's Club Vine Maple STS
3-6 (small shrub)	Salmonberry Thimbleberry	Salmonberry Thimbleberry	Salmonberry Thimbleberry	Salmonberry Thimbleberry STS	Salmonberry Thimbleberry STS	Salmonberry Thimbleberry STS
<3 (ground cover)	Grasses, Sedges, Forbs	Grasses, Sedges, Forbs	Grasses, Sedges, Forbs, STS	Grasses, Sedges, Forbs, STS	Grasses, Sedges, Forbs, STS	Grasses, Sedges, Forbs, STS

Figure D-3: Forest Successional Pathways, Western Washington (Continued)

5. STARTING POINT = Shade Intolerant Species, fully stocked

Height Above Ground (ft)	Column A < 40 years	Column B 40-70 years	Column C 70-100 years	Column D 100-140 years	Column E 140-200 years	Column F 200-250 years
200+					Douglas-fir	Douglas-fir
150-200				Douglas-fir	Douglas-fir	Douglas-fir
100-150		Douglas-fir	Douglas-fir	Douglas-fir		
50-100	Douglas-fir	Douglas-fir	Douglas-fir	Douglas-fir		Shade Tolerant Species
15-50	Douglas-fir	Douglas-fir	Douglas-fir Vine Maple		Shade Tolerant Species	Shade Tolerant Species
6-15 (all shrub)	Vine Maple Devil's Club	Less	Less	Less STS	Shade Tolerant Species	Shade Tolerant Species
3-6 (small shrub)	Salmonberry Thimbleberry	Less	LessSalmonberry LessThimbleberry Huckleberry	Huckleberry STS	Shade Tolerant Species	Shade Tolerant Species
<3 (ground cover)	Grasses, Sedges, Forbs	Less Grasses, Less Sedges, More Forbs	Forbs, STS	Forbs, Ferns, STS	STS, Forbs, Ferns	Shade Tolerant Species

6. STARTING POINT = Shade Tolerant Species (STS), fully stocked

Height Above Ground (ft)	Column A < 40 years	Column B 40-70 years	Column C 70-100 years	Column D 100-140 years	Column E 140-200 years	Column F 200-250 years
200+						Shade Tolerant Species
150-200				Shade Tolerant Species	Shade Tolerant Species	Shade Tolerant Species
100-150			Shade Tolerant Species	Shade Tolerant Species	Shade Tolerant Species	Less
50-100	Shade Tolerant Species	Shade Tolerant Species	Shade Tolerant Species	Less		
15-50	Shade Tolerant Species	Shade Tolerant Species	Less			
6-15 (all shrub)	Vine Maple STS	Vine Maple	Less	Less		Shade Tolerant Species
3-6 (small shrub)	Vine Maple Salmonberry	Less	Less	Less	Shade Tolerant Species	Shade Tolerant Species
<3 (ground cover)	Grasses, Sedges, Forbs	Less	Less	Shade Tolerant Species	Shade Tolerant Species	Shade Tolerant Species

Figure D-3: Forest Successional Pathways, Western Washington (Continued)

Riparian LWD Recruitment Assessment Report

The assessment report is intended to convey the riparian analyst's results to other members of the assessment team, to the prescription team, and to those who may be interested in a concise, written description of the analysis. It should describe the results of the analysis and any conclusions reached relative to the critical questions. The assessment report should include the following:

- Documentation of all information used in the assessment of both the early and current conditions of the riparian zones in the WAU. This includes aerial photos, maps, anecdotal information, timber stand inventory data, aerial flights made, and any other information used to characterize riparian conditions.

- A discussion of early land use practices that may explain the current condition of the riparian zone. Areas that were historically hardwood-dominated such as river or large stream floodplains, and areas that were historically low in LWD recruitment such as wetlands, beaver ponds, rock outcrops, etc. should be identified where possible. Land use practices may include splash damming, log jam removal, stream "cleaning", harvest of riparian vegetation, large scale disturbances such as debris flows or dam-break floods, conversion from forest land, agricultural practices, or development.

- A summary of the riparian vegetation conditions, in-channel LWD levels, and hazard calls for the WAU. The information should be presented in tabular format so the reader can quickly assess the current riparian condition relative to LWD recruitment. The summaries should provide answers to questions such as, "What percent of the WAU's riparian zones are in a CMD timber condition?", and "What percent of the assessed riparian zones received HIGH hazard calls?"

- A description of any deviations from the standard methods and why the changes were necessary.

- A description of the sampling methodology used in the long-term assessment of LWD recruitment potential (if this assessment was performed). A discussion of the analyst's confidence in the work products. Consider factors such as skill level, variability of riparian conditions, extent of field-checking photo calls, accessibility of the WAU, quality of aerial photos used, quality and quantity of additional information and any additions or deviations from the standard methods.

- Answers to the **critical questions** presented at the beginning of the section. While it is not necessary to include this as a separate section, be sure that the critical questions are addressed somewhere in the body of the report.

Maps

- D-1: Riparian Vegetation Condition (including Water Types)
- D-2: Near-term LWD Recruitment Hazard Calls
- D-3: Long-term LWD Recruitment Potential (if additional analysis was performed)

Summary Data

- Worksheet D-1, Stream Length by Riparian Vegetation Condition
- Worksheet D-2, LWD Recruitment Hazard Call by Channel Segment
- Any additional worksheets or field data used in the analysis

An important reminder: The steps outlined in this module are meant to provide guidance to the analyst and aid in answering the critical questions as thoroughly and efficiently as possible. The evidence obtained through these steps should lead to and satisfactorily support answers to the critical questions. However, each WAU will present its own interpretive challenges and the analyst is encouraged to do what is necessary to focus on the critical questions, not merely the step-by-step instructions. Where deviations from these methods are made, the analyst is expected to supply supporting rationale and documentation.

Part 2. Canopy Closure/Stream Temperature

Introduction

Timber harvest within riparian zones can have a significant effect on canopy closure, which affects stream temperature. Canopy cover is an important factor governing stream heating and cooling. Fish require relatively cool, stable stream temperatures.

The purpose of this assessment is to evaluate the current degree of the canopy closure on fish-bearing and selected non-fish-bearing streams in the WAU. The standard assessment procedure relies on topographic maps and the TFW temperature screen (Sullivan et al. 1990) to identify the approximate minimum shading values needed to meet state water quality criteria for maximum stream temperatures. By analyzing aerial photographs and making field checks, this method estimates whether current conditions meet target shade values. More detailed procedures to determine current conditions and boost confidence in the results of the standard assessment may be needed. If the TFW temperature screen is not sufficient because of unusual conditions, additional analysis may justify the use of a temperature prediction model.

Critical Questions

What was the early condition of the riparian zone relative to its ability to provide shade?

What is the current condition of the riparian zone relative to its ability to provide shade necessary to maintain desirable summer stream temperatures?

Assumptions

- Forest practices may influence stream temperature regimes directly by reducing riparian shade through harvest or indirectly through mass wasting processes.

  (Unless otherwise noted, the following assumptions are based on information obtained from the TFW temperature report (Sullivan et al. 1990).

- Stream temperature can both warm up and cool down along its course due to the amount of shade provided by riparian vegetation.
- By the time a free-flowing stream has traveled 1000 feet (300 meters) or more under relatively uniform canopy closure, water temperatures will be in equilibrium with local environmental conditions.
- Non-fish-bearing Type 4 tributaries contributing 20% of the flow to a fish-bearing Type 1-3 waters will significantly influence water temperature (Caldwell, Doughty, and Sullivan 1991).
- At elevations above 3,600 feet (1,100 meters) in western Washington and 4,450 feet (1,370 meters) in eastern Washington, environmental conditions are such that streams are not likely to exceed water quality standards for maximum temperature.
- The target shade requirements differ depending on whether the stream of interest is rated by the DOE as Class A, AA, or B.
- Riparian shade is unlikely to have a significant influence on stream temperatures where the natural low flow wetted stream width exceeds 100 feet (33 meters).
- When riparian shade levels are below target levels, maximum water temperature standards may be exceeded.

General Approach and Products

In this part of the riparian assessment, the analyst again uses aerial photos to assess the level of canopy closure on all fish-bearing and selected non-fish-bearing waters in the basin. Some field work is involved in ground truthing interpretations from the standard assessment. Additional field work is required to complete more detailed, non-standard assessments. Stream temperature data or stream temperature models should be considered to complement canopy closure estimates where such information is available. As with LWD recruitment, some locations may be shade-limited due to natural conditions. These special situations are identified during the assessment.

Confidence in Work Products

The most reliable results will be achieved when the analyst has validated the remote assessment abilities through ground-truthing shade estimates with a densiometer. The analyst's confidence in their ability to answer the critical question with the methods used should be evaluated.

Qualifications

Same as for LWD Recruitment, in addition to:

- Ability to estimate canopy closure from aerial photographs

For additional analysis, it is recommended the analyst have experience using stream temperature monitoring equipment, and experience using the TFW temperature model or similar models.

Startup Materials

Maps and Photographs

- Use the base map from the LWD assessment to define the assessment area.
- Use the same photographs that were used in the LWD assessment.
- Use the forest practices temperature standards map. (Contact DNR or DOE.)

Field Data

- Average canopy closure estimates for selected riparian areas (obtained using a densiometer). Check with the TFW Ambient Monitoring Program, Northwest Indian Fisheries Commission (360) 438-1180, for existing data.

Analysis Procedure

Standard Analysis

- To evaluate the degree to which fish-bearing waters and selected non-fish-bearing waters of the WAU are adequately shaded, follow these general guidelines:

Define Assessment Area

Prepare an overlay map labeled Map D-4: Stream Type Overlay for Target Shade (mylar or other material). Mark the boundaries of the Class AA, A, and B target shade zones illustrated in the forest practices temperature standards map. The assessment area will encompass Type 1-3 waters and selected Type 4 waters. Use the following criteria to delineate the stream network to be assessed:

- Include all streams that contribute at least 20% of the flow to a Type 1-3 water. This 20% criterion can be estimated by evaluating either: (a) the proportion of lineal stream length of the mainstem and all tributaries upstream from the Type 4 confluence (determined with a map wheel); or (b) the proportion of total basin area above the confluence contributed by the Type 4 tributary (determined with a planimeter).

- Do not include Type 4 waters above 3,600 feet in elevation for western Washington or 4,450 feet in elevation for eastern Washington.

- Do not include any water bodies with a low flow width greater than 100 feet. Include streams that have been widened due to mass wasting events (consult with Mass Wasting Analyst).

- Do not include Class B streams as defined on the forest practices temperature standards map. A temperature study of small (i.e., Type 4) streams showed that where harvesting within riparian zones had occurred, logging debris and understory brush provided substantial shade to maintain water temperatures below state water quality standards (Caldwell et al. 1991). These streams often occur at higher elevations and were easily shaded with residual streamside vegetation. Therefore, Type 4 waters not typically vulnerable to temperature increases are not included in the assessment.

Determine Target Shade Levels

Use Tables D-7 and D-8 to identify target shade values for sections of Class AA and A streams (1,000 feet minimum length), then mark the boundaries on the base map. Note that the eastern Washington target values presented in Table D-8 are applicable to a geographic area different from the standard TFW minimum shade guidelines (Figure D-4). Also note that in some stream segments, state water quality classifications may conflict with predicted AA and A zones because riparian shade is naturally unlikely to maintain stream temperatures within Class AA standards in streams greater than 13 miles (21 km) from the WAU divide. Record the target shade value next to the boundary (Figure D-5).

Table D-7: Riparian target shade (canopy closure) values for non-glacial streams in western Washington.

Minimum Shade Category (%)	Elevation Zones (feet)	
	Class AA DOE Standard -16°	Class A DOE Standard -18°
<10	>3600	>2320
10	3280-3600	1960-2320
20	2960-3280	1640-1960
30	2400-2960	1320-1640
40	1960-2400	1000-1320
50	1640-1960	680-1000
60	1160-1640	440-680
70	680-1160	120-440
80	320-680	<120
90	<320	N/A
(**Note** that glacier fed streams tend to be naturally cooler than other forested streams for some distance downstream of their sources; these and other anomalous basin conditions may warrant special consideration.)		

Table D-8: Riparian target shade (canopy closure) values for non-glacial streams in eastern Washington.

Minimum Shade Category (%)	Elevation Zones (feet)	
	Class AA DOE Standard -16°	Class A DOE Standard -18°
<10	>4450	>3900
10	4200-4450	3700-3900
20	4000-4200	3450-3700
30	3800-4000	3250-3450
40	3600-3800	3050-3250
50	3350-3600	2850-3050
60	3200-3350	2600-2850
70	2900-3200	2450-2600
80	2750-2900	2200-2450
90	<2750	<2200
(**Note** that glacier fed streams tend to be naturally cooler than other forested streams for some distance downstream of their sources; these and other anomalous basin conditions may warrant special consideration.)		

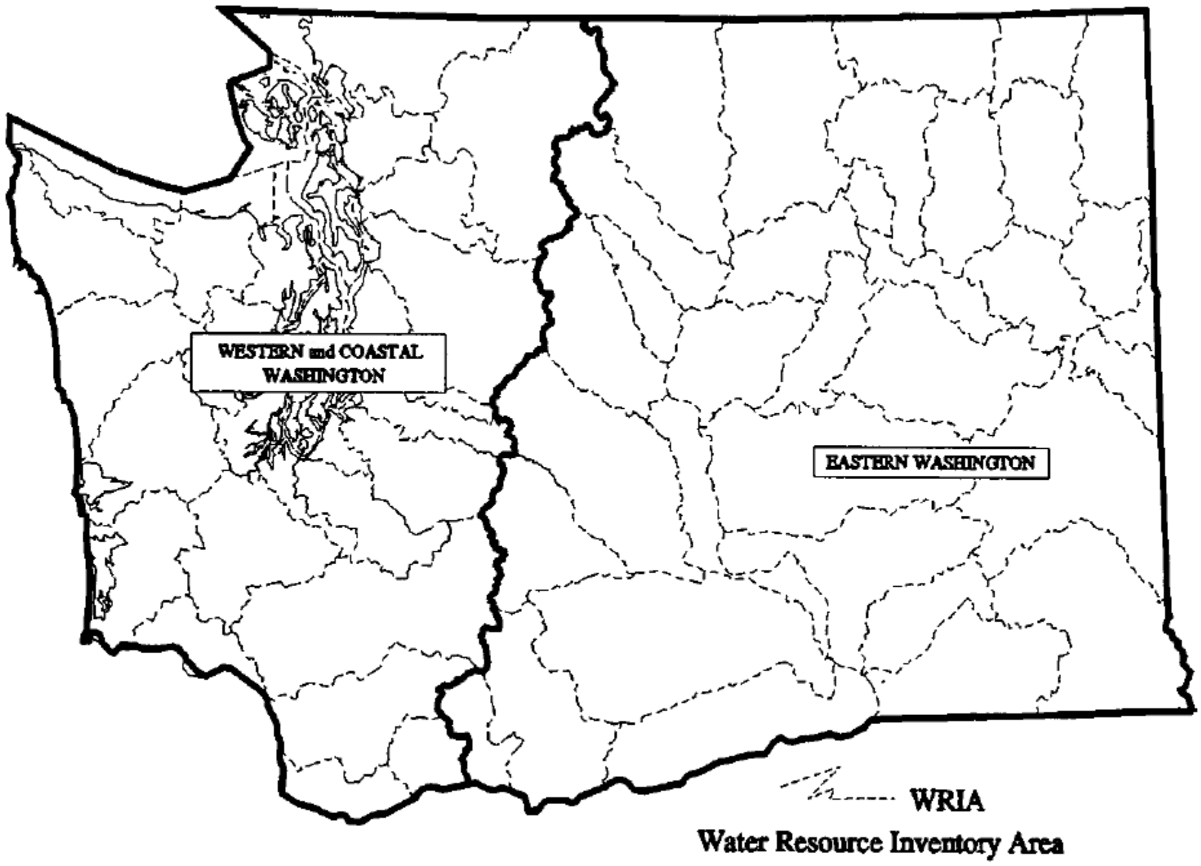


Figure D-4: Stream Temperature Regions of Washington For Applying TFW Temperature Screens

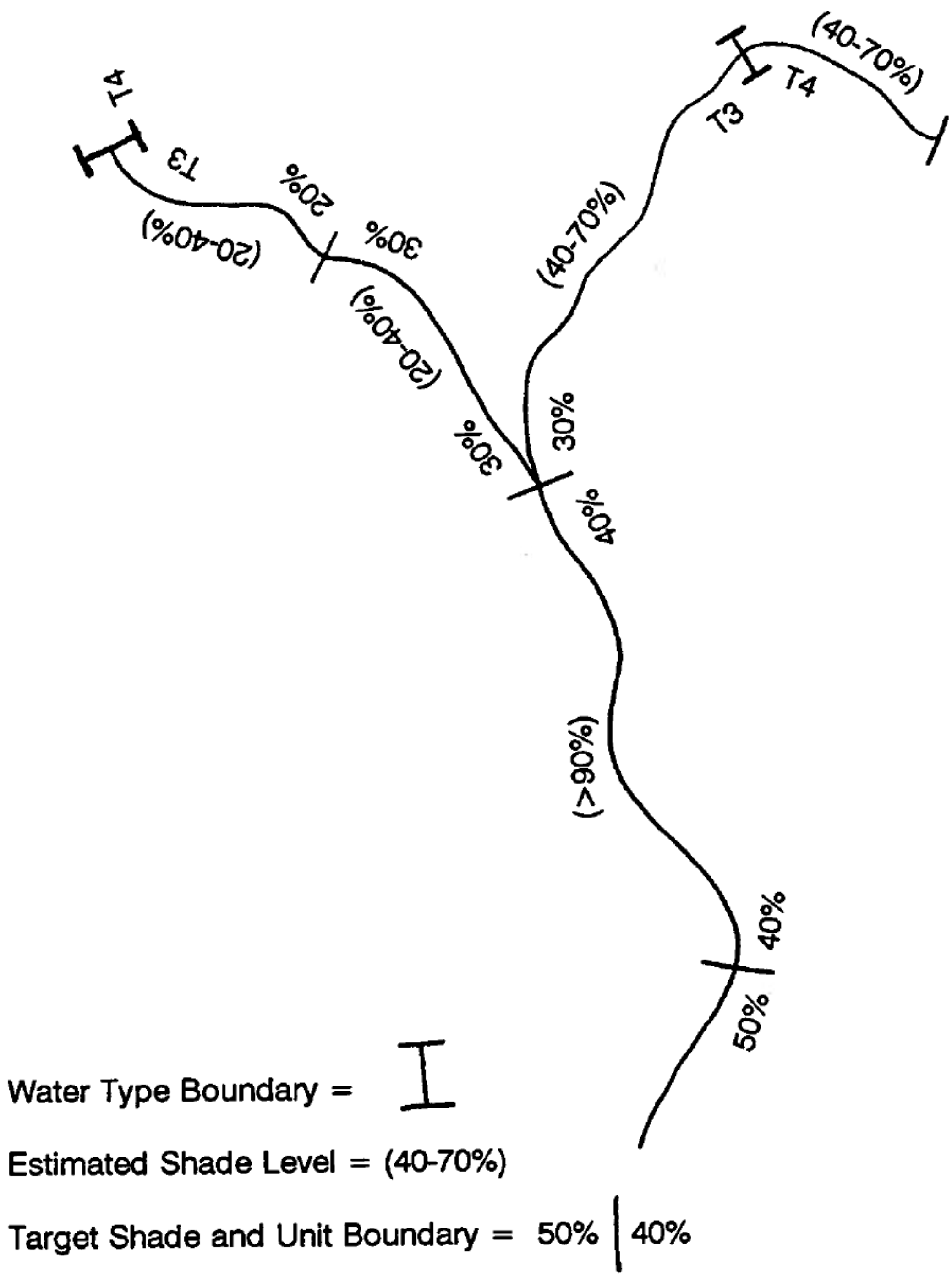


Figure D-5: Example of Map D-4: Target and Estimated Shade Levels

Also, use aerial photographs to identify stream segments that may be unusually wide relative to their position within the drainage (distance from WAU divide). These areas are candidates for additional assessment to verify low flow widths and to estimate shading and its influence on downstream temperatures.

Target values for Class B streams are not shown because the elevations of these streams are relatively low and shade does not ensure stream temperatures will meet state water quality standards.

Determine Existing Shade Levels

Existing shade levels are determined from an analysis of aerial photographs. If available, this analysis may be supplemented with ambient monitoring (canopy closure inventory data). For the photograph analysis, select stereo pairs of the most recent photographs that cover the Type 1-4 waters delineated earlier. Using a stereoscope with a 1x or 2x magnification, examine the riparian canopy cover and estimate the percentage of canopy shading to the nearest 10%. A general guide for shade estimates is contained in Table D-9.

Table D-9 Estimated Levels of Canopy Closure from Aerial Photos

Stream surface not visible	>90% shade
Stream surface slightly visible or visible in patches	70-90% shade
Stream surface visible but banks are not visible	40-70% shade
Stream surface visible and banks visible at times	20-40% shade
Stream surface and banks visible	0-20% shade

Record the shade estimates on the overlay (in brackets) next to the target shade values (Figure D-5).

The units should be coded on the map as follows:

20+ (40)

where 20+ denotes the percent target shade for the given elevation (i.e., 20% shade required), and (40) is the estimated percentage shade level for the reach (Table D-9).

The accuracy of this method is strongly dependent on ground-truthing of photograph interpretations and review of any supplemental information that may be available. First, preliminary estimates of riparian conditions are made in the office using the photographs and supplemental information. These estimates are coded on a mylar attached to representative photographs of the WAU. Second, field surveys are conducted as needed to check the accuracy of estimates for the representative areas selected. The analyst should focus on those stream reaches where their confidence in the photo calls was low. Use a canopy densiometer to make shade measurements at 50-foot intervals within the representative area. (See TFW Ambient Monitoring methods manual for detailed procedures.) Determine the average shade from the densiometer measurements. Finally, record the existing and target shade codes on Map D-4.

Identify Riparian Shade Hazard

Hazard calls for shade are determined by comparing estimates of existing shade levels with target shade levels. High hazard calls apply where existing shade, estimated from photographs or field measurements, is less than the target value for that stream reach. Low hazard calls apply to those stream reaches where existing shade meets or exceeds target shade levels. Because estimates of existing shade levels either fall short of target levels (High hazard) or meet/exceed target levels (Low hazard), no moderate hazard calls are assigned. Reaches needing field verification receive an indeterminate hazard call until canopy measurements can be completed.

An example of a field verified indeterminate hazard riparian zone may be as follows: A stream appears on aerial photography to be unusually wide for its position in the basin. Actual channel width and thus shading and target shade requirements must be established on the ground. Field examination finds large gravel bars derived from mass wasting inputs and a poorly shaded channel below target shade for its actual size. The indeterminate call is then reassessed to a high hazard call.

There are also some areas where water quality classifications and predicted natural maximum temperatures conflict, such as in eastern Washington where vegetation types may be inadequate to provide shade. These are often referred to as anomalous reaches and may include such things as beaver ponds, wetlands, or unnaturally wide channels. Field verification to determine if additional analysis is needed may be necessary. These naturally low shade reaches are identified separately. (See Table D-10: Map Labeling Guidelines for Shade Impact.) Record riparian shade hazard calls on Map D-5: Riparian Shade Hazard using a colored line code as defined in Table D-10.

Table D-10: Map Labeling Guidelines for Shade Impact

Solid Red Line	High Shade Hazard
Solid Green Line	Low Shade Hazard
Dotted Black Line	Naturally Low Shade Level
Dashed Blue Line	Indeterminate Shade Hazard

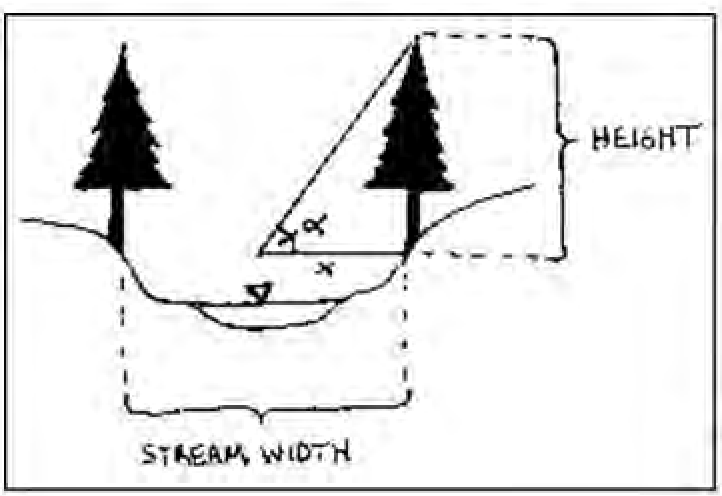
Identify Potential Contributing Activities

For those channel segments where existing shade does not meet the established target, identify the contributing activities that produced a high riparian shade hazard. Using the aerial photographs and supplemental information (talk with other analysts), determine if the reduction in shade is due to land use practices (e.g., logging, road construction, grazing, residential development) or natural influences. This information should be recorded in tabular format and included in the assessment report.

Additional Assessment for Wide Streams

Determine Potential Shade Levels

Using geometric parameters, the analyst can estimate the potential shade for a stream assuming a mature riparian tree height typical of the site. The following geometric configuration should be used as a general guide to estimate the effective tree height as a function of stream width. Assuming a solar angle, the height of riparian vegetation needed to provide shade to the middle of the stream channel can be calculated as:



where: HEIGHT = (tan α)X
X = ½ STREAM WIDTH

Given a solar angle of 60° (as in mid-summer, June-August), the HEIGHT of vegetation required to provide shade to the middle of the stream nearly equals the STREAM WIDTH. For example, a stream that is 50 feet wide requires vegetation nearly 50 feet in height for one-half of the stream to be shaded, or nearly 90 feet for the entire stream to be shaded.

If a constant solar angle of 60° is assumed, the equations can be simplified as follows:

HEIGHT = 1.73(½ STREAM WIDTH) or,

STREAM WIDTH = 2(HEIGHT/1.73)

For example, given a HEIGHT of 140 and 90 feet for effectively mature Douglas-fir and ponderosa pine, respectively, the maximum stream width measured from the vegetation edge that provides shade to one-half of the stream are 162 and 104 feet, respectively. It should be noted that topographic relief can reduce the necessary height. For an example of how this methodology has been applied in the past, the analyst should refer to the Griffin/Tokul Watershed Analysis (Weyerhaeuser Co. 1995).

Canopy Closure/Stream Temperature Assessment Report

The assessment report is intended to convey the analyst's results to other members of the assessment team, to the prescription team, and to those who may be interested in a concise, written description of the work. It should describe the results of the analysis and any conclusions reached relative to the critical questions. The assessment report should include the following:

- Documentation of all information used in the assessment of both the early and current conditions of the riparian zones in the WAU. This includes aerial photos, maps, anecdotal information, aerial flights made, and any other information used to characterize riparian conditions.
- A discussion of the riparian history land use practices that may explain the current condition of the existing riparian vegetation. Shade-limited areas such as floodplains, wetlands, beaver ponds, rock outcrops, etc. should be identified where possible. Land use practices may include harvesting within riparian areas or large scale disturbances such as debris flows or dam-break floods.
- A summary of the current shade levels, target shade levels, and hazard calls for the WAU. The information should be presented in tabular format so the reader can quickly assess the current riparian condition relative to target conditions. The summaries should provide answers to questions such as "What percent of the WAU's riparian zones are currently meeting target shade levels?", and "What percent of the assessed riparian zones received HIGH hazard calls?".
- A description of any deviations from the standard methods and why the changes were necessary.
- A description of any additional analysis that was performed.
- A discussion of the analyst's confidence in the work products. Consider factors such as skill level, variability of riparian conditions, extent of field-checking photo calls, accessibility of the WAU, quality of aerial photos used, quality and quantity of additional information, and any additions or deviations from the standard methods.

- Answers to the critical questions presented at the beginning of the section. While it is not necessary to include this as a separate section, be sure that the critical questions are addressed somewhere in the report.

Maps

- D-4: Target and Estimated Canopy Closure Levels
- D-5: Riparian Shade Hazard

Summary Data

- Worksheet D-3, Estimated Canopy Closure By Channel Segment.
- Contributing Activities Table
- Any additional worksheets or field data used in the analysis.

Riparian Function Assessment Report

I. **Title page** with name of watershed analysis, name of module, level of analysis, signature of qualified analyst(s), and date

II. **Table of contents**

III. **Maps**
- Riparian stand conditions and water type map (map D-1)
- Near-term large woody debris recruitment potential map (map D-2
- Long-term large woody debris recruitment potential map (map D-3) -- if assessment of long-term potential was performed
- Target riparian shade conditions map (map D-4)
- Riparian shade potential map (map D-5)

IV. **Summary Data**
- Stream length by riparian vegetation condition (form D-1) or equivalent
- LWD recruitment impact call by channel segment (form D-2)
- Estimated canopy closure by channel segment (form D-3)

V. **Summary Text**
- Summary of all information used to document historic and current riparian conditions
- Summary of historic land use practices in riparian zones
- Summary of riparian vegetation conditions, in-channel LWD levels, and hazard calls
- Summary of current shade levels, target shade levels, and hazard calls
- Study methods, including description of sampling methods and any deviations from standard methods
- Statement of the author's confidence level in the analysis and results
- Recommendations for Level 2 (at Level 1 only)
- Does module report address all critical questions?

VI. **Aerial Photos**
- List and resolution of aerial photos
- Photo series (flight line photo number, etc.) and where stored

VII. **VII. Other Information (optional)**
- Monitoring strategies and design and implementation suggestions
- Learning resources (a.k.a., references, bibliography) section
- Acknowledgments section

Acknowledgments

This module represents the work of many people over the course of several years. The current version was revised by Jeff Grizzel, Jeff Light, Steve Toth, Curt Veldhuisen, and Chris Earle. Bob Gustavson, Jerry Gorsline, and Mark Hunter reviewed the final draft and provided valuable comments. Judith Holter edited the final version in preparation for its presentation to the Forest Practices Board. The Board approved this revised module in February 1996.

References

Andrus, C.W., B.A. **Long,** and H.A. **Froehlich.** 1988. Woody debris and its contribution to pool formation in a coastal stream 50 years after logging. Can. J. Fish. Aquat. Sci., 45: 2080-2086.

Beschta, R.L. 1979. Debris removal and its effects on sedimentation in an Oregon Coast Range stream. Northwest Science 53: 71-77.

Bilby, R.E. 1984. Removal of woody debris may affect stream channel stability. Journal of Forestry 10: 609-613.

Bilby, R.E. and G.E. **Likens.** 1980. Importance of organic debris dams in regulating the export of dissolved and particulate matter from a forested watershed. Ecology 62: 1234-1243.

Bisson, P.A., R.E. **Bilby,** M.D. **Bryant,** C.A. **Dolloff,** G.B. **Grette,** R.A. **House,** M.L.**Murphy,** K.V. **Koski,** and J.R. **Sedell.** 1987. Large woody debris in forested streams in the Pacific Northwest: past, present, and future. In: E.O. **Salo** and T.W. **Cundy** (eds.), Streamside Management: Forestry and Fishery Interactions. College of Forest Resources, University of Washington, Seattle, WA. p. 143-180.

Caldwell, J.E., K. **Doughty,** and K. **Sullivan.** 1991. Evaluation of downstream temperature effects of Type 4/5 waters. Wash. Dept. Nat. Res. Rep. TFW-WQ5-91-004, Olympia, WA. 71 pp. with 2 appendices.

Coho, C. and S.J. **Burges.** 1994. Dam-break floods in low order mountain channels of the Pacific Northwest. Wash. Dep. Nat. Res. Rep. TFW-SH9-93-001, Olympia, WA. 70 pp.

Doughty, K., J.E. **Caldwell,** and K. **Sullivan.** 1991. TFW stream temperature method: user's manual. Wash. Dep. Nat. Res. Rep. TFW-WQ4-91-002, Olympia, WA. 43 pp.

Dunne, T. and L.B. **Leopold.** 1978. Water in environmental planning. W.H. Freeman and Company, San Francisco, CA. 818 pp.

Grette, G.B. 1985. The role of large organic debris in juvenile salmonid rearing habitat in small streams. Masters Thesis, University of Washington, Seattle, WA. 105 pp.

Harmon, M.E., J.F. **Franklin,** F.J. **Swanson,** P. **Sollins,** S.V. **Gregory,** J.D. **Lattin,** N.H. **Anderson,** S.P. **Cline,** N.G. **Aumen,** J.R. **Sedell,** G.W.

Lienkaemper, K. **Cromack,** Jr., and K.W. **Cummins.** 1986. Ecology of coarse woody debris in temperate ecosystems. Advances in Ecological Research. 15: 133-302.

Heede, B.H. 1985. Channel adjustments to the removal of log steps: an experiment in a mountain stream. Environmental Management 9(5): 427-432.

Keller, E.A. and F.J. **Swanson.** 1979. Effects of large organic material on channel form and fluvial processes. Earth Surface Processes 4: 361-380.

McDade, M.H., F.J. **Swanson,** W.A. **McKee,** J.F. **Franklin,** and J. **VanSickle.** 1990. Source distances for coarse woody debris entering small streams in western Oregon and Washington. Can. J. For. Res., 20: 326-330.

Megahan, W.F. 1982. Channel sediment storage behind obstructions in forested drainage basins draining the granitic bedrock of the Idaho batholith. In: F.J. Swanson, R.J. Janda, T. Dunne, and D.N. Swanston (eds.), Sediment budgets and routing in forested drainage basins, p. 114-121. USDA For. Serv. Gen. Tech. Rep. PNW-141. Pac. Northwest For. and Range Exp. Stn., Portland, OR.

Montgomery, D.R. and J.M. **Buffington.** 1993. Channel classification, prediction of channel response, and assessment of channel condition. Wash. Dept. Nat. Res. Rep. TFW-SH10-93-002, Olympia, WA. 86 p.

Murphy, M.L. and K.V. **Koski.** 1989. Input and depletion of woody debris in Alaska streams and implications for streamside management. North American Journal of Fisheries Management, 9: 427-436.

Oakley, A.L., J.A. **Collins,** L.B. **Everson,** D.A. **Heller,** J.C. **Hoverton,** and R.E. **Vincent.** 1985. Riparian zones and freshwater wetlands. In: E.R. Brown (tech. ed.), Management of Wildlife and Fish Habitats in Forests of Western Oregon and Washington. USDA Forest Service PNW Region. p. 57-80.

O'Connor, M. and R.D. **Harr.** 1994. Bedload transport and large organic debris in steep mountain streams in forested watersheds on the Olympic Peninsula, Washington. Wash. St. Dept. of Nat. Res. Report TFW-SH7-94-001. Olympia, WA. 125 pp.

Potts, D.F. and B.K.M. **Anderson.** 1990. Organic debris and the management of small stream channels. Western Journal of Applied Forestry 5(1): 25-28.

Platts and 12 co-authors. 1987. Methods for evaluating riparian habitats with applications to management. USFS Intermountain Research Station, Gen. Tech. Rep. INT-221. 177 pp.

Robison, E.G. and R.L. **Beschta.** 1990a. Characteristics of coarse woody debris for several coastal streams of southeast Alaska, USA. Can. J. For. Res., 47: 1684-1693.

Robison, E.G. and R.L. **Beschta.** 1990b. Coarse woody debris and channel morphology interactions for undisturbed streams in southeast Alaska, U.S.A. Earth Surf. Proc. and Landforms, 15: 149-156.

Sedell, J.R. and F.J. **Triska.** 1977. Biological consequences of large organic debris in Northwest streams. In: Logging debris in streams workshop. Oregon State University Press, Corvallis, OR. 10 pp.

Sedell, J.R. and K.J. **Luchessa.** 1982. Using the historical record as an aid to salmonid habitat enhancement. p. 210-223. In: N.B. Armantrout (ed.), Acquisition and Utilization of Aquatic Habitat Inventory Information. Am. Fish. Soc., Bethesda, MD.

Sullivan, K., J. **Tooley,** K. **Doughty,** J.E. **Caldwell,** and P. **Knudsen.** 1990. Evaluation and prediction models and characterization of stream temperature regimes in Washington. Wash. Dep. Nat. Res. Rep. TFW-WQ3-90-006, Olympia, WA. 224 pp.

Swanson, F.J., L.E. **Benda,** S.H. **Duncan,** G.E. **Grant,** W.F. **Megahan,** L.M. **Reid,** and R.R. **Ziemer.** 1987. Mass failures and other processes of sediment production in Pacific Northwest forest landscapes. In: E.O. **Salo** and T.W. **Cundy** (eds.), Streamside Management: Forestry and Fishery Interactions. College of Forest Resources, University of Washington, Seattle, WA. p. 9-37.

TFW Water Quality Steering Committee. 1993. Recommended temperature screen for eastern Washington. Results of the temperature workshop held in May 1993.

Toews, D.A.A. and M.K. **Moore.** 1982. The effects of streamside logging on large organic debris in Carnation Creek. Land Management Report Number 11, ISSN 0702-9861. Province of British Columbia, Ministry of Forests. 29 pp.

VanSickle, J. and S.V. **Gregory.** 1990. Modeling inputs of large woody debris to streams from falling trees. Canadian Journal of Forest Research, 20: 1593-1601.

Worksheet D-1: Stream Length by Riparian Vegetation Condition and Channel Segment

Worksheet D-1: Stream Length by Riparian Vegetation Condition and Channel Segment

Riparian Condition Code	**Stream Channel Segment***																	
Hardwood/Small/Sparse																		
Hardwood/Small/Dense																		
Mixed/Small/Sparse																		
Mixed/Small/Dense																		
Conifer/Small/Sparse																		
Conifer/Small/Dense																		
Hardwood/Medium/Sparse																		
Hardwood/Medium/Dense																		
Mixed/Medium/Sparse																		
Mixed/Medium/Dense																		
Conifer/Medium/Sparse																		
Conifer/Medium/Dense																		
Hardwood/Large/Sparse																		
Hardwood/Large/Dense																		
Mixed/Large/Sparse																		
Mixed/Large/Dense																		
Conifer/Large/Sparse																		
Conifer/Large/Dense																		
Segment TOTAL**																		

*** Lengths measured using a map wheel (record in centimeters or inches)**

****Segment TOTAL = 2 X Actual Segment Length because both sides are measured**

Worksheet D-2: LWD Recruitment Impact Call by Channel Segment

Worksheet D-2: LWD Recruitment Impact Call by Channel Segment

Riparian Condition Unit	Channel Segment Number	Riparian Condition Code	Recruitment Potential Rating	Channel Sensitivity Rating	In-channel LWD Rating	LWD Recruitment Impact Call	Comments

Worksheet D-3: Stream Length by Estimated Canopy Closure and Channel Segment

Worksheet D-3: Stream Length by Estimated Canopy Closure and Channel Segment

Canopy Closure Estimate From Photo Interpretation	**Stream Channel Segment***																	
>90%																		
80-89%																		
70-79%																		
60-69%																		
50-59%																		
40-49%																		
30-39%																		
20-29%																		
10-19%																		
<10%																		
From Field Measurements																		
Number of Plots -->																		
Plot Average (% Cover) >																		
Segment TOTAL																		

*** Lengths measured using a map wheel (record in centimeters or inches)**

APPENDIX E
Stream Channel Assessment Module

Table of Contents

Introduction

Assessment of channel condition is one of the most difficult aspects of watershed analysis. This difficulty arises, in part, because channels are complex, dynamic systems. The channel assessment procedure presented here provides a framework for objectively assessing both past changes in channel morphology and processes and current channel conditions throughout a watershed. Although this procedure was developed for channels in the Pacific Northwest, the process orientation makes the general approach transferable to other regions with minimum modification.

Channels are defined by the transport of water and sediment confined between identifiable banks (Montgomery and Dietrich, 1989; Dietrich and Dunne, 1993). In spite of this basic similarity, there are many types of natural stream channels, reflecting spatial differences in channel processes, historical disturbance, lithologic and structural controls, and geologic history (e.g., Paustain et al., 1983; Rosgen, 1985; Frissel et al., 1986; Cupp, 1989; Montgomery and Buffington, 1993). Channel morphology reflects and inte-grates processes operating in a watershed because material eroded from hillslopes ultimately is delivered to and routed through the channel network. Consequently, channel condition provides a logical metric for diagnosing watershed conditions. Channel assessment would be impractical, however, were all channels unique in their potential response to disturbance or changes in watershed processes. Thus, a fundamental tenet of applying watershed analysis to stream channel assessment is that patterns in channel morphology and processes may be used to simplify the wide variety of natural channels into a manageable analysis framework.

Channel morphology and condition reflect the input of sediment, water, and wood to the channel, relative to the ability of the channel to either transport or store these inputs (Sullivan et al., 1987). Systematic and local differences in transport capacity and the nature and magnitude of inputs through a channel network result in a distribution of different channel types throughout a channel network, reflecting spatial differences in channel slope, flow depth, sediment supply, and the availability of large woody debris. Because of these differences, certain channels are more or less sensitive to similar changes in these input factors. Identification of differences in channel processes and sensitivity is a major goal of the channel assessment component of a watershed analysis.

The channel assessment method developed in this module stratifies the channel network to guide analysis and interpretation of channel condition and response potential. The different channel types so identified provide a coarse stratification of the channel network into reaches with similar channel-forming processes. Within each channel type, qualitative assessments of various indicators of channel history, transport capacity, and sediment supply provide for a more detailed diagnosis of channel condition and guide determination of major processes controlling channel morphology and habitat structure throughout the channel network. The assessment divides the channel network into segments that define areas of the network that respond to disturbance in a similar fashion based on similarities in channel-forming processes. This allows assessment of channel conditions on a watershed basis and provides a context for evaluating the influence of changes in land management on channel conditions and processes.

Critical Questions

The purpose of the channel assessment module is to guide development of information necessary to address several key questions critical to understanding channel processes and conditions in a watershed context:

What is the spatial distribution of channel response types?

Is there evidence of channel change from historic conditions?

What do existing channel conditions indicate about past and present active geomorphic processes?

What are the likely responses of channel reaches to potential changes in input factors?

What are the dominant channel- and habitat-forming processes in different parts of the channel network?

Answering these key questions relies on a combination of map, aerial photo, and field work. They may be answered at many levels of confidence and detail. The module developed here is designed to generate sufficient information to introduce sound information into forest land use decision making.

Assumptions

A number of fundamental assumptions underlie the approach developed here. The most fundamental requirement is that the analysis is based on the best available scientific information and techniques. Thus, the module analysis methods themselves are designed to change as newer methods are developed. The underlying assumptions and analysis framework, on the other hand, are not. Rather, these assumptions dictate a rigorous, yet flexible, framework for the analysis. Our primary assumptions include:

- Major changes in channel morphology are caused by changes in discharge, sediment supply, and vegetation influencing the channel (e.g., riparian and large woody debris).
- We can meaningfully simplify (classify) the complex array of natural channels.
- There is enough pattern in channel conditions to allow diagnosis of current conditions.
- The style and magnitude of potential response to input changes can be recognized.

An Overview of the Assessment and Products

The stream channel assessment is conducted using maps, aerial photographs and field observations. Based on this information, the analyst interprets stream processes relative to the critical questions for the watershed as a whole and for sub-areas within it. Watershed analysis requires the stream channel analyst to develop information to address each critical question. The method developed in this manual describes the standard channel assessment.

A series of exercises designed to either confidently answer the key questions, or identify more detailed information necessary to do so, is developed in the module. The objective of these exercises is to generate information sufficient to establish:

- *Channel segments liiely to respond similarly* to changes in the input factors (water, sediment, wood).
- *Historical changes* in channel morphology to identify past and continuing natural and management-related impacts.
- The *current channel condition* indicating the status of present regimes of input factors.
- The likely future response of channels with and without potential changes in input factors, given the nature of the channel and its present condition (*channel sensitivity*).
- Interpretation of the *habitat-forming processes* dependent on the geomorphic processes controlling channel morphology. The influence of channel processes on habitat attributes identified as important for fish or other aquatic organisms.

Each of these objectives is an integral component of the stream channel assessment. Together, these questions and objectives provide the foundation for assessing contemporary channel conditions and interpreting potential channel response. Only in smaller watersheds are channel form and dominant processes likely to be uniform throughout the basin. An important element of the assessment is to stratify the watershed into areas of similar condition and response, ultimately relating channel form and process to the terrain, geology, and disturbance history of the locale.

Products from the analysis consist of maps, interim worksheets, and narrative provided by the analyst. Interim work products captured on forms preserve the trail of information, observations, and logic used by the analyst in developing interpretations. These work products are easy to follow for review purposes, and importantly, make data available for monitoring hypotheses through future years as well as provide a data base against which to evaluate new assessment techniques. Narrative summaries are necessary for communication of results, but because of time limitations, they are intended to be short and focused. The analysis is expected to provide at a minimum the products listed in Table E-1.

The analysis consists of a series of steps that successively build the framework for assessing past, current, and potential future channel conditions. First, the analyst uses topographic maps to provide a general stratification of channel segments according to channel gradient and confinement. Each segment in the watershed is numbered on the *channel segment map* (Map E-1). Segment numbers are entered onto the *channel segment worksheet* (Form E-1) for easy reference of the distribution of segment types in the watershed and the probable response potential to changes in watershed processes and input factors. At sometime early on in the analysis, it is useful to do a one day reconnaissance survey of the watershed to verify gradient/confinement calls.

Next the analyst examines a series of historical aerial photographs to confirm channel confinement categorizations and to document past macroscopic channel changes such as changes in channel pattern and riparian canopy openings due to debris-flow scour or flooding. Remotely sensed data from each segment is recorded both on the *channel disturbance worksheet* (Form E-2) and in a narrative describing the overall history of the watershed as revealed by the aerial photographs.

Based on these preliminary analyses, the analyst selects representative channel segments for field inspection. (Field site selection rationale is recorded on Form E-3). At selected sites, the analyst makes qualitative and quantitative observations to assess channel conditions for interpretation of channel-and habitat-forming processes. These include features of the streambed, the active channel and the flood plain. Field observations can be recorded on the *channel assessment field data forms* (Form E-4).

Table E-1. Products of the Stream Channel Assessment

Critical Question	Information Used	Product
Distribution of Response Segments	• Topographic Maps	• Channel segment map (Map E-1) • Channel segment worksheet (Label Form E-1)
Evidence of Historic Change	• Aerial Photographs • Anecdotal Information	• Channel disturbance worksheet (Label form E-2) • Narrative summarizing historic watershed riparian width pattern
Current Channel Condition	• Field Observations	• Site selection rationale (Form E-3) • Field forms (Label form E-4) • Segment diagnostic worksheet (Label form E-5)
Channel Sensitivity to Changes in Input Factors	• All of the above	• Geomorphic unit map (Map E-2) • Geomorphic unit worksheet (Label form E-6) • Narrative describing dominant geomorphic processes and condition
Habitat-forming Processes	• Field Observations and Channel Sensitivity Worksheet	• Narrative describing habitat-forming processes by geomorphic unit

Once representative stream segments have been observed for streambed, active channel, and flood plain attributes, the analyst must interpret the channel-forming processes influencing both channel and habitat features using their experience and some guidance provided in this manual. Typically, a series of characteristics provides a reasonable indication of the current relations between sediment supply, transport capacity and flow obstructions governing channel processes and morphology. Additional features may indicate the occurrence of past changes in these regimes or the occurrence of catastrophic events such as dam-break floods or debris flows. In turn, the watershed, valley and channel conditions determine the availability of key habitat features for fish or other aquatic life. Conditions and observations regarding the channel- and habitat-forming processes for each segment visited in the field are summarized on the *channel segment summary worksheet* (Form E-5).

Since only a limited number of segments can be visited, the analysis will need to extrapolate the results from the channel segments sampled to the remainder of the segments in the watershed. The analyst classifies which stream segments look, behave, and respond to changes in input factors in a similar fashion. Data from field verified segments is then extrapolated to the entire grouping of segments. Extrapolation results and key information used in the determination is then summarized.

The next step is to interpret dominant channel- and habitat-forming processes, and determine segment sensitivity to each input factor. The analyst associates segments with similar responses with the watershed processes and characteristics that influence them. Typically, there will be an association of channel form with landforms, geology, and so on. The analyst will need to use all the information available including terrain, segment maps, field observations, and aerial photographic data to interpret geomorphic units, which delineate areas into similar governing processes and sensitivities to change. Clustering segments in this fashion will facilitate integration of results with other module results to develop a watershed-scale interpretation of the linkage between hillslope and channel processes during the synthesis phase of watershed analysis. The geomorphic units generated through this interpretation are delineated onto a geomorphic unit map (Map E-2). Based on the interpretation of dominant channel-forming processes, the analyst provides an assessment of channel sensitivities to future changes in input factors. Interpretations are recorded on the *Geomorphic Unit Worksheet (*Form E-6) and summarized in narrative form.

The channel analyst also discusses how channel-forming processes operating in each area are likely to determine the availability of key habitat qualities. Based on concerns raised by the fish module analysts regarding factors such as the qualities of spawning and rearing habitat in areas of particular interest in a watershed because of species use and critical habitat needs, the channel analyst provides a narrative describing how channel processes in those locations currently or potentially influence the factors specifically related to fisheries or other resource concerns identified in the other watershed analysis modules.

Qualifications

Channel assessment depends on highly-qualified individuals to interpret channel morphology and conditions. Channel assessment is a complicated undertaking that relies on both qualitative assessment of subtle differences in channel features and solid theoretical background in fluvial geomorphology. Certain skills, training, and experience are necessary for effectively implementing the standard channel assessment module. Level 2 analyses presuppose a higher level of training and ability to independently develop and implement relevant analyses to address issues and observations not satisfactorily explained by the standard analysis. While there are many possible backgrounds that could provide the foundation necessary for applying this module, the following criteria provide minimum expectations for the background of those performing the channel assessment module:

Skills: Level 1

Knowledge of the processes active in stream channels in forested and mountainous terrain and the ability to recognize and interpret hydraulic and geomorphic features of stream channels.

Thorough understanding of the principles of channel processes reviewed and synthesized in Channel Classification, Prediction of Channel Response, and Assessment of Channel Conditions (Montgomery and Buffington, 1993).

Additional Skills: Level 2

Experience with quantitative methods of channel assessment (e.g., sediment budgets).

Education and Training: Level 1

Bachelor's degree in geology or related field (civil engineering, hydrology) or specific course work in fluvial geomorphology.

Additional Education and Training: Level 2

M.S. degree in geology or related field (civil engineering, hydrology) with graduate course work in fluvial geomorphology.

Experience: Level 1

Two years field experience in channel assessment, or research in fluvial geomorphology.

Additional Experience: Level 2

Experience conducting relevant independent research or channel assessments.

Self-Evaluation
For Level 2 assessment: Ability to read and understand basic references on channel processes such as:

> **Richards**, K. 1982. Rivers--Form and Process in Alluvial Channels. Methuen and Co., N.Y., N.Y.
>
> **Leopold**, L.B., M.G. **Wolman**, and J.P. **Miller**, 1964. Fluvial processes in geomorphology. W.H. **Freeman**, San Francisco, CA.

Background Information

Initial information needs for the standard channel assessment are minimal, in keeping with the reconnaissance-level orientation. Further information needs may be identified during the course of the analysis, but topographic maps, photographs and other available historical information provide the background data for the standard channel assessment.

The following information is needed to conduct a channel assessment.

Maps
Topographic maps of the watershed (7.5 minute series required where available; finer scale encouraged for working maps).

Photographs
At least two sets of aerial photographs separated by a period of at least ten years (1:12,000 scale or better, if available). The more photographic sets that are available the higher the confidence possible in the remote sensing component of the channel assessment. Also, photographs taken following major storm events and harvest activities are particularly useful for assessing changes in channel conditions. Use the earliest and latest coverage available and decadal coverage for the intervening period, as available. The Mass Wasting Module analysts will also be using sets of historical photos, and sharing of photos between modules may be possible.

Other
Available historical data, anecdotal descriptions, and photographs of channels in the watershed.

Results of the channel assessment are presented on the official watershed base map to ensure mapping consistency between analysis modules.

If time is available, the analyst should also try to track down any studies that may have stream channel data, such as instream flow studies, or United States

Geological Survey (USGS) channel cross-section data from 9-207 forms. (Discharge measurement notes).

Analysis Procedure

There is a certain level of information necessary to analyze channel processes in a watershed context. The following procedure defines a standard methodology appropriate for watershed analysis and must be completed.

Level 1 and Level 2 watershed analysis levels specify the qualified individuals and time frames available for the assessment. Given the status of our scientific knowledge regarding watershed-scale fluvial processes, there are likely to be uncertainties in the interpretations of any assessment conducted according to these procedures. In addition, limitations of time and resources for performing the assessment, and the analyst's qualifications will also determine the degree of resolution and confidence in assessment interpretations.

It is expected that Level 1 assessments produce the standard products, which includes all forms and maps identified in the channel assessment report section of this chapter. Greater uncertainty of results and indeterminate interpretations can be expected, because less time for field-work is allowed. It is important that uncertainties be noted so that decisions based on this information can account for them. Level 2 analysis should be invoked when analysts are not satisfied with their ability to answer a critical question based on the standard analyses, and improving interpretations is considered important for decision-making.

Level 2 assessment requirements are more flexible and exploratory allowing the analyst to invest his or her effort in gathering data and observations as warranted by the nature of the question to be answered and the watershed situation to be resolved. Level 2 teams are expected to produce similar assessment products augmented by additional information for specific situations. This may include specific analyses of particular processes or sub-areas within the watershed. In addition, to facilitate the scientific review of assessment procedures, the format for presentation of results shown in the channel assessment report section must be followed when standard assessment forms are not used by Level 2 teams.

To aid in the interpretation of channel environments, the individual conducting the channel module should be communicating with the individuals conducting the appropriate modules (e.g., mass wasting, riparian, surface erosion and fish habitat) during the time of the assessment. This communication between module leaders is particularly important before, during and after field work. This is necessary for construction of working hypotheses regarding changes in the input variables, which other module leaders may be more familiar with, and the subsequent response of the channel.

Distribution of Channel Response Types

There is a need to initially identify similar channel segments in order to develop hypotheses for response potential throughout a watershed. Such an initial classification must be done from either topographic maps, aerial photographs, or digital terrain data. Channel attributes that may be so determined are typically restricted to slope, width, drainage area, and associated land forms. For this analysis, consider channel segments as the primary mapping unit of stream classification and watersheds as a series of channel segments defined by changes in gradient and confinement discernible at map scales of 1:24,000. Stream segment slope and confinement provide a useful orientation for stream classification in that valley morphology is insensitive to most disturbances of stream processes occurring over decades or centuries. A combination of gradient and confinement provides a simple method to distinguish response potential. The approach to stream classification em-ployed in the channel assessment module largely focuses on describing segments, understanding their distribution relative to watershed features, their probable condition under baseline and disturbed regimes, and their potential for biological productivity under a variety of conditions.

The influence of valley conditions on stream channels has been characterized in several classifications that describe relatively homogeneous lengths of stream contained within similar geomorphic settings (e.g., Paustain et al., 1983; Rosgen, 1985; Cupp, 1989). Stream segments are associated with valley gradient and are demarcated by contacts between lithologies of variable resistance, or by abrupt change in valley conditions or land forms. Gradient is a surrogate for stream energy, the dominant control on channel morphology. Confinement controls aspects of potential response and reflects the long-term history of a valley where past events, such as glaciation, leave an imprint. Gradient and confinement are also general indicators of transport capacity and the balance between sediment supply and transport capacity.

A simple method for categorizing channel response potential in terms of gradient and confinement was developed based on geomorphic reasoning and experience (Table E-2). Lacking more detailed information about channels, we may expect those with similar gradient and confinement to respond similarly to changes in input variables. These gradient classes generally correlate with morphologically distinct channel types (Montgomery and Buffington, 1993), but they are not absolute, and considerable overlap can exist depending upon local conditions. For example, the 8-20% gradient category may have a transition category that includes distinct geomorphic characteristics and thus results in a different set of responses to changes in input factors. This can be included in the assessment because the matrix is a first cut. Nonetheless, the channel response matrix (Table E-2) approximates sediment transport and response characteristics expected for channel segments defined through remote assessment. Furthermore, the response matrix provides a way to develop hypotheses about channel processes that may be tested through limited field observations.

The segment types in the channel response matrix (Table E-2) occur broadly in watersheds throughout the Pacific Northwest region and are for the most part independent of changes in erosion or hydrology caused by watershed disturbance. Segment types are expected to have similar characteristics under equivalent watershed conditions and to respond similarly to changes in sediment and hydrologic input to a watershed. From a conceptual standpoint, segments are seen as discrete lengths of stream, with characteristic spatio-temporal erosional and depositional profiles.

Table E-2. Channel Response Matrix

SEDIMENT
FS _ Fine Sediment Deposition
CS - Coarse Sediment Deposition

DISCHARGE
SC - Scour Depth
SF - Scour Frequency
BE - Bank Erosion

WOOD
WL - Wood Loss
WA - Wood Accumulation

CATASTROPHIC EVENTS
DFS - Debris Flow Scour
DFD - Debris Flow Deposition
DB - Dam Break Flood

VW > 4CW UNCONFINED	FS BE WA	WL SF FS BE	DB DFD BE CS SF WL	DFS/DFD DB WL	DFS	
2CW < VW < 4CW MODERATELY CONFINED	FS BE WA	CS BE SD WL FS	CS BE DB SD DFD WL SF	DFS/DFD DB SF WL	DFS	DFS
VW < 2CW CONFINED		CS WL	CS SD WL DFD DB	DFS/DFD DB SF WL	DFS	DFS
	<1.0 Pool-Riffle	1.0 - 2.0 Pool-Riffle, Plane-Bed	2.0 - 4.0 Plane-Bed, Forced Pool-Riffle	4.0 - 8.0 Step-Pool	8.0 - 20.0 Cascade	> 20.0 Colluvial

VALLEY GRADIENT AND TYPICAL CHANNEL BED MORPHOLOGY

Define the Channel Network

The channel network must be defined prior to identifying channel segments. Mapping and visiting all channels in a watershed is extremely time consuming and would make the assessment intractable. Instead, we differentiate between fluvial and mass-wasting dominated channels and adopt the approach of delineating the full extent of the channel network, but only analyzing in detail representative reaches of the fluvially-dominated portions of the channel network.

Defining the channel network entails locating its upper extent. There are many ways to approximate the extent of the channel network and the blue lines portrayed on topographic maps only rarely reflect the actual extent of the channel network (Morisawa, 1957; Mark, 1983). Field surveys show that the drainage area necessary to initiate a channel is inversely proportional to slope (Montgomery and Dietrich, 1988; 1989), allowing determination of channel network extent if the appropriate relation is known. When this relation is not known, as is generally the case, the extent of v-shaped, or crenulated, contours may be used to approximate the extent of the channel network (Morisawa, 1957). Preliminary data suggests in mountain drainage basins in the western United States that a gradient of approximately 20% defines the upper limit of fluvially-dominated systems (Seidl and Dietrich, 1992; Montgomery and Foufoula-Georgiou, in press). Field studies in the Pacific Northwest also have shown that mass-wasting processes, such as debris flows, are important sediment processes in channels steeper than approximately 15 to 20% (Benda, 1990). Consequently, these channels are investigated in the mass wasting module.

After delineating the entire channel network, channel reaches with less than a 20% gradient are included in the stream channel assessment and are labeled and numbered on the channel segment map. Channel reaches greater than 20% need to be delineated in order to identify the break point. The extent of the channel network used in the analysis may be modified based on field reconnaissance. The linkage between channels dominated by mass-wasting and fluvial processes should be considered during the analysis and prescription phase of watershed analysis. Labels and numbers also can be given to streams with gradients of greater than 20%, if needed for addressing specific resource concerns or linkages of hillslope and channel processes. For example, it is useful to label and number those channel reaches greater than 20% that directly enter fish-bearing water and drain a large proportion of a watershed. This gives the analyst an opportunity to check historic aerial photo review for mass wasting run-out areas.

Classify Segments

Once the channel network is delineated, it is divided into segments with similar gradient and confinement. A segment is a unique part of a stream with beginning and end-points corresponding to stream coordinates. As such, they are the basic stream mapping unit for all stream channel-oriented components of watershed analysis (Channel, Fish, Hydrology, and Riparian modules). The segments allow the analyst to interpret general expected variations in channel morphology and processes and provide a guide for focusing field work. It is important to divide the channel network into a minimum number of segments in order to facilitate the analysis. Although some judgment is required to delineate segments, the following criteria are suggested as a guide. (The analyst may also refer to the "Ambient Monitoring Program Manual" of July, 1993, edited by Schuett-Hames, et al., for guidance in identifying stream segments.)

Channel Gradient

Gradient is readily determined from topographic maps from the distance between contours. Six gradient ranges are used that generally correspond to gradients associated with changes in channel morphology that reflect relative transport capacity, and thus response potential (Table E-2). Gradient breaks need to be consistent for at least three consecutive contours. This will provide a minimum distance for each segment and will subsume short reaches of steeper or lower-gradient channel into longer reaches with more representative average slopes. If three consecutive contours is too long for low gradient reaches (e.g., less than 1%) or too short for steep gradient reaches (e.g., greater than 20%), then the analyst should make a decision on the minimum number of contours or distance and identify the criteria used in the methods section of the channel assessment report.

Confinement

Channel confinement is more difficult to determine, but it may be considered to be the ratio of the valley or flood plain width (VW), to the channel width (CW). Confinement is an important control on potential channel response. Channels with wide flood plains may shift laterally over the valley bottom, changing course, sinuosity, or pattern (e.g., meandering, braided) in response to disturbance, whereas channels confined by bedrock valley walls can only respond in other ways (e.g., bedform modification or channel armoring). Channel confinement generally cannot be measured directly from topographic maps, especially for small channels, because channel widths are not portrayed accurately. Wherever possible, confinement estimated from topographic maps should be confirmed with either aerial photographs or field observations. Each channel reach is classified as confined (VW < 2CW), moderately confined (2CW < VW < 4CW), or unconfined (VW > 4CW) (Table E-2).

In addition, it is also useful to delineate a stream segment break at major tributaries that contribute 10% or more of the total upslope drainage area. Although gradient and confinement may not change within a reach with a major incoming tributary, the tributary itself could influence channel features sufficiently that the segment could differ above and below the tributary.

Average segment length (distance between slope breaks) probably increases with watershed and stream size. The occurrence of segment types varies within watersheds according to stream size, and regionally according to differences in geology, geomorphology and climate. Again, it is important to check the gradient/confinement calls during the field sampling phase of the assessment report.

Numbering the Segments
Channel segments are assigned a number and classified following the convention illustrated in Figure E-1. Segments on the channel map are labeled with the gradient/confinement codes from Table E-2. A copy of this map should be provided to the fish habitat and riparian analysts upon completion. In larger watersheds with numerous tributaries, it may be useful to assign a letter code or prefix to each tributary system.

Recording Segments
Tabulation of the segment numbers on the channel segment worksheet (Form E-1) provides the analysts with a record of the frequency of segment types in the watershed. This information gives the analyst information on the frequency distribution of channel types and helps guide selection of representative channel segments for field observations.

Initial Interpretation of Response Segments
Segments are stream types determined by valley conditions and as such their location and morphology tend to remain constant over time frames important to forest management conditions. Segment types represent the "potential" of the stream and provide constraints on the probable form that the channel can have within it.

As an aide to planning the subsequent field component of the module, it is useful to synthesize segment information into general response potential zones. Classification of segments into source, transport, and response reaches using gradient criteria of greater than 20% for source, 3 to 20% for transport and less than 3% for response reaches reveals general patterns of sediment transport characteristics associated with reach-level morphologies (Montgomery and Buffington, 1993). The 3% gradient break unfortunately is not used to define segment categories, so the segment breaks will be different than the general response potential zones. Source reaches are likely to be storage sites for colluvium and they are subject to mass wasting events, and correspond to debris-flow dominated channels (Benda and Cundy, 1990). Within the fluvially-dominated channel network, transport reaches are likely to act as conduits for rapid sediment transport and delivery to downstream reaches. Response reaches, on the other hand, are most likely to exhibit pronounced and persistent morphologic adjustments to changes in sediment supply.

The distribution of source, transport, and response reaches governs the distribution of potential impacts and influences recovery times in the channel network (Montgomery and Buffington, 1993), as well as the composition and structure of the biologic communities inhabiting the stream channel. Thus, identification of these potential response zones in a watershed reveals spatial linkages between upstream sediment inputs and downstream response.

Transport reaches rapidly deliver sediment to downstream response reaches, where sediment is more gradually transported downstream. Response reaches immediately downstream of transport reaches thus are relatively susceptible to changes in sediment supply. Delineation of channel types and response zones also aids in selection of sites for field visits and for interpreting causes of historical channel change revealed during examination of aerial photographs. If a source, transport, and response map is made prior to aerial and field work it, should be modified when the field component of the assessment is complete.

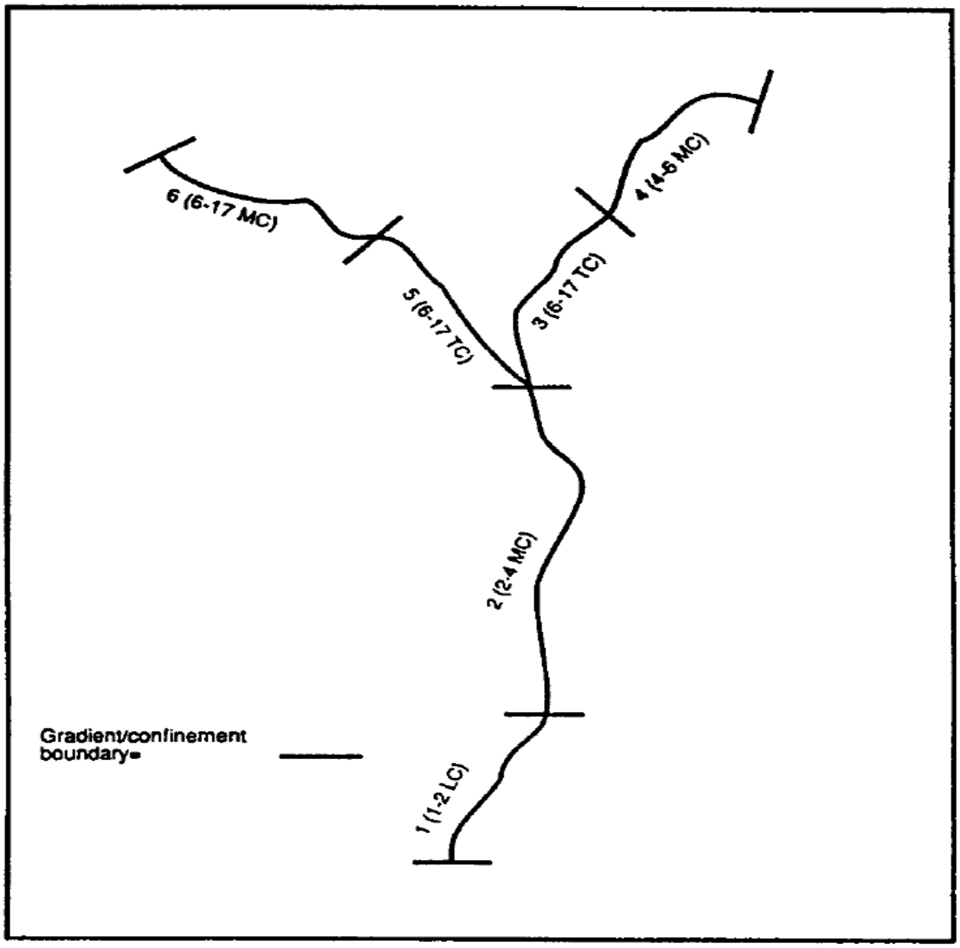


Figure E-1. Example of Channel Segment Labeling and Numbering

An example from the Tolt River

The channel network in the 100 mi^2 watershed was divided into 166 numbered segments (Figure E-2). Comparison of the channel response table with the channel segment worksheet (Figure E-3) provided the channel group with hypotheses for the type of input factors that may influence specific segments. Generalization of the channel segment map into transport and response segments (Figure E-4) allowed the channel group to identify areas that may be more sensitive to a change in input factors based on channel network position. These distributions helped interpret evidence of historic changes in channel conditions observed in subsequent analyses of aerial photographs.

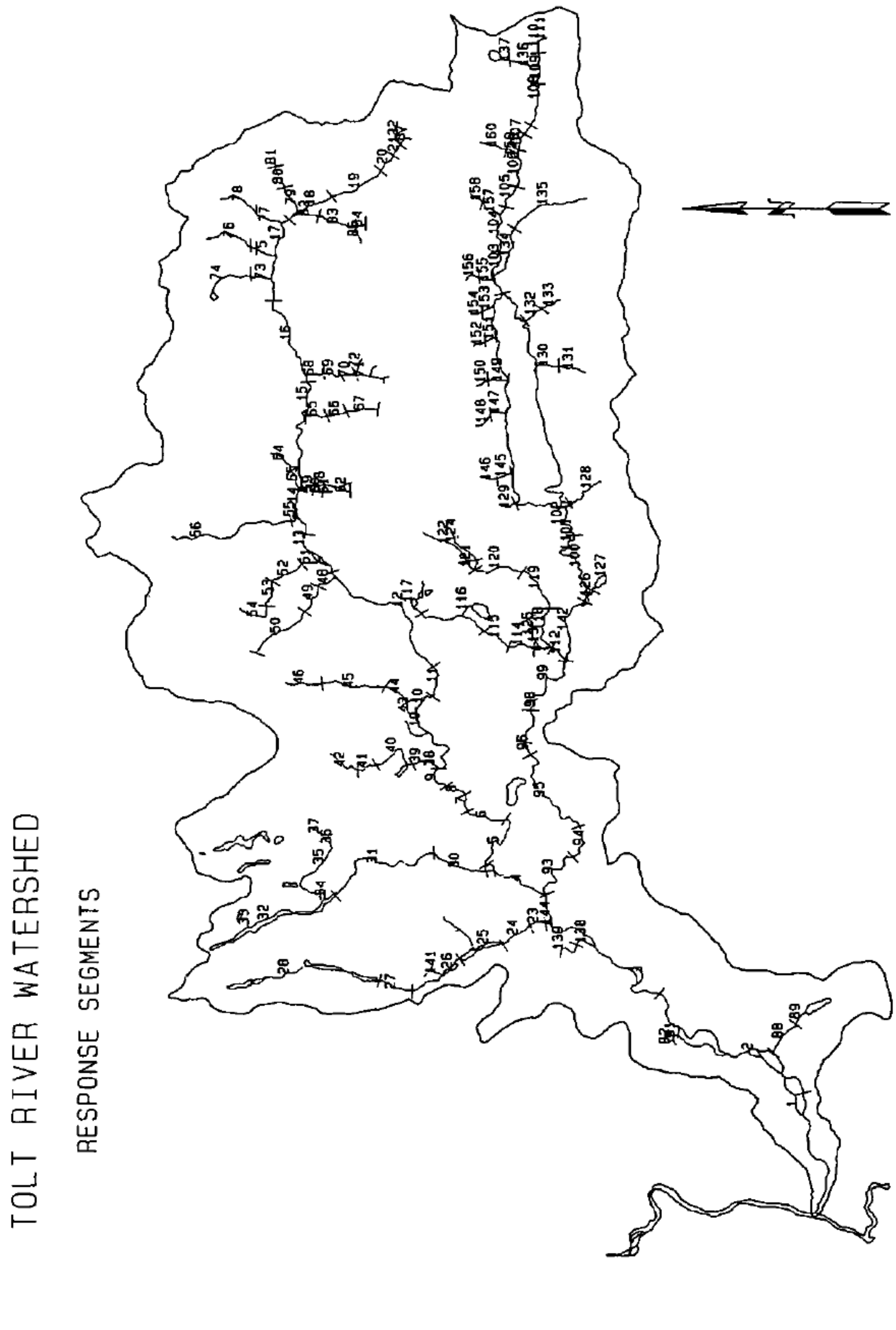


Figure E-2. Example of Channel Segment Labeling and Numbering

Form E-1. Channel Segment Worksheet

SEDIMENT
FS – Fine Sediment Deposition
CS - Coarse Sediment Deposition

DISCHARGE
SC - Scour Depth
SF - Scour Frequency
BE - Bank Erosion

WOOD
WL - Wood Loss
WA - Wood Accumulation

CATASTROPHIC EVENTS
DFS - Debris Flow Scour
DFD - Debris Flow Deposition
DB - Dam Break Flood

VW > 4CW UNCONFINED	1, 25, 114, 116, 2, 90, 13, 109, 28 (9)	15, 17, 103, 127, 138, 63 (6)				....
2CW < VW < 4CW MODERATELY CONFINED	15, 119, 32 (3)	63, 11, 26, 31, 64, 93, 134, 97, 99, 105, 113, 117, 120, 125, 140, 141, 142 (17)	40, 54, 69, 89, 102, 104, 106, 121, 123, 135, 143, 144, 16, 35 141, 94, 19 (17)	46, 73, 108, 110, 132, 65 (6)	75, 77, 79, 91, 130 (5)	
VW < 2CW CONFINED	....	3, 5, 7, 14, 24, 27, 30, 39, 50, 115 (10)	10, 18, 83, 95, 98, 100, 118, 49, 6, 4 (10)	8, 23, 33, 41, 44, 56, 57, 101, 112, 139 (10)	9, 21, 29, 34, 36 38, 45, 43, 47, 51, 53, 60, 66, 68, 70, 81, 82, 87, 88, 96 107, 126, 128, 129, 133, 137 (26)	22, 37, 42, 48, 52, 58, 59, 61, 62, 67, 71, 72, 74, 76, 78, 80, 84, 85, 86, 92, 111, 122, 124, 126, 136, 31 (26)
	<1.0 Pool-Riffle	1.0 - 2.0 Pool-Riffle, Plane-Bed	2.0 - 4.0 Plane-Bed, Forced Pool-Riffle	4.0 - 8.0 Step-Pool	8.0 - 20.0 Cascade	> 20.0 Colluvial

VALLEY GRADIENT AND TYPICAL CHANNEL BED MORPHOLOGY

Figure E-3. Example of a Channel Segment Worksheet

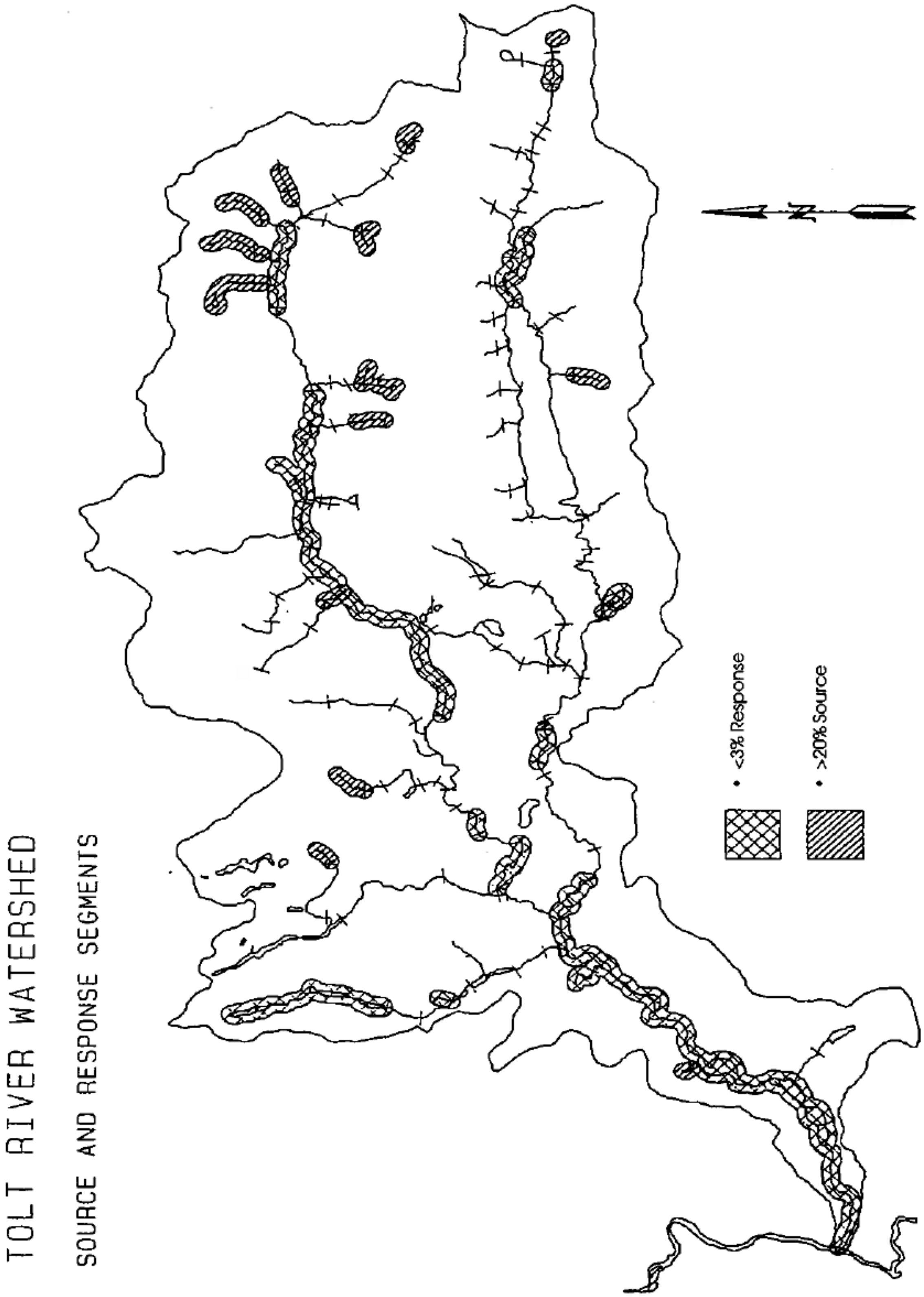


Figure E-4. Example of Source, Transport, and Response Reaches

Historic Changes

Historic changes and trends in channel attributes provide an important component of the context within which to assess current and potential future channel conditions. A wide variety of historical data are useful for reconstructing past channel change, and all available information should be utilized. In most cases, aerial photography will provide the primary source of historical data, although terrace and floodplain deposits can be mapped and dated to learn about past erosional regimes and channel response. Analyses that can be done with aerial photography largely address the question of historical trends in macroscopic channel morphology, such as channel widening, incision, migration, or transformation from a meandering to a braided channel pattern. Reconstruction of historic changes involves comparison of channel conditions through time with some reference standard to determine the degree of disturbance and recovery in a basin. Lacking other information, channel conditions apparent on the earliest available photographs may provide an appropriate reference standard.

Field interpretations allow further comparison of existing channel conditions to reference standards that define desirable channel conditions. The chosen reference conditions, however, must be appropriate for the channel type under consideration, as imposition of simple numerical standards (e.g., pools per mile) on all channel types is inappropriate. Aerial photo analysis is an efficient way to focus field effort, as well as a valuable indicator of past channel response.

Multiple-decade photo coverage is necessary to provide a reasonable determination of trends in channel condition through time. Accurate portrayal of these trends becomes very important when trying to infer causality through comparison of channel change with spatial or temporal patterns of natural and land-use disturbance (i.e., during construction of a diagnostic sediment budget). Evidence of change or trends through time can occur on both larger and more local scales. Large-scale changes in channel morphology may reflect landslide scour, flow diversions or additions from road drainage, and changes in sediment supply. Local changes can include bank erosion and channel widening following riparian disturbance and harvest, direct disturbance to the channel, depletion in the amount of in-channel wood, and increased or decreased pool frequency or area.

Interpreting Photos

Once the channel network has been segmented, the analyst examines aerial photographs for changes in channel width, bar positions and stability, wood loading, channel pattern, canopy opening and channel position. Channel widths should be compared at the same characteristic and recognizable points for each reach on successive aerial photographs. Measuring the same cross-sectional area (transect) allows the stream channel analyst to compare the change in channel width and area over time. For small channels, direct observation of channel width may not be possible due to dense riparian vegetation. In these channels, canopy opening provides a useful surrogate for channel width (Grant et al, 1984; Grant, 1988). In larger channels, gravel bar size and vegetation cover also can be seen and reconstructed through time.

Recording data

For each numbered channel segment, the analyst estimates and records whether the average width of the segment canopy opening increases, decreases or remains the same through each time interval in the photo record. The channel disturbance worksheet (Form E-2) provides a convenient method for documenting observations of channel conditions and change determined from aerial photograph analyses. For reaches that exhibit gross changes such as extensive widening or braiding, it is often useful to trace the active channel area for each photo year available. Channel area and width can be plotted over time to display changes in the channel. Other changes in channel conditions noted during aerial photograph analysis also are noted on Form E-2. (e.g., riparian disturbance, buffer size, road crossings, if yarding occurred across a channel, or if LWD was pulled). Segment selection is an iterative process; as sampling proceeds, questions will be raised that guide selection of additional field sampling segments. Consultation with the other analysts is critical in raising questions and identifying sites for field inspection.

The aerial photo analysis will also help guide site selection for field assessment, which will help the analyst answer other questions pertaining to interpretation of channel and fish habitat conditions.

The analyst should develop a brief narrative describing the overall results of the historic photo analysis for the watershed.

An example from the Tolt River

The channel disturbance worksheet from the Tolt River watershed analysis (Figure E-5) identifies locations where change has occurred (segment response number), the style of change (e.g., increased channel width), the period of change, and gives a brief description of disturbance indicators. For example, the upper North Fork Tolt (Segments 12 through 16) increased in width between 1945 and 1980, started to narrow between 1980 and 1990, and lost riparian and bar vegetation after several floods in 1990. Before 1954, all of the riparian vegetation was cut in these reaches. By 1954 there was evidence of extreme widening leading to channel braiding. Less intense widening subsequently occurred downstream. Widening continued until the late 1970's, when the upper North Fork started to narrow. At present, reaches of this braided section of the North Fork Tolt continue to narrow.

Channel Response Segment Number	Change in Channel Width (+ or -)	Time Interval (years)	Disturbance Indicators: Channel pattern change, alluvial fans, adjacent landsliding, channel widening, narrowing, catastropic damage
15 (1-2MC)	ΔW + '58-76 - '76-'87/90 upper ½ - '76-87 lower ½ + 87-90	32 years 1958 - 90	+'58-76; 100% of riparian veg harvested (~50% of harvest between '64-70) Narrowing of channel '76-87 - upper ½. Increased width in lower half during this period. Same trend continues to '90 "widening" is propagating downstream. Titicaed harvested '70-76. Two distinct areas of widening in segment, propagating downstream
16 (2-4 MC)	Ø	26 years	Bridge constructed between 64-70. Open trib at upper end of segment (Holman Cr) in '64 - remains open for entire period. 50% of riparian area cut pre-64; 100% by '76.
17 (1-2LC)	ΔW + '58-64 Ø '64-70 + '70-76 Ø 76-82 - 82-87 Ø 87-90 + 90-91	32 years 1958 - 1990	Sporadic increase in width from '58-'82, then decrease in 82-89 period. 50% of riparian area cut pre-64; 100% by '76, 4 open tribs; 1 debris flow in 64 - 2 closed and 2 open tribs by '89. Renewed widening in lower ½ between 90-91 ('90 Flood)
18 (2-4TC)	+ '70-'82 Ø 82-90 + 90-91	64-90-91 27 years 1964 - 91	Increased width slows between 82-87. Titicaed opened in between '70-'76 (enters mid-segment.) 0% riparian harvested in 64; 50% by 70; 100% by '76. Greatest enlargement between 70-76-82. No harvest upstream (NF boundary at upper end of segment) Renewed widening between 90-91. '90 Flood effect
19 (2-4MC)	- or Ø 64-87 + in '91 photos	27 years 1964 - 91 64-87-91	Appears widened in '64 photos; gradual narrowing thru '87. Increased vegetation on bars '91 NF photos show channel open, splitting and braiding. '92 FS stream survey says extensive braiding - natural landslides from Red Mtn. upstream, mature forest has kept stream channel intact despite erodible banks.
20 (4-6TC)	+ pre '64 Ø or + 64-91	1964 - 91 27 years 64-87-91	Appears widened in 64 photos - openings in canopy. ('92 FS stream survey says mostly steep BR channel, transports sediment generated by natural landslides off Red Mtn. Little or no change '91. Riparian veg intact but several open areas. Fresh debris slide off Red Mtn enters at top of segment.
21 (8-20 TC)	+ pre '64 Ø, or + 64-91	27 years	Appears widened in '64 photos - openings in canopy ('92 FS stream survey indicates large natural landslides off Red Mtn - probably experienced debris flow in this segment) Sparse riparian vegetation (natural); actively eroding.

Figure E-5. Example of Channel Disturbance Worksheet

Interpreting the cause of this channel response provides a good example of extending the analysis beyond the standard method when faced with uncertainty. The cause of this widening and resulting change in channel morphology was uncertain from the standard analysis. The assessment team decided to analyze discharge records for the period covered by aerial photographs. This further analysis supported the interpretation that riparian harvest and direct channel disturbance, followed by several greater than 10-year flow events, resulted in bank erosion, channel widening and eventually braiding in response to the increased supply of coarse sediment remobilized from flood plain deposits.

Current Channel Conditions

Physical features indicative of channel conditions reflect the interaction of many processes that influence transport capacity, bank stability, sediment supply, and availability of flow obstructions. Different types of channels respond differently and there is no single metric for assessing the condition of a stream channel. Nonetheless, impacts resulting from land use can change bed and channel configurations in ways that may affect public resources, perhaps most importantly aquatic life and water quality. Such changes in channel conditions can manifest in a variety of ways in the bed, active channel and flood plain. Some channel characteristics or potential responses are only applicable in certain channel types and establishing direct evidence for such changes is further complicated by the potential for complementary or opposing channel response to contemporaneous changes in discharge and sediment supply. Consequently, we adopt the approach of synthesizing available evidence into a diagnosis of channel conditions. We feel that with enough experience this approach will identify the dominant controls on current channel conditions, but we do not know how good it will prove for more subtle interactions. This approach differs considerably from previous channel assessment methodologies (e.g., Pfankuch, 1975) in that it adopts a process orientation and rejects the temptation to develop a single numerical score for interpretation of current and potential channel conditions. Our philosophy is to design a robust framework within which to analyze channel processes that allows for assessment of both existing conditions and prognosis of potential future conditions. The method more closely resembles medical diagnosis techniques.

The segment categorization is applied from remote data and it simply suggests probable stream conditions. Units mapped in this fashion contain no information about present stream states, although most probable states might be inferred, given knowledge of watershed condition and experience with the segment type. This is important, because at finer spatial scales the structure of channels can be highly variable through time responding to changes in the rates of important processes that determine stream morphology including sediment and discharge regimes and the frequency of channel obstructions (Sullivan et al., 1987). This spatial-temporal variability is an inherent characteristic of a segment type defined by more stable features, although the frequency and magnitude of natural variability is generally unknown.

A major task is to identify and assess relationships between channel characteristics and the volume and quality of sediment and obstructions and to flow regime by segment type for the watershed under assessment. The primary environmental factors determining channel condition within a segment at a point in time are the sediment regime (amount and size), discharge regime (frequency and magnitude), and channel obstructions (substrate, LWD, confinement). Consistent with general systems theory (Orsborn and Anderson, 1986), these are referred to as input variables in that they are factors that are extrinsic to a channel segment.

Geology and climate may strongly influence stream channels by determining both the type and input rate of sediment and the quantity and timing of flows available to transport sediment. Forest management and other land use activities can affect each of the input variables directly or indirectly with resultant effects on stream channels. Forest management may result in accelerated rates of sediment input, altered flow regimes, and depletion or removal of channel obstructions (especially LWD).

The current "state" of a segment may vary over the range of potential channel conditions characteristic of each type depending on current and historic interplay of the input variables, reflecting climatic variability and the history of natural or land-use disturbance influencing each segment. Although the channel characteristics of a segment can also vary over time, the potential state of each segment has finite boundaries. Within a watershed it is feasible that, at any one time, two segments of the same type may be at opposite ends of the scale of potential conditions for that particular segment type.

By classifying channels into segments we can identify general stream properties and responses associated with stream types that occur widely within broad geographic areas. However, an evaluation of stream conditions and probable response to watershed disturbance only can be done by considering each local site within a watershed context. Each watershed has unique combinations of geologic and climatic conditions, as well as a history of storms and past disturbance.

A channel segment will have different characteristics depending on sediment loading, hydrologic conditions and obstruction frequency. Interpretations of channel response for segments of a given gradient/confinement class would necessitate determining the current position on a sediment loading continuum from "sediment poor" to "sediment rich". Channels of a given segment class will respond to an absolute increase in sediment input in a manner related to its present position on the "loading continuum". To develop the relationship between input variables and stream channels, we must identify variables to be measured that respond to changes in the input factors. Response variables are defined as characteristics that change in relation to input variables.

Hypothetically, current input factor levels could be determined by indices of response variables that reflect the prevailing sediment rates, flow regime or obstruction characteristics stratified by segment type. Such indices may be one or more response variables that indicate the general level of an input variable. However, there currently is no scientifically-validated channel condition index available that estimates rates of input factors with quantitative channel measures, although qualitative indices have been used for specific channel interpretations (e.g. Pfankuch, 1975). Until a quantitative method is available, we adopt the approach of using all available evidence to generate a diagnosis of channel conditions.

Our method involves making field observations of key attributes of the stream bed, active channel and flood plain in selected locations and, using geomorphic theory as a basis, diagnosing relative levels of input factors from the weight of the evidence provided by the conditions examined. Interpretations will be guided by the diagnostics of this method but the quality of the interpretations will remain largely dependent on the experience and skills of the analyst. Some interpretations may be augmented at later stages of assessment when geologic and hydrologic history of the watershed are available.

Channel conditions reflect spatial and temporal linkages through the watershed. Causality of potential linkages should guide interpretation of channel conditions and selection of representative reaches for field assessment.

For example, sediment perturbations can be greatly damped with increasing drainage area, and therefore spatial scale is important when predicting sediment impacts to channels (Benda, 1993). In addition, tributary junctions of first and second order channels with third and higher order channels are typically depositional sites of debris flows, and abrupt changes in channel morphology at those locations can be expected (Perkins, 1989; Benda, 1990). Dam-break floods laden with organic debris can affect certain portions of a channel network (Coho and Burgess, 1991).

The current state of a segment has a strong influence on probable response to management activity and is an important starting point for understanding observed trends or predicting probable changes with a management activity. Assessing the current stream channel requires several steps:

- select representative sites for field observations
- make field observations relevant to interpreting aspects of channel processes
- diagnose channel conditions relative to input factors
- interpret potential future conditions based on channel processes.

Selection of Segments for Field Assessment

Remotely sensed information is useful in assessing only certain aspects of channel morphology. Other aspects crucial for evaluation of geomorphic processes (e.g., downcutting or aggradation) and habitat condition (e.g., pool frequency or depth) rely on field observations. Unless unlimited time and resources are available, the analyst will need to focus field assessment on representative reaches and extrapolate conditions to other portions of the channel network.

Sample Size

In order to adequately characterize the watershed, the analyst should sample 15 to 25% of the numbered segments in a basin. Sampling should be stratified and based on the distribution of gradient/confinement classes and an attempt should be made to sample a reach representative of each class. Depending upon the variability of physical factors present in the basin, it also may be necessary to include several segments for each class to collect a representative sample. The channel segment map and worksheet will assist in identifying the mix of response segments in the watershed and the disturbance assessment worksheet may guide selection of channel segments for field examination. Again, it is the most important phase of this module, so an increase in sample size will increase confidence in the overall assessment. If time permits, reconnaissance surveys can be made in the beginning and end of the assessment in order to gain a more qualitative understanding of the similarity and dissimilarity between segments.

Selection Criteria

There are a variety of criteria for selecting sites for field visits. We suggest the following in approximate order of utility:

1. The number of segments of a given type in the watershed (see Form E-1).
2. Segments of known resource importance (consult with fish habitat and hydrology analysts). Candidate segments may include unique combinations of response segment and public resources.

3. Representative physiographic and geologic areas of the watershed.

4. Segments which represent both disturbed and undisturbed conditions.

5. Segments likely to respond to changes in specific input factors (sediment supply, LWD, etc.).

6. Segments likely to respond significantly to changes in independent variables (i.e., 2-4% gradient, moderately confined reaches).

7. Segments subject to inputs from hillslope hazards (consult with mass wasting and surface erosion analysts).

8. Segments that are unique or unusual. (e.g. steep, unconfined reaches)

Selected segments should represent a mix of responses reasonably distributed throughout watershed. Site selection is one of the most important steps in the channel module because if the analyst looks for change in locations where it is unlikely, then resulting information will be misleading. Consequently, recording rationale for site selection is an important component of the channel assessment process. The field site selection worksheet (Form E-3) is provided to briefly document rationale for each segment the analyst will visit.

It will be important to consult with the mass wasting, surface erosion, hydrology, and fisheries analysts for input on critical sites while developing the rationale for site selection, and throughout the field phase of the assessment.

Field Observations

The condition of a stream channel and its flood plain reflect the sediment supply, discharge, and roughness regime of the present, imprinted over any remaining effects of past disturbance (Sullivan et al., 1987). The channel analyst uses key features to identify the occurrence of historic events as well as to diagnose the current regime of key watershed processes. **During this phase of the assessment, the analyst should communicate with individuals conducting the other modules to begin developing working hypotheses on whether the existing conditions are normal for the watershed and reflect geology and climate, or are due to natural or landuse disturbance.** However, causal interpretations are developed during the synthesis stage of the resource assessment using information on erosional and hydrologic history of the watershed.

Fluvial geomorphologists have developed a number of relationships showing patterns of channel characteristics, such as hydraulic geometry, within and between watersheds (Leopold et al., 1964). There has been less progress equating variability of these characteristics within and between watersheds with varying sediment supply, flood hydrographs, and channel roughness. Nevertheless, geomorphologists use key features to qualitatively and, in some recent cases, quantitatively relate specific channel conditions with variations in watershed processes. We draw upon this experience to suggest a diagnostic method that relies on field observations of stream and flood plain features.

Diagnosis of channel condition relies, to a large extent, on qualitative and quantitative field observations of diagnostic characteristics of the channel bed, active channel, and flood plain. These characteristics help indicate the relative magnitude of channel processes, and reflect the style and magnitude of past and potential future responses to changes in sediment supply, discharge, LWD, and large-scale disturbance.

The field component of the channel module is designed to assess, in a simple and repeatable manner, key characteristics of the stream channel that are useful for interpreting channel condition and response potential. The point is to help generate a story. These key features include:

- Channel bed morphology
- Gravel bar characteristics
- Pool characteristics
- Channel dimensions (slope, width and depth)
- Fine sediment deposits
- Roughness elements
- Stream bed material
- Channel pattern
- Bank and riparian conditions
- Flood plain attributes

Unless the analyst justifies the exclusion of features, each should be addressed in some way. Although methods are provided here, the analyst may use discretion in the detail and methods employed to characterize key features. **Although these characteristics are appropriate indicators of channel conditions, not all are relevant and need to be measured in each channel segment.** Table E-3 includes a description of the channel types in which different attributes are most appropriate. (see column in Table E-3 entitled "Applicable to segment type").

The field measurements and observations described below is a list of tools that can be used to interpret stream channel conditions. If other scientific methods are used, they need to be fully explained in the channel methods section of the assessment report. For some of these characteristics, the confidence level of interpretations based on the field assessment can be increased, and uncertainty commensurately decreased, through additional more detailed observations or modeling. The analyst compiles as much information on key channel features as possible, and uses them to diagnose channel condition, as described in a subsequent section of this module.

The following section discusses field methods for collecting observations on each of these channel characteristics. It is not feasible to conduct field observations and measurement of channel features throughout entire channel segments which are long in any kind of reasonable time frame. Rather, field observations should be collected at a characteristic reach within a numbered channel segment. A channel reach may be considered to be on the order of 20 channel widths in length. A longer length can be sampled if 20 channel widths does not capture the variability within a reach. The key is to capture segment variability, which is part of the overall channel variability.

Channel Bed Morphology

Channel bed morphology provides a general indication of the style of potential channel response (Montgomery and Buffington, 1993). The gradient/confinement classes determined from map and aerial photograph analyses should be supplemented on the basis of field observation for each channel reach visited in the field assessments. This classification will provide context to the subsequent channel diagnosis.

The nature and organization of channel bed material defines the channel type in this classification (Montgomery and Buffington, 1993). There are eight general channel types; colluvial, bedrock, braided, regime, pool-riffle, plane-bed, step-pool, and cascade, but intermediate morphologies are common in many watersheds. There are two important issues to consider. Several channel types can exist within a channel segment. Secondly, some channel types can alternate between bed morphologies listed below (Benda, in prep.)

Colluvial channels are recognized by the presence of colluvial deposits in channel banks and the presence of only a thin layer of alluvium overlying colluvium in the valley bottom.

Bedrock channels are floored in bedrock and lack a contiguous bed of alluvial material. The other six channel types are all alluvial channels in which the channel bed and valley fill are composed primarily of material transported by the channel.

Regime channels are often sand-bedded and are recognized by the presence of ripples or dunes on the low-flow channel bed.

Braided channels are those with multiple active channel ways.

Pool-riffle channels may be either free-formed pool and bar sequences or pool and bar sequences by flow obstructions, such as bedrock outcrops, boulders, and LWD. In the latter case the channel has a forced pool-riffle morphology.

Plane-bed channels are those that exhibit a flume-like bed morphology lacking distinct pools.

Step-pool channels are those in which tumbling flow over regularly-spaced accumulations of coarse grains separates channel-spanning pools.

Cascade channels are those characterized by essentially continuous tumbling flow.

At each channel reach visited, the channel morphology is classified according to the above criteria. Intermediate channel morphologies (i.e., plane-bed/step-pool or step-pool/cascade) are acceptable classifications for reaches exhibiting poorly-developed characteristics representative of different channel types. Further descriptions of these channel types are presented elsewhere (Montgomery and Buffington, 1993).

The classification scheme is one way to describe where there is a change in channel bed morphology. It is also important why channel bed morphology changes and what is the process that causes a change within a given reach. For example, if a forced pool-riffle reach goes to a plane bed reach, is it due to a change in gradient or a reduction in the amount of LWD? It is important to note what variables (e.g., gradient, confinement, input factors [wood, sediment], or processes [fluvial v. mass wasting dominated] have changed within a reach. Field form E-4 entitled "**CHANNEL BED** -*Channel Bed Morphology*" gives a recommended format to identify the different channel types, as well as, source, transport and response zones, in a given reach or segment. It includes a comment section to document what and why changes to input factors and processes occur.

Gravel Bar Characteristics
Most of the readily available sediment in moderate to large channels is stored in bars--sediment accumulations within the channel that are one or more channel widths long (Church and Jones, 1982). Bars may lie in the center of the channel, along one side, or across the entire width, thereby forming riffle-pool sequences. Areas of shallow flow over bars are commonly called riffles; deep areas located between bars are pools. Differential patterns of entrainment, transport, and deposition of sediment during floods set up the general morphology of the channel bottom, which then determines the flow characteristics at lesser flows (Sullivan et al., 1987).

Sediment bars may be forced by local flow divergence associated with in-channel obstructions or freely-formed. Bars may be generalized into point, medial, multiple and forced bars. Point bars occur on the inside of meander bends, medial bars are topographic high points in the middle of a channel, multiple bars across the active channel define channel braiding, and forced bars are local sediment storage elements forced by flow divergence imposed by in-channel flow obstructions, such as boulders, bedrock outcrops, or LWD. Bars forced by flow attributes may be due to either direct physical impoundment or result from local hydraulic divergence. The location and area of gravel bars reflects the sediment load of the stream as well as the presence of flow obstructions.

The type of gravel bars present in the segment, their association with obstructions, and their relative proportion of the active channel area should be noted. The size of the riparian opening relative to the active channel width also may be measured during field inspection. Field form entitled "**ACTIVE CHANNEL** -*Gravel Bar Characteristics*" gives a recommended format to help quantify the amount, size and activity level of gravel bars present in a reach. Information on side channels can also be incorporated.

Pool Characteristics
Pools represent the deep topographic depressions between the crests of the gravel bars. They may be formed by a variety of processes involving interactions between discharge and sediment transport, disruption of flow by in-channel obstructions that create local flow convergence and bed scour, and from the focusing of flow into channel banks that causes local scour. Pools may be either hydraulically formed by the interaction of sediment and water movement, or they may be forced by local flow obstructions, such as boulders, bedrock outcrops, and LWD (Lisle, 1986). Increased LWD loading forces creation of additional pools, which contributes to the complexity of in-channel habitat. Although different types of pools have distinctly different habitat values, the pool spacing provides a simple quantitative index of both habitat availability and complexity. Pool spacing is a primary channel attribute that is

very sensitive to the loading of in-channel LWD in certain channel types (Montgomery et al., 1993). Different pool spacing typify different channel types, as discussed further in the channel diagnosis portion of the channel module.

Pool frequency should be assessed for each channel segment visited during the field assessment. This involves simply counting the total number of pools within a selected reach. The pool frequency is expressed in terms of the channel length normalized by the channel width divided by the number of pools, yielding an expression for the channel widths per pool. (Channel width/pool=[reach length/channel width]/number of pools). The analyst needs to identify if there is a minimum size pool or criteria which they use to define what pools will be measured. For example, an analyst can measure pools greater than one-half the channel width, or they can measure all pools including small pocket pools on the lee side of obstructions. It is up to the analyst to decide and note their criteria.

The factors controlling pool formation in a channel reach are an important observation for interpreting pool spacing. In each channel reach visited the total number of free and forced pools should be recorded. Forced pools can be subdivided into those controlled by LWD, boulders, and interactions with channel banks. The pool forming factors is often more than one control.

Field form E-4 entitled "**ACTIVE CHANNEL** -*Pool Forming Factors (PFFJ*" is a recommended format to record information on what forms a pool, the pool dimensions, what type of substrate the pool is formed in, and how big of an obstruction is needed to form it. This data gives the analyst basic information on the distribution of pool forming factors and the relationship between obstruction size and residual pool depth (maximum depth - tailout depth). **Empirical information can be derived from such data that can be useful to assess what the role of different pool forming factors and associated obstruction sizes are in the different geomorphic units.**

Subsampling a reach to identify PFF may be a more efficient way to gather this type of information because it takes time and may preclude the analyst from measuring and observing other important parameters.

Channel Dimensions (Slope, Width, and Depth).
Stream channel dimensions are primary channel characteristics related to the channel-forming, or bankfull, discharge. Channel slope, and bankfull width and depth measurements should be taken in the same area where pebble counts are conducted so that they will provide compatible data for subsequent analyses. Slope

Although the approximate valley slope will have already been inferred from topographic maps in the channel segment delineation portion of the channel assessment, channel slope should be field surveyed for channels visited in the field assessment. Accurate measurement of channel slope is necessary for calculations pertaining to the channel condition diagnosis and is especially important if the analyst intends to pursue more detailed analyses involved calculation of sediment transport rates for the watershed.

There are many ways to measure channel slope, but a hand or engineering level should be used to measure channel slope in the field. Although popular among biologists and foresters, clinometers are not an acceptable technique, in low gradient channels (e.g., < 3%), as they are accurate to only $\pm 1^{o}$ in the hands of experienced users. Moreover, they provide little improvement over reach-average estimates derived from topographic maps. In low-gradient channels in particular, differences of less than 0.5^{o} may be significant and errors of 1% are common using clinometers. Channel slope should be measured over a distance of at least 10 channel widths to ensure characterization of the reach-average slope. If a clinometer is used in higher gradient channels, then approximate measures should be taken to ensure accuracy such as tying flagging at eye level and standing at water level to improve accuracy. If a clinometer is used, it should be noted.

Bankfull width

Bankfull stage (Wolman and Leopold, 1957) often is considered to represent the dominant discharge associated with channel-forming events. The recurrence interval of bankfull events varies between channels and regions, but is generally between 0.5 and 2.0 years (Williams, 1978). The bankfull width is the horizontal distance between the channel banks measured directly across the channel.

Bankfull depth

The bankfull depth is the average flow depth across the channel at bankfull stage. The number of bankfull width and depth measurements should be adjusted to capture variability within a channel segment. The bankfull depth may be approximated by dividing the channel cross-sectional area by the bankfull width. This requires surveying a cross-section across the channel. A hand-level, tape, and rod survey capturing major topographic changes along the cross-section is sufficient to portray the cross channel form. The survey should be done at the same locations as pebble counts. Identification of the bankfull flow depth is not always straightforward. Often it coincides with the topographic break-in-slope at the top of the channel banks. In channels that are incised into terrace or debris-flow deposits, however, the bankfull discharge may be significantly lower than this topographic feature. The top of in-channel bars, the limit of vegetation growing along channel margins, and other features may help in estimating the bankfull flow depth.

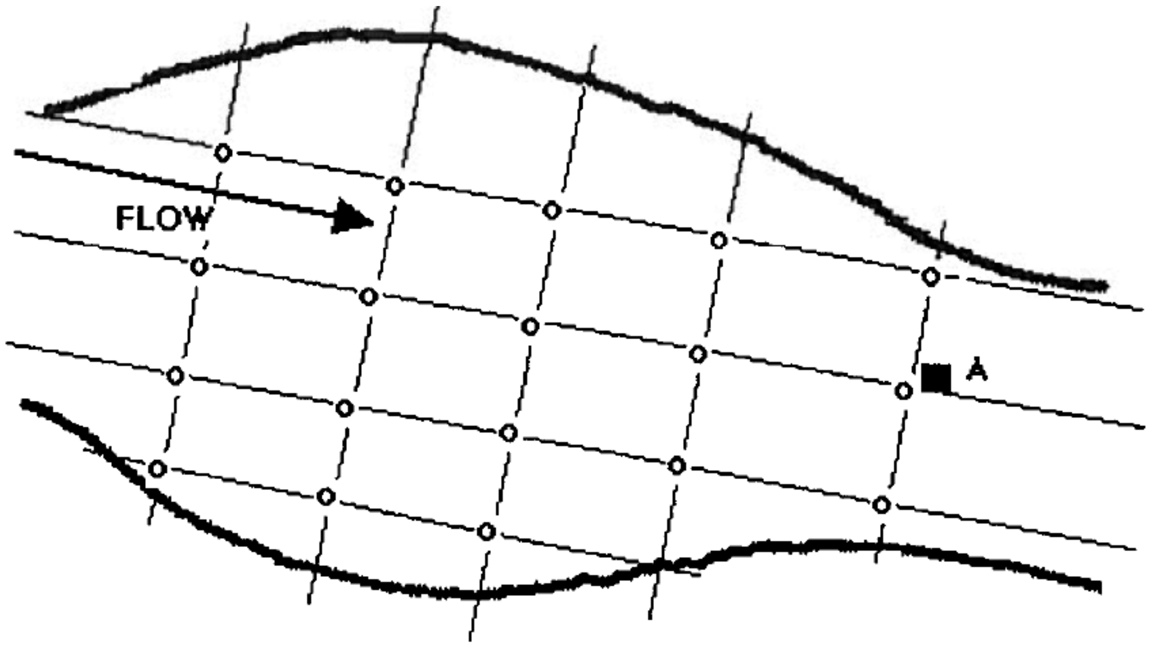


Figure E-6. Longitudinal and Cross-sectional Breakdown of a Pool

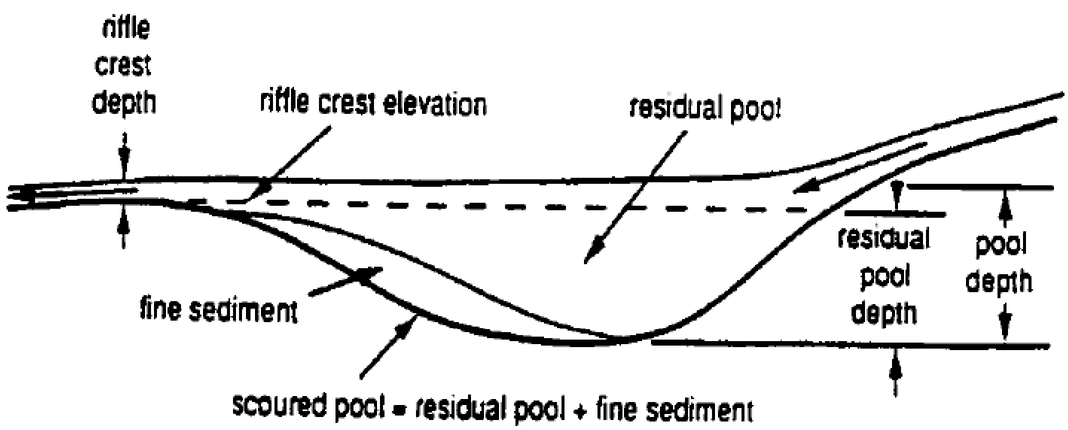


Figure E-7. Longitudinal Profile showing Residual Pool Depth
(From Lisle and Hilton, 1992)

Field forms E-4 entitled "**ACTIVE CHANNEL** - *Long Profile and Cross-Section Data Sheets*" can be used to help gather survey information.

Fine Sediment Deposits

The amount and distribution of fine sediment (e.g., material less than 2mm diameter) on the bed of a channel reflects the combined influences of local hydraulic controls, flow obstructions, and sediment supply. Examination of locations where fine sediment occurs helps to sort out these influences. These locations may be generalized into the following categories: fine sediment occurs 1) locally in pools, 2) in pools and as patches on riffles and bars, and 3) extensively in pools and over riffles. Different additional observations and measurements of fine sediment distribution are appropriate for pools and riffles.

In Pools

The volume of fine sediment overlying coarser channel bed material provides an index of the fine sediment supply to a channel (Lisle and Hilton, 1992). Measuring the volume of fine sediment in a pool involves division of the pool into longitudinal and cross-sectional transects (Figure E-5). The depth of fines is measured using a probe to assess the depth to larger material of the pool bottom at each location where longitudinal and cross-sectional transects intersect. A single point measurement of the fine sediment thickness within a pool is inadequate in all but unusual circumstances because of the variability of sediment depth within the pool. The residual pool depth (Lisle, 1989) also is measured at each sampling location. This is determined as the elevation difference between the pool bottom and the elevation of the pool overflow (Figure E-6). This is readily determined using a hand level and survey rod. The number of points measured within a pool should reflect the size of a pool, but typically at least nine measurement points are necessary to capture the in-pool variability of the fine sediment thickness. Field form E-4 entitled "*V* Data*" is a recommended format to help gather data on the amount of fine sediment in a pool.

Within riffles

The nature and extent of fine sediment distribution over riffles provides an additional observation to record for each channel reach visited in the field assessment. In particular, it should be noted as to whether fine sediment occurs 1) locally within the lee of large clasts and in other hydraulically-sheltered locations; 2) as strands extending downstream from large clasts; 3) over most of the channel bed; or 4) as a thin draping over larger clasts composing the bed surface.

Roughness Elements

Features that provide resistance to flow are an important determination of channel architecture. Energy dissipation results from drag induced as water flows over the bed particles, as well as around the larger scale bedforms including gravel bars meander bends and channel obstructions. In many mountain channels LWD is a dominant source of channel roughness (Sullivan et al., 1987). Wood and alternating obstructions serve as focal points of scour and deposition, ordering the position of gravel bars and sediment storage sites, and intervening scour holes as pools (Lisle, 1986).

The type and distribution of roughness elements can be a major control on channel architecture. The amount of in-channel LWD may be influenced by forest practices while other roughness elements may not. Overall and localized transport capacity of a stream segment is reduced with increased size and numbers of large roughness elements, which could influence the sorting of sediment within the active channel as well as the particle size characteristics of the bed (Buffington, in prep.). Recognizing the role and nature of roughness within a stream segment is important to understanding channel condition and potential sensitivity to land use practices.

Prior to doing field work, the stream channel analyst should meet with the fish habitat and riparian analyst to decide who will count LWD. The stream channel analyst should, regardless of who does the actual wood count, identify the form and function of LWD through the pool-forming factors data, or type and distribution of roughness elements data collection process.

Field forms E-4 entitled "**CHANNEL BED** - *Dominant Roughness Elements (DRE)*" and "**ACTIVE CHANNEL** - *LWD Functions(F)*" are recommended formats which help the stream channel module leader gather qualitative and quantitative information on roughness elements (e.g., boulders bedforms, and LWD), bed surface patterns, fine sediment deposits, LWD functions (e.g., pool scour, stability and sediment storage sites) and the amount of stored sediment behind LWD structures. Such data can be used to derive empirical relationships, at a segment type or geomorphic unit scale, on the role of obstructions in forming and maintaining channel morphology.

Stream Bed Material

Surface Particle Size**.** The size of particles on and below the channel bed surface are primary channel characteristics that are sensitive to changes in sediment supply, discharge, and in-channel roughness elements (Buffington and Montgomery, 1992). The channel bed typically is coarser than the under-lying substrate. This surface layer of coarser material, often referred to as an armor layer, represents the material providing shear resistance to flow at the channel bed. The characteristics and size of the coarse surface layer control bed mobilization and initiation of sediment transport.

There are many possible sampling techniques and strategies for characterizing channel bed surface textures (c.f. Diplas and Sutherland, 1988) within and between reaches, and several of these techniques are discussed below.

The analyst's choice may reflect a combination of the time allotted and the detail required for characterizing a given reach.

The most common method of grain size sampling is the pebble count technique proposed by Wolman (1954). The basic procedure is to measure the intermediate diameter of 100 grains over a given area of the channel. In order to characterize the full range of grain sizes at a particular location one should conduct a bank-to-bank cross-channel sampling by traversing the channel and measuring for each step the clast immediately in front of one's boot toe. Grain sampling is intended to be random; look away from the bed while advancing across the channel and while reaching for a grain. Measurement locations within a sampling area are determined by either taking random steps or pacing several fixed-interval transects. Accurate representation of the distribution of grain sizes in a reach depends on both the number of sample sites chosen and the area sampled. The analyst should sample enough locations to capture the variability within the channel segment. Any criteria used to establish sampling area size should probably be scaled by the channel width.

Sampling across the active channel may be impossible during high flows or for other dangerous conditions. Two possible strategies can be used in this case. The first is to walk the reach, observing the variability in surface textures, and conduct pebbles counts at several locations that are deemed representative of the general textural conditions of the channel. The second method involves a systematic sampling of a particular morphologic point on several bars within the reach. Typically, high velocity core cross-over locations on point bars (Dietrich and Smith, 1983) is chosen. This technique is attractive, because it is based on systematic sampling of morphologically similar locations in a channel. However, the technique may not accurately represent the full range of grain sizes present in a channel, nor is it recommended for complex LWD-dominated channels, because of the non-systematic nature of barform characteristics and morphogenesis in these streams. For both of these sampling strategies, pebble counts over small areas (order of 1 sq m) can be conducted by point counts using the same techniques discussed above for cross-channel sampling.

A final technique involves identification, sampling, and spatial averaging of discrete textural patches within a channel (c.f. Buffington, in prep.). The analyst first walks the study reach, visually partitioning the bed into distinct textural patches. One or more pebble counts are conducted for each specific textural type and subsequently assumed to be representative for that texture throughout the reach. Textural pebble counts are then spatially averaged based

on areal representation of each texture within the channel. Areal extent can be quantified rigorously through detailed textural mapping or estimated by visual inspection.
A variety of other sampling techniques also exist, such as wax casting, spray painting, and photo inspection (Diplas and Sutherland, 1988). The particular technique employed should be done consistently throughout a watershed, as different methods and strategies are not necessarily comparable.

The pattern of sediment distribution on the bed surface should also be noted. In particular, both the dominant surface texture (i.e., boulder/cobble) and the variance of surface textures should discussed. For example, a channel bed may be composed primarily of cobbles, with gravel bars impounded behind LWD jams. A simple description of the distribution and patterns in the variation of surface grain sizes is an important piece of information regarding channel attributes.

Subsurface Particle Size. The substrate underlying the surface armor of a channel is thought to be representative of the bedload material transported by the channel following disruption of the armor layer (Parker et al., 1980). Thus the percentage of fine sediment in the subsurface reflects the supply of fine sediment to the channel.

Estimating the subsurface particle size is more difficult than the surface sampling methods because of the difficulty of removing surface sediments to the subsurface. The simplest method involves a modification of Wolman's pebble count method. First, the surface armor layer is removed from an approximately $1m^2$ area of a medial or point bar. The surface layer normally extends as deep as the larger clasts exposed on the bar. Second, subsurface material exposed in the excavation is mechanically mixed. Finally, a pebble count is conducted on at least 100 grains randomly selected from the excavation. Subsurface pebble counts should be taken in the same area as surface pebble counts. Care should be taken, however, to avoid sampling in hydraulically sheltered locations, (e.g., in proximity to large woody debris). Because of the modifications resulting from sampling difficulties, the accuracy of this method is likely to be lower than other more intensive methods. Greater certainty in the subsurface particle size analysis may be attained through sieve samples of the channel substrate in order to more accurately assess the grain size distribution, and thus channel sensitivity to changes in sediment supply and transport capacity, or the potential influence of fine sediment on fish populations. The percentage of fine sediment in subsurface gravel should be characterized by any method only after removal of the surface armor layer. Sediment samples for sieve analyses can be collected using a variety of methods including a bucket and shovel and the McNeil sampler used by fisheries biologists (NWIFC, 1993).

Field forms E-4 entitled "*Pebble Count Data*" are example formats to use to collect surface and subsurface particle size distribution data. The data should be plotted up to get information on the median grain size (D50), D84, and to compare the overall surface and subsurface particle size distribution within a given reach. The data will also be useful in identifying the relationship between sediment supply and transport capacity within a given reach (e.g., Q*).

Channel Pattern

Channel pattern refers to the configuration of a river as it would appear from an airplane (Leopold et al., 1964). River patterns represent an additional mechanism of channel adjustment which is tied to channel gradient and cross section. The pattern itself affects reach-scale resistance to flow and is closely related to the amount and character of the available sediment and to the quantity and variability of the transport capacity (Leopold et al. 1964).

Aerial photography generally is used to determine large scale channel pattern, and may record temporal changes at a location, although field observations may confirm interpretations. A measure of channel pattern is channel sinuosity, defined as the ratio of channel length to down-valley distance. Channels may also be described as meandering, straight, braided, and so on. This may best be estimated during the historic photo analysis.

Bank and Riparian Conditions

Bank conditions observable in the field include assessment of bank erodibility, observations of the extent of active bank erosion, and estimation of the proportion of the available shear stress transmitted to channel banks. Bank erodibility primarily reflects bank material composition (% fine or coarse alluvium, colluvium, and bedrock), whereas active bank erosion is influenced by both bank protection offered by roots or LWD and the recent history of flows in the channel. Channel geometry controls the distribution of stress between the channel bed and banks. These factors will help determine the relationship between potential erodibility and how much stress the bank receives.

It is important to note bank material, potential sources of bank reinforcement, and current bank conditions when observing evidence of bank erosion. For example, a bank composed of lacustrine deposits may be highly erodible, but protected by LWD, and thus actual bank erosion may be minor. A bank composed of colluvium overlying bedrock, on the other hand, may not have a high erosion potential, but if there is no bank protection, then concentration of stress on the colluvial portion of the bank may cause slumping. The ratio of bankfull width to depth can help determine the distribution of shear stress between the channel bed and banks during high discharge events.

Bank erosion is both a natural process and a disturbance indicator. Evaluation of the extent and location of bank erosion provides an indication of both average flow conditions and evidence for recent disturbance. Bank erosion should be noted as occurring 1) in local areas along the channel where obstructions force flow into the channel banks; 2) on the outside of meander bends where flow is focused into the banks by the channel geometry; 3) intermittently along channel banks independent of channel geometry; 4) extensively along one side of the channel; and 5) continuously along both channel banks. These qualitative descriptions of bank erosion may be supplemented with an estimate of the percent of the channel banks undergoing active erosion.

Channel-margin landslides are an important bank erosion process contributing sediment to channels and they should be noted during field surveys. Where such features are encountered their size and style of failure should be described. Many of these features are difficult to detect from aerial photographs and thus may elude detection in the mass wasting module. Prior and during the field component of the channel assessment, the analyst should consult with the mass wasting and surface erosion analyst to devise a way to capture the appropriate data on channel-margin landslides.

The focus on bank erosion and bank and riparian conditions also begs two more important questions the stream channel analyst can help answer in the field:

1. What is the role of riparian vegetation in bank protection for a particular segment?

2. And how is LWD recruited into the streamchannel network?

Field forms E-4 entitled "**ACTIVE CHANNEL** - *Bani Erosion Factors (BEF)*" and "**ACTIVE CHANNEL** - *Riparian Composition (RC)* " give a recommended format to gather data that helps answer the preceding questions. Bank erosion factors (e.g., % of bank eroding) and bank dimensions can help quantify the amount of bank erosion occurring in the different segment types and geomorphic units. Sources of bank protection can help identify what the role of riparian vegetation and obstruction are, as well as how and where they are working.

The *Riparian composition* field format asks the analyst to identify what the active riparian recruitment processes (ARRP) are and where they change. This information can be tabulated to identify where and how much of a segment recruits LWD due to bank cutting, log jams, etc. This information can then be compared to riparian composition and bank erosion factors to identify what may occur in the future.

Flood Plain Attributes

Flood plain attributes that should be examined in the field include entrenchment, overbank deposits of sediment and wood, the nature of terrace-forming materials, and out-of-channel evidence for extreme discharge events, or other catastrophic events, such as debris flows or dam-break floods.

Entrenchment

Entrenchment is defined as the vertical containment of a channel and the degree to which it is incised in the valley floor (Kellerhals et al., 1972). Entrenchment reflects the relationship between a channel, its valley, and surrounding hillslope features. Bank and valley bottom disturbance are the most common causes of historic channel entrenchment. Channel entrenchment is defined by the relation of the current channel flood plain, as defined by the bankfull flow depth, and the topographic terrace associated with the valley bottom. The channel is not entrenched when these two features are at least approximately coincident (Figure E-7). Frequent floods would inundate both the flood plain and terrace. A moderately-entrenched channel has a small active flood plain established within a larger trench cut by the channel. The terrace level will be inundated during moderately frequent (i.e., 20-yr) discharge events. An entrenched channel is one where a small active flood plain is effectively isolated from the terrace level during even rare discharge events.

The nature of the material forming the terrace is an important observation to make for interpreting controls on channel entrenchment. Terrace-forming materials should be exposed at least locally along the channel banks in most reaches. While the active flood plain will be composed of alluvial material, it is important to note whether the terrace-forming material is bedrock, colluvium, alluvium, or debris-flow deposits. Alluvium and debris-flow deposits often may be differentiated by examination of clast contacts in channel-bank exposures. Alluvium typically has a clast-supported sedimentary framework. Imbrication, or interbedded layers of sand and gravel also imply an alluvial origin. Debris-flow deposits, on the other hand, typically have a matrix-supported architecture in which large clasts "float" within a finer-grained matrix.

Overbank deposits

A number of other flood plain features are indicative of recent disturbance. In particular, the presence of wood berms on the channel margins, scour damage to channel-margin vegetation, "trash lines" of debris deposited by high flows, and levees or boulder berms are important to note and describe. The approximate age and type (i.e., herbaceous, coniferous, or deciduous) of channel-margin riparian vegetation is also important to note.

Overbank deposits can also help identify historic aggradation. Evidence of flood plain development within larger terrace features normally indicates a historic change in channel condition and sediment supply. Cultural debris exposed in channel banks provides an excellent control on the age of over-bank deposits. Partially-buried trees provide further evidence of active aggradation.

Field form E-4 entitled "**FLOODPLAIN** - *Entrenchment*" gives a format that may be useful in collecting data on terrace materials, entrenchment, and overbank deposits. Sketches or photographs of cross-sections can also be extremely beneficial when trying to identify the relationship between the terrace floodplain and active channel.

Indicators of catastrophic disturbance
Indicators of past catastrophic channel disturbance often are most clearly expressed in flood plain deposits. Floods, debris flows, and dam-break floods, are the primary form of catastrophic channel disturbance in forested mountain drainage basins. They can be dominant and overriding factors to consider when interpreting channel conditions.

Debris flows and dam-break floods are often lumped together in studies of catastrophic stream events in the Pacific Northwest. These two processes, however, have very different rheologies and they affect different parts of the channel network in different ways. It is recommended in watershed analysis that an attempt be made to differentiate between these processes based on field evidence in the mass wasting and channel modules. If they cannot be differentiated, then they are referred to as undifferentiated debris torrents. Note that Pierson and Costa (1987) have recommended abandoning the term debris torrent because it lacks specificity in describing the actual physical process and introduces confusion.

Debris flows are mapped and inventoried as part of the mass wasting module. Debris flows move through and typically erode colluvium stored in first- and second-order channels, or those channels greater than approximately 8 to 10 degrees (Benda and Cundy, 1990). Although debris flows typically do not move long distances down channels studied in the channel module (because of low gradients), debris flow deposits can profoundly effect morphology and habitat of low gradient channels. As a result, recognition of the effects of historic debris flows on the morphology of low-gradient channels maybe critical for appropriate channel interpretation.

Prior to and during the field component of the stream channel assessment, the analyst should consult with the mass wasting analyst to determine if there is a need to identify the historic lengths of debris flow run-out tracks. Such information can be useful in synthesis to determine the direct impact of debris flows.

Dam-break floods can occur when a landslide or debris flow deposit temporarily dams the valley floor. When such a dam fails, the resultant flood wave often entrains large amounts of organic debris which can increase the magnitude of the flood with travel distance. Dam-break floods can occur in much lower-gradient channels than debris flows and they can affect channels that are studied under the channel assessment module. Refer to Coho and Burges (1991) for a discussion of the characteristics of dam-break flood in low-order mountain channels and Johnson (1991) for descriptions of the effects of dam-break floods on channel and valley floor morphology.

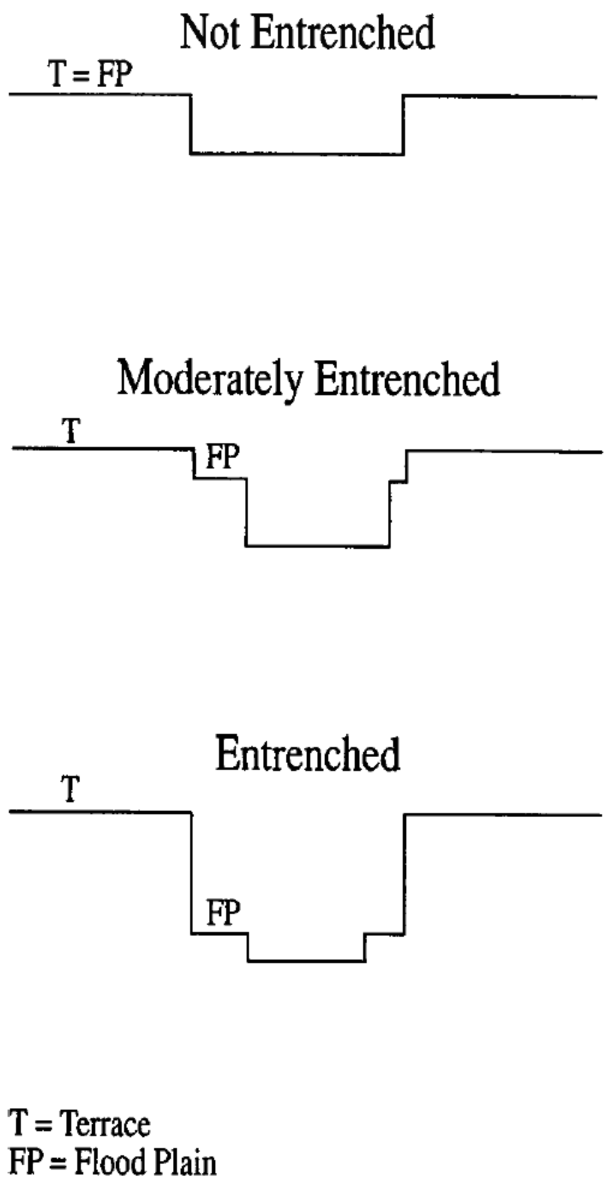


Figure E-8. Entrenchment Types

Additional Observations or Measurements

Additional observations and measurements that relate to specific channel processes or attributes important in the watershed under analysis are encouraged, but such additional analyses should supplement rather than supplant the approach developed here.

Channel Diagnosis Indicators

Conditions of the stream bed, active channel, and flood plain of a stream segment reflect the magnitude of input factors (sediment, discharge, LWD) and the occurrence of catastrophic events (landslides or floods). The manner in which these input factors are processed by a stream are set to some degree by valley characteristics. Consequently channel conditions may be interpreted as indicators of the relative magnitude of input factors.

To date, there is no single quantitative model that can simultaneously and reliably interpret channel condition relative to geomorphic regimes of sediment, water, and imposed obstructions. There are, however, several methods in use that employ channel characteristics as indicators of stream processes. For example, Pfankuch's (1975) channel stability index uses qualitative observations of a variety of stream features to generate a numeric score for channel "stability", although stability is neither explicitly defined, nor interpreted relative to input factors. Kaspesser's RASI index uses particle size characteristics to infer sediment load. We feel that the search for a single quantitative index that characterizes channel condition is misguided.

Streams are complex to diagnose because channel conditions simultaneously reflect a variety of input factors that can be influenced by both natural and land use related disturbance. Furthermore, the impacts of past disturbance may persist for different periods in adjacent portions of the channel network. In the absence of universal quantitative indicators of channel condition, we suggest a diagnostic technique that interprets the stream bed, active channel and flood plain characteristics observed in the field to infer channel condition in relation to channel and hillslope processes. The selected characteristics reflect channel-forming processes, and use quantitative relationships as much as possible. The primary assumption of this approach is that active processes leave a recognizable imprint on key channel features. Even when other processes are active, those characteristics may be evident when the signal is strong enough, and when several processes are active the channel will have a mixture of characteristics that indicate their relative dominance. The diagnostic approach assumes that one indicator is rarely sufficient to determine the input factor regime. Therefore, our approach relies on examining a variety of features, whose collective condition suggest the relative relations between input factors, and which thus govern channel condition. Moreover, by using a variety of features, the analyst can separate, to the extent possible, channel conditions relative to each input factor.

Thus, we rely on observing a number of features and look for the weight of the evidence to interpret channel conditions with confidence. These features may be organized into channel bed, active channel, and flood plain attributes. As the sediment supply changes relative to the transport capacity of the segment, the composition of the bed surface adjusts. Features of the channel bed that can be interpreted relative to input factors are the bed surface particle size distribution, the relation between the median surface and subsurface grain sizes, the distribution of fine sediment on the bed surface, and subsurface proportions of fine sediment. Larger features that characterize the active channel also reflect geomorphic regimes of the reach. These features include characteristics of depositional bars, fine sediment deposits, pool dimensions and locations, and bank conditions. Finally, certain flood plain characteristics may record or reflect past or continuing processes and disturbance. The diagnostic characteristics discussed below, and shown in Tables E-3-a through E-3-c, provide a minimum set of criteria for channel assessment. The approach developed here can be expanded to incorporate new or additional diagnostic attributes as procedures for their analysis and interpretation are developed and tested.

Tables E-3-a (**Stream Bed Attributes and Diagnostics**)**, E-3-b** (**Active Channel Attributes and Diagnostics**) and E-3-c (**Floodplain Attributes and Diagnostics**) lists the attributes, mechanisms for change, qualitative and quantitative interpretive indicators ("dial levels"), and the segment types attributes are most applicable towards. The table, coupled with the proceeding discussion, is meant to help the analyst assess and interpret the different attributes which are measured or observed. The "dial level" is there to help gauge what the attributes, and its observed or measured level, means in the context of the assessment. Again, a weight of evidence approach should be used, thus one dial level for one attribute does not determine whether a channel is high in sediment supply relative to transport capacity. Instead, several attributes together may point to a trend or direction a particular channel is moving towards. Use these and other attributes to determine the current channel conditions for the different segment types.

Channel Bed Attributes
(See table E-3-a **Stream Bed Attributes and Diagnostics**) Channel bed attributes are particularly revealing for interpreting the relative relation between sediment supply and channel transport capacity. The basis for these interpretations is the assumption that the material on the channel bed surface reflects hydraulic sorting of the bedload material to generate a stable alluvial bed and that the amount of fine sediment in transport at low flow can be

interpreted from the amount and distribution of fine sediment on the channel bed relative to the distribution of hydraulically-sheltered locations.

Channel Type

The channel type defined by the channel bed morphology provides the context for interpreting channel condition. Different channel types have different potential responses and evidence for previous impacts based on existing conditions need to be interpreted in the context of the channel type. Channel bed morphologies and potential channel responses are discussed in more detail by Montgomery and Buffington (1993). In addition, different channel types (i.e., bedrock v. pool-riffle with the same drainage area gradient) may reflect changes in sediment regime that can be diagnostic (Benda, in prep.).

Median Grain Size

The median grain size on the channel bed reflects a number of influences including discharge, sediment supply, and the hydraulic roughness provided by flow obstructions. An increase in basal shear stress causes winnowing that results in bed-surface coarsening. Increased sediment supply favors bed-surface fining (Dietrich et al., 1989). Limited sediment supply can also lead to bed surface coarsening or bedrock channels. Higher LWD loading provides greater hydraulic roughness which favors bed-surface fining (Buffington and Montgomery, 1992). Lower LWD, in forced pool-riffle channels, can decrease hydraulic roughness and result in bed surface coarsening. As noted in table E-3-a hydraulic roughness and sediment supply v. transport capacity are the two primary mechanisms which affect if a segment is coarser or finer than expected.

Bed Surface Pattern

The spatial variability of grain sizes on the bed surface may reflect channel morphology or interactions with in-channel flow obstructions. For example, sorting of gravel and boulders into pools and steps, respectively, in step-pool channels is a natural consequence of hydraulic channel-forming processes. In contrast, the distribution of gravel-sized substrate on the bed surface in some forced pool-riffle channels is controlled primarily by the distribution of large woody debris. Finer patches of the bed surface in any channel type may reflect hydraulically-sheltered locations. The spatial organization of grain sizes on the channel bed surface can be used to help assess channel condition by considering the channel type and the role, or potential role, of flow obstructions. In particular, the spatial distribution of grain sizes on the bed surface has important implications for interpreting the availability of spawning gravel in some channel reaches.

Particle Size Distribution
Particle size distributions in most channels are approximately log normal. A bimodal surface or subsurface particle size distribution can indicate a high amount of fine sediment in transport either during bed-mobilizing events in the case of the subsurface distribution, or over the gravel bed between armor-mobilizing events in the case of the surface distribution. Plotting up surface and subsurface particle size distribution helps to determine whether there is a strong or weak bimodal distribution.

q* ("qstar")
Surface textures of gravel-bedded rivers respond dynamically to changes in sediment supply. Bed surfaces fine when inundated with sediment and coarsen when deprived of sediment. Dietrich et al. (1989) proposed a dimensionless ratio, q*, which quantifies textural response to sediment supply. The ratio is defined an the transport rate of the bed surface material normalized by that of the load, or subsurface, and quantifies the transport capacity of a channel relative to sediment supply. The dimensionless ratio can be used to assess both current sediment loading conditions and sensitivity to increased sediment supplies.

One conceptually simple equation that expresses the bedload transport rate (q_s) as a function of the difference between the effective basal shear stress and the critical shear stress is given by

$$q_s = k\,(t' - t_c)^{1.5} \qquad \text{eq. 1}$$

where k is a constant, t' is the effective basal shear stress, and t_c is the critical shear stress for incipient motion, and thus the onset of sediment significant bedload transport (Meyer-Peter and Miller, 1948). The ratio of the transport rate for the surface grain sizes and the subsurface, or bedload, grain sizes is q*, which using this general bedload transport expression is given by

$$q^* = (t' - t_{cs})^{1.5} / (t' - t_{css})^{1.5} \qquad \text{eq. 2}$$

where t_{cs} and t_{css} are, respectively, the critical shear stress for the surface armor and subsurface material. The average basal shear stress may be expressed as the product of fluid density (r), gravitational acceleration (g), flow depth (D), and water surface slope (S):

$$t = rg\,D\,S \qquad \text{eq. 3}$$

The fraction of the basal shear stress available for sediment transport, defined as the effective boundary shear stress (t'), depends upon the amount of in-channel roughness and energy dissipation. The critical shear stress (t_c) represents the shear stress necessary to mobilize the median grain size (d_{50}) and is expressed as

$$T_c = t_* \ (r_s - r) \ g \ d_{50} \qquad \text{eq. 4}$$

where r_s is the sediment density and t_* is a dimensionless critical shear stress (Shields, 1936), the value of which is controversial, but has recently been estimated at 0.045 (Komar, 1987). Assuming that grain roughness provides the only in-channel roughness implies that t = t' and, thus, q* may be expressed as

$$q^* = \left\{ \frac{[r \ D \ S \ / \ t_* \ (r_s - r) \ d_{50s}] - (d_{50s} \ / \ d_{50ss})}{[r \ D \ S \ / \ t_* \ (r_s - r) \ d_{50ss}] - 1} \right\}^{1.5} \qquad \text{eq. 5}$$

A well-armored bed has low q* values and is interpreted to have the capacity to accommodate an incremental increase in sediment supply through bed surface fining. A poorly-armored channel with a high q*, on the other hand, is vulnerable to other morphologic change in response to altered sediment supply. Channels that have a high q* will have a higher potential to aggrade or lose pool area because the surface has little potential to fine in response to increased sediment loading. A low q* means a channel has a larger potential to react to an increase in sediment load by textural fining. Concurrent morphological change may occur, however, and q* provides only an index of the capacity for the bed surface to fine. Table E-3-a gives approximate q* levels that correspond to the low and high value descriptions.

While q* is a useful assessment tool, we caution that it provides only a "snap-shot" of current sediment loading conditions and care should be taken to interpret q* measures within the context of the fluvial processes occurring in the channel. Analysis of q* made in isolation of other channel processes and diagnostic features can lead to erroneous interpretations of sediment loading (Buffington, in prep.). Furthermore, since q* assumes that grain roughness provides the dominant channel roughness, it is most applicable in obstruction-free sections of gravel-bedded channels (e.g., plane-bed channels or riffles in pool-riffle channels).

% Fines in subsurface

The substrate underlying the surface armor of a channel is thought to be representative of the bedload material transported by the channel (e.g., Parker et al., 1980). Thus the percentage of fine sediment in the subsurface material reflects the supply of fine sediment to the channel. The percentage of fine sediment in the channel subsurface also is an important influence on fish survival to emergence. Preliminary data from subsurface pebble counts in Washington suggests that values of 5 - 15% <2mm defines a typical range in undisturbed basins (Montgomery, unpublished data). The percentage of fine sediment in the subsurface gravel estimated by a subsurface pebble count is less accurate than if measured by techniques such as those recommended by the NWIFC (1993). Because subsurface pebble counts are not expected to be as accurate, data collected in this manner is best interpreted as distributions of values collected in different parts of a watershed. This may reveal areas of the watershed with consistently higher percentages of subsurface fines. Causal mechanisms may be explored when potential sources of fine sediment are identified.

Table E-3-a summarizes the diagnostic attributes for channel bed features. The analyst is encouraged to use additional diagnostic features they find to be useful.

Active channel attributes
A number of active channel attributes reveal aspects of channel condition through the distribution and amount of gravel bars and fine sediment deposits, pool characteristics, channel pattern, and the nature and extent of bank erosion. Most of these indicators involve comparison of existing channel condition with those expected for the channel type. Consequently, both experience and objectivity are crucial for interpreting channel conditions. We believe, however, that consideration of the full suite of channel characteristics examined in this module will lead to a reasonable assessment in most cases.

Gravel Bar Characteristics

Bars can best form where the channel is wide enough to accommodate them (bankfull width/depth ratios greater than about 12; Jaeggi, 1984), and stream gradient is low enough to allow deposition (less than about 2%; Ikeda, 1975). In steeper and narrower channels, bars and small deposits tend to form exclusively around obstructions. Large central bars and braided channels commonly form where valley bottoms and channels widen downstream of steep narrow valleys and canyons. They may also form upstream of channel constrictions due to backwater effects of hydraulic control during storms (Sullivan et al., 1987). Bars usually grow and shrink seasonally because of local imbalances between deposition and erosion; but, other than in braided channels, bars tend to keep the same location as long as channel boundaries remain intact and obstructions in place (Leopold et al., 1964; Lisle, 1986).

Table E-3-a. Stream Bed Attributes and Diagnostics

Channel Attribute	Potential Mechanisms for Change	Dial - Low	Dial - Medium	Dial - High	Applicable to Segment Type:
D50	Sediment supply relative to transport capacity LWD loading	Coarser than expected		Finer than expected	Pool-riffle Plane-bed Forced pool-riffle
Particle Size Distribution	Fine sediment supply	Unimodal	Weakly bimodal, still dominated by larger clasts.	Bimodal, especially high proportions in sand fractions	Pool-riffle Plane-Bed
q *	Sediment supply relative to transport capacity	q* = 0	q* = 0.30	q* approximately = 1	Pool - riffle Plane - bed
Surface fines (<2mm)	Sediment supply	Do not see accumulation of fine sediment on the lee side of obstructions such as boulders and LWD	Do see accumulations of fine sediment on the lee side of obstructions.	Large tails of fine sediment behind boulders and other obstructions	Pool – riffle Plane – bed Forced pool – riffle
Subsurface fines (<2mm)	Sediment supply	Low percentages <10%	Mid-range 10-20%	High Percentages >20%	Should work everywhere, although percentages may vary by type

The size, stability and location of gravel bars can be an indication of changing sediment supply or transport capacity. The presence of medial bars in a channel or deposition occurring on the outside of a meander bend can be an indicator of an increasing sediment supply and decreasing transport capacity in a channel segment. Channel narrowing and evidence for an increase in stable bar features (such as vegetation encroachment) can be an indicator of a low sediment supply relative to previous sediment loads.

Pool Characteristics
The pool spacing in some channel types in forested mountain drainage basins is related to the supply of LWD within the bankfull channel. The size and residual depth of pools; also reflects the influence of LWD. The magnitude of these influences differ for different channel types. The influence of LWD on pool spacing is greatest in pool-riffle and plane-bed channels. A pool spacing on the order of 5-7 channel widths is expected in pool-riffle channels with low LWD loading (Leopold et al., 1964); much higher pool spacing are expected in low LWD loading plane-bed reaches. Pool spacing on the order of 0.5 to 1.0 channel widths characterizes both of these channel types with high LWD loading (Montgomery et al., in press). At such high loading these channel types may be impossible to distinguish except by channel slope (Montgomery and Buffington, 1993), or by reference to nearby reaches with low LWD loading. Preliminary data implies that pool spacing in steeper step-pool channels is related to LWD loading. Imposition of simple numerical standards of pool frequency on all channel types may be inappropriate.

Channel Pattern
Channel pattern to some degree reflects the interaction between sediment supply and transport capacity (Leopold et al., 1964). For example, a downstream change in channel pattern from meandering to braided may reflect an extreme increase in sediment supply (e.g., Smith and Smith, 1984). Downstream channel narrowing and an increase in stable, vegetated bar features can be an indicator of a decrease in sediment supply or flood discharge. Multiple active channels often indicate a high sediment supply. Significant changes in channel sinuosity evident on sequential aerial photographs may indicate change in sediment supply or transport capacity.

Channel braiding and side channel development also may be controlled by flow perturbations induced by LWD. Historical removal of LWD from some large rivers, for example, changed the channel pattern from a complex braided system of channels and side channels to a single thread channel morphology (Sedell and Froggatt, 1984). Consequently, channel pattern must be interpreted in the context of channel processes, especially the complementary and potentially competing effects of sediment supply and LWD loading.

Fine Sediment Deposits in Pools

The distribution of fine sediment on the channel bed can be interpreted in regard to the fine sediment loading of lower-gradient pool-riffle and plane-bed channels. Fine sediment accumulations in local hydraulically-sheltered locations typically do not reflect fine sediment supply. Extensive fine sediment deposits in both pools and riffles, on the other hand, indicate an abundance of fine sediment in all but extremely low-gradient channels. While description of the general distributions of fine sediment deposits within a channel provides a good general indicator of fine sediment supply, the amount and distribution within pools and riffles can be further interpreted separately.

V*

Lisle and Hilton (1992) defined the average ratio of the volume of fines to the residual pool volume for an entire pool as V*. When fine sediment and residual pool depth are measured on transects, this may be expressed quantitatively as

$$V^* = \sum [D_s / (D_r \quad D_s)] / n$$

eq. 6

where n is the number of measurement locations, and D_s and D_r are, respectively, the thickness of fine sediment and the residual pool depth at each measurement location. This index provides a measure of the most mobile portion of the channel bed and helps evaluate and detect sediment inputs along the channel on a local scale.

The index correlates with perceived sediment supply and varies in response to local increases in sediment supply (Lisle and Hilton, 1992). $V^* < 0.1$ is considered to reflect low sediment supply, whereas a $V^* > 0.2$ is considered indicative of high sediment supply (Lisle and Hilton, 1992). Local sources of fine sediment should be examined if a channel has a high V* prior to interpreting potential causes. V* is not a reliable indicator of channel disturbance if the local geology causes large spatial variance in sediment supply. Although it is not appropriate to use V* when the channel is bedrock-floored, it can still be used if there is limited bedrock exposure. In massively aggraded channels, V* is not an appropriate index of channel condition. V* is most useful in pool-riffle and forced pool-riffle segment types.

Fine Sediment Deposits Within Riffles

The distribution of fine sediment on the channel bed may reflect the supply of fine sediment to the channel. In many gravel-bed channels, some sand-size material moves over the channel bed at discharges insufficient to break the gravel pavement, or armor, and initiate significant bedload transport (Jackson and Beschta, 1982). Observation of the distribution of fine sediment over the low-flow bed surface in a riffle thus provides an indication of the fine sediment supply of the channel. At a low supply of fine sediment, sand and fine gravel exposed on the bed surface occur only locally in sheltered locations behind flow obstructions or large clasts. As the amount of fine sediment moving over the bed increases, these local depositional sites tend to expand downstream into elongated sand stripes (Figure E-9). At extremely high fine sediment loading, the entire channel be may become buried by a blanket of fine sediment overlying a coarser armor layer. This style of channel response to increased sediment supply is unlikely in steep step-pool or cascade channels that have a high transport capacity. Thus, this type of response is most relevant to lower-gradient pool-riffle and plane-bed channel.

Bank erosion

Bank erosion should be interpreted in the context of channel-forming processes. Erosion on the outside of meander bends, even large channel-margin landslides, is to be expected in many situations. Extensive erosion on both channel banks, however, typically is uncommon, but is to be expected in some situations, as in the case of a high-gradient channel deeply incised through unconsolidated sediments. The nature and extent of bank erosion must be interpreted in the context of the channel geometry and patterns and the nature of the bank-forming materials. Increases in channel bed elevation, occurrences of dam-break floods, and increases in discharge can all cause bank erosion.

Table E-3-b summarizes the diagnostic attributes for active channel features. The analysts are encouraged to use additional diagnostic features found useful in the past.

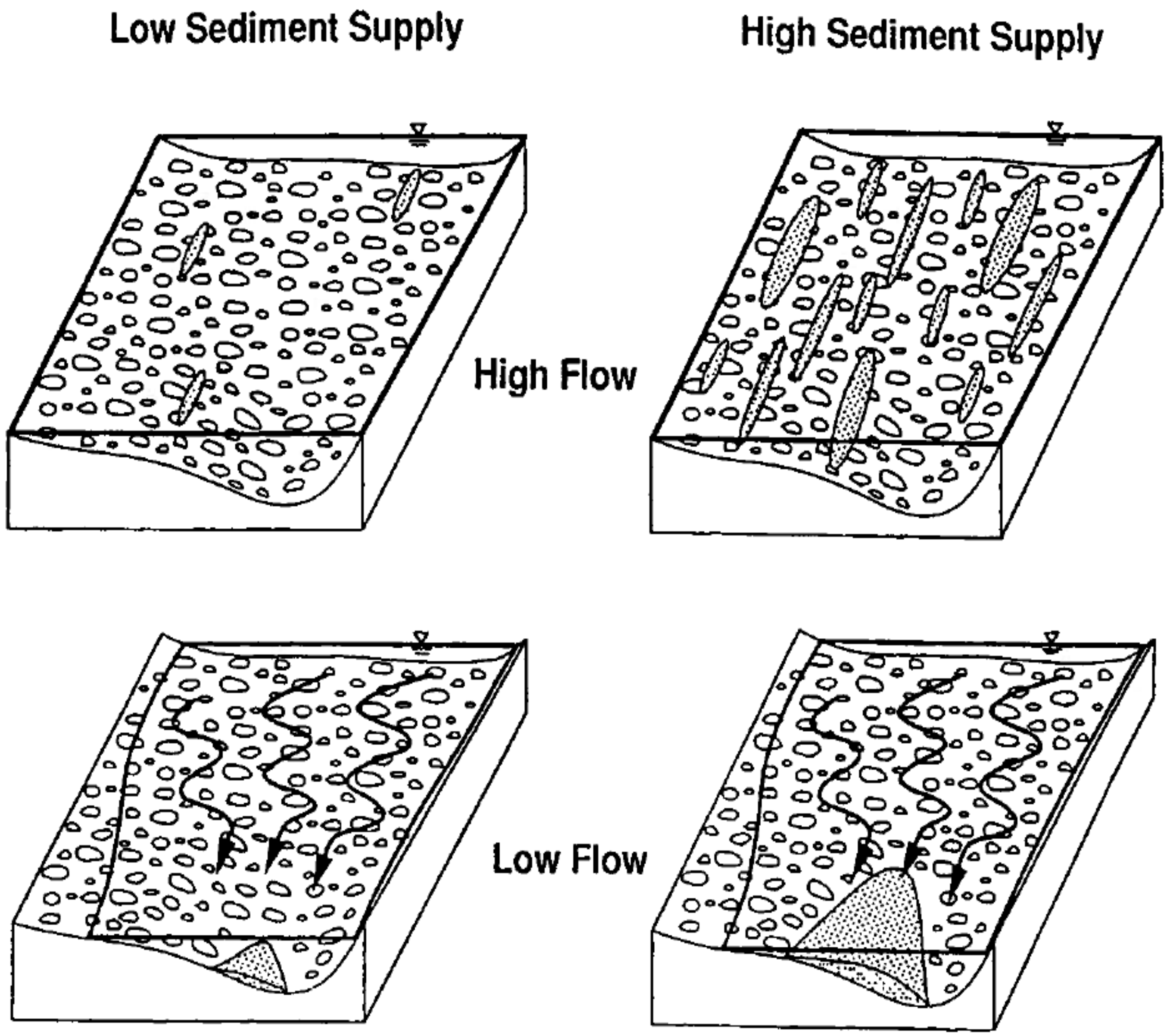


Figure E-9. Pool Filling with Fine Sediment

(Conceptual model of filling of pools with fine sediment during waning stages in gravel-bed channels with high and low sediment supplies. At high stages, fine sediment, as well as coarse gravel (arrows), are transported over much of the channel. At low flow, the flow over riffles (curved lines), converges into pools and carries fine sediment winnowed from the bed surface. From Lisle and Hilton, 1992.

Table E-3b. Active Channel Attributes and Diagnostics

Channel Attribute	***Potential Mechanisms for Change***	***Dial - Low***	***Dial - Medium***	***Dial - High***	***Applicable to Segment Type:***
V*	Local source of fine sediment	Gravel bottom pools, little difference between pool bottom and riffles. V* <0.1	Small amount of fine deposits on pool bottoms 0.1<V*<0.20	Large amount of fine sediment (sand) at pool bottom. V*>0.20	Pool-riffle Forced pool-riffle
Channel Pattern - Sinuosity	Sediment Supply	Single thread, meandering	Multiple stable channels	Braided	Pool-riffle
Channel Pattern-side channels	• Riparian Condition • LWD Loading	No side channels, single channel	Multiple minor side channels	Significant side channels	Pool-riffle Forced pool-riffle Plane-bed
Gravel Bars	Sediment supply	Small point bars isolated along the edge of the channel	Point bars take up greater portion of the active channel. Deposition in some places are not expected.	• Medial bars • Bars on the outside of meander bends	Pool-riffle Forced pool-riffle
Pool dimension	• Sediment supply	Pools span channels		Pools diminish in size and become isolated	Pool-riffle Forced pool-riffle
% Pool formed by LWD	LWD	Nearly all free pools		Nearly all forced pools	Pool-riffle Forced pool-riffle Plane-bed
Channel width/pools	LWD	Infrequent pools (>4 CW per pool)	Between 1 to 4 CW/ per pool	High pool frequency, less than 1 CW per pool	Different for each channel type
Pool dimension	LWD loading	Small pools		Large pools	Forced pool-riffle Place-bed
Pool dimension	• Sediment supply	Large in volume and depth	Shallower than expected	Small, often not fully spanning, shallow.	Forced pool-riffle Plane-bed Step-pool
Bank Condition and Erodibility	• Loss of bank strength • Dambreak flood or debris flow • Peak flows	Eroded and raw banks on outside of bends	Eroded and raw banks on the inside of meander bends and in straight reaches	Nearly all banks eroded and raw	Anywhere

Flood plain Attributes

Interpreting flood plain conditions typically is more straightforward than interpreting in-channel conditions. Log berms, levees, and boulder deposits generally indicate recent catastrophic impacts. The age and condition of the near-channel riparian vegetation can corroborate such interpretations. Direct evidence for aggradation also is relatively simple to interpret.

Channel entrenchment is somewhat more difficult to interpret because it reflects different processes in different portions of a watershed. In low-gradient portions of a watershed where terraces are formed primarily by fluvial processes, the flood plain and terrace should be coincident (Figure E-8), unless there has been a relatively recent change in either one of the channel input factors, or in external boundary conditions, such as base level. In steeper portions of a watershed in which debris-flow processes are active, the stream terrace may be composed of debris-flow deposits through which the channel has re-incised. In these portions of the channel network entrenchment may not reflect recent channel disturbance. Thus, evidence for channel entrenchment must be interpreted in the context of the dominant channel-forming processes for a given reach.

Table E-3-c summarizes the diagnostic attributes for flood plain features. Again the analyst is encouraged to use additional diagnostic features found useful in the past.

Table E-3-c. Floodplain Attributes and Diagnostics

Channel Attribute	*Potential Mechanisms for Change*	*Dial - Low*	*Dial - Medium*	*Dial - High*	*Applicable to Segment Type:*
Entrenchment	• Bank disturbance • Change in historic condition	Flood plain coincident with terrace	Flood plain inset within terrace	Flood plain deeply inset within, and isolated from terrace	Anywhere, but does require a spatial context
Overbank sediment deposits	• Sediment supply • Large flood event • Debris flow or dambreak flood.	Normal flood plain stratigraphy	Scattered lenses of fine and coarse sediment	Deposits with depth of coarse and fine sediment	Any type of channel and defined flood plain
Wood deposits	Debris flow or dambreak flood	Deposits on front ends of gravel bars and along margin		Nearly all wood thrown from channel onto flood plain	Any type of channel with defined flood plain
Boulder berms	Debris flow	No boulder berms	Vegetated boulder berms on channel	Fresh boulder berms on channel margins	Colluvial Cascade Step-pool Plane-bed Forced pool-riffle

Channel Segment Diagnosis

The goal, of the channel segment diagnosis is to help the analyst identify which processes and input factors are most important for a segment that was visited.

Systematically diagnosing channel condition requires compiling key observations relative to the bed, active channel and flood plain into a summary of characteristics related to relative channel condition. Once the data is complied and displayed, the analyst weighs the evidence for channel condition relative to each of the input variables, noting both patterns and inconsistencies. For example, several attributes of both the bed and active channel indicating a high supply of fine sediment, provide strong evidence. If only one attribute suggests high sediment loads, the evidence may be weak, depending on the nature of the feature showing symptoms. Like a medical diagnosis, the analyst must weigh the suite of characteristics, using data and professional judgment to arrive at an interpretation of channel condition. We expect the objectivity of this assessment to improve as researchers develop more quantitative relationships between these diagnostic features and input variables. Furthermore, critical additional information is found in the other modules, which can be used to help aid in the interpretation of channel condition.

Each of the input variables is operative in every stream segment and each can currently experience any combination of levels of input variables. Some segments may have one dominant process which strongly influences channel condition, whereas other channel segments may have several interacting factors controlling channel morphology conditions.

A worksheet is provided offering a format for compiling this information (Form E-5). The analyst may use alternative forms for compiling the information although the format should be followed reasonably closely. The analyst should provide a brief narrative describing channel condition interpretations. The second page of the form encourages the analyst to bring results from the historic photo assessment to bear on the channel interpretation. This portion of the assessment may support conclusions based on current channel features.

Sensitivity to Input Factors

Segment Clustering and Geomorphic Units

At this point in the assessment procedure, the channel network has been divided into discrete valley segments, of which a representative sampling has been observed in the field. Channel characteristics of these representative stream segments have been interpreted with respect to local regimes of sediment, water and wood. Results from what are usually a limited number of observed segments must now be extrapolated to other segments. We term this scaling up step "segment clustering" and the result is delineation of the watershed into "geomorphic units," areas encompassing portions of the channel network that are representative of similar fluvial processes. Recognizing the dominant channel-forming processes, and their magnitude, frequency, and distribution, operating in each area with commensurate channel conditions is the primary objective.

The goal for the stream channel analyst is to describe the clusters of segments that relate to a geomorphic unit. The basic assumption behind identifying geomorphic units is that segments within the unit will look similar and will respond similarly to external forcing (i.e. forest practices, urbanization, grazing, climate change and so on). The sensitivity of particular streams to changes in watershed processes occurring as a result of natural or land use effects is likely to reflect the relative importance of fluvial processes acting on materials in the area. The current condition and likely response of similar segment types is likely to differ throughout the watershed depending on local influences of terrain, geology, past disturbance and drainage position.

Geomorphic unit delineation uses assessment of both channel conditions and sensitivity. Channel conditions are considered in relation to the regime of each input factor based on the integration of field observations into a channel diagnosis. Channel sensitivity is an assessment of the degree to which a unit change in any input factor results in a significant change in channel morphology or processes. While channel sensitivity depends on current channel conditions, it reflects the potential for future changes.

Stream channel conditions are likely to be related to the land form/geology associations within the watershed. These will, reflect, among other things, lithology, soils, slope gradients, and hydrologic input. The analyst may already have formed hypotheses associating channel conditions and sensitivity with land form and geology in the watershed, having used these criteria for field site selection (see criteria for site selection). Field observations and diagnostic characteristics may confirm original ideas or suggest new interpretations.

The analyst defines boundaries separating stream segments into areas with similar geomorphic response. "Geomorphic units," so defined include both the stream segments and any landforms associated with them. **In drawing these units, the channel analyst uses judgment and may wish to consult with analysts performing mass wasting and surface erosion assessments who should have developed an understanding of the landforms in the watershed.** Although the geomorphic units are likely to be related to landforms, their delineation is not restricted to this criteria.

Analysts may identify any part of the stream system that they believe has significantly different responses or sensitivities from other units in the watershed.

Clustering channels into geomorphic units composed of segments with similar channel conditions, response potential and sensitivity provides a way to organize information gathered in the channel assessment with information gathered by other modules to describe causal linkages and appropriate land management prescriptions. Identification of geomorphic units so defined may involve generalization and some segments that do not share the same response or sensitivity may be incorporated into the same unit. Such is the price we pay for developing a functional method that is likely to facilitate rather than paralyze the decision-making process.

Channel Sensitivity Interpretation

An understanding of the factors presently controlling and likely to influence channel morphology and process is crucial to the synthesis side of watershed analysis. Consequently, analysts should describe for each geomorphic unit channel conditions and interpretations of channel-forming processes. Each input factor should be considered. It is helpful to record key observations for each unit that form the basis for the analyst's interpretations. Form E-6 is provided to facilitate note-taking. These observations form the basis for the sensitivity interpretation, which is a subjective assessment of likely response to each input factor. To determine channel sensitivity, the analyst should consider the relative effectiveness of each input factor (LWD, sediment, discharge, and catastrophic events) on channel morphology and processes. The analyst should provide a brief narrative providing the scientific basis and justification for the interpretation of sensitivity, observations which back the interpretation, and relative potential rating of channel response. The analyst needs to consider the magnitude, frequency, and distribution of the processes that effect each input factor when coming up with the potential ratings for channel response. This will help link past to current channel conditions.

In essence, the analyst customizes the interpretation of response originally based on the response matrix (Table E-2) for the particular watershed location in question. This step is crucial if the analyst is to develop an interpretation of channel processes tailored to the watershed under study. Performing this step relies on the analyst's experience and expertise. Although the generalized response table provides a good starting point for the assessment, simply parroting its interpretations as conclusions of the analysis yields no insight into the watershed under study since the table cannot account for geologic materials and local situations. Failure to adjust the response table for the geomorphic unit in question will result in low confidence in the analysis.

The channel analyst's response rating is a first approximation based on the findings of the previous sections of the channel assessment. These interpretations may be refined during the synthesis stage when additional information regarding watershed processes is available from the other module assessments.

Aggregating discrete channel segments into areas of similar watershed conditions and response potential will also greatly facilitate the next steps of the watershed analysis resource assessment. During the synthesis stage, the full resource assessment team further develops a watershed-scale perspective of the linkages between sources of inputs, channel response and habitat or water quality conditions that builds on existing working hypotheses developed earlier in the assessment. They will systematically work their way through the watershed, building a story of local and watershed scale connections based on their collective observations. Performing this analysis for segments grouped into larger representative areas will reveal dominant watershed and biological processes operating at a scale appropriate for hypothesis-testing and decision-making in Watershed analysis. To perform this linking exercise for each mapped channel segment would be exceptionally time-consuming and yield little interpretive benefit, since only rarely will the cause and effect relationships between hillslope and channel processes or the management actions prescribed for them be relevant to just one segment.

The geomorphic units are delineated on a mylar overlay of the official base map and numbered as Map E-2. The analyst should provide a brief narrative describing the geomorphic unit and justification for why it was identified.

An Example From the Tolt River

The Tolt River WAU contains 166 segments. After visiting 22 segments and assessing them for channel and valley conditions, the stream channel team determined that for the purpose of making generalized descriptions of channel condition and sensitivity, the 166 segments could be collapsed into 14 geomorphic units. In this case, the channels in each area currently look alike, although in several units channels were noted as either already responding to input variables or potentially responsive. (That is, they would look like those streams already responding if changes in the input factor occurred.) Each of the units was judged sufficiently distinctive such that differences in both channel-forming processes and sensitivity to input variables was evident. Most geomorphic units were closely related to landforms in the watershed, although the team identified a variety of units that did not always relate to a land form. Figure E-10 shows the geomorphic unit map for the Tolt River. The channel assessment team adopted a convention of naming units descriptively to reflect the dominant channel-forming processes that caused them to distinguish them initially. Some of the units represented tributary streams on similar landforms (e.g., steep tributaries draining convergent topography), several related to specific river segments experiencing certain conditions (e.g., the North and South Fork braided sections) and two units of similar segment clusters were distinguished because of the influence of beaver activity.

For the most part, geomorphic units and interpretations were judged to be applicable only to the type location in the watershed and there was little carryover of a mapped unit to other parts of the basin. The exception was the North Fork Braided Reaches located primarily on the North Fork of the Tolt, where one similar unit was identified on a segment of the South Fork Tolt River.

The sensitivity interpretation for the North Fork Braided Reaches demonstrates the tailoring of the interpretations of channel-forming processes and sensitivity to input variables based on the channel's segment type, position in landscape, and current condition. Note that this interpretation would not have been reached by using the response matrix (Table E-2) alone.

Fourteen geomorphic units were identified in the Tolt River WAU. Segment field observations were qualitatively matched to terrain and land forms to identify areas of similar condition and response to input factors. Following is a brief description and the key observations produced by the team for a geomorphic unit along the valley of the main river.

North Fork of the Tolt River Canyon

Featurest This is a deep, tightly confined canyon incised into bedrock and glacial till deposits. Stream gradients average 2-6%, with a short segment of approximately 10% which includes a waterfall that blocks upstream fish passage.

Transport Zone

Characteristics: There has been very little change in these segments throughout the photographic record (1942-1990).

Coarse Sediment: Response rating = LOW

- Stream energy appears to be sufficient to carry the sediment load (which is relatively large considering the braided reaches upstream).
- q* = 0.13-0.16, highly armored

Fine Sediment: Response rating = LOW

- High stream energy due to gradient!confinement, capable of flushing fines
- Very few fines observed
- V*: pools too deep to measure, estimated 0.1

- Localized area of higher V*, upstream end of Segment 4 at mouth of tighter canyon

Peak Flows: Response Rating = MODERATE

- Till valley walls can be eroded, channel could widen in places during high flows
- relatively large substrate makes significant scour unlikely
- No evidence of existing damage, but moderate potential for damage in future

LWD: Response Rating = MODERATE

- Slight reduction in number of pieces per channel width
- Function as bank protection in alluvial/till segments, and some sediment trapping
- Bedrock!compact till creates bank protection where present

Catastrophic Damage: Response Rating = HIGH

- Dambreak floods could occur (evidence of jam that spanned channel in upper end of Segment 6)
- Lower end of scour!transport gradient, but high stream energy due to canyon 4th order stream.

Applies to: Segment 6 (field verified), and Segments 4, 7, 8, 9, 10.

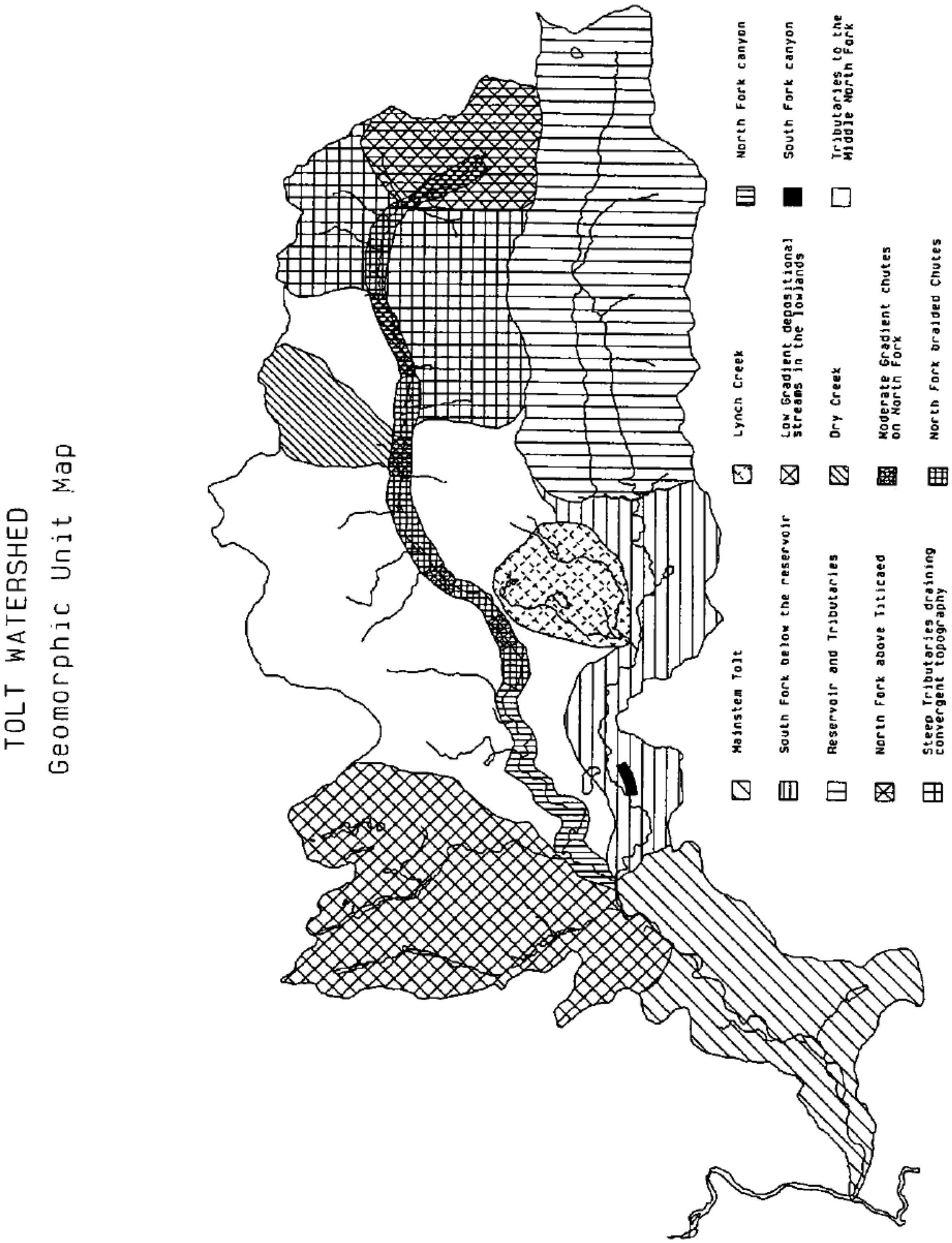


Figure E-10. Tolt Watershed Geomorphic Unit Map

Habitat-Forming Processes

The final task in the channel module is to describe the geomorphic processes controlling channel morphology relevant to the creation of fish habitat. Previous steps in the assessment yield conclusions regarding the sensitivity of the channel to changes in hillslope input factors. This portion of the assessment assists in translating those effects into fish habitat conditions. The channel analyst does not attempt to inventory habitat conditions. Rather, the channel analyst describes the origins and channel controls on the environments associated with key components of the life cycle of fish.

These life history stages include (1) upstream anadromous migration, (2) spawning and incubation, (3) rearing, and (4) over-wintering. The channel analyst is not expected to interpret channel condition relative to each life-history stage, rather the channel analyst interprets processes controlling key habitat elements determined by the fish biologist to be important for one or more life-history stage. These attributes include; deep pools, undercut banks, areal extent and size characteristics of gravel to small cobbles, pool characteristics and the nature of pool-forming agents, and the availability and access to slow water and off-channel areas.

The channel analyst's interpretation of the factors controlling the local physical environment in a segment will assist the fisheries analyst to interpret the vulnerability of fish to forest practices during the synthesis stage of the resource assessment. This procedure is enhanced when the channel analyst works closely with the fish habitat analyst, particularly in the field portions of the assessment.

The fish analyst may pose a more refined set of conditions for the channel analyst to address. The fish analyst may request a number of more specific interpretations...for example, they may ask the channel analyst to focus interpretation for stream segments, specific life-history environments rather than all four, or habitat conditions specifically defined for a particular fish species that may occur in the reach. This is why it is important for the fish habitat and stream channel analyst to spend some time in the beginning of the process to focus their efforts on the fish-habitat issues of concern. This may be best accomplished by having a preliminary meeting or doing a reconnaissance survey together. The advantages of this approach are several. Field data collection would be focused on the important issues, and coordination between the fish and channel module analysts could make data collection more efficient. The issues identified by the analysts could then be investigated based on subsequent data collection.

The channel analyst briefly describes the geomorphic factors influencing the four life-history environments in narrative form. If the fish analyst does not provide guidance for focusing discussion towards specific features in a given segment, the channel analyst describes the channel features for each of the characteristics in a general way.

If there is significant uncertainty in this analysis, the channel analyst may recommend further steps to reduce that uncertainty to a level acceptable to both the fish and channel groups.

Channel Assessment Report

The Channel Assessment Report organizes and presents results of the channel assessment. The report is a compilation of key work products, maps and narrative summarizing interpretations. Narrative may be on the order of only several pages long and provide a concise discussion summarizing results of each section of the analysis module. While the Channel Assessment Report should be concise, it should be complete enough so that, together with the other module products, it provides the input necessary for the synthesis and prescription phases of Watershed analysis where the information developed in the analysis modules is incorporated into land use decision making.

Realistically, there will not always be the type of data or information available that the analyst would desire for high confidence in the analyses and interpretations. Assessment of the confidence level possible based on available information thus may be important for decision-making based on these analyses. The degree of confidence that can be assigned to the products of this analysis depends upon a number of factors. Considering the amount, type, and quality of available information, analysts should determine their relative confidence in the interpretation based on each work product. Other factors to consider in this evaluation may include, but are not limited to, extent of field work, experience of the analyst, complexity of the geology and terrain, aerial photographs and map quality, and multiple lines of evidence for inferred changes.

Where a Level 2 team chooses not to use the recommended forms, they must follow the stream channel assessment outline (see below). Additional methods employed need to be fully explained and justified in the channel assessment report.

Channel Condition Assessment Report

I. **Title page** with name of watershed analysis, name of module, level of analysis, signature of qualified analyst(s), and date

II. **Table of contents**

III. **Maps**
- Channel-response segment map (map E-1)
- Geomorphic unit map (map E-2)

IV. **Summary Data**
- Distribution of segments worksheet (form E-1)
- Basic trend information - channel disturbance worksheet (form E-2)
- Field site selection worksheet (form E-3)
- Channel assessment field forms (forms E-4) or equivalent
- Channel segment summary sheet (form E-5)
- Geomorphic unit description and sensitivity justification (form E-6)

V. **Summary Text**
- Watershed overview; network-wide influences
- Historic trends in channel changes
- Summary of current channel conditions and justification for interpretation
- Description of geomorphic map units (GMUs) and justification for interpretation
- Discussion of habitat-forming processes
- Study methods
- Descriptions of any deviations from the standard methods and why the changes were necessary
- Recommendations for Level 2 (at Level 1 only)
- Statement of the author's confidence level in the analysis and results
- Does module report address all critical questions?

VI. **Other Information (optional)**
- Monitoring strategies and design and implementation suggestions
- Learning resources (a.k.a., references, bibliography) section
- Acknowledgments section

All module work products should be archived for use during the Synthesis of this assessment and in future years.

Table E-4. Channel Assessment Task Checklist

Below is the channel assessment checklist, which helps guide the channel analyst through the watershed analysis.

Review	Task	Schedule	Complete
	Analysis materials in place		
	Startup meeting--brief team on process and intent Schedule module tasks		
	Map segments--Complete Response Segment worksheet (Form E-1)		
	Produce channel segment map on mylar overlay (Map E-1)		
	Provide map to fish and hydrology analyst		
	Meet with fish and hydrology analysts for input on analysis sites		
	Perform aerial photo interpretation; complete the channel disturbance worksheet (Form E-2)		
√	Review products and checkoff with team:		
	Select field sites and complete field site selection worksheet (Form E-3)		
	Complete field work-- (Field forms E-4)		
	Derive diagnostic variables and assess channel condition—complete channel diagnostic worksheet (Form E-5)		
√	Team meeting: review results of field work and channel interpretations		
	Cluster segments and determine channel sensitivity Complete Geomorphic Unit worksheet (Form E-6)		
	Complete the geomorphic unit map (Map E-2)		
	Interpret habitat-forming processes by geomorphic unit. Complete narrative		
	Produce module report		
√	Review module report		

Summary

The channel assessment module is intended to organize collection and presentation of the information necessary to make informed decisions about potential watershed management impacts on stream channels. The module relies on trained specialists to conduct and interpret analyses in order to provide effective information. The general approach is oriented around answering questions critical for developing a sufficient understanding of watershed processes to allow decision makers to weigh the benefits and potential risks of land management activity and to develop effective management prescriptions to avoid adverse impacts, enhance resource conditions and values, and accelerate recovery from past disturbance. The underlying philosophy is that only through incorporation of high quality information into the decision-making process can potential adversaries agree on a common decision-making framework. Recognition of when, where, and how to undertake more detailed analyses necessary to adequately understand watershed processes is a crucial component of Watershed analysis that must not be constrained prior to conducting the standard analysis.

Acknowledgments

This module represents the results of many people over the course of many years. This version was written by Kate Sullivan, Dave Montgomery, George Pess, and John Buffington. Mary Raines and Peter Whiting drafted the first version of this module based, in part, on a draft manuscript of report TFW-SH10-93-002. Development of the channel diagnostic procedure also benefited from discussions with Walt Megahan, Bill Dietrich, Lee MacDonald, Lee Benda, Matt O'Conner, Larry Schmidt, and JoAnn Metzler. This version of the module incorporates field forms that were aided in development by JoAnn Metzler.

The current module represents a work in progress on a complex issue completed under a statutory time table. Further revision of the manual and methods are required to maintain the technical viability and credibility of the channel assessment procedure. Periodic revision and incorporation of new methods and insight is a fundamental assumption of the diagnostic approach upon which this module relies.

References

Benda, L. in prep. Stochastic Geomorphology in a Humid Mountain Basin. PhD. Dissertation. Department of Geological Sciences, University of Washington, Seattle.

Benda, L. and T.W. **Cundy**, 1990. Predicting deposition of debris flows in mountain channels; Canadian Geotechnical Journal, v. 27, pp. 409-417

Buffington, J. M., and D.R. **Montgomery**. 1992. Effects of hydraulic roughness and sediment supply on bed surface textures in gravel-bed streams. Transactions of the American Geophysical Union 73(43): 231.

Buffington, J.M.. In prep. Effects of Hydraulic Roughness and Sediment Supply on Surface Textures of Gravel-bedded Rivers. Implications for Channel Assessment, M.S. thesis.

Buffington, J.M.. In prep. Fluvial processes and interpretation of stream-bed surface textures, in: Geomorphological Watershed Analysis Project Annual Report, in press.

Church, M., and D. **Jones**. 1982. Channel bars in gravel-bed rivers. In R.D. Hey, J.C. Bathurst, and C.R. Thone (eds.) Gravel-bed rivers, p. 291-338. John Wiley and Sons, New York.

Coho, C. and S.J. **Burgess**. 1991. Analysis of initiation mechanisms of dam-break floods in managed forests, Water Resources Technical Report, University of Washington, Department of Civil Engineering, Seattle, Washington.

Cupp, C. E. 1989. Stream corridor classification for forested lands of Washington, Report Prepared for Washington Forest Protection Association, 44p.

Dietrich, W. E., and T. **Dunne**. 1993. The channel head. In K. Beven and M. J. Kirkby (eds) Channel Network Hydrology. J. Wiley and Company, p. 176-219.

Dietrich, W. E., **Kirchner**, J. W., **Ikeda**, H., and F. **Iseya**. 1989. Sediment supply and the development of the coarse surface layer in gravel-bedded rivers. Nature 340:215-217.

Dietrich, W.E. and J.D. **Smith**, Influence of the point bar on flow through curved channels, Water Resources Research, 19, 1173-1192, 1983.

Diplas, P. and A.J. **Sutherland**. 1988. Sampling techniques for gravel size sediments, Journal of Hydraulic Engineering, 114, p. 484-501.

Frissell, C. A., **Liss**, W. J., **Warren**, C. E., and M.D. **Hurley**. 1986. A hierarchical framework for stream habitat classification: Viewing streams in a watershed context. Environmental Management 10: 199-214.

Grant, G., 1988. The RAPID technique: a new method for evaluating down-stream effects of forest practices on riparian zones, U.S. Department of Agriculture, Forest Service, General Technical Report PNW-GTR-220; 36p.

Grant, G. E., **Crozier**, M. J., and F.J. **Swanson**. 1984. An approach to evaluating off-site effects of timber harvest activities on channel morphology. In Proceedings, Symposium on the Effects of Forest and Land Use on Erosion and Slope Stability, Environment and Policy Institute, East-West Center, University of Hawaii, Honolulu: 177-186.

Ikeda, J. 1975. On the bed configuration on alluvial channels: Their types and condition of formation with reference to bars. Geographical Review of Japan 48(10):712-730 (in Japanese).

Jackson, W. L., and R.L. **Beschta**. 1982. A model of two-phase bedload transport in an Oregon Coast Range stream. Earth Surface Processes and Landforms 7:517-527.

Jaeggi, M.N.R. 1984. Formation and effects of alternate bars. J. Hyd. Engr. 110(2):142-156.

Johnson, A. 1990. The effects of landslide dam-break floods on the morphology of channels. Unpublished master's thesis, College of Forest Resources, University of Washington, TFW-SH17-91-001, 90p.

Kellerhals, R., C.C. **Neil** and D.I **Bray**. 1972. Hydraulic and Geomorphic Characteristics of Rivers in Alberta. Research Council of Alberta. River Engineering and Surface Hydrology Reports, 72-1, 50p.

Leopold, L.B., M.G. **Wolman**, and J.P. **Miller**. 1964. Fluvial processes in geomorphology. W.H. Freeman, San Francisco, 522 pp.

Lisle, T., 1986. Stabilization of a gravel channel by large streamside obstructions and bedrock bends, Jacoby Creek, northwestern California. Geol. Soc. Am. Bull. 97:999-1011.

Lisle, T., 1989. Using 'residual depths' to monitor pool depths independently of discharge. Research Note PSW-394, U.S.D.A. Forest Service PSW Station, Berkeley. 4 pp.

Lisle, T., and S. **Hilton**. 1992. The volume of fine sediment in pools: An index of sediment supply in gravel-bed streams. Water Resources Bull. 28:371-383.

Mark, D. M. 1983. Relations between field-surveyed channel networks and map-based geomorphometric measures, Inez, Kentucky. Annals of the Association of American Geographers 73:358-372.

Meyer-Peter, E., and R. **Muller**. 1948. Formulas for bed-load transport. Second Meeting of the International Association for Hydraulic Structures Research, Stockholm, p. 39-64.

Montgomery, D. R., and J.M. **Buffington**. 1993. Channel Classification, Prediction of Channel Response, and Assessment of Channel Condition, Washington Dept. of Natural Resources Report TFW-SH10-93-002., Olympia, WA. 86p.

Montgomery, D.R., **Buffington**, J.M., **Smith**, R.D., **Pess**, G.R., **Beechie**, T.J., **Schmidt**, K.M., and **Abbe**, T.M. 1993. Pool frequency in forested mountain drainage basins, paper to be presented at Fall 1993 American Geophysical Union Meeting, San Francisco, CA.

Montgomery, D. R., and W.E. **Dietrich**. 1988, Where do channels begin? Nature 336: 232-234.

Montgomery, D. R., and W.E. **Dietrich**. 1989. Source areas, drainage density and channel initiation. Water Resources Research 25:1907-1918.

Montgomery, D.R., and E. **Foufoula-Georgiou**. In prep. Channel network source representation using digital elevation Models. Water Resources Research.

Morisawa, M. E. 1957. Accuracy of determination of stream lengths from topographic maps. Transactions, American Geophysical Union 38:86-88.

Northwest Indian Fisheries Commission, 1993. Ambient Monitoring Program Manual, TFW-AM9-93-001.

Orsborn, J. F., and **Anderson**, J. W. 1986. Stream improvements and fish response: A bioengineering assessment, Water Resources Bulletin, v. 22, p. 381-388.

Parker, G., **Klingeman**, P. C., and D.G. **McLean**. 1980. Bedload and size distribution in paved gravel-bed streams. Journal of the Hydraulics Division, Proceedings of the American Society of Civil Engineers 108:544-571.

Paustain, S. J., **Marion**, D. A., and D.F. **Kelliher**. 1983. Stream channel classification using large scale aerial photography for southeast Alaska watershed management. In: Renewable Resources Management Symposium, American Society of Photogrammetry, Falls Church, VA: 670-677.

Perkins, S. 1989. Interactions of landslide-supplied sediment with channel morphology in forested watersheds. Unpublished Master's thesis, Department of Geological Sciences, University of Washington, Seattle.

Pfankuch, D. J. 1975. Stream reach inventory and channel stability evaluation. U.S.D.A. Forest Service, R1-75-002. 26p.

Pierson, T.C., and J. E. **Costa**. 1987. A rheological classification of subaerial sediment-water flows. Geologic Society of America, Reviews in Engineering Geology, v. VII, p.1-12.

Rosgen, D. L. 1985. A stream classification system. In Johnson, R.R., C. D. Zeibell, D. R. Patton, P. F. Ffolliott, and R. H. Hamre (eds). Riparian Ecosystems and Their Management: Reconciling Conflicting Uses. U.S. Forest Service General Technical Report RM-120: p. 91-95.

Sedell,J.R. and J.L. **Froggatt**. 1984. Importance of Streamside Vegetation to Large Rivers: The Isolation of the Willamette River, Oregon, U.S.A. from its Floodplain. Verhandlunger der Internattional Vereingung fur Theoretisuke und Angewandte Limnologie. 22:1828-1834.

Seidl, M., and W. E. **Dietrich**. 1992. The problem of channel incision into bedrock. In Schmidt, K.-H. and J. de Ploey (eds). Functional Geomorphology. Catena Supplement 23, Catena-Verlag, Cremlingen: 101-124.

Shields, A. 1936. Anwendung det Anlichkeitsmechanik und der Turbulenzforschung auf die Geschiebebewegung, Translated by W. P. **Ott** and J. C. **van Uchelen**, California Institute of Technology, Pasadena, California. 26p.

Smith, N. D., and D.G. **Smith**. 1984. William River: An outstanding example of channel widening and braiding caused by bed-load addition. Geology 12:78-82.

Sullivan, K., T.E. **Lisle**, C.A. **Dolloff**, G.E. **Grant**, and L.M. **Reid**. 1986. Stream channels: the link between forests and fishes. In: **Salo** E. O. and T. W. **Cundy** (eds). Streamside Management: Forestry and Fishery Interactions. Proc. of a Symposium held at the Univ. of Washington, Feb 12-14 1986, Seattle WA: 39-97.

Williams, G. P. 1978. Bank-full discharge of rivers. Water Resources Research 14:1141-1154.

Wolman, M. G. 1954. A method of sampling coarse river-bed material. Transactions American Geophysical Union 35:951-956.

Wolman, M.G. and Leopold, L.B. 1957. River Flood Plains: Some Observations on Their Formation. USGS Professional Paper. 282-C.

Form E-1. Channel Segment Identification Worksheet

FORM E-1. SEGMENT IDENTIFICATION WORKSHEET

SEDIMENT
FS – Fine Sediment Deposition
CS - Coarse Sediment Deposition

DISCHARGE
SC - Scour Depth
SF - Scour Frequency
BE - Bank Erosion

WOOD
WL - Wood Loss
WA - Wood Accumulation

CATASTROPHIC EVENTS
DFS - Debris Flow Scour
DFD - Debris Flow Deposition
DB - Dam Break Flood

VW > 4CW UNCONFINED						
2CW < VW < 4CW MODERATELY CONFINED						
VW < 2CW CONFINED						
	<1.0 Pool-Riffle	1.0 - 2.0 Pool-Riffle, Plane-Bed	2.0 - 4.0 Plane-Bed, Forced Pool-Riffle	4.0 - 8.0 Step-Pool	8.0 - 20.0 Cascade	> 20.0 Colluvial

VALLEY GRADIENT AND TYPICAL CHANNEL BED MORPHOLOGY

Form E-2. Channel Disturbance Worksheet

Channel Response Segment Number	Change in Channel Width (+ or -)	Time Interval (years)	Disturbance Indicators: Channel pattern change, alluvial fans, adjacent catastrophic damage

Form E-3. Field Site Selection Worksheet

SEGMENT CHOSEN	RATIONALE

Form E-4: Channel Assessment Field

Stream____________________________ WAU_____________ Observers________________
Segment No.___________ Response Type___________ Date____________
Length Sampled________ Total Segment Length_________ Flow: high mod low

Channel Dimensions Mean bkfl width:________________________ Wetted width:___________ Mean bkfl depth:________________________ Wetted depth:___________ Valley bottom width:_____________________ Channel slope:__________			
Bed Conditions Morphology: colluvial bedrock regime braded pool-riffle forced pool-riffle plan-bed step-pool cascade			
Gravel Bars: point medial multiple forced ___________% active area in bars Riparian opening wider than active channel?			
Channel Pattern: meandering sinuous straight braided Sinuosity:________			
Pool spacing:	POOL TALLY (approx. width X length X mas depth)		
Free	LWD Forced	Bldr Forced	Banks Forced
Total:	Pool spacing = (reach length/channel width)/number of pools =		
Primary LOD Function(s): pool scour bank stability Bar stability sediment trap step former Describe:____ ____			LWD Tally (> “)
Fine Sediment Deposits: In pools: avg V* and range (see V* forms): _________________ _________________ In riffles: 1) Locally in sheltered locations 3) over most of bed 2) Strands extending downstream 4) thin draping over larger clasts			
Stream Bed Material: Surface Texture: ____________________________ Distribution & patterns: ____________________________ ____________________________ D50 (see pebble count forms):			
Other Comments:			

Bank Conditions

Bank Material:

Texture: ____

Source: ____

Sources of protection: ______________________________

____

Bank erosion: % of reach

Location:
1) locally where forced by obstructions
2) outside of bends
3) intermittent; independent of channel geometry
4) extensively along one side
5) continuously along both banks

Mass Wasting (record approx. length and height; mark on map)

Floodplain Conditions

Entrenchment:____________________ Cross-Section Sketch

Terrace material, source and size:

____

____

Overbank Deposits:

1) Wood berms
2) Debris trash lines
3) Boulder berms
4) Other, _____________

Channel margin vegetation:_____________________________________

____

Riparian condition: _____________________________________

____

Other Comments:

____

____

____

____

____

Migration:

Spawning (gravel presence & stability):

Rearing (pool formation):

Overwinter (off-channel):

Stream Channel Assessment Forms E-4

Date:
Stream:
Segment #:
Weather:
(air temp & visibility)
General Flow condition:
(flow level & visibility)

Observers:
Length Sampled:
Total Segment Length:
Mean bankfull width:
Mean bankfull depth:
Wetted width:
Wetted depth:

CHANNEL BED

Channel Bed Morphology

1=colluvial, 2=bedrock, 3=cascade, 4=step-pool, 5=plane bed, 6=forced pool/riffle, 7=free pool/riffle, 8=regime, 9=braided (depositional channels include 5-8; transport include 4-2; source includes 1. Note where this is not the case and note the primary depositional, transport and source channels.)

Distance (ft or M)	Type	Slope (Clino or level)	Comments

ACTIVE CHANNEL

Gravel Bar Characteristics

1=Point; 2=Lateral; 3=Medial; 4=Tranverse; (controlled by bed obstructions such as boulder); 5=Single Obstruction (e.g., LWD or Boulder); 5=LWD (a=bar apex; b=meander bend/channel cutoff or avulsion).

Activity Level (AL)

1=Active (all within floodplain & no evidence of vegetation); 2= Semi-active (>50% in floodplain and non-vegetated, or side channel around outside end of bar active during high flow events); 3=Not active (bar is above floodplain, part of terrace, or entire bar is vegetated except for banks)

Side Channel (SC[W]) – give width of side channel.
Side Channel (SC[L]) – give width of side channel.

Note – Measure bar dimensions as a function of activity level within bar. One bar can have several activity levels.

Distance (ft or M)	#	Type	Lgth (ft or M)	Wdth (ft or M)	Hght (ft or M)	AL	SC (W) (ft/m)	SC (L) (ft/m)

ACTIVE CHANNEL

Pool Forming Factors (PFF)

PFF key

1=Channel meander (free) or bedform, 2=Bank, 3=Log, 4=Log jam, 5=Rootwad, 6=Roots of standing tree or stump, 7=Boulder, 8=Bedrock (indicate type), 9=Beaver dam, 10=Manmade (artificial bank, culvert, bridge, etc.), 11=Gravel bar (for backwater & side channel pools). Can be more than one element. (Please refer to Ambient Monitoring Manual for definition of pool forming factors).

Substrate (Dominant [dom] and subdominant [sub])

1=Bedrock; 2= Boulder; 3=Cobble; 4=Gravel; 5=Sand; 6=Organics; 7=Silt

Obstruction size (size of obstruction creating pool) Can be more than one element. Record length and width of structure that creates the pool.

Start Dist (ft or M)	End Dist Ft or M	PFF	L FT or M	W Ft or M	MaxDpth Ft or M	TIDepth Ft or M	Subste Dom & sub	Obs Size W) ft or M	Obs Size (L) Ft or M

ACTIVE CHANNEL
Long Profile Data Sheets
Date: Watershed: Stream:
Segment#: Surveyors:

Unit #	**Dist (ft or M)**	**Backsight (ft or M)**	**Foresight (ft or M)**	**Comments (Benchmark, turning point, pool, riffle, etc.)**

ACTIVE CHANNEL

Cross Section Data Sheets

Date: Watershed: Stream:

Segment#: Surveyors:

Dist (ft or M)	Type	Distance (ft or M)	Depth (ft or M)	Comments

No. 312

V* Data

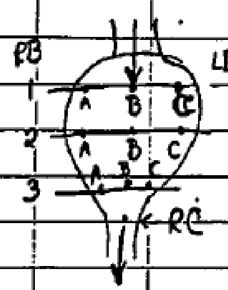
Observer: ______

Date: ______

Segment #: ______

Pool Type: ______

Caused by: ______



Width: wetted ______ bkfl ______

Length: wetted ______ bkfl ______

Riffle Crest.

	Transect # 1			Transect # 2			Transect # 3		
	A	B	C	A	B	C	A	B	C
Depth to fines D_F									
Depth to gravel D_G									
$F = D_G - D_F$:									
$RD: D_G - RC$									
$V^* = F/RD$									

Avg V* for pool = ______

Represents ______ % of pools in the segment

Comments:

No. 312

V* Data

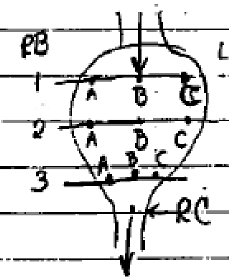
Observer: ______

Date: ______

Segment #: ______

Pool Type: ______

Caused by: ______



Width: wetted ______ bkfl ______

Length: wetted ______ bkfl ______

Riffle Crest.

	Transect # 1			Transect # 2			Transect # 3		
	A	B	C	A	B	C	A	B	C
Depth to fines D_F									
Depth to gravel D_G									
$F = D_G - D_F$:									
$RD: D_G - RC$									
$V^* = F/RD$									

Avg V* for pool = ______

Represents ______ % of pools in the segment

Comments:

CHANNEL BED

(For particle size distribution (surface and subsurface see pebble count form)

Dominant Roughness Elements (DRE)

1= structure controlled (steps & obstructions), 2= Particles (a=bedrock, b=boulder, c= cobble, d=gravel), 3= bed form (bars, pools, riffles), 4= LWD, 5= sinuosity, 6=banks

Bed Surface Pattern (BSP)

1= Glide; 2=Riffle; 3=Rapid; 4=Side Channel

Substrate (Subste) (Dominant [dom] and subdominant [sub])

1=Bedrock; 2=Boulder; 3=Cobble; 4=Gravel; 5=Sand; 6=0rganics; 7=Silt

Fine Sediment Deposits

In Pools (also see V form) (FSD-p)*

1 = local accumulation behind obstructions and in slackwater; 2= accumulation local and in patches; 3= widespread accumulation.

In Riffles (FSD-r)

1= locally in sheltered locations; 2= strand extending downstream of obstructions; 3= over most of the bed; 4= thin draping over large clasts

Dist (ft or M)	**DRE**	**BSP**	**Subste (dom& sub)**	**FSD-p**	**FSD-r**	**Comments**

ACTIVE C HANNEL

LWD

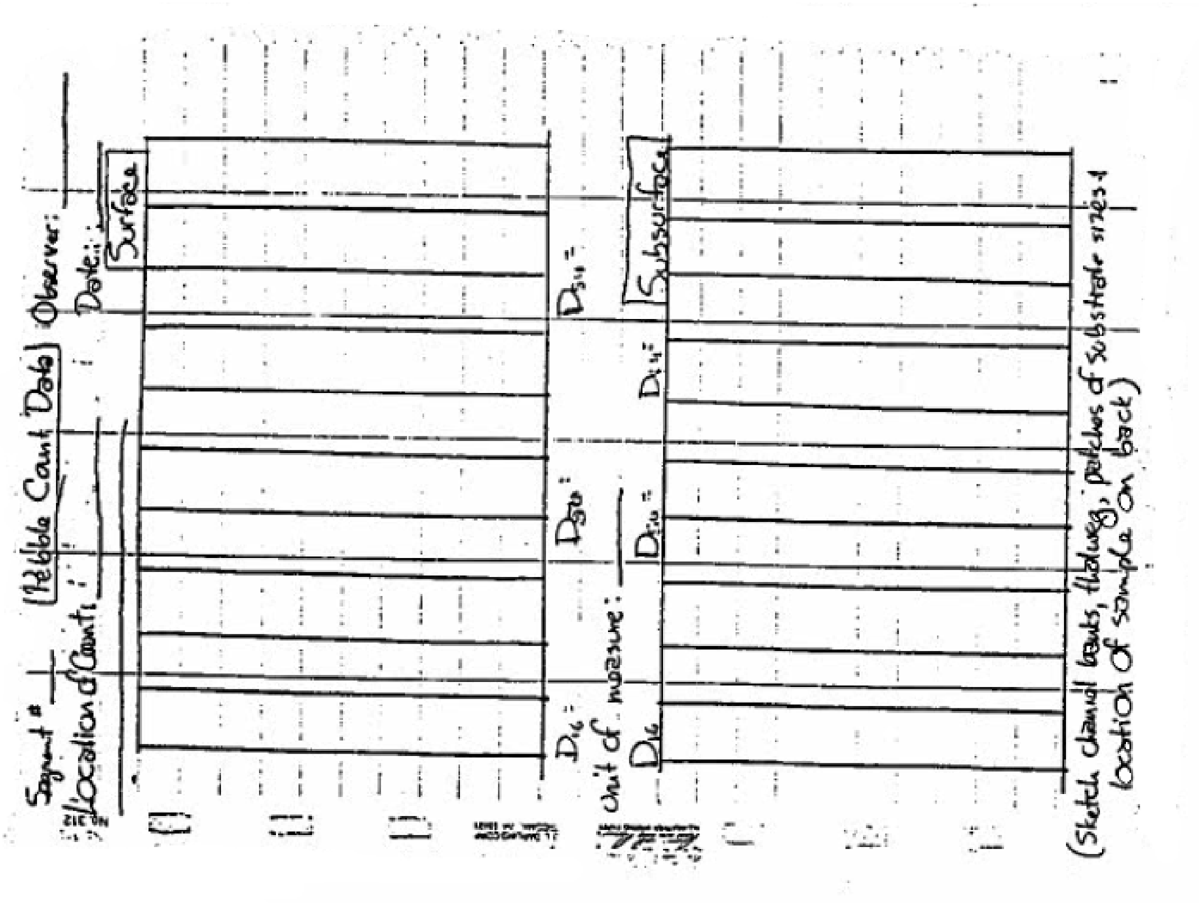
Functions(F)

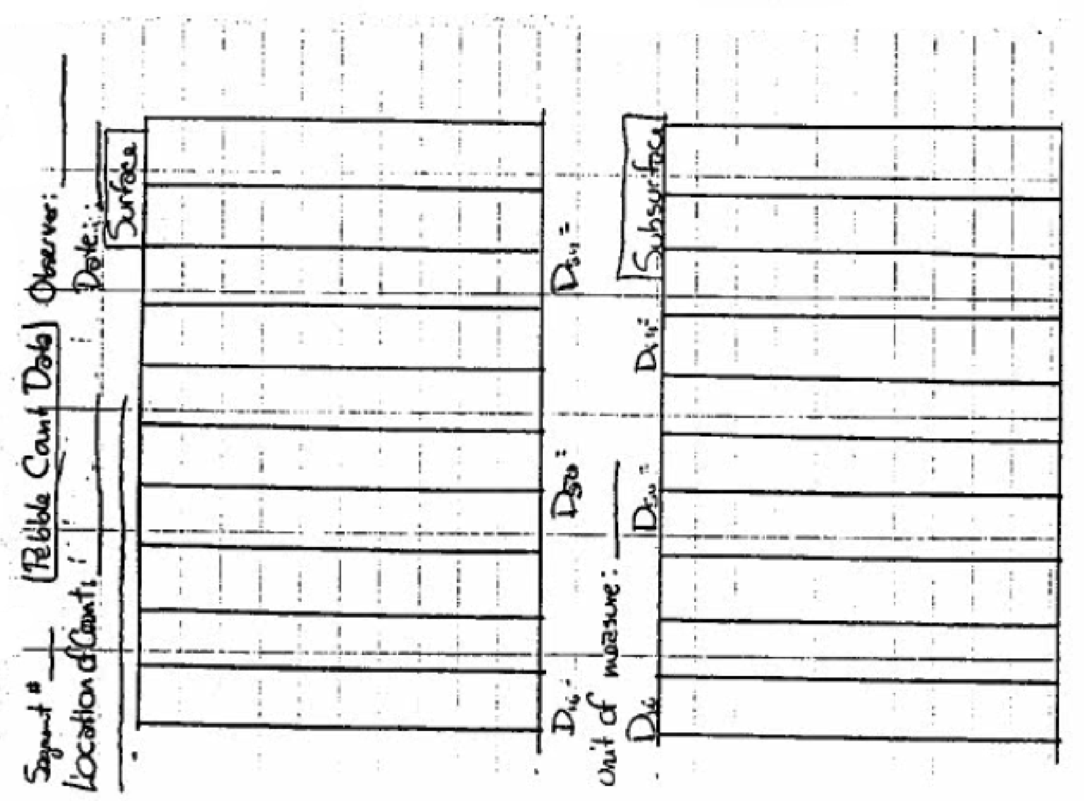
1=pool scour; 2=bank stability (a=single piece, b=debris), 3=bar stability (a=single, b=bar apex jam, c=meander bend, d=channel cutoff jam), 4= sediment storage, 5=step or terracette former, 6= channel creator. Note - function can be more than one at any given time. Record channel width at various points to compare to LWD size. For jams estimate number of pieces and rough size distribution.

#pieces - scale number of pieces to appropriate size based on bankfull width.

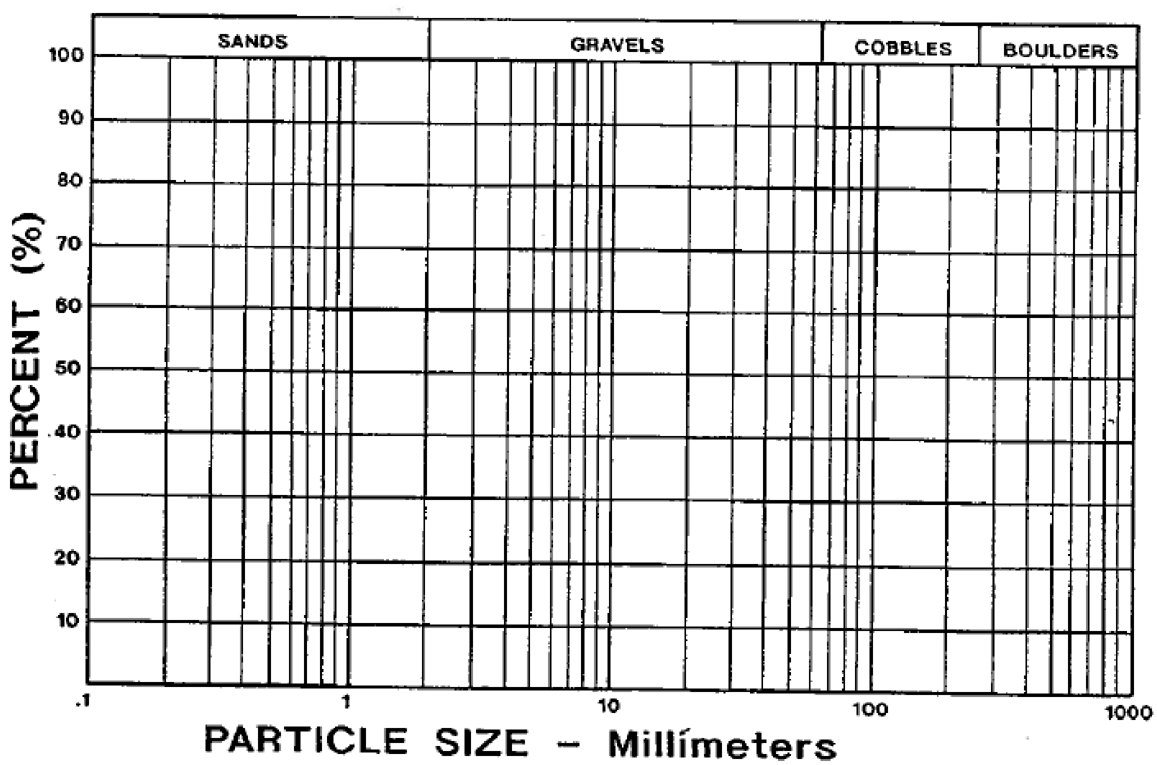
Log Jam or Channel Stored Sediment (LJ/CSS) (Only applies to LWD that create log jam or exhibits sediment storage as a primary function) Measure Height (Upstream bed v. Downstream of obstruction bed elevation), Length (Upstream end of obstruction to Upstream end of log jam or sediment accumulation), and Width. Minimum dimensions should be .2Mx.3Mx.6M long. Volume=(H/2)LW

Distance (ft or M)	F	#pieces (> cm)	#pieces (> cm)	LJ or CSS L (ft or M)	LJ or CSS W (ft or M)	LJ or CSS H (ft or M)	Comments


Segment # ___ Location of Count: ___
Pebble Count Data
Observer: ___
Date: ___
Surface
D_{16} = D_{50} = D_{84} =
Unit of measure: ___
Subsurface
D_{16} = D_{50} = D_{84} =
(Sketch channel banks, thalweg, patches of substrate sizes + location of sample on back)


Segment # ___ Location of Count: ___
Pebble Count Data
Observer: ___
Date: ___
Surface
D_{16} = D_{50} = D_{84} =
Unit of measure: ___
Subsurface
D_{16} = D_{50} = D_{84} =

PEBBLE COUNT								PEBBLE COUNT			PEBBLE COUNT		
Watershed Name:				Date:				DATE:			DATE:		
Party:				Reach:				REACH:			REACH:		
Inches	PARTICLE	Millimeters		Particle Count	TOT #	ITEM %	% CUM	TOT #	ITEM %	% CUM	TOT #	ITEM %	% CUM
	SILT/CLAY	< .062	S/C										
	Very Fine	.062 - .125	S										
	Fine	.125 - .25	A										
	Medium	.25 - .50	N										
	Coarse	.50 - 1.0	D										
.04 - .08	Vry Coarse	1.0 - 2	S										
.08 - .16	Very Fine	2 - 4											
.16 - .24	Fine	4 - 6	G										
.24 - .31	Fine	6 - 8	R										
.31 - .47	Medium	8 - 12	A										
.47 - .63	Medium	12 - 16	V										
.63 - .94	Coarse	16 - 24	E										
.94 - 1.26	Coarse	24 - 32	L										
1.26 - 1.9	Vry Coarse	32 - 48	S										
1.9 - 2.5	Vry Coarse	48 - 64											
2.5 - 3.8	Small	64 - 96	C										
3.8 - 5.0	Small	96 - 128	O										
5.0 - 7.6	Large	128 - 192	B										
7.6 - 10	Large	192 - 256	L										
10 - 15	Small	256 - 384	B										
15 - 20	Small	384 - 512	L										
20 - 40	Medium	512 - 1024	D										
40 - 160	Lrg-Vry Lrg	1024 - 4096	R										
	BEDROCK		BDRK										
				TOTALS									



D_{16} = D_{50} = D_{84} =

ACTIVE CHANNEL

Bank Erosion Factors
1=locally where forced by obstructions; 2=outside of bends; 3=intermittent, independent of channel geometry; 4= extensively, along one bank; 5=continuously along both banks.
Bank & vegetation
1=80% covered, 2=50 to 80% covered. 3=25 to 50% covered. 4=<25% covered
Bank material composition:
Texture (alluvium, colluvium, bedrock, etc.):
D50 observed:
Source:
Sources of protection:

Dist (ft|M)	BEF (LB)	BEF (RB)	BV (LB)	BV (RB)	Lgth (ft|M)	LBHght (ft|M)	RBHght (ft|M)	%Bank Eroding	Com

ACTIVE CHANNEL

Riparian Composition (RC)

1=mixed; 2=coniferous; 3=deciduous; 4=herbaceous; FP=floodplain. Note % of each and cross-sectional or longitudinal change in vegetation.

Riparian Age (RA)

a=Young (<40yrs), b=Mature(between 40-80yrs), c=Old (120 for coniferous, 80 for mixed or deciduous). Note whether sparse or dense.

Active Riparian Recruitment Processes (ARRP)

l=bankcutting; 2=windthrow; 3=floodplain; 4=jams; 5=upstream sources

Distance (ft or M)	RC (LB)	RC (RB)	RA (LB)	RA (RB)	ARRP (LB)	ARRP (RB)	Comments

FLOODPLAIN

Entrenchment (Ent)

1= Not entrenched (floodplain & terrace connected); 2= Moderately entrenched (small active floodplain in a larger trench that may be inundated during 20 yr event); 3= entrenched (small floodplain, isolated terrace).

Terrace material (TM)

Note % of each terrace forming material (e.g. bedrock, alluvium, colluvium, and debris flow deposit) and D50 (observed). There may be more than one terrace, please note each terrace material source, and estimate terrace D50 of each.

Overbank deposits (OD)

1= wood berms; 2= debris trash lines; 3= boulder berms; 4= other

Terrace observed D50

Overbank deposit observed D50:

Dist (ft or M)	Ent	TM	OD	Comments

Form E-5 Segment Summary Sheet

page 1 of 2

Segment:____________________________ WAU:______________________

Attributes		Sediment Supply	Transport Capacity	LWD Function	Catastrophic
Channel Bed	Channel type				
	Median grain size				
	Bed surface pattern				
	Particle Size Distribution				
	q*				
	% fines in Subsurface				
	Roughness elements				
Active Channel	Gravel bar characteristics				
	Pool characteristics				
	Channel Pattern				
	Fines in pools				
	V*				
	Fines in riffles				
	Bank Erosion				
Flood-plain	Overbank deposits				
	Entrenchment				
	Riparian vegetation				

Form E-5 Segment Summary Sheet

page 2 of 2

Input Factor	Existing Condition	Change from Historic	Response
Coarse Sediment			
Fine Sediment			
Peak Flow			
Large Woody Debris			
Catastrophic Damage			
Geomorphic Unit			

Form E-6. Geomorphic Unit Description and Sensitivity Justification

Geomorphic Unit: ____

Description: ____
(including ____
gradient & ____
confinement) ____

Input Factor	Conditions	Response Potential	Relative Sensitivity
Coarse Sediment			
Fine Sediment			
Peak Flow			
Large Woody Debris			
Catastrophic Damage			

	Field-verified	Extrapolated
Segments in Geomorphic Unit		

APPENDIX F
Fish Habitat Module

Table of Contents

Introduction

The many elements of fish habitat that affect the production of salmonids during the freshwater phases of their life history can be organized into two general categories: elements of physical habitat and factors that affect food production. Physical habitat features include depth and velocity ranges (usually grouped by channel units, e.g., pools, riffles), cover, spawning gravels, and temperature ranges. Influences of forest management on these features as well as on other aspects of water quality and food production are extensively discussed in Meehan (1991).

A number of studies indicate that the characteristics of physical habitat influence the density and survival of salmonids during the freshwater phases of their life history (Salo and Cundy 1987, Fausch et al. 1988, and Meehan 1991 provide extensive reviews), and that forest practices directly affect these elements of physical habitat (Salo and Cundy 1987, Meehan 1991). At present, the strongest link between forest practices and their effect on fish habitat is the description of physical habitat characteristics. We therefore assume that degradation of physical habitat features will result in reductions in salmonid production.

One difficulty in assessing fish habitats in a watershed is that of the spatial scale at which the analysis is focused. Classification systems are frequently used to aid in describing habitat conditions and channel response at the reach scale (Cupp 1989, Beechie and Sibley 1990, Naiman et al. 1991, Montgomery and Buffington 1993), whereas limiting factors analyses are more properly approached at the scale of the WAU or larger (Reeves et al. 1989). The spatial scale at which to conduct the analysis is further complicated by the fact that different salmonid species have differing ranges during their freshwater life history phases. For example, coho salmon may occupy summer rearing habitats within a WAU and then move downstream beyond the WAU boundaries to find winter rearing habitats, whereas resident cutthroat trout can spend their entire life within a portion of a WAU. The complete assessment requires that both scales be considered, and that care be taken to avoid incorrect assumptions about seasonal migrations into or out of the WAU.

Temporal scale is also an important consideration in fish habitat management. Habitats in a reach or watershed can be degraded over short time periods and can recover over a variety of time scales, and disturbances can be either acute or chronic. It is therefore important to define the scales at which watershed assessments occur. This is an especially important concept when stock status is considered. When stocks are clearly at risk, habitat management measures may include immediate stop-gap measures in conjunction with more comprehensive watershed restoration. When stocks are relatively healthy, stop-gap measures may not be cost-effective and habitat restoration may be focused on broader scale watershed management measures.

Another difficulty is that of multiple species management, where managing for a single species may be detrimental to other species. The idea that biodiversity can be conserved when managing for habitats preferred by a single species appears unlikely to succeed. We chose to approach the problem of watershed level fish habitat assessment with the idea that the range of potential habitat conditions at the reach scale is controlled by geomorphic setting, and that old-growth conditions most closely represent the conditions to which multiple species have adapted over the past several thousand years (Benda et al. 1992, Peterson et al. 1992). When possible, we have used data from undisturbed systems to develop habitat diagnostics that reflect habitat conditions preferred by salmonid species at their various freshwater life history stages. This approach does not imply that preferred fish habitat only occurs in old-growth forests. Rather the strategy is to use knowledge of habitat in old-growth forest as a basis for identifying changes in habitat conditions.

The analysis is structured around the habitat needs of individual species and life history stages on a temporal and spacial scale. Indices of habitat conditions are based on habitat utilization and on stream characteristics which have supported a multitude of species at healthy levels prior to extensive habitat changes. These two components of the approach are driven by 1) concept of limiting factors analysis (Reeves et al. 1989, Reeves et al. 1991) and 2) the understanding that the nature of stream habitats is strongly influenced by geomorphic setting (Benda et al. 1992). The result is a comprehensive understanding of the distribution of fish species in a WAU and the factors that appear to most strongly influence the abundance of individual species.

Because most salmonid species migrate seasonally within or beyond a WAU to occupy preferred habitats, most accessible reaches are considered to be important habitats for at least one species during any season. However, some reaches can be identified as reaches of greater importance due to concentrated use (e.g., a chum spawning reach), limited availability of a habitat type (e.g., a single area that accounts for most of the coho winter rearing habitat), habitat degradation (e.g., evidence indicates that pool quantity and quality have been dramatically reduced), or other factors. These reaches deserve special attention because they help to focus the efforts of channel assessment, they provide insight into the causes of degradation, and indicate reach types that may be especially sensitive to impacts. They also focus attention on reaches that require more careful prescriptions to address habitat protection and restoration.

The products produced by the fish habitat module are intended to identify and delineate the fisheries resources in the WAU. The vulnerability of fish habitat to potential impacts from the five input variables is not determined in this module as was the case in Version 1.0. Habitat vulnerability is a function of fish habitat utilization, habitat condition, and the sensitivity of habitat to physical disturbance. The latter information is developed by the channel module for the purpose of assessing habitat vulnerability. The strategy is to use the results from the fish habitat and channel module during the Synthesis Phase to create habitat vulnerability calls for the five input variables.

Critical Questions

The goal of the fish module is to locate all accessible fish habitat in the WAU and to identify existing habitat conditions including habitats of special concern. The latter includes degraded habitats, habitats with a high use by fish, and habitats of limited availability. Critical questions addressed by the fish module are:

What is the distribution and relative abundance of salmonid fish species in the WAU?

Where are areas of degraded habitats in the WAU (by species and life history stage)?

Where are areas of high existing or potential habitat use (by species and life history stage)?

Where are areas of limited habitat availability.

To answer these critical questions the fish module will address the following objectives:

- Determine the historic and present fish distribution in the basin
- Identify the historic trends in fish abundance by stock.
- Determine the existing habitat conditions.
- Evaluate distribution changes, abundance trends, and existing habitat conditions to identify degraded habitats.
- Evaluate habitat utilization and habitat preference information to identify high use areas and habitats of limited availability.

Assumptions

The fundamental assumptions upon which the analysis is based are:

- Fish distribution is a function of the quantity and quality of habitat types available in a WAU. That is, reach type strongly influences the types of habitats available within the reach, which in turn influences the species use in the reach. The distribution of fish species in a WAU is therefore a function of the distribution of reach types in a WAU.

- The habitat conditions to which salmonid species have been exposed during the past several thousand years are accurately represented by conditions in streams in unmanaged forests, and where known, these conditions provide appropriate reference points for indices of habitat condition. (This does not necessarily imply that these conditions can be achieved only in old-growth forests.)

- Fish abundance is dependent on the success of each life phase, which is limited in part by the quantity and quality of habitat available for each life phase.

- Factors that limit salmonid abundance can be accurately described as the sum of reach level habitat conditions across the WAU. Therefore, habitat conditions within a reach accurately reflect incremental impacts to both salmonid habitat and production.

- No single measure of habitat is sufficient to describe habitat conditions in a reach. Nor is any habitat index accurate 100 percent of the time. Use of several habitat diagnostics to describe conditions is a more robust method of habitat evaluation.

Overview of Assessment and Products

During the fish habitat assessment, the analyst gathers information concerning the fisheries resources and habitat conditions in a basin, asks specific questions about habitat conditions that may limit fish production, identifies limiting factors (when possible) and areas of special concern in the basin. The assessment is an iterative process that requires repeated evaluation of information and testing of hypotheses. Habitat evaluation and hypothesis development is initially based on existing information, and follow-up analyses are targeted on verification of these hypotheses using new information from a field survey.

The method allows for Level 1 and Level 2 assessments, with the basic difference between the two levels being the degree of confidence with which the critical questions can be answered. The method encourages Level 2 effort to avoid incorrect interpretations of habitat conditions that stem from limited data. Because interpretations of habitat data are rarely simple, the analyst should constantly be aware of the objectives of the module and should apply the level of effort necessary to accomplish them with reasonably high confidence. The basic difference between Levels 1 and 2 is the level of field effort applied to the analysis. At Level 1 the analyst visits fewer sites and relies more on visual assessments of habitat conditions. Because of time limitations for Level 1, a set of habitat quality indices based on channel geomorphic characteristics is provided. This enables the analyst to evaluate potential habitat conditions when field data is not available. Level 2 involves broader coverage of stream reaches in the WAU and generally requires field measurement of habitat parameters used as diagnostics. However, at both levels the same questions are asked and the same parameters are used. Confidence in the habitat assessment is lower for Level 1 because the results rely on assumed habitat potential rather than actual data.

The general process of fish habitat assessment is the same in all watershed analyses. However, because the nature of fish habitats and the availability of data within WAUs will vary widely around the state, the development of hypotheses and the focus of assessment efforts will vary from between individual watershed analyses. That is, the fish habitat assessment is intended to be focused differently depending species of importance in the WAU and on the types of habitat problems identified during the assessment. These differences will often be related to the location of the WAU (e.g., east side of Cascades vs west side of Cascades) and on interpretations of stock status (e.g., limiting wild stocks or stocks at risk).

The analyst begins by gathering as much existing data as possible (typically allowing several weeks lead time for responses to surveys of local biologists and requests for compiled or raw data). Data gathered at this phase of the analysis include species distributions, spawning and escapement data, habitat data, description of "critical" habitat areas, and descriptions of known habitat problems. Data are organized according to the reach stratification developed in the channel assessment (Map E-1, Form E-1).

The analyst examines the data with the critical questions in mind with respect to four life history phases; upstream migration, spawning and incubation, summer rearing, and winter rearing. When habitat data are available, the analyst examines them relative to the reference ranges and tentatively identifies areas of degraded and preferred habitats. Other data (e.g., spawner escapement trends) are used as supporting evidence to aid in interpreting the likely effects of habitat data on the populations in the WAU. Based on hypotheses of habitat degradation and habitat utilization, the analyst identifies further information needs and specific reaches where field examination is required. When habitat data are not available the analyst uses descriptions of critical habitat areas and areas of degraded habitat to formulate the initial working hypotheses and to direct field efforts toward the most important reaches.

During field surveys, the analyst should give special attention to diagnostics that are related to the important life history phases identified with the existing data. The analyst should always be mindful of the critical questions to be answered. More specifically, the analyst should try to 1) identify areas of degraded habitat and to locate other reaches with similar habitat functions that may have similar sensitivities to impacts, 2) locate reaches that are of greater importance to the species in the basin (e.g., high utilization or limiting habitats), and 3) note other factors that indicate habitat problems, species of special importance, or potentially sensitive habitats.

Based on the new information, the analyst must identify and locate all habitats of special concern on a map overlay. Data supporting these decisions are summarized in a table that indicates the reach location and source of the data. This allows for easy data retrieval for each reach. A summary form will be used to condense the data results for all reaches so that the analyst can get a better understanding of habitat conditions in the entire WAU.

The products include four maps and short narrative descriptions for the general status of fish habitat by life history stage, plus additional details for each area of special concern. The map for each life history phase will show the Water Type 3 and 4 boundaries, species distribution, and areas of special concern for the specific life phase. The identification of areas of special concern are intended to focus the attention of other analysts and prescription writers on areas that require special attention for habitat protection or restoration. Areas not identified as a special concern should also receive a brief description of their functions as habitat and their relative importance in the WAU.

Whenever possible, the analyst should identify the perceived cause of habitat problems (i.e., which of the five input variables most influence a given habitat condition). This helps to focus the analysis and provides hypotheses that can be tested later in synthesis. At all times, the analyst must be communicating with those conducting the channel and riparian assessments so that data gaps can be filled as efficiently as possible.

Qualifications

Skills

- Familiarity with information and data bases (e.g., WARIS, SASSI) relevant to stream habitat.
- Knowledge of habitat requirements (at all life stages) of resident and anadromous fish common in the Pacific Northwest.
- Knowledge of the habitat forming processes active in stream channels in forested and mountainous terrain.
- Ability to evaluate stream habitat conditions.

Education and Training

- Bachelor's degree in fisheries biology, or in a related field such as zoology, wildlife biology, with a significant amount of course-work or other training (academic or commercial short courses, etc.) in stream habitat characteristics relevant to freshwater fisheries (particularly in forested basins).

Experience

- Level 1 - At least one year of field experience in data collection and analysis, management, or research regarding fish habitat assessment in forested and/or mountainous areas.

- Level 2 - A minimum of two years experience conducting relevant independent research or fish habitat assessments in streams.

Background Information

Several types of information are used repeatedly throughout the habitat assessment. Gather this information from the respective sources during the startup process.

Maps

- Water-type maps are available from DNR's Photo and Map Sales. Revisions may be available from land owners, tribes, and agencies. These maps indicate the water type (a legal classification) of many streams and rivers in the state. They are also available on DNR's ARC-INFO-based Geographic Information System (GIS).

- WAU base map (from startup).

Other

- Washington Rivers Information System (WARIS) information is available from the state Department of Fish and Wildlife (WDFW). WARIS is essentially an updated GIS version of the Washington Department of Fisheries (WDF) stream catalogue with added resident fish data. It contains valuable information on fish distribution, migration barriers, passage facilities, and hatchery locations. Unless you have GIS capabilities, WARIS information will come to you in map form at the 1:24,000 scale.

- Limited numbers of the catalog of Washington Streams and Salmon Utilization are available from the state Department of Fish and Wildlife. Catalog 1 covers streams flowing into Puget Sound; Catalog 2 covers streams flowing into coastal waters. No Columbia River streams are included in the catalogs. All information in these catalogues is dated 1972 or earlier and includes data on the distributions of the five Pacific salmon species, the location of fish migration barriers, summer and winter wetted stream widths, spawning substrate characteristics, river mileage and stream lengths, timing information, passage facilities, and hatcheries. Only a limited number of these publications are available, so cooperators who already have them are encouraged to share. Local cooperators may have updated sections of the catalogue.

- The Washington State Salmon and Steelhead Stock Inventory (SASSI) is available from the Washington Department of Fish and Wildlife.

- An inventory of resources within the watershed, a source of information on the presence/absence and location of vulnerable, threatened, and endangered fish species in the study area, is available from the Priority Habitats and Species Division of the state Department of Fish and Wildlife.

- Personal and first-hand knowledge of the area. Conduct interviews or request information from appropriate resource managers to acquire local knowledge. Use the form Fisheries Information Request for Watershed Analysis (Form F-1) as a guide for an interview or send the form to the appropriate person. This form provides a list of questions that should be answered as completely as possible. Contact the state Department of Fish and Wildlife to identify biologists with watershed analysis responsibility. In either agency, several biologists may have relevant expertise. Requests for fisheries information should be made to the appropriate respondents several weeks in advance of the watershed analysis.

- If the drainage is within the Usual and Accustomed Area of any federally recognized treaty tribes, contact these tribes to determine appropriate resource management personnel.

- Contact the Northwest Indian Fisheries Commission (206) 438-1180 to determine if any ambient monitoring stream surveys were conducted for the basin.

- If the U. S. Forest Service is a landowner in the WAU, they may have habitat inventory information and information concerning fish distribution.

Analysis Procedure

The procedure is performed in three steps; first, existing information is collected and evaluated to describe the fisheries resource conditions in the basin and to identify information gaps; second, new information is collected by a field survey to fill the information gaps; and third, all existing and new information is evaluated to identify and qualify habitat conditions in the basin.

Analysis of Existing Information

Fish Distribution and Abundance

All waters in the WAU utilized by salmonids are the primary areas of concern for the fish habitat assessment. The upstream extent of salmonid occurrence can be initially identified using the state Department of Natural Resources Water Type 3/4 boundary. The distribution of salmonid species within Water Types 1, 2, and 3 is determined from a variety of sources, including WARIS, Stream Catalog, Tribal records, interviews, etc. The analyst should be aware that these maps and data base sources are often inaccurate and that interviews and field information may often be needed to update the information. The analyst is requested to get any updated information back to the sources for corrections to the maps and databases. Based on this information, prepare a mylar overlay map, indexed to the WAU base map, showing the distribution of salmonids by species in the WAU. This will be labeled Map F-1 and should show historical and present fish distribution throughout the WAU. If present and historical distribution is significantly different, please footnote Map F-1 with a brief description of the reasons(s).

Check for inconsistencies between fish distribution data and water type boundaries. If a conflict is detected, contact the regional Department of Natural Resources office for confirmation of a boundary or visit the site and determine the extent of fish use. Indicate the upstream boundaries for all Type 3 Waters and the species occurrence zones by using the species and water type coding scheme shown in Figure F-1. Complete Map F-1 using Figure F-1 as a reference for water type coding schemes and the following codes to identify fish species:

Table F-1: Species Code Table

Species	Code
Coho Salmon	CO
King Salmon *	K
Sockeye Salmon	S
Chum Salmon	CH
Pink Salmon	P
Steelhead Trout *	SH
Dolly Varden Char	DV
Bull Trout	BU
Cutthroat Trout	CT
Rainbow Trout	RB
Brook Trout	BK
Brown Trout	BR

*May be further distinguished by race, where SPK + Spring Chinook, SK = Summer Chinook, FK = Fall Chinook, SSH = Summer Steelhead, and WSH = Winter Steelhead.

Using the fish distribution information, partition the watershed into zones of dominant species/life history use. These zones are:

- resident
- anadromous with brief freshwater residence (i.e., pink and chum)
- anadromous with long term freshwater residence (i.e., coho, chinook, sockeye, steelhead, and other anadromous trout)

The mylar overlay is a working map, which will be used to formulate your initial hypotheses concerning fish occurrence and habitat conditions in the WAU.

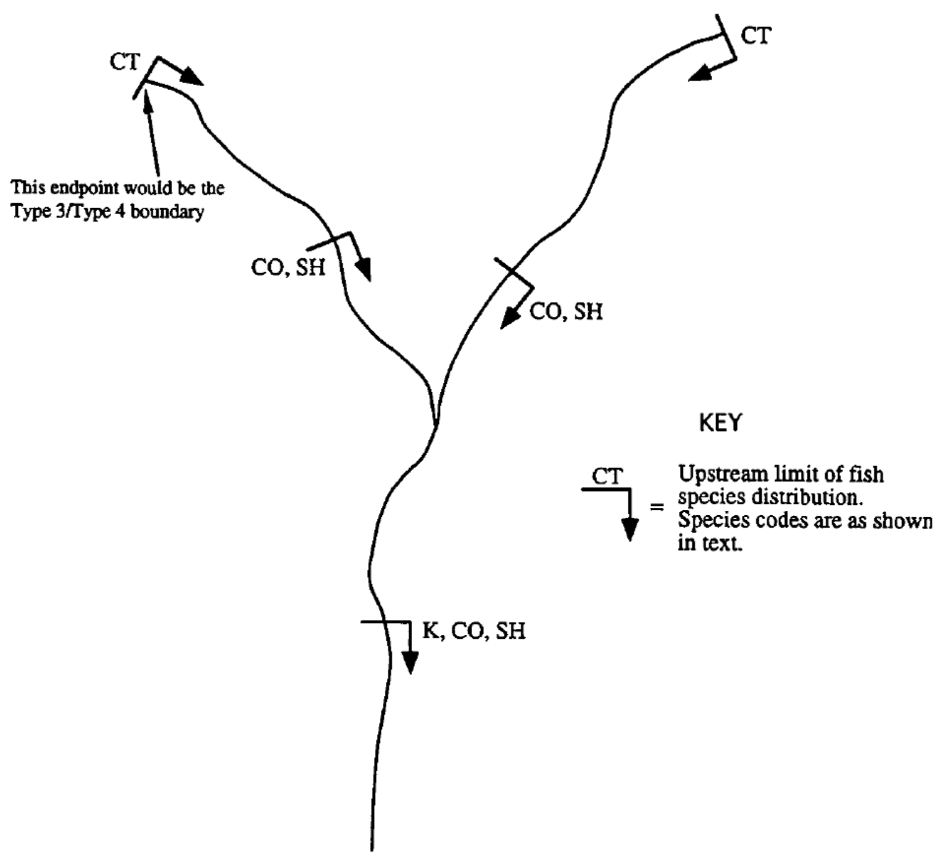


Figure F-1: Example map showing salmonid species distribution.

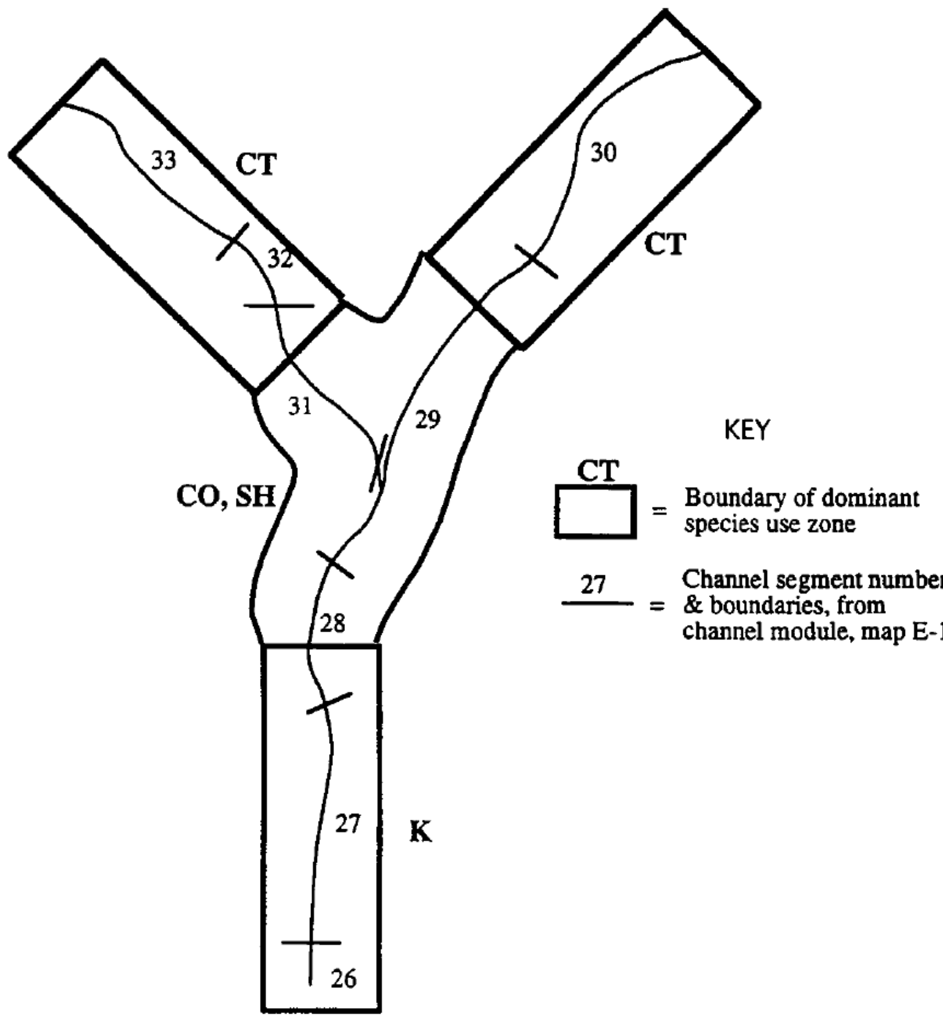


Figure F-2: Example map showing zones of dominant species use.

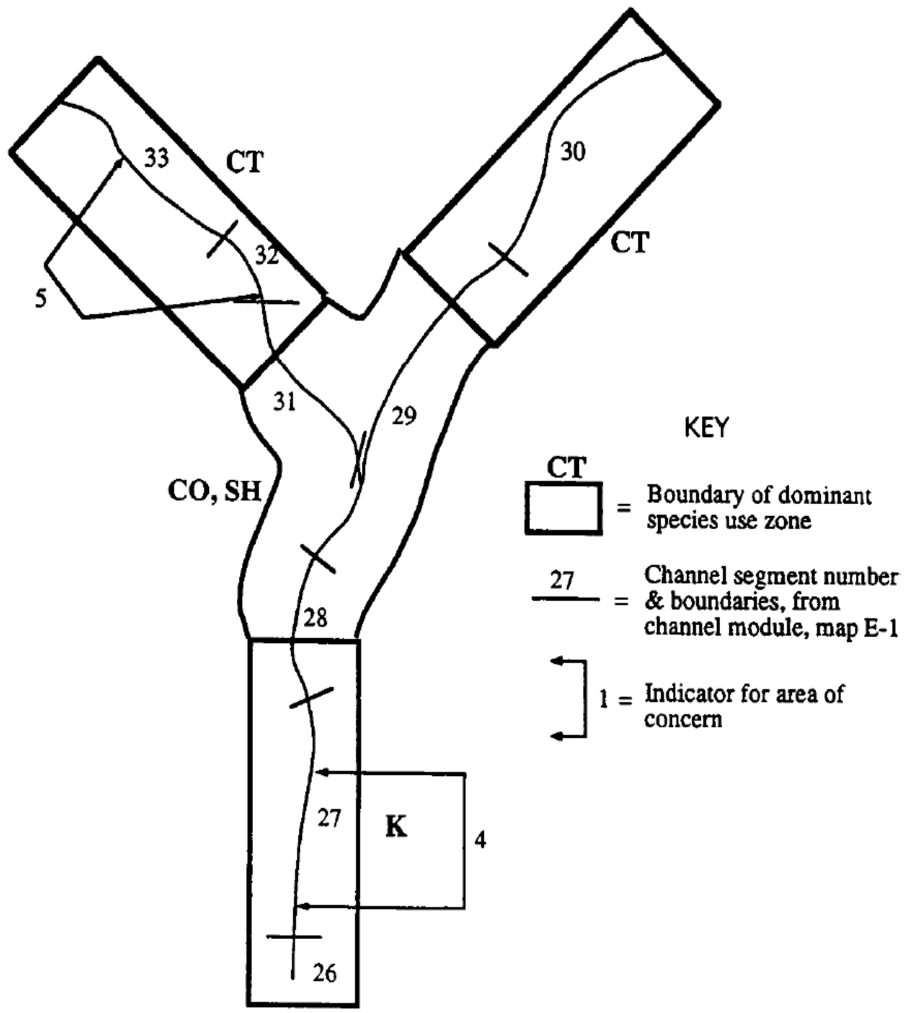


Figure F-3: Example map showing zones of dominant species use and areas of special concern for spawning habitat. Three additional maps are required to display concerns for upstream migration, summer rearing, and winter rearing habitats.

A summary of historic trends in fish abundance and the status of fish stocks in the WAU needs to be developed for the fish habitat assessment. Historic changes in fish abundance may be linked to habitat changes and may be used to identify specific historic events or locations within the WAU that are associated with population changes. Trends in fish abundance also indicate stocks that may be particularly sensitive to habitat degradation because of their low abundance at the present time.

Using agency/tribal documents and information from interviews with local biologists, prepare a tabular summary of historic trends in fish abundance for each salmonid species in the WAU. This summary should indicate the following information for each species:

- estimated historic population size
- estimated current population size
- current escapement goal
- general trends in relative abundance for past 30 years (i.e., increasing, decreasing, stable)

Annual escapement estimates based on spawner surveys or redd counts are the most likely information available. Some basins will have weir counts of adult migrants or smolt trap counts but this information is limited. Summarize the data by sub-basin if available. If data is not available at the WAU scale, use the next largest basin, where data is available. In the latter case, try to determine from interviews what proportion of the total population utilizes the WAU.

Because the time allowed to complete the watershed analysis is limited (21 days at Level 1 or 60 days at Level 2), do not spend more time than is necessary to briefly describe trends. Habitat information is the more important aspect of the fish habitat module.

Habitat Conditions and Habitat Use

An evaluation of present habitat conditions based on historic habitat survey and habitat use information is the primary information used to formulate initial hypotheses about habitat conditions in the WAU. Using agency/tribal documents and interviews with local biologists prepare a list of the habitat concerns by life phase and species. This list may include spawning and rearing habitats that have been degraded and habitats that are limited in availability or have high utilization by a particular species/life phase. Identify the location of special concern areas on the working mylar overlay. Use the segment stratification map developed by the channel assessment module (Map E-1) to index these areas on the reference list.

To develop a list of habitat special concerns review the following questions during the evaluation of information and during an interview with a local biologists. Responses to these questions will help to answer the critical questions. Summarize the findings of this evaluation by fish zones. Locate special concerns on the mylar overlay.

Adult upstream migration conditions
Is there evidence of obstructions to upstream migration? If yes, explain. Consider at least the following possible obstructions:

- Are there impassable culverts? Due to poor design? Due to inadequate maintenance? Is it perched?
- Are there impassable debris jams?
- Are there impassable reaches due to subsurface flow? What time of year are they present?
- Are there impassable reaches due to hydro projects or irrigation diversions?
- Are there reaches where upstream migration is blocked or impeded due to high water temperature or other water quality issues?

Is there evidence of reduced or inadequate quantity or quality of adult holding habitat? This is particularly important for summer steelhead, spring/summer Chinook, and resident species (or other species with prolonged periods of holding between stream entry and spawning). If yes, explain. Consider at least the following questions:

Is the frequency, size, or depth of pools along the migration corridor or in historical holding areas less than suitable for adult use?

Do the pools lack hiding cover?

Is there evidence of unsuitably high water temperatures in adult holding habitats?

Is there evidence of poaching? If yes, explain. This question is asked because forest road systems often permit poacher access to formerly remote areas.

Spawning and incubation conditions
Determine where fish spawn in a basin, by species. Spawner survey data can be especially helpful for this task as can performing field surveys during the spawning season. Check with channel module and knowledgeable biologists to determine if there have been past channel disturbances that may have altered the amount or composition of spawning habitat. Then respond to the questions to characterize availability, stability, and quality of spawning gravels.

Availability
- Is spawning gravel generally abundant or scarce in the WAU?

- Is there evidence that spawning gravels have been covered or replaced by sand, silt, or clay? If yes, explain.

- Is there evidence that the spawning gravels have been removed leaving a cobble, boulder, or bedrock substrate? If yes, explain.

Stability

- Is there evidence of increased severity or frequency of redd scour to egg pocket depth? If yes, explain.

- Is there evidence of extensive redd dewatering? If yes, explain.

Quality

- Is there evidence of reduced permeability or low dissolved oxygen due to fine sediment infiltration into spawning substrate?

Summer rearing conditions

- Is there evidence of diminished pool area, pool depth, or distribution? If yes, explain.

- Is there evidence of reduced cover for summer rearing habitat? If yes, explain.

- Is there evidence of unsuitably high water temperatures or low dissolved oxygen during the summer rearing period? If yes, explain.

- Is there evidence of reaches that dry up (subsurface flows) during the summer low flow period? If yes, explain.

Winter rearing conditions

- Is there evidence that large, deep pools with cover have been diminished? If yes, explain.

- Is there evidence that availability or suitability of off-channel over-wintering habitat has been diminished? If yes, explain.

- Is there evidence of reduced availability of winter hiding habitat in coarse substrate (increased cobble embeddedness)? If yes, explain.

Formulate Working Hypotheses

Using the working map, existing information, and a list of habitat concerns develop some initial working hypotheses to describe the habitat conditions in the WAU. These hypotheses are directed at answering the four critical questions by species and life phase. These hypotheses do not need to be recorded in any formal manner; they are used as an intermediate step for the final analysis. A list of information needs to better address the questions should be identified with each hypothesis.

Collection of New Information

An inventory of the current habitat conditions can be used to evaluate the quantity and quality of habitat available for salmonid production in the WAU. Areas with degraded or undisturbed habitats can in some cases be delineated by comparing the values of specific habitat parameters under current conditions to a set of habitat values that indicate the relative quality or condition of the habitat. Evaluation of only one or two habitat parameters can be misleading, therefore the habitat survey is designed to include several habitat parameters that indicate the quality of habitat for a particular life phase. The survey is also designed to provide a representative sampling of all habitat conditions in the WAU, which gives a high probability that areas with a special habitat concern are detected.

Level 1 Assessment

Approach

The purpose of the Level 1 field survey is to obtain additional information to help confirm or revise the initial hypotheses that were developed from existing information. Because field time is limited (i.e., several days) the survey can only provide a synoptic view of fish habitat conditions in the WAU. The strategy is to visit as may areas as possible and to make quick observations or estimates of the habitat conditions. The emphasis is to survey areas that are know or suspected to be of special concern. Habitat parameters that need to be inventoried during the survey include:

- adult holding pools
- migration blockages
- spawning gravel quantity, quality, and stability
- canopy shade
- pool area and frequency
- wood cover in pools
- large woody debris
- dominant and subdominant substrate composition
- off-channel habitat

Selection of Field Survey Segments

Because time is limited for a Level 1 field survey, only stream segments with the highest priority can be visited. The analyst needs to review the information needs listed with the initial hypotheses and identify all of the locations that would need to be surveyed to obtain the required information. To make the best use of time the analyst will need to prioritize and select survey segments according to the following criteria:

- Segments with known or suspected habitat degradation
- Segments with known important, holding, spawning, and rearing areas
- Segments that may have the only habitat available for a particular species/life phase
- Segments that are likely to be considered sensitive to five input variables (consult channel module leader)
- Segments that are close to potential impact areas (consult team members from other modules)
- Segments with questionable migration barriers or where no barrier information is known

Identify the survey segments on the working map and check to see if all high priority areas are included in the survey.

Survey Procedure

The field survey should be conducted over the length of a stream segment or approximately 1000 ft (300 m). The survey is performed by a quick walk-through of the stream segment. The surveyor visually estimates the dimensions or conditions for each habitat parameter. Measurements of unit length and channel width at periodic points is recommended to calibrate visual estimates. Estimates and observation of habitat condition may be recorded on the form *Fish Habitat Conditions Field Inventory Data* (Form F-2) or on your own form.

Habitat parameter descriptions and data codes used for field inventories are included with Form F-2.

In addition to the information listed above, record the stream gradient, channel width, and canopy shade for the survey segment. Gradient should be measured with a clinometer and reported as a percentage slope. Channel width should be measured at the bankfull flow level and should be representative of the survey segment. Percentage canopy shade should be representative of the segment and can be estimated or measured with a densiometer.

Data Summary

A summary of fish habitat conditions for each segment should be prepared from the field data. The summary should specify the following data and/or ratings for each segment. The results of this analysis should be recorded on the form *Summary of Field Data Results and Habitat Diagnostic Calls* (Form F-3).

- segment number and distance surveyed percentage canopy shade and pool area
- channel widths per pool [Length of surveyed reach (m)/Average bankfull width (m)] / # Qualifying pools
- LWD count per channel width key piece count per channel width (W. WA only)
- percentage of pools with wood cover percentage occurrence of the dominant and subdominant substrate by size category
- percentage of habitat units with spawning gravel
- observations indicating the locations and conditions for adult holding pools, migration blockages, and off-channel habitat

The methodology for the collection of the above habitat condition parameters is obtainable through several forums. The TFW Ambient Monitoring Program Manual (**NWIFC**, 1993) for example, may provide a useful data collection format for: 1) stream segments delineation, 2) percent canopy shade, 3) pool area and frequency, 4) channel widths per pool, 5) LWD count, 6) off-channel habitat, and 7) spawning gravel quality. The USDA Forest Service Stream Survey Methodology may provide an effective framework for acquiring information on 1) spawning gravel size distribution, stability, and quality; 2) LWD cover in pools, 3) migrational blockages; and 4) fish population information. Other methodologies exist for the above data collection points, and it should be noted that many of them are sufficient in gathering various information.

Table F-2: Indices of resource condition for interpretation of field survey results and habitat analysis

Note: these indices may be applied to channel types not indicated in the table but with a lower degree of confidence. Also, these are not the only parameters that can be used to describe the condition of habitat in a reach. Other indices or habitat descriptions can be used when they are clearly documented.

Habitat Parameter	Channel Type	Life Phase Influenced	Habitat Quality		
			Poor	Fair	Good
Percent Pool	< 2%; < 15 m wide	Summer/winter rearing habitat	< 40%	40 thru 55%	>55%
	2-5%; < 15 m wide	Summer/winter rearing habitat	<30%	30 thru 40%	>40%
	> 5%; < 15 m wide	Summer/winter rearing habitat	< 20 %	20 thru 30%	>30%
Pool Frequency	< 2%; < 15 m wide	Summer/winter rearing habitat	> 4 channel widths per pool	2 - 4 channel widths per pool	< 2 channel widths per pool
	2-5%; < 15 m wide	Summer/winter rearing habitat	> 4 channel widths per pool	2 - 4 channel widths per pool	< 2 channel widths per pool
	> 5%; < 15 m wide	Summer/winter rearing habitat	> 4 channel widths per pool	2 - 4 channel widths per pool	< 2 channel widths per pool
Debris pieces / channel width * (> 10 cm diam. x 2m length)	< 20 m wide	Summer/winter rearing habitat	< 1	1 thru 2	> 2
Key pieces / channel width (for Western Washington only)	BFW < 10 m	Summer/winter rearing habitat	< .15	.15 thru .30	> .30
	BFW 10 - 20 m	Summer/winter rearing habitat	< .20	.20 thru .50	> .50
% wood cover in pools	< 2%; < 15 m wide	Summer/winter rearing habitat	Most pools in low category	Most pools in moderate category	Most pools in high category
	2-5%; < 15 m wide	Summer/winter rearing habitat	Most pools in low category 0-5%	Most pools in moderate category 6-20%	Most pools in high category > 20%
Substrate	all	Winter rearing habitat	Sand or small gravel is sub-dominant in boulder or cobble dominant units (i.e.,interstices filled)	Sand is sub-dominant in some units with cobble or boulder dominant (interstices reduced)	Sand or small gravel is rarely sub-dominant in any unit (interstices clear)

Table F-2: Continued

Habitat Parameter	Channel Type	Life Phase Influenced	Habitat Quality		
			Poor	*Fair*	*Good*
Off-channel	< 3%, all widths	Winter rearing habitat, especially coho salmon	*Few or no backwaters, no off-channel ponds*	*Some backwaters and high energy side-channels*	*Backwaters with cover, and low energy off-channel areas (ponds, oxbows, etc.)*
Holding Pools	all types	Upstream Adult Migration	*Few pools/km (> 1 m deep with good cover, cool)*		*Sufficient pools / km (> 1 m deep with good cover, cool)*
Access to Spawning Areas	all types	Upstream Adult Migration	*Access blocked by low water, culvert, falls, temperature, etc.*		*No blockages*
Gravel Quality	all types	Spawning and Incubation	*Absent or infrequent*		*Frequent spawnable areas*
Fines in Gravel	all types	Spawning and Incubation	*> 17% (< 0.85 mm)*	*12 - 17% (< 0.85 mm)*	*< 12 % (< 0.85 mm)*
Gravel Quality	all types	Spawning and Incubation	*Sand is dominant substrate in some units*	*Sand is sub-dominant substrate in some units*	*Sand is never dominant or sub-dominant*
Redd Scour	all types	Spawning and Incubation	*Evidence and/or potential for extensive redd scour*	*Some scour evidence, or may have potential for scour*	*Relatively stable, low potential for scour*

Under the habitat condition of LWD in the indices matrix (Table F-2), counts of "Key Piece" information will provide a useful assessment for habitat quality in relation to wood for streams. Although overall debris piece count is important, it is also necessary for the stream channel to contain a few larger pieces that provide stability and function in unison with these smaller pieces. These larger pieces have been identified by some researchers as "Key Pieces". A Key Piece is defined as a log and/or rootwad that:

1) is independently stable in the stream bankfull width (not functionally held by another factor, i.e., pinned by another log, buried, trapped against a rock or bedform, etc.), and

2) is retaining (or has the potential to retain) other pieces of organic debris. Without the Key Piece, the retained organic debris will likely become mobilized in a high flow (approximately equal to or greater than a 10 year event).

To simplify this definition, the following table has been compiled (Fox, 1994) to define the minimum size necessary for a piece of wood to function as a Key Piece for a given channel width (Western Washington):

Minimum Size to Qualify LWD as a Key Piece		
BFW (m)	**Diameter (m)**	**Length (m)**
0 thru 5	0.4	8
6 thru 10	0.55	10
11 thru 15	0.65	18
16 thru 20	0.7	24

Table F-3

Conversion factor: 1m = 3.28 ft

It is recognized, however, that a piece of wood can function as a Key Piece without meeting both the above minimum diameter and length criteria, but in terms of volume. Therefore, the following table will also define a minimum size classification for Key Piece qualification.

Minimum Volume to Qualify as a Key Piece	
BFW (m)	Volume (m3)
0 thru 5	1
5 thru 10	2.5
10 thru 15	6
15 thru 20	9

Table F-4

$1\ m^3 = 35.3\ ft^3$

Volume is estimated with the mid-point diameter (OR^2 x length)

This table will enable an LWD piece to fall below the minimum diameter or length, and still be classified as Key because of its overall volume. To define a Key Piece in the field using Table F-4, it would be helpful to use a volume estimation table (see Estimated Wood Volumes for a Given Length and Diameter, Table F-5).

Level 2 Assessment
Approach

The purpose of the Level 2 field survey is to obtain sufficient habitat information to be reasonably confident that all areas of special concern can be delineated and that hypotheses developed for the WAU are based on current information. The strategy is to conduct a basin level habitat survey using an inventory procedure that will provide an objective measure of habitat conditions. The emphasis is to survey all areas that are know or suspected to be of special concern. Habitat parameters that need to be inventoried during the survey are the same as for Level 1. Other habitat data (e.g., percentage fines in spawning gravel) may be added to the field survey at the discretion of the fish biologist. Because this is a Level 2 analysis the habitat survey approach described below is considered as a recommendation and may be supplemented with an alternate procedure provided methods are described.

Selection of Field Survey Segments

The criteria for selecting field survey segments described for Level 1 also applies for Level 2. The only difference is, more segments can be surveyed in Level 2, because more time is allocated for field surveys. Because most WAU's are relatively large, all segments with fish habitat can not be surveyed, therefore the survey segment should be prioritized as for Level 1.

Survey Procedure

The recommended survey procedure for Level 2 is the same as for Level 1. Other basin level surveys and survey parameters may be used to provide the needed information. This procedure is recommended because it is designed to provide data compatible for the habitat diagnostic analysis. Alternative procedures must be well documented and performed by a qualified fisheries biologist.

Data Summary

A summary of fish habitat conditions for each segment should be prepared from the field data. The summary can be in a tabular and text format and should specify the information identified for Level 1. The results of this analysis can be recorded on Form F-3 if the habitat data was collected by the survey procedure defined for Level 1.

Table F-5: Table for Assessing Volumes of Individual LWD Pieces to Determine Qualification

Estimated Wood Volumes for a Given Length and Diameter

(Volume in m^3)

Length (m)	Diameter (m) 0.10	0.15	0.20	0.25	0.30	0.35	0.40	0.45	0.50	0.55	0.60	0.65	0.70	0.75
1	0.01	0.02	0.03	0.05	0.07	0.10	0.13	0.16	0.20	0.24	0.28	0.33	0.39	0.44
2	0.02	0.04	0.06	0.10	0.14	0.19	0.25	0.32	0.39	0.48	0.57	0.66	0.77	0.88
3	0.02	0.05	0.09	0.15	0.21	0.29	0.38	0.48	0.59	0.71	0.85	1.00	1.16	1.33
4	0.03	0.07	0.13	0.20	0.28	0.38	0.50	0.64	0.78	0.95	1.13	1.33	1.54	1.77
5	0.04	0.09	0.16	0.25	0.35	0.48	0.63	0.80	0.98	1.19	1.42	1.66	1.93	2.21
6	0.05	0.11	0.19	0.29	0.42	0.58	0.75	0.95	1.18	1.43	1.70	1.99	2.31	2.65
7	0.05	0.12	0.22	0.34	0.49	0.67	0.88	1.11	1.37	1.66	1.98	2.32	2.70	3.09
8	0.06	0.14	0.25	0.39	0.56	0.77	1.01	1.27	1.57	1.90	2.26	2.66	3.08	3.54
9	0.07	0.16	0.28	0.44	0.63	0.87	1.13	1.43	1.76	2.14	2.55	2.99	3.47	3.98
10	0.08	0.18	0.31	0.49	0.70	0.96	1.26	1.59	1.96	2.38	2.83	3.32	3.85	4.42
11	0.09	0.19	0.35	0.54	0.77	1.06	1.38	1.75	2.16	2.61	3.11	3.65	4.24	4.86
12	0.09	0.21	0.38	0.59	0.84	1.15	1.51	1.91	2.35	2.85	3.40	3.98	4.62	5.30
13	0.10	0.23	0.41	0.64	0.91	1.25	1.63	2.07	2.55	3.09	3.68	4.32	5.01	5.75
14	0.11	0.25	0.44	0.69	0.98	1.35	1.76	2.23	2.74	3.33	3.96	4.65	5.39	6.19
15	0.12	0.27	0.47	0.74	1.05	1.44	1.88	2.39	2.94	3.56	4.25	4.98	5.78	6.63
16	0.13	0.28	0.50	0.79	1.12	1.54	2.01	2.54	3.14	3.80	4.53	5.31	6.16	7.07
17	0.13	0.30	0.53	0.83	1.19	1.64	2.14	2.70	3.33	4.04	4.81	5.64	6.55	7.51
18	0.14	0.32	0.57	0.88	1.26	1.73	2.26	2.86	3.53	4.28	5.09	5.98	6.93	7.96
19	0.15	0.34	0.60	0.93	1.33	1.83	2.39	3.02	3.72	4.51	5.38	6.31	7.32	8.40
20	0.16	0.35	0.63	0.98	1.40	1.92	2.51	3.18	3.92	4.75	5.66	6.64	7.70	8.84
21	0.16	0.37	0.66	1.03	1.47	2.02	2.64	3.34	4.12	4.99	5.94	6.97	8.09	9.28
22	0.17	0.39	0.69	1.08	1.54	2.12	2.76	3.50	4.31	5.23	6.23	7.30	8.47	9.72
23	0.18	0.41	0.72	1.13	1.61	2.21	2.89	3.66	4.51	5.46	6.51	7.64	8.86	10.17
24	0.19	0.42	0.75	1.18	1.68	2.31	3.02	3.82	4.70	5.70	6.79	7.97	9.24	10.61
25	0.20	0.44	0.79	1.23	1.75	2.41	3.14	3.98	4.90	5.94	7.06	8.30	9.63	11.05
26	0.20	0.46	0.82	1.28	1.82	2.50	3.27	4.13	5.10	6.18	7.36	8.63	10.01	11.49
27	0.21	0.48	0.85	1.33	1.89	2.60	3.39	4.29	5.29	6.42	7.64	8.96	10.40	11.93
28	0.22	0.49	0.88	1.37	1.96	2.69	3.52	4.45	5.49	6.65	7.92	9.30	10.78	12.38
29	0.23	0.51	0.91	1.42	2.03	2.79	3.64	4.61	5.68	6.89	8.21	9.63	11.17	12.82
30	0.24	0.53	0.94	1.47	2.10	2.89	3.77	4.77	5.88	7.13	8.49	9.96	11.55	13.26

Length (m)	0.80	0.85	0.90	0.95	1.00	1.05	1.10	1.15	1.20	1.25	1.30	1.35	1.40	1.45	1.50
1	0.50	0.57	0.64	0.71	0.79	0.87	0.95	1.04	1.13	1.23	1.33	1.43	1.54	1.65	1.77
2	1.01	1.13	1.27	1.42	1.57	1.73	1.90	2.08	2.26	2.45	2.65	2.86	3.08	3.30	3.53
3	1.51	1.70	1.91	2.13	2.36	2.60	2.85	3.12	3.39	3.68	3.98	4.29	4.62	4.96	5.30
4	2.01	2.27	2.54	2.84	3.14	3.46	3.80	4.16	4.52	4.91	5.31	5.72	6.16	6.60	7.07
5	2.52	2.84	3.18	3.55	3.93	4.33	4.75	5.20	5.66	6.14	6.64	7.16	7.70	8.26	8.84
6	3.02	3.40	3.82	4.25	4.71	5.20	5.70	6.23	6.79	7.36	7.96	8.59	9.23	9.91	10.60
7	3.52	3.97	4.45	4.96	5.50	6.06	6.65	7.27	7.92	8.59	9.29	10.02	10.77	11.56	12.37
8	4.02	4.54	5.09	5.67	6.28	6.93	7.60	8.31	9.05	9.82	10.62	11.45	12.31	13.21	14.14
9	4.53	5.10	5.72	6.38	7.07	7.79	8.55	9.35	10.18	11.04	11.94	12.88	13.85	14.86	15.90
10	5.03	5.67	6.36	7.09	7.85	8.66	9.50	10.39	11.31	12.27	13.27	14.31	15.39	16.51	17.67
11	5.53	6.24	7.00	7.80	8.64	9.53	10.45	11.43	12.44	13.50	14.60	15.74	16.93	18.16	19.44
12	6.04	6.80	7.63	8.51	9.42	10.39	11.40	12.47	13.57	14.72	15.92	17.17	18.47	19.81	21.20
13	6.54	7.37	8.27	9.22	10.21	11.26	12.35	13.51	14.70	15.95	17.25	18.60	20.01	21.46	22.97
14	7.04	7.94	8.90	9.93	10.99	12.12	13.30	14.55	15.83	17.18	18.58	20.03	21.55	23.11	24.74
15	7.55	8.51	9.54	10.64	11.78	12.99	14.25	15.59	16.97	18.41	19.91	21.47	23.09	24.77	26.51
16	8.05	9.07	10.18	11.34	12.56	13.86	15.20	16.62	18.10	19.63	21.23	22.90	24.62	26.42	28.27
17	8.55	9.64	10.81	12.05	13.35	14.72	16.15	17.66	19.23	20.86	22.56	24.33	26.16	28.07	30.04
18	9.05	10.21	11.45	12.76	14.13	15.59	17.10	18.70	20.36	22.09	23.89	25.76	27.70	29.72	31.81
19	9.56	10.77	12.08	13.47	14.92	16.45	18.05	19.74	21.49	23.31	25.21	27.19	29.24	31.37	33.57
20	10.06	11.34	12.72	14.18	15.70	17.32	19.00	20.78	22.62	24.54	26.54	28.62	30.78	33.02	35.34
21	10.56	11.91	13.36	14.89	16.49	18.19	19.95	21.82	23.75	25.77	27.87	30.05	32.32	34.67	37.11
22	11.07	12.47	13.99	15.60	17.27	19.05	20.90	22.86	24.88	26.99	29.19	31.48	33.86	36.32	38.87
23	11.57	13.04	14.63	16.31	18.06	19.92	21.85	23.90	26.01	28.22	30.52	32.91	35.40	37.97	40.64
24	12.07	13.61	15.26	17.02	18.84	20.78	22.80	24.94	27.14	29.45	31.85	34.34	36.94	39.62	42.41
25	12.58	14.18	15.90	17.73	19.63	21.65	23.75	25.98	28.28	30.68	33.18	35.78	38.48	41.28	44.18
26	13.08	14.74	16.54	18.43	20.41	22.52	24.70	27.01	29.41	31.90	34.50	37.21	40.01	42.93	45.94
27	13.58	15.31	17.17	19.14	21.20	23.38	25.65	28.05	30.54	33.13	35.83	38.64	41.55	44.58	47.71
28	14.08	15.88	17.81	19.85	21.98	24.25	26.60	29.09	31.67	34.36	37.16	40.07	43.09	46.23	49.48
29	14.59	16.44	18.44	20.56	22.77	25.11	27.55	30.13	32.80	35.58	38.48	41.50	44.63	47.88	51.24
30	15.09	17.01	19.08	21.27	23.55	25.98	28.50	31.17	33.93	36.81	39.81	42.93	46.17	49.53	53.01

Habitat Condition Evaluation

The objective of habitat analysis is to identify and characterize fish habitat in the WAU. Emphasis is placed on identifying habitats of special concern (i.e., degraded habitats, habitats with high utilization, and habitats of limited availability) because impacts on these areas could have the greatest effect on the fisheries resources in the WAU. Habitats that are not a special concern are not ignored, but are appropriately identified for their contribution to the habitat network in the WAU. Habitats of special concern are identified by the analysis of existing information and by an analysis of the field survey data using a set of indices of resource condition (Table F-2). The habitat analysis is performed for each species/life phase within a dominant fish use zone and the results are recorded on mylar overlay maps (one for each life phase) and in a habitat condition summary.

If the evaluation is for a Level 1 assessment and limited data are available (i.e, from existing information or field surveys), then evaluation of potential habitat conditions may be determined from a habitat quality rating matrix (Table F-6). This matrix provides general guidelines for rating the habitat potential based on stream gradient and confinement. Segments of gradient and confinement are determined from the channel module Map E-1. This alternative evaluation is less reliable, therefore less preferred.

The standard assessment of habitat conditions is performed by comparing the results of the field data (summarized in Form F-3) to resource condition indices shown in Table F-2 and by recording these results on Form F-3. The value categories in the indices table indicate the relative quality of habitat (i.e., ranges from poor to good) for a particular parameter and life phase in a survey reach. Habitat values that fall into the poor range suggest that habitat conditions may be degraded and values in the good range suggest that habitat conditions may be fully functional. Values that fall into the fair range may indicate that conditions are changing either to poor or to good. The habitat condition indicated by the parameter value should be verified before concluding a special habitat concern exists. This can be done by identifying supporting evidence among related habitat parameters and from the analysis of existing information. For example, if percentage pool area values are in the poor quality range, it is likely that pool frequency and LWD are also in the poor or fair range. If this is the case the result from three diagnostic parameters are in agreement suggesting that pool area is low and that an absence of LWD may be responsible. Existing information may also lend support to this conclusion, for example, if the local biologist reported that historically the reach in question was a good juvenile rearing area with complex habitat. Based on a review of all available information, the analyst may conclude that the summer rearing habitat in a particular reach is de-graded. This approach can be used to evaluate each life phase for each reach or area of the basin where information is available. Areas of good habitat need to be delineated as well as areas of poor habitat. If conflicting evidence exists the analyst must use professional judgment and make a decision about the habitat conditions in a reach. If no information is available for a particular area, additional new information may need to be collected. In the latter case, check with other module leaders to see if they may have pertinent information about the area.

Table F-6: Potential habitat quality rating based on gradient and confinement.

Note: this table should only be used for a Level 1 assessment when limited data are available. Rating in the upper left of each box applies to anadromous salmon species. Rating in the lower right of each box applies to anadromous and resident forms of trout and char species.

Spawning and Winter Rearing

CHANNEL CONFINEMENT	GRADIENT					
	<2%	2-4%	4-8%	8-12%	12-20%	>20%
Unconfined (VW>4CW)	GOOD GOOD	GOOD GOOD	FAIR GOOD	POOR GOOD	POOR FAIR	POOR POOR
Moderately Confined (2CW≤VW≤4CW)	GOOD GOOD	GOOD GOOD	FAIR GOOD	POOR GOOD	POOR FAIR	POOR POOR
Confined (VW<2CW)	FAIR GOOD	FAIR GOOD	POOR FAIR	POOR FAIR *E-GOOD*	POOR POOR *E-FAIR*	POOR POOR

E = rating for East of Cascade Crest

Summer Rearing

CHANNEL CONFINEMENT	GRADIENT					
	<2%	2-4%	4-8%	8-12%	12-20%	>20%
Unconfined (VW>4CW)	GOOD GOOD	GOOD GOOD	GOOD GOOD	FAIR GOOD	POOR FAIR	POOR POOR
Moderately Confined (2CW≤VW≤4CW)	GOOD GOOD	GOOD GOOD	GOOD GOOD	FAIR GOOD	POOR FAIR	POOR POOR
Confined (VW<2CW)	GOOD GOOD	FAIR GOOD	FAIR GOOD	POOR GOOD	POOR FAIR	POOR POOR

VW = Valley Width
CW = Channel Width (bankfull)

The results of the habitat analysis should be recorded on mylar overlay maps and in a text summary that is cross-referenced to the maps. Each mylar overlay for a life phase should show the salmonid species distribution and delineate the habitat areas of special concern. The latter areas are delineated by a bracket and a cross reference number to the text summary (see example in Figure F-2). Whenever possible, the areas of concern should be grouped to avoid repetitive summaries. That is, all areas with similar conditions or concerns can be grouped and summarized together in a single form or text summary. The text summary should include the following information:

- dominant fish use zone
- species/life phase
- map reference number
- segment location (identify segment or segments covered using Map E-1)
- segments visited during the field survey, if any
- description of special habitat concern using results of diagnostic analysis and other supporting information. This is a paragraph that should be thorough but concise.
- list sources of information used to develop the description of special habitat concerns.

An example of a text summary for a special habitat concern and the recommended format for preparing these summaries in shown in Figure F-4. These summaries constitute the final hypotheses for habitat conditions in the WAU. After the summaries are prepared, check to see if the critical questions are addressed for all species and all areas of WAU.

Chinook Salmon Spawning and Incubation Special Habitat Concerns

Map Reference Number 4

Segments 1-2

Segments Visited 2

Description: This is the only reach of the river utilized for spawning by fall chinook salmon as indicated by annual spawner surveys. The field survey indicated that in segment 2 gravel quantity and quality was good and fair, respectively. Observations of water visibility associated with spawner surveys conducted by WDF indicate turbid water and poor visibility conditions were more common during the past ten years than in earlier years of the survey.

Information Sources: Field Survey Summary, e.g., Form F-2
Mr. Jack Salmon, Wash. Dept. Fish & Wildlife, Olympia

Resident Cutthroat Spawning and Incubation Special Habitat Concerns

Map Reference Number 3

Segments: 6-8, 2324

Segments Visited: 7, 23

Description: These reaches are known to be cutthroat spawning areas. The gravel quality was poor in one of the segments visited (i.e, segment 6) indicating a potential problem in similar areas. All of the segments listed above are similar and need protection from potential degradation.

Information Sources: Field Survey Summary, e.g., Form F-2
Ms. Jill Bio, Wash Dept. Fish & Wildlife, Olympia

Figure F-4: Example of text summary for reporting special habitat concerns

Fish Habitat Assessment Report

The intent of the summary report for the fish habitat module is to provide a very brief but clear description of the results of the assessment. These results will be used in synthesis in two ways. First, the results of habitat assessments and the descriptions of areas of concern are a key component of making vulnerability calls. Second, the broader description of fish distribution and habitats in the WAU are used to develop a fish habitat context for synthesis and for completion of the resource sensitivity calls.

All text components of the summary should be as concise as possible. Supporting information, references, and data summaries are included in tables attached to the report. The summary report for the fish habitat module should include the elements listed in the following outline. When two or more areas have the same description they should be grouped and all segments which apply to the description should be listed in the summary.

Fish Habitat Assessment Report

I. **Title page** with name of watershed analysis, name of module, level of analysis, signature of qualified analyst(s), and date

II. **Table of contents**

III. **Maps**
- Fish distribution map (map F-1)
- Areas of concern maps for spawning habitat (map F-2)
- Areas of concern maps for upstreammigration habitat (map F-3)
- Areas of concern maps for summerrearing habitat (map F-4)
- Areas of concern maps for winterrearing habitat (map F-5)

IV. **Summary Data**
- Fisheries information request for watershed analysis (form F-1) - **optional**
- Habitat conditions field inventory data (form F-2)
- Field data summary and habitat diagnostic calls (form F-3)

V. **Summary Text**
- Study methods
- Summary of distribution and population information
- Descriptions of each habitat area of special concern, as shown on maps F-2-F-5
- Fish habitat vulnerability calls
- Descriptions of any deviations from the standard methods and why the changes were necessary

- Statement of the author's confidence level in the analysis and results
- Does module report address all critical questions?

VI. Other Information (optional)

- Monitoring strategies and design and implementation suggestions
- Learning resources (a.k.a., references, bibliography) section
- Acknowledgments section

Acknowledgments

This module was developed over a course of several years by numerous fish biologists representing, agencies, tribes, and private industry. This version was written by Douglas Martin, Tim Beechie, and Jeff Light. Helpful contributions were made by Kevin Bauersfeld, Kurt Beardslee, Ron Campbell, Martin Fox, Carl Hadley, Mark Hunter, Jim Mathews, Randy MacIntosh, and George Pess.

References

Beechie, T. J., and T. H. **Sibley**. 1990. Evaluation of TFW stream classification system: stratification of physical habitat area and distribution. Final Report TFW-16B-90-011.

Benda. L., T. J. **Beechie**, R. C. **Wissmar**, and A. **Johnson**. 1992. Morphology and evolution of salmonid habitats in a recently deglaciated river basin, Washington State, USA. Can. J. Fish. Aquat. Sci. 49: 1246-1256.

Cupp, C. E. 1989. Stream corridor classification for forested lands of Washington. Report to Washington Forest Protection Association, Olympia, Washington.

Fausch, K. D. J., J. **Lyons**, J. R. **Karr**, and P. L. **Angermeier**. 1990. Fish communities as indicators of environmental degradation. American Fisheries Society Symposium 8:123-144.

Meehan, W. R. 1991. Influence of forest and rangeland management on salmonid fishes and their habitats. American Fisheries Society Special Publication No. 19.

Montgomery, D. R., and J. M. **Buffington**. 1993. Channel classification, prediction of channel response, and assessment of channel condition. Final Report TFW-SH10-93-002.

Naiman, R. J., D. G. **Lonzarich**, T. J. **Beechie**, S. C. **Ralph**. 1992. General principles of classification and the assessment of conservation potential in rivers. Pages 93-123 in **Boon**, P. J., P. **Calow**, and G. E. **Petts**. River Conservation and Management. John **Wiley & Sons, Ltd**.

Peterson, N. P., A. **Hendry**, and T. P. **Quinn**. 1992. Assessment of cumulative effects on salmonid habitat: some suggested parameters and target conditions. Final Report TFW-F3-92-001.

Reeves, G. H., J. D. **Hall**, T. D. **Roelofs**, T. L. **Hickman**, and C. O. **Baker**. 1991. Rehabilitating and modifying stream habitats. American Fisheries Society Special Publication 19: 139-179.

Reeves, G. H., F. H. **Everest**, and T. E. **Nickelson**. 1989. Identification of physical habitats limiting the production of coho salmon in Western Oregon and Washington. USFS Gen. Tech. Rep. PNW-GTR-245.

Salo, E. O., and T. W. **Cundy**. 1987. Streamside management: forestry and fisheries interactions. University of Washington, Institute of Forest Resources Contribution 57, Seattle.

Form F-1: Fisheries Information Request for Watershed Analysis

Basin: ______________________________

WAU: ______________________________

Boundary: ______________________________

A watershed analysis is being conducted in the basin and WAU named above. Information on the fish habitat utilization, fish distribution, and habitat conditions are needed for this analysis. Your knowledge of this basin, professional judgements, and comments are important for the success of this assessment. Please answer the questions or identify (provide if available) any documents, maps, computer print outs, and other sources of information that would help the assessment. We appreciate your prompt attention to this matter.

Respondent Information

Name: ______________________________

Affiliation: ______________________________

Position: ______________________________

Phone Number: ______________________________

Fish Information

- What fish species occur in this WAU?
- What is species distribution (identify on map provided).
- What are boundaries for resident and anadromous bearing waters?
- What are the trends in relative abundance?
- What locations are important for adult holding, spawning, summer rearing and winter rearing?
- Are there threatened or endangered species?
- What are non-sport species?
- What juvenile and adult population data is available (e.g., smolt counts, spawner surveys, redd counts).

Habitat Information

- Identify locations of known or potential passage barriers (natural and man caused).
- Identify data on spawning gravel fines or sediment.
- Identify data on gravel scour or loss of spawning gravel.
- Identify data on pool area or frequency.
- Identify other habitat inventory data concerning habitat units, large organic debris, cover, riparian canopy shading, water temperature, substrate composition, embeddedness.
- Identify locations of side channels, beaver ponds, and other off-channel over-wintering habitat.
- Are there any special or unusual conditions in the basin.

Management

- Are there any habitat management problems in the WAU?
- Are there any fisheries management problems in the WAU?
- What is the escapement goal by species?

Form F-2: Fish Habitat Conditions Field Inventory Data

WAU STREAM NAME SURVEY UNIT # CREW DATE PAGE

		---------- POOLS ONLY----------					-----SUBSTRATE-----			-----LWD TALLY-----			
DISTANCE	HAB TYPE	MAXDP	RFCDP	RESDP	FORM	%WCVR	DOM	SBDOM	SPGRV	10-20CM	20-50CM	>50CM	NOTES

SUMMARY:

WATER TEMPERATURE		SUMMARY TOPICS	
STREAM FLOW		OFF-CHANNEL REARING	
AVERAGE PERCENT SHADE		HOLDING POOLS	
AVERAGE CHANNEL WIDTH		REDD SCOUR POTENTIAL	
AVERAGE BED SLOPE		Provide summary paragraph describing survey reach characteristics and check box when done	

LWD: FUNCTIONAL LWD

10-20 CM		DISTANCE SURVEYED	
20-50 CM		NON FUNCTIONAL LWD	
>50CM			
TOTAL			

Form F-2: continued

DISTANCE

Distance indicated on a hip chain at the beginning of each distinct habitat type. Subtracting the previous measured distance will produce the total length of each habitat type.

HABITAT

To be classified as a distinct habitat type, the average pool area must equal or exceed the minimum unit size (Table 1) and the residual depth must equal or exceed the depth in Table 2.

Table 1.

Bankfull Channel Width	Min. Unit Size
0 – 2.5 meters	0.5 sq. meters
2.5 – 5 meters	1.0 sq. meters
5 – 10 meters	2.0 sq. meters
10 – 15 meters	3.0 sq. meters
15 – 20 meters	4.0 sq. meters
> 20 meters	5.0 sq. meters

Table 2.

Bankfull Channel Width	Min. Residual Depth
0 – 2.5 meters	0.10 meters
2.5 – 5 meters	0.20 meters
5 – 10 meters	0.25 meters
10 – 15 meters	0.30 meters
15 – 20 meters	0.35 meters
> 20 meters	0.40 meters

HAB TYPE	Habitat type	Pool or other (Only pools are used for data analysis)
MAXDP-	Maximum Depth	Maximum pool depth down to the gravel or cobble substrate.
RFCDP-	Riffle Crest Depth	Water depth measurement at the riffle crest (pool control).
RESDP-	Residual Depth	Subtract the riffle crest depth from the maximum depth.
FORM-	Pool Formation Feature	B – Bed feature, including rocks D – Beaverdam W – Wood (logs, rootwads).
%WCVR	Percent Wood Cover	Estimate the percent of woody material and brush covering the pool surface.

SUBSTRATE

Characterize the dominant and sub-dominant streambed substrates using the following codes:

1 – Sand, silt, clay, organic or other fine material.
2 – Gravel 2 – 64 mm (0.1” – 2.5”)
3 – Cobble 64 – 130 mm (2.5” – 5.0”)
4 – Boulder > 130 mm (5.0”)
5 – Bedrock

SPGRV - Spawning Gravel Presence.
Using the following criteria, assess whether there is adequate spawning habitat available for salmonids.
The gravel should be located in an area where water depth (>18 cm) and velocity (0.3 – 1.0 mps) conditions are expected to be favorable during the respective spawning seasons.

A – An area of gravel suitable for anadromous salmon (10 – 150 mm) of at least 1.5 m^2
R – An area of gravel suitable for resident trout (2 – 75 mm) of at least 0.1 m^2
AR – Both anadromous salmon and resident trout spawning habitat is available.

NOTES

Reference any comments relative to factors influencing fish habitat or migration. Water temperature and flow, channel width, bed slope and shade measurements should be taken as necessary and averaged in the summary section. Attach a description of off-channel rearing (access, condition), holding pools (number, distribution) and redd scour (evidence, potential). Large woody debris can be tallied in the columns provided and results entered below the summary statistics. Non-functional LWD can be counted or estimated. Functional LWD should be separated into the three size classes.

Form F-3: Summary of Field Data Results and Habitat Diagnostic Calls

Segment No.	Pool (%)		Pool Freq.		LWD No Pieces/CW		Key Piece* No Pieces/CW		Wood Cover (%)		Dom. Substrate		Off-Channel		Holding Pools		Gravel Quantity	
	Value	Rating	Value	Rating	Value	Rating	Value	Rating	Value	Rating	Value	Rating	Value	Rating	Value	Rating	Value	Rating

Form F-4: Fish Habitat Assessment Task Checklist

TASK	SCHEDULED	COMPLETED	REVIEWED
Assemble Startup Materials: •Water type map •WARIS, Stream catalogue info., WDFW data, research reports for the area •Mylar			
Identify local biologists, contact them & complete habitat evaluation questionnaire.			
Startup meeting to brief team on process and intent, assign tasks, set schedule.			
Complete office assessment of habitat conditions: •Identify fish species and their distribution (map f-1) •Delineate zones of dominant fish use (map f-2) •Identify preliminary hypotheses of habitat concerns by species and life history stage (draft map f-3)			
Team meeting: review results of office assessment			
Complete estimates of relative abundance, by spp. •Stock Status (SASSI) •Escapement goals and trends •Spawner survey results •Redd counts •Other abundance measures			
Conduct field work as needed to validate office assessment: •Obtain segment map from channel team •Indentify areas where field visits are necessary •Coordinate with channel and riparian teams •Visit field to examine habitat conditions, confirm or reject initial hypotheses, and develop new ones.			
Complete diagnostic summary sheet for habitat conditions (form f-3)			
Provide LWD and shade data to riparian team leader			
Are there any Type 4 Waters requiring assessment? •Talk with channel, riparian, and other team leaders			
Construct final map of habitat concerns by species zone and life history stage (map f-3)			
Team meeting: review results of assessments •If performing standard assessment, determine where additional, more detailed information (if any) would help clarify situations in the basin. •Identify potential monitoring opportunities			
Produce Module Report			
Review Module Report			
Prepare for meeting with channel team to identify habitat vulnerabilities.			
Complete and sign module completion sheet (team leader)			

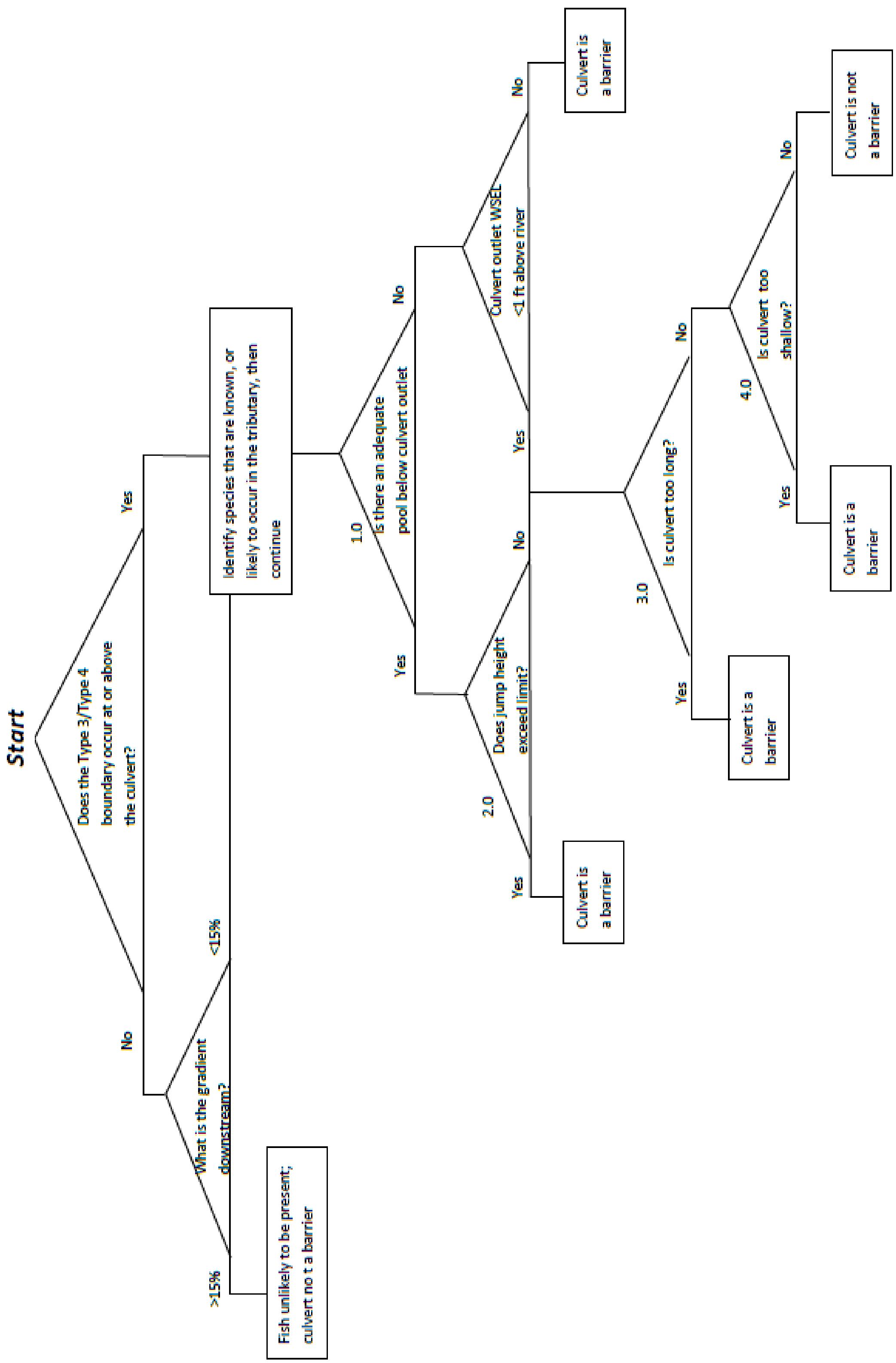


Figure F-5: Culvert Barrier Evaluation Decision System

APPENDIX G
Water Quality Module

Table of Contents

Introduction

The quality and quantity of water in forest streams and lakes, wetlands, and nearshore marine/estuarine waters is a fundamental property important to their use as habitat for aquatic ecosystems, water supplies and recreation. Land use activities, including forest management, can affect important water quality conditions, such as temperature, clarity, and concentrations of organic and inorganic substances.

Water quality can be impacted by forest practices in a variety of ways. Sediment concentrations can increase due to accelerated erosion (Swanson et al., 1987); water temperatures can increase due to removal of overstory riparian shade (Brown, 1969; Sullivan et al., 1990; Adams and Sullivan, 1990); slash and other organic debris can accumulate in waterbodies, depleting dissolved oxygen, and altering water pH (Plamondon et al., 1982); wetlands may be directly altered or created by physical modification resulting from culvert installation and placement of fill material (Binkley and Brown, 1993; Richardson, 1994; Shepard, 1994). Dissolved oxygen, nutrients and pH can have direct and indirect effects on stream water chemistry and aquatic ecosystems, but problems with these parameters are not commonly associated with well-managed forest practices. The degree of change in water quality that may result from forest practices depends on a number of factors including the water quality parameter, the type of waterbody, the physical and vegetative condition of the watershed, the type and location of land use, the design and application of forest practices, the intensity of site disturbance, and climatic conditions (Rice and Datzmann, 1987; Riekerk et al., 1989). Although not typically associated with forest practices, water withdrawals may adversely impact water quality in forested areas and heighten water quality sensitivity.

State water quality standards specify chemical and physical water quality parameters of importance as turbidity, water temperature, dissolved oxygen, and pH. Federal water quality standards also provide standards for nitrogen concentration with regards to drinking water supplies. The purpose of the water quality module is to determine whether these and other parameters within waterbodies found in the WAU are vulnerable to forest practices at the watershed scale. Vulnerability is defined as the reasonable likelihood that state water quality standards may be exceeded by the effects of forest practices. This module also addresses other indicators of water quality that are within the authority of the Forest Practices Board, although they may not necessarily have been adopted as numeric water quality criteria. Biological conditions are not directly assessed in this module.

This assessment will predict the locations of waterbodies occurring in the watershed where numeric water quality criteria, or other criteria as specified in this module, are likely to be exceeded as a result of forest practices. Other land use practices that may also occur in the watershed, such as agriculture, grazing, or urbanization can have equal or greater effects on water quality and quantity. These effects may be identified where important in the interpretation of watershed processes, but they are not the focus of this assessment.

Water quality prediction at the scale required by Watershed Analysis required development of new methods for evaluation. Methods provided in this module are seen as preliminary and the module is expected to be refined with use and with the addition of new methods to address a broader range of water quality characteristics as they evolve. Other modules in Watershed Analysis address the vulnerability of specific beneficial uses such as fish habitat or public works. This module more sharply focuses on water quality and quantity as a mechanism influencing those beneficial uses. There is inevitably overlap between these perspectives, and the water quality analyst is expected to be highly interactive with other analysts throughout the assessment.

Critical Questions

The water quality module collects information to determine whether water quality parameters for waterbodies within the watershed are vulnerable to the cumulative effects of forest practices. The following critical questions address water quality concerns and functionally outline the assessment procedure.

- What waterbodies occur in the watershed and where are they located?
- What is the vulnerability of waterbody parameters to potential changes in input variables?
- What do current water quality conditions or changes from past conditions indicate about the vulnerability of the waterbodies?
- If a waterbody is found to be vulnerable to an input, is there information to identify sources of sediment, nutrients, heat, or organic matter in order to establish sensitivity?

Assumptions

A number of fundamental assumptions underlie the approach developed within this module. The most fundamental assumption is that the analysis use the best available scientific information and techniques in accordance with the expected scope of analysis. The module analysis methods themselves are designed to change as newer, more refined methods are developed. The module provides a framework for the assessment of water quality based on several principle assumptions.

1. The need to address water quality applies to all surface waters of the state.

2. State and federal surface water and drinking water quality standards identify important water quality characteristics.

3. Changes in input variables (e.g., sediment, wood, heat energy, and water quantity and chemistry) to each waterbody can result in changes in water quality and changes in the level of support to beneficial uses.

4. Water quality parameters vary significantly in both short-term time and space. Separating natural variability from land use effects may be possible when evaluating spatial variability. However, a realistic characterization of the frequency and magnitude of water quality conditions through time based on watershed analysis field surveys may not be feasible due to time constraints.

5. Waterbodies differ in their "functional characteristics." These characteristics determine the beneficial uses of the waterbody and its vulnerability to changes in input variables.

6. A variety of land use activities and natural processes can cause changes in water quality. The presence of land uses other than forest management can have significant effects on water quality that may not be fully characterized in the watershed analysis. The Watershed Analysis methodology may not adequately characterize non-forestry effects on water quality.

7. The current condition of a waterbody represents its response to past and current watershed processes. Current condition and past changes are indicators of the potential of the waterbody to be influenced by watershed processes and land use activities.

Overview of Assessment and Products

The objective of the Water Quality Module is to (1) identify waterbodies within the WAU or waterbodies outside the WAU that may be directly affected by watershed processes within the WAU, and (2) to assess the potential for their characteristics to change with forest management. The analyst establishes the potential response based on watershed characteristics using such tools as topographic and geologic maps and soil surveys. The occurrence of specified features identifies locations where water quality response are reasonably likely to occur if protection is not provided during forest practices.

The first step of the water quality module is to identify and map all of the waterbodies existing in the watershed (Waterbody and Water Supply Identification, Characterization and Mapping). Any waterbodies not already found on the WAU basemap are added and the updated WAU basemap is re-distributed to other module analysts. (In most cases, it will be beneficial for other module analysts to assist in production of the map.) Wetlands identified during aerial photo analysis, field assessment, or interviews with local landowners or tribes, or from map data sources that are not on WAU basemaps should be included. The water quality analyst is expected to identify only larger wetlands with aerial photographs during this assessment. It is assumed that smaller wetlands are identified during site-specific activities according to Forest Practices Wetlands Regulations so there is no expectation that these are to be identified during Watershed Analysis. The public works analyst identifies public works with water quality concerns such as water supplies and fish hatcheries (information is provided on Form H-1 in the Public Works module). These sites are also added to the revised WAU basemap.

Next, waterbodies and their associated water quality parameters are assessed for vulnerability to input variables (Waterbody Vulnerability Assessment). For purposes of Watershed Analysis, vulnerability is defined as the potential for adverse response of the water quality characteristics to changes in input of sediment, heat energy, nutrients, organic matter, or chemicals resulting from forest practices. Vulnerability to change is not based on current water quality condition although the current status is useful in evaluating the validity of vulnerability determinations based strictly on watershed conditions.

Through the adoption of water quality standards, the state of Washington defines the beneficial uses to be protected in each waterbody as well as numeric water quality criteria necessary for specific parameters that help protect these uses. A number of water quality parameters have been adopted as standards by the Department of Ecology. Water quality parameters that may be affected by land use activities (timber harvest, grazing, urbanization, etc.) include numeric values for temperature, turbidity, pH, and dissolved oxygen (DO). Water quality criteria can also be in narrative form, such as general prohibitions against the presence of toxic, radioactive, or deleterious materials in amounts harmful to designated uses, and prohibition on the deterioration of aesthetic values. For the most part, this module uses watershed criteria selected as indicators of adverse change in water quality relative to state water quality and federal drinking water numeric criteria. Habitat vulnerability and sensitivity to coarse and fine sediment loading is determined in the Fish Habitat and Channel modules for streams and wetlands where the dominant beneficial use is fish (WFPB, Watershed Analysis Manual, Appendices E and F, 1993).

The vulnerability of waterbody parameters to input variables is assessed by examining the potential for change from forest practices, using specific physical and biological conditions in the watershed that are likely to trigger changes in input of sediment, energy, organic matter or nutrients that would be sufficient to affect the ability of the waterbody to meet water quality standards. Criteria for identifying watershed situations such as soils, elevation, or flow where adverse change to water quality parameters may occur are provided based on review of the scientific literature and professional knowledge and experience. If specified watershed conditions that can influence a receiving waterbody are found, the water quality parameter is assumed to be vulnerable to the identified input variable for that waterbody, regardless of whether or not it has already been affected.

There are considerable differences among waterbodies and water quality parameters in their response to forest practices (MacDonald et al., 1991). Therefore, the need for analysis, and the likelihood of identifying vulnerability in water quality parameters, differs with each watershed. Table G-1 lists the status of analysis of water quality parameters by waterbody in this module. State water quality standards need to be met, but this module focuses on conditions likely to be affected by forest practices.

The vulnerability assessment for each water quality parameter is guided by a flow chart specifying methods for evaluating each type of waterbody. All watersheds will have streams and most will have wetlands. Many watersheds will not have lakes, water supplies, or estuaries and no assessment steps are required for water quality parameters where they do not exist. The assessment flow chart provided for each parameter guides the analyst to identify watershed conditions and vulnerability by directing them to specific methods of assessment for each.

Conditions and observations of the vulnerability assessment are recorded on the Waterbody Vulnerability Determination Worksheets (Form G-1 and G-2). Water Quality Vulnerability Maps drawn for each water quality parameter show locations where a moderate or high vulnerability was identified, and the zone of influence if it can be determined. It is assumed that other water-bodies have low vulnerability if not specifically depicted on the maps. Water-bodies and water quality parameters vary significantly in the likelihood of response to land use effects. Some water quality parameters are often vulnerable to changes in input factors due to forest practices (temperature, sediment) and assessment products will always be included in module results and considered for resource sensitivity during the Synthesis stage of Watershed Analysis. Several water quality parameters are only vulnerable in relatively few situations (e.g. nutrient concentration and dissolved oxygen) and these are reported only when specific watershed conditions exist. All water quality parameters may vary naturally in watersheds but some are not significantly influenced by forest practices (pH and fecal coliform). These receive a standard call of low vulnerability to forest practices and are not assessed further during watershed assessment. This is not to infer that these parameters could not be adversely affected by other land use activities within the watershed, nor that naturally occurring conditions may not also influence their status.

The hypothesis of water quality vulnerability may be tested with water quality data when they exist. Usually, the analyst will not directly measure water quality parameters, though data may be available from a variety of sources. Historic information and water quality data may allow the analyst to test hypotheses. The utility of data for evaluating the validity of vulnerability determinations varies depending on the initial call and whether past management has triggered a response. If data demonstrate existing exceedance of water quality criteria, the information can directly affect the vulnerability call if no vulnerability had been identified or could be used to validate the call if moderate or high vulnerability had been hypothesized. The usefulness of data will also be dependent on the data itself--how, where, and why it was collected will influence its value in addressing watershed analysis questions.

The assessment may be an iterative process that requires repeated evaluation of information and testing of hypotheses. Water quality evaluation and hypothesis development is initially based on existing information. Level 2 or follow-up analyses may try to verify these hypotheses using appropriate monitoring techniques. Opportunities for additional measurements may be seasonally influenced because many water quality parameters are highly variable over the course of a year.

The final step of the water quality module assessment is to produce a report of the findings and notify other module analysts of the vulnerability determinations for each waterbody present in the watershed. These analysts may need to develop additional information that is not normally called for to determine the sensitivity of the waterbody to forest practices during the Synthesis phase of the Watershed Analysis. The water quality analyst will work with the other module teams such as mass wasting, surface erosion, hydrology, stream channel and fish habitat during synthesis to further refine potential secondary or synergistic effects of forest practices and to combine the hazard and risk assessments into the rule call and causal mechanism reports. Prescriptions to address identified water quality sensitivities will be developed by the prescription team.

Table G-1. Water quality parameters and input variables

		Waterbody Type				Water Supplies	
Water Quality Condition	**Input Variable**	**Streams**	**Lakes**	**Wetlands**	**Nearshore Marine-Estuarine**	**Drinking Water**	**Fish Facilities**
Physical							
Temperature	Heat Energy	1	1	1	4	1	1
Turbidity	Fine Sediment	3	3	3	3	3	3
Accretion	Fine Sediment	5	1	1	6	5	5
	Coarse Sediment	5	1	1	6	5	5
Water Quantity	Low Flow	6	6	6	6	6	6
Chemical							
Nitrogen	Nitrogen	1	1	4	6	6	6
Phosphorus	Fine Sediment	1	1	2	6	4	4
Dissolved Oxygen	Organic Matter	1	1	4	4	1	1
Acidity/Alkalinity (pH)	Organic Acids/ inorganic bases	4	4	4	4	4	1
TOC	Organic Matter	4	4	4	4	6	4
Fecal Coliform/ Cryptospridium/ Giardia	Animal or Human Waste	4	4	4	4	4	4
Toxic Contaminants	Organic and Synthetic Chemicals	2	2	2	2	2	2
	Fertilizer	2	2	4	4	1	1
Biological	Biologic Integrity	3	3	3	3	1	1
	Physical Habitat	5 (fish-bearing) 3 (non-fish)	4 4	1 1	4 4	-- --	1 --

1 = Routinely assessed in the Water Quality Module.
2 = Usually addressed by Standard Forest Practices. Only assessed by the Water Quality Module if specific conditions exist.
3 = Probably affected by forest practices but not currently addressed in module due to incomplete methods at time of adoption of current version of the WFPB manual.
4 = Unlikely to be significantly affected by forest practices except where criteria specified in manual exist.
5 = Addressed in other modules in WFPB Watershed Analysis Manual.
6 = Methods not included in module although recommended that specialists conduct assessment, if needed.

Qualifications

The water quality assessment depends on qualified individuals to identify waterbodies and interpret their conditions in relation to water quality. This assessment requires expertise in identifying waterbodies, analytical skills in evaluating water quality data, and understanding of the physical and chemical characteristics of the aquatic system. Certain basic skills, training, and experience are necessary to effectively implement the standard water quality assessment module. Most natural resource scientists with the appropriate qualifications should be able to do this module. Given the broad range of parameters evaluated, training should orient the analysts to the scope of the module. The water quality analyst may incorporate other specialists participating in a watershed analysis to help them with the assessment.

A level 2 analysis presupposes a higher level of training and ability to independently develop and implement relevant analysis to address issues and observations not satisfactorily explained by the standard analysis. It would be beneficial for a water quality analyst to exhibit an interdisciplinary background to successfully perform this module. While there are many possible backgrounds that could provide the foundation necessary, the following criteria provide necessary qualifications for those performing the water quality assessment.

Skills

Level 1. Knowledge of the physical, chemical, and biological characteristics of aquatic systems and processes affecting water quality in forested and mountainous terrain. The ability to identify waterbodies with aerial photography is highly desirable, although this skill may be drawn from the watershed assessment team.

An understanding of the primary parameters affecting water quality in the forested environment as reviewed and synthesized in:

MacDonald, L.H., A.W. Smart, and R.C. Wissmar. 1991. Monitoring guidelines to evaluate effects of forestry activities on streams in the Pacific Northwest and Alaska. EPA910/9-91-001. USEPA Region 10, Seattle, WA. 166p.

Level 2. In addition to level 1 skills:

- Experience with water quality sampling and monitoring methods and quantitative analysis.
- Experience in detecting physical changes to waterbodies over time (e.g., eutrophication of lakes, roading, diking, or ditching of wetlands.)

Education and Training
Level 1. Bachelor of Science degree in a physical or biological science with significant course work in, but not limited to: water chemistry, water resources, aquatic biology, limnology, forest hydrology, wetland science or ecology, and/or marine science or fisheries.

Level 2. Master of Science degree in physical or biological sciences with a significant amount of course work or other training in, but not limited to: water chemistry, water resources, aquatic biology, limnology, water quality sampling and monitoring, forest hydrology, wetland science or ecology, and/or marine science. Five years of experience and level 1 qualifications may be substituted for an MS.

Experience
Level 1. A minimum of two years of applied experience gaining the above-mentioned skills.

Level 2. Experience conducting relevant independent research and/or water quality sampling and monitoring, and a minimum of two years of professional experience.

Background Information

To begin the assessment, several key data sources are necessary including the DNR hydro- layer and wetlands maps, soil maps, and aerial photographs. Once the initial screen of waterbody/parameter conditions is completed, some additional data may be necessary. This section identifies necessary start-up information. Additional data sources are listed within the specific methods for each waterbody.

Maps

- Topographic maps of the watershed (USGS 7.5 minute series required, where available).
- WAU boundary base map overlaid with DNR's hydrography layer at 1:24,000 scale and wetlands delineations.
- National Wetlands Inventory (NWI) maps (7.5 minute series). These maps show wetlands which have previously been identified. NWI maps vary considerably in their relative accuracy and reliability because varying levels of ground verification occurred across regions after aerial photos were initially interpreted. Therefore, it is up to the analyst to determine how to use these maps. NWI maps may soon be available in digital format from DNR GIS (Forest Practices Division, 360/902-1400) or hard copy maps

from http://www.dnr.wa.gov/BusinessPermits/Topics/Data/Pages/gis_data_center.aspx. Digital wetlands map data is also available over the Internet from US Fish and Wildlife Service (Herman Robinson, 813/893-3624).

- Soil Survey Maps, Soil Descriptions. Existing soil survey information can be obtained from local offices of the National Resource Conservation Service (NRCS), DNR, US Forest Service, and in some cases, local landowners. A limited number of NRCS soil surveys are also becoming available in digital format.

In addition, the water quality analyst should consult with the public works and fish habitat analysts to identify the location of municipal or domestic water supplies and fish hatcheries.

Aerial Photographs
Use the most recent coverage available (1:12,000 scale or better, if available). It is recommended that the analyst also examine past photos, if available.

Information Provided to Water Quality Analyst By Other Modules

General:	• DOE water class designation for WAU. • Sub-basin designations.
Riparian:	• Potential and existing shade conditions (Riparian Shade Situation Map D-4).
Channel:	• Gradient/confinement of all typed waters (Gradient Map E-1).
Hydrology:	• Flow data from existing stream gages.
WS/PW:	• Information about water quality concerns of public resources and fish facilities.

Water Quality Data and Other Information

- Washington Department of Ecology (DOE)
- *Section 303(d) List* (DOE, 1996)- A state list of water quality-limited waterbodies (streams, lakes, and estuaries) where State water quality standards are not met and where technology-based controls are not sufficient to achieve water quality standards.
- Supporting information used to determine listing from appropriate DOE representative.

Other water quality data may be available for the watershed. The analyst is encouraged to proceed with waterbody identification and initial stages of analysis prior to querying for data from the following sources since many will not be relevant if watershed screening criteria are not met. Sources of water quality data, though often variable in their availability, coverage, and usefulness, may include:

- *Local Tribal Ambient Water Quality Data.* Limited ambient water quality data are available from the tribes, existing in various formats for various parameters (e.g., temperature and some water chemistry). Data requests can be made to the Northwest Indian Fisheries Commission (360-438-1180) or directly to local tribes.

- *County Water Quality Data.*

- *Washington Department of Ecology*-Water Quality Monitoring Data. Extensive permit-related and some ambient monitoring data exist for various facilities, locations, and parameters across the State. Information is available from the DOE Water Quality Program at (360)407-6400, or write: WQ DOE, P. O. Box 47600, Olympia, WA 98504-7600.

- *Washington Department of Ecology*—Environmental Investigations Laboratory Services (EILS) has some ambient water quality data dating back to 1959 from some sites located statewide. Current water year from 82 stations is available on web page (http://www.wa.gov/ecology/ecyhome.html) and annual report.

- *United States Geological Survey Miscellaneous Water Quality Data and National Water Quality Assessment (NWQA) data.* This data is published annually for selected stations but varies considerably in the completeness, coverage, and frequency of data collected. It may be acquired from local libraries or by contacting the USGS directly. USGS hydrology data is also available on CD ROM from several suppliers.

- *Washington Water Resources Inventory System (WRIS).* An inventory of fish habitat maintained by the Washington Department of Fisheries and Wildlife.

- *National Pollutant Discharge Elimination System (NPDES) Permit.* On limited occasions there may be a facility within the watershed which has been required to collect specific point discharge and ambient monitoring data under a NPDES Permit which may provide useful information.

- *Drinking Water Utility Records—Annual Report to the Department of Health (DOH), Operational Records, Annual Analysis.* This valuable information should be obtained from any local water purveyors in the watershed.

Assessment Methods

Startup

Unlike other modules, the scope and scale of the water quality assessment may vary from watershed to watershed depending on team decisions regarding the need for water quantity assessment and the allocation of duties among the riparian, fish habitat, and stream channel analysts. Decisions regarding the sharing of tasks and the extent to which water quantity is assessed should be made at the beginning of the watershed analysis process. Undoubtedly, continual interaction among scientific analysts will also be needed. These interactions may be initiated at any time during assessment, although it may be useful for the water quality analyst to develop the water-bodies map beforehand.

The need to include water quantity in the watershed assessment and prescriptions should be scoped by the watershed analysis team at the startup of watershed analysis. Forest practice effects on peak flow are addressed in the hydrology module. The extent to which low flow may affect water quality conditions should be addressed by the water quality analyst working with the hydrology analyst. Although forest practices generally do not reduce summer lowflow, water withdrawals from non-forestry related activities could reduce flow and increase water quality vulnerability to forest management activities. It is not expected that this will be an issue in most watersheds and the need to assess non-forestry related impacts on water flow is determined by the entire Watershed Analysis team based on prior knowledge of impacts.

Scoping is done by the analysts and managers responsible for the watershed. Agencies and others with information are encouraged to bring this information forward as a contribution to scoping. The group considers important linkages between water rights, non-forestry activities, forest practices, and water quality. If there is likelihood of additional vulnerability from forest-related activities, then some analysis of that is expected in the watershed analysis. The team develops a workplan for considering what water quality parameters might be affected and where, the relationship between forestry and non-forestry related activities, and the scope of their work. If analysis of water quantity occurs and a relationship to forestry or non-forestry activities is discovered, a causal mechanism report on water quantity is developed. Ultimately, the appropriate jurisdiction(s) is notified if problems are found.

In addition, there are many tasks that may be potentially shared with other module analysts. Water quality problems may be discovered by the public works or fish habitat analysts. The stream channel analyst may identify streams where sedimentation or other channel disturbance may also impact temperature. The riparian analyst works with shade and evaluates current, and to some extent potential shade. Many of the relationships between public resources and watershed conditions will be identified during the synthesis phase of the analysis. However, consultation among these analysts before and during assessment will greatly facilitate sharing of duties and development of interpretations and products.

Waterbody and Water Supply Identification, Characterization and Mapping

The first step of the water quality assessment is to identify and map all of the waterbodies in the watershed on the DNR hydrography base map. In most cases, this task is best accomplished jointly with fish habitat, public works, stream channel, and hydrology analysts. This map should be labeled Map G-1. Streams and major wetlands occur in virtually all watersheds, while lakes and nearshore marine/estuarine waters are more watershed-specific.

Streams

The WAU basemap developed for the project (see startup products) will have the hydrography of the watershed. Streams, lakes, and some major non-forested wetlands, reservoirs, and marine waters will be depicted on the DNR base map. However, the base map may be missing some large wetlands and public water supplies, as well as small or intermittent streams. To the extent possible, the water quality analyst will attempt to update the stream type map by consulting with local tribes, DNR, and landowners using stream typing criteria adopted by the Forest Practice Board in November 1996. Public water supplies will be identified by the water supply/public works analyst. Hence, mapping of additional waterbodies sensitive to changes in inputs affecting water quality will be limited to locating all readily identifiable wetlands and incorporating information collected by the water supply/public works analyst.

Wetlands

Wetland Classification

Lakes are commonly defined as waterbodies with water deeper than 6.6 feet (2m), and wetlands are all shallower waterbodies. Wetlands are classified into groups based on similar attributes to facilitate decision-making and further analysis. There are several classifications of wetlands that are used for different administrative or scientific purposes. One of the oldest, and best known is the U.S. Fish and Wildlife Service system used in the National Wetland Inventory (NWI) (Cowardin 1979). The Cowardin system is based on shared characteristics of landscape setting, vegetation and water regime. It was designed to help identify different wetland habitat types.

The Forest Practices Board developed a wetlands classification system for administering forest practices in 1992 (WAC 222-16-035). Criteria for classification of wetlands according to the Forest Practices Board method (WFPB 1993) is provided in Table G-2. The major criteria for grouping under this classification are the size of the wetland, presence or absence of open water, and the type of vegetation present (forested, nonforested, bog or fen).

Table G-2. Definition for Wetland Typing System Washington Forest Practices Board (1993)

Wetland Class	Wetland Type	Definition
Nonforested Wetlands		Any wetland or portion thereof that has, or if the trees were mature would have, a crown closure of less than 30 percent
	Type A Wetland	Greater than 0.5 acre in size, including any acreage of open water where the water is completely surrounded by the wetland; and associated with at least 0.5 acre of ponded or standing open water. The open water must be present on the site for at least 7 consecutive dates between April 1 and October 1. Bogs and fens greater than 0.25 acres, as well as forested bogs and fens.
	Type B Wetland	Applies to all other nonforested wetlands greater than 0.25 acres.
Forested Wetland	Forested	Any wetland or portion thereof that has, or would have mature trees, and crown closure of 30 percent or more.

The FPB and NWI classifications provide some information that may be useful in establishing the effectiveness of a wetland at trapping sediments because they are partially based on vegetation. Unfortunately, these classifications are not very useful in assessing the probability of sediment retention because they do not contain any criteria based on connections to the stream system. The NWI classification considers streams and rivers as separate wetlands and does not provide any information about the connectivity between a wetland and an adjacent stream, a common condition in forested watersheds. Title 222 WAC classifies riverine associated wetlands as Type 2 water if they are used by salmonids for off-channel habitat.

A hydrogeomorphic classification of wetlands (HGM) was developed by Brinson (1993a). The HGM approach has been specifically named in the National Action Plan as the vehicle through which regionally specific methods are to be developed (GPO, 1996) and Washington has decided to base its Wetland Function Assessment Project on the national HGM approach (DOE 1996). The HGM wetlands classification method is designed to categorize wetlands by characteristics that strongly influence wetland functions. These include: geomorphic setting, dominant sources of water, and hydrodynamics. Geomorphic setting refers to the landform of a wetland and its topographic position in the landscape. Water source refers to the origin of the water in the wetland, and hydrodynamics refers to the direction of movement and energy level of water in the wetland. Table G-3 displays the hydrogeomorphic classes of wetlands with associated dominant water source and hydrodynamics.

Table G-3. Hydrogeomorphic Classes of Wetlands Showing Associated Dominant Water Source and Hydrodynamics

Hydrogeomorphic Class	Dominant Water	Dominant Hydrodynamics
Riverine	Overbank flow from channel	Unidirectional, Horizontal
Depressional	Return flow from groundwater and inter-flow	Vertical
Slope	Return flow from groundwater	Vertical
Flats	N/A	N/A
Lacustrine Fringe	Overbank flow from lake	Bidirectional, Horizontal
Estuarine Fringe	Overbank flow from estuary	Bidirectional, Horizontal

The water quality module wetlands assessment is based on the HGM approach to naming and determining wetland function. This is because the HGM approach is more consistent with the purpose of watershed analysis to determine the effect of changes in watershed processes on wetland function than the Forest Practice Board classification system, and because analysis will be consistent with evolving agency approaches to be applied on all lands within Washington.

HGM classification is hierarchical. At the highest level, wetlands are grouped into classes based on geomorphic characteristics. Subclasses for each of these Classes are then defined regionally. Table G-4 displays the HGM Classes and Subclasses for Washington proposed by the Washington State Wetland Function Assessment Project (DOE, 1996). Table G-5 summarizes the main characteristics of the subclasses that will be employed in this assessment.

Table G-4. Regional Hydrogeomorphic Classes and Subclasses for Washington State

Class	Subclass
Riverine	Flow-through and impounding
Depressional	Flow-through and closed
Slope	Connected and unconnected
Flats	None
Lacustrine Fringe	None
Estuarine Fringe	Tidal saltwater and tidal freshwater

Table G-5. Definitions of Regional Hydrogeomorphic Subclasses

Regional Subclass	Definition
Riverine **I**mpounding **(RI)**	Retain surface water significantly longer than the duration of a flood event (>1 week)
Riverine **F**low-through **(RF)**	Do not retain surface water significantly longer than the duration of a flood event
Depressional **F**low-through **(DF)**	Depressional wetlands that have a surface water outflow to a stream or river for at least part of the year
Depressional **C**losed **(DC)**	Unconnected depressional wetlands may have surface water inflow but no outflow through a defined channel
Slope **C**onnected **(SC)**	Slope wetlands with a surface water connection, at least periodically, to an intermittent or perennial stream or other surface water body connected to a stream or river
Tidal **S**altwater Fringe **(TS)**	Estuarine fringe wetlands in which the dominant water flow has salinity that is higher than 0.5 parts per thousand
Tidal **F**reshwater Fringe **(TF)**	Estuarine fringe wetlands in which the dominant water flow is tidal but freshwater, with salinity below 0.5 parts per thousand

Identification and Mapping

Using available maps, aerial photography, and field inspection as warranted, the analyst classifies each wetland included in analysis, using both the DNR regulatory categories in Table G-2 and the regional hydrogeomorphic classes and subclasses in Tables G-4 and G-5 based on geomorphic setting, water source, and hydrodynamics. This information is included on the Wetlands Assessment worksheet (Form G-1). See Appendix section, "Profiles of Wetland

Classes and Subclasses for Lowland Washington" (DOE, 1997) for detailed descriptions of HGM categories. The Washington State Wetlands Function Assessment Project has established an Eastern Washington Technical Committee which will determine if other regions or subclasses are needed for eastern Washington wetlands.

Wetlands are not comprehensively identified on the DNR hydrography base map or on topographic maps, and will require the analyst to review other data sources. The National Wetlands Inventory (NWI) maps provide a "first cut" at identifying wetlands and DOE has a complete set of NWI maps in a GIS data base for Washington. However, these maps were drawn using aerial photographs at a very small scale, thus the accuracy of the maps can be poor. Hydric soils mapped on NRCS soil surveys further identify the general areas where wetlands may be found.

Using aerial photographs, an experienced analyst should be able to identify a majority of wetlands in the WAU by noting their distinctive characteristics. For example, major wetlands can sometimes be detected through changes in vegetative composition and structure (e.g., distinct changes from conifer to deciduous trees; trees to shrubs or emergent herbs; and differences in canopy density). Surface water connections are most apparent during high flows. In most cases, stream connections will be apparent. In other cases, field verification may be necessary.

Aerial photos taken at different times in the year, and historical photos, may help identify additional wetlands due to temporal differences in wetland appearance. However, wetland identification presents some unique challenges because of the varied geology and climate found in our state: hydrologic conditions vary due to seasonal variation in precipitation. Wetlands east of the Cascade Mountains can be very different from wetlands west of the Cascades because of the different climate. Wetlands in glaciated areas can have very different characteristics than those in areas that were never glaciated. Lastly, human activities have altered surface and groundwater hydrology, soils and vegetation in many parts of the state. All these elements influence where wetlands are found and what they look like.

Wetland boundaries should be mapped as accurately as possible, but field identification of boundaries is not needed for this assessment. The most critical datum to determine for each wetland is whether it has a surface water connection (either perennial or seasonal) to a stream or river. If a surface water connection is known to exist in a wetland, it is important to draw the boundary of the wetland so it intersects the appropriate stream arc in the DNR hydrographic database.

Form G-1. Wetland Assessment Worksheet

Wetland Identifer	Wetland Hydro-geomorphic Class and subclass	Legal Location	NWI Code (if available)	DNR Wetland Class/Type	Wetland Area (acres)	Open Water Area (acres)	Season Observed	Input Variable	Vulnerability Call (describe situation)	Comments

Local land managers, tribal representatives, other resource professionals, and local residents will be interviewed to obtain information on the location of additional wetlands that may not have been detected. The analyst should coordinate with the stream channel analyst to ensure that riverine wetlands encountered during the channel survey are also included in the wetland inventory. The analyst should coordinate with the channel condition analyst to ensure that wetlands encountered during the channel survey are also included in the waterbody inventory. Special resource characteristics such as deep peat soils and bog environments should be noted where identified.

Multiple-decade photo coverage is necessary to provide a reasonable determination of trends in wetland condition through time. The analyst shall combine time-series analysis of at least 2 sets of aerial photos encompassing the period of photo record for the WAU, anecdotal information, and information derived from field verification to provide a historical perspective and identify gross changes (such as effects resulting from filling and draining or changes in water regime) and resource trends where possible. Changes in vegetative composition based on aerial photographs should be field verified since local environment characteristics (such as aspect, geology, disturbance history) can shift land from upland to wetland conditions. Beaver-impounded wetlands on stream floodplains should also be noted.

Lakes

Lakes will usually be on the DNR hydrography layer and most will also be on the USGS topographic map. The analyst will ensure that lakes within the WAU are put on the Waterbody Map (Map G-1) and that other analysts are aware of them.

Lakes are listed on Form G-2 and key characteristics recorded. These include surface area and estimated depth. Many lakes in Washington have been studied by the DOE or other agencies. The analysts will interview DOE and tribal representatives to determine what may be known about the lake and any known water quality concerns.

Water Supplies

The quality of water is critical to public drinking water and will require assessment by the water quality analyst. Fish enhancement facilities are also often sensitive to changes in water quality parameters. The water quality analyst acquires the location of public water supplies and their point of withdrawal and fish enhancement facilities from the public works/water supply analyst and adds them to Map G-1. The water supply/public works analyst conducts interviews with local water supply personnel to acquire detailed information regarding each facility and will likely contact local re-source managers, tribal personnel, and irrigation districts (Form H-1). The water quality analyst will need to know the location and water quality concerns of each identified facility, and will assist the water supply/public works analyst conduct interviews.

Form G-2. Lake Assessment Worksheet

Lake Identifier	Legal Location	Available Data	Area of Open Water (acres)	Approx. Max. Depth of Open Water (feet)	Season Observed	Input Variable	Vulnerability Call (Justification)	Comments

Water diversions and return flows can have a significant effect on water quality in streams and lakes. For instance, reductions in flows can increase water heating in streams or return flows from fields can introduce high levels of nutrients to waterbodies. Evaluation of the effects of non-forestry landuse are outside the scope of analysis. However, the water quality analyst will locate and map the facilities since they may affect the interpretation of data assembled during the analysis.

Upon completion of this phase of the water quality assessment, the analysts will have located and assigned an identification number (e.g., 1, 2, 3, ...) to each major wetland and the lakes and reservoirs, streams, water supply and fish facilities, and nearshore marine/estuarine waters on the Waterbody Map (Map G-1) or, alternately, on the project base map. If unique identification numbers currently exist, such as segment numbers, or identifiers from agencies it is recommended that the analyst use these numbers. Surface water classifications (Class AA, A, B, C, and Lake Class) can be obtained from the riparian analyst or from the Forest Practices temperature standards map and noted on Map G-1. The waterbody identification and mapping process must be completed early in the watershed analysis. The updated waterbody map (G-1) will then be distributed to all assessment team members so that these resources can be included in their analyses.

Land Use

If other analysts have not done so, the analyst will also develop a Land Use Map (Map G-2) using aerial photography to delineate the general land use classes currently existing (e.g., forested, agriculture, residential). Land use classifications based on remote sensing imagery (e.g., Landsat) may be available in GIS format from local counties or municipalities. This map will be useful as a general reference during assessment and synthesis.

Waterbody Vulnerability Assessment

The vulnerability of waterbody parameters to potential changes in input variables with forest practices is assessed by identifying specific physical conditions where research or past experience in similar watershed situations has documented reasonable likelihood of a water quality response sufficient to exceed criteria. The assessment is intended to be predictive, and a water-body may be identified as vulnerable based on potential to exceed standards, or, if already affected, its current condition.

This module will identify waterbody vulnerability to some or all of the following parameters: temperature, fine sediment, nitrogen, phosphorus, dissolved oxygen, and pH. (See Table G-1 for module status for all water quality characteristics). It also addresses sediment accretion in wetlands. Which methods are needed in each watershed will depend on the waterbodies present and whether certain watershed conditions are met. It should be noted that identification of vulnerability of a waterbody in this module does not necessarily mean water quality is currently degraded. Also, the finding of a vulnerability of a water quality condition in a stream does not necessarily mean that a vulnerability will also be found in its downstream waterbodies such as lakes, and conversely, a receiving water may accumulate effects that are not detrimental in streams (e.g., nutrients).

Historical and present data, although probably limited, are important along with "modeled" calls based on estimates from watershed conditions. All three should be integrated where available to form the final vulnerability call. The watershed and management history of the area will determine how historical and present data may be informative in relation to the vulnerability determination. Data may either confirm or deny a hypothesis. Where data alters a hypothesis, the analyst should record their justification for changing the determination.

The methods are organized by water quality parameter. Within each parameter, a flowchart guides the level and steps of analysis, in some cases providing a vulnerability determination based on simple screening variables. A vulnerability map for each parameter is produced for use by all analysts in synthesis to identify potential sources of adverse impacts to vulnerable waterbodies, although if only low vulnerability is found no map will be included among the module products. For temperature and sediment effects, there usually is reasonable potential for effects from forest practices if adequate protection is not provided, and these assessments will nearly always be included. Vulnerability of dissolved oxygen and pH is rarely found and the need for analysis of these parameters is not common.

The analyst should refine the area of water vulnerability. Recognizing that water quality impacts are affected by factors that dilute or accumulate within the watershed, the assessment of each parameter should be limited to the zone of influence of the waterbody, if it can be determined. This zone of influence will be specified as a Water Quality Map Unit (WQMU) and mapped on the Water Quality Vulnerability Maps. The standard assessment allows the entire contributing watershed to be considered unless specified in the assessment criteria. A level 2 assessment may broaden or narrow the zone based on rationale or information documented in the watershed report. The WQMUs are coded on the maps by water quality parameter and input variable (e.g. Water Temperature Vulnerability to Shade Removal or Dissolved Oxygen Vulnerability to Organic Matter/Slash Input).

Water Temperature Assessment

Scientific Background

Water temperature is a fundamental parameter of water quality and an integral component of aquatic habitat. Chronic and significant water temperature exceedances above the natural variability of a stream are likely to impact the aquatic biota (e.g., Hynes, 1970; Beschta et al., 1987). Furthermore, elevated temperatures can trigger conditions which affect other water quality parameters such as dissolved oxygen. Local and downstream changes in temperature associated with shade removal is an important land use consideration. Table G-6 lists the natural watershed parameters that are most influential in determining stream temperature. These include: solar radiation, air temperature, stream width, stream depth, shading, and groundwater inflow. Forest practices can affect these parameters. For example, removal of riparian vegetation increases the solar radiation received by a stream reach; logging can alter streamflow, either decreasing or increasing summer low flows depending on local situations, and sedimentation can decrease channel depth and increase channel width.

Table G-6. Types of Variables Affecting Stream Heating Processes
(from Sullivan et al. 1990)

General Variable	Example
Geography	latitude, longitude, elevation
Climate	air temperature, relative humidity, wind velocity, cloudiness
Stream Channel Characteristics	stream depth, width, velocity, substrate composition, water clarity
Riparian or Topographic Blocking	sky-view (% shade), canopy density, vegetation height, crown radius, topographic angle

Many studies conducted throughout the United States have documented the effects of riparian vegetation and its removal on summer stream temperatures with consistent results (reviewed by Beschta et al., 1987). Brown and Krygier (1970) demonstrated that reduced stream shading results in generally higher stream temperatures and increased diel temperature fluctuation.

There is natural variability in the vulnerability of waterbodies to shade removal due to differences in their size and location within the watershed. The magnitude of potential temperature change with removal of streamside vegetation varies with stream depth (Brown, 1969; Adams and Sullivan, 1990; Sinokrot 1993). Shallow streams have the greatest response while change in larger, deeper streams is less. In the case of streams, the farther from the watershed divide, the less influential is riparian vegetation in maintaining temperatures as channels naturally widen as they convey more water. The wider the waterbody, the taller the vegetation must be to effectively block the view-to-the-sky. Large lakes are often too wide for any vegetation to be an effective control of water temperature. Small or moderate-sized lakes may not be fully shaded but they can still be affected by the blocking of radiation by streamside vegetation. The ability of vegetation to block incoming and outgoing radiation depends on its height relative to the width of the waterbody. Along very small streams almost any vegetation and streambanks themselves will provide shade, while tall trees and major topographic features are necessary for significant shading of larger rivers. The maximum potential shade depends on the features of native vegetation.

The DOE classification of rivers and streams partially accommodates this natural variability (Table G-7). Streams near headwaters are usually forested and are generally classed as AA with expectations of cool water temperature. The boundary between AA and A streams generally occurs a significant distance downstream from headwaters but the location has been assigned for each river according to several criteria, and may not reflect the natural capability of the river to achieve water temperature conditions. Similarly, the boundary between A and B streams is generally found much lower in the watershed and may be assigned for a variety of reasons besides water temperature.

Table G-7. Water Temperature Standards

DOE Waterbody Classification	Annual Maximum Temperature	Incremental Increase
Class AA Waters	16.0º C (61º F)	<2.8º C (5º F)
Class A Waters	18.0º C (64º F)	<2.8º C (5º F)
Class B Waters	21.0º C (70º F)	<2.8º C (5º F)

An extensive study of temperature in Washington streams confirmed relationships between temperature, watershed and landuse factors established in previous research (Beschta et al., 1987). The study was also able to identify a simple relationship between view-to-the-sky and elevation that could be used to predict the maximum allowable view-to-the-sky that would maintain temperature within water quality criteria for purposes of guiding riparian area management in state forest practice regulations. Documentation of the basis of the simple model is provided in Sullivan et al., 1990, see chapters 6 and 7). Relationships for streams east and west of the Cascade Mountain divide have been adopted as the temperature screen by the Washington Forest Practices Board (WFPB 1993) to be used in managing riparian areas for protecting shade on a site by site basis. This screen demonstrates that less shade is needed at higher elevations than lower elevations to maintain the same water temperature.

The methods presented in this module estimate expected changes in annual maximum stream temperature at a stream-reach scale, based on different scenarios of riparian vegetation type and extent, and hence, different degrees of shading provided by the riparian vegetation. Many important aspects of the physical processes and geomorphic conditions controlling water temperature at a basin scale are reviewed as scientific background in the Appendix of this module. Derivation of analysis techniques and simple models used in steps of this assessment are provided. Water quality analysts must familiarize themselves with these principles in order to conduct the water quality module and synthesis steps determining temperature vulnerability.

The degree of vulnerability of water temperature to forest practices is determined by the relative importance of riparian vegetation in limiting view-to-the-sky sufficient to maintain water temperature within the standards. Stream water temperature is considered vulnerable if the maximum temperature is capable of exceeding state water quality criteria.

Although temperature is primarily assessed in relation to the shade provided by riparian vegetation, there may also be secondary effects on temperature from other watershed disturbances. For example, sedimentation may widen the channel and increase view-to-the-sky. Water depth may also be reduced with sediment accretion or water withdrawals, although this effect is expected to be relatively less important than increased exposure except in more extreme cases of sedimentation or where cool water refuges are lost. Identifying these effects on temperature from causes other than direct shade removal is also an important product of watershed analysis although these determinations will be made in interdisciplinary analysis during synthesis. During watershed synthesis, the water quality analyst must work with other analysts and the products they developed from the hydrology, mass wasting, habitat, channel and riparian modules, as well as ancillary data on fisheries resources, in order to develop an integrated assessment of the likely effects of forest practices on stream temperature.

Assessment

The vulnerability of waterbodies within the WAU to shade removal is determined by different procedures, depending on whether they are riverine and flowing or wetlands with water above or below the ground surface (Figure G-3). Several "screening level" criteria can be used to indicate whether temperature assessment for particular waterbodies is needed at all. No temperature assessment is needed if waterbodies are at very high elevation (>3600 ft west side of the Cascades and >4600 on the east side of the Cascades). High elevation streams and lakes are unlikely to have high water temperatures, regardless of shade conditions according to results of the TFW Temperature study (Sullivan et al. 1991). Assessment will be necessary for all streams and riverine wetlands that are not at high elevation. The necessity for assessing isolated wetlands and lakes depends on the surface area of the waterbody. Shallow seeps may also be susceptible to temperature increase with shade removal, depending on the proximity of the water table to the ground surface.

Many of the assessment products described in this module were produced by the riparian analyst as part of the shade assessment portion of the riparian module in previous versions of the Watershed Analysis Manual. The water quality analyst should obtain these products from the riparian analyst to avoid duplication of effort, or the riparian analyst may produce the additional products specified in this module and complete this water quality module temperature assessment. The water quality module provides methods for all products relating to reference temperature and vulnerability to shade removal while the riparian module provides methods for products relating to current shade and hazard to shade loss. Products of the water quality module assessment include maps and determinations of vulnerability to shade loss.

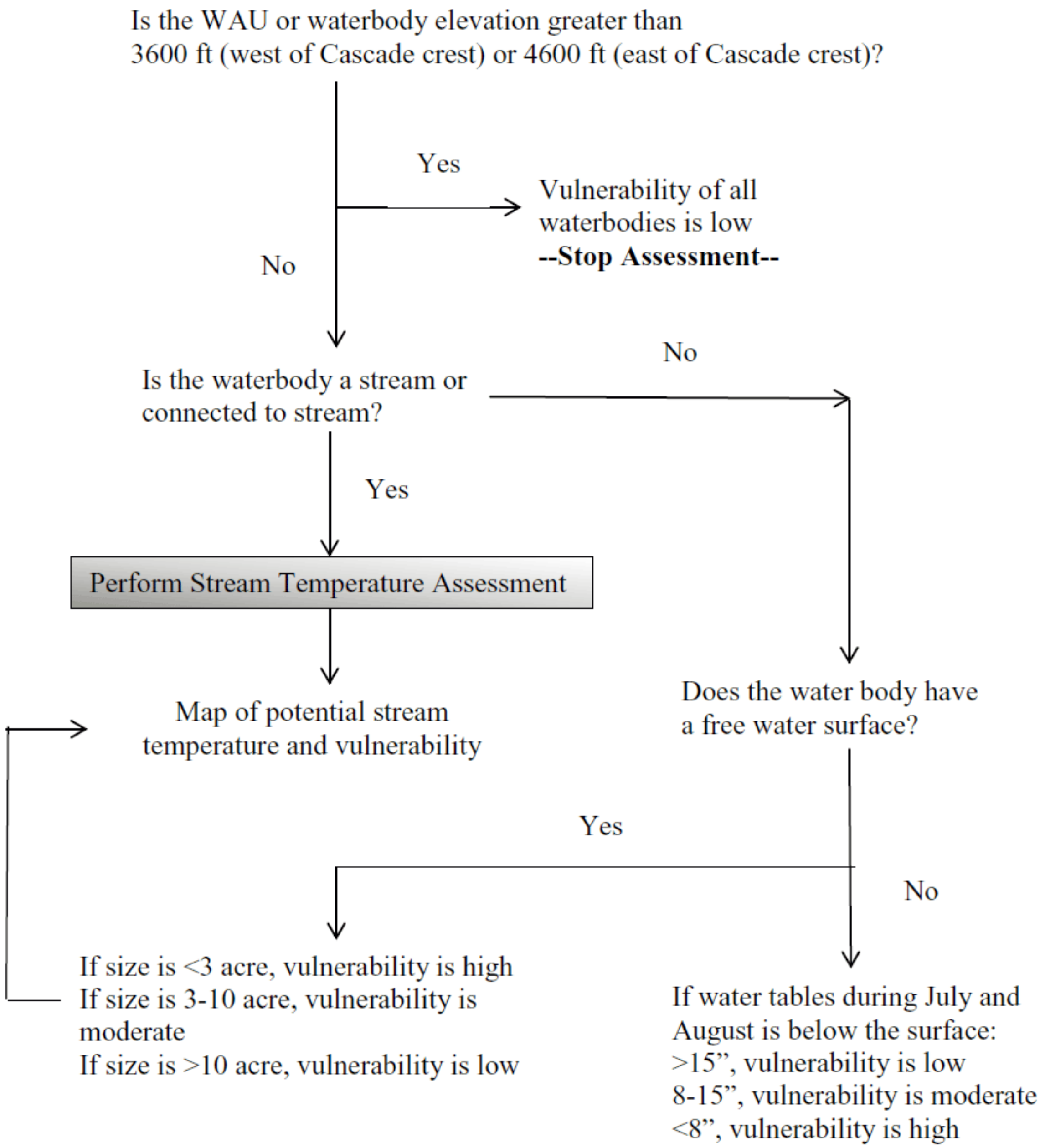


Figure G-3. Temperature Analysis Flow Chart
(Criteria are developed in the text.)

Level 1 Stream Temperature Procedure

Temperature vulnerability assessment is primarily oriented to evaluating potential effects on water temperature from removal of vegetation. The analyst determines minimum potential view-to-the-sky considering the relationship between mature vegetation height and channel width as it controls the openness of the channel. View-to-the-sky estimates are coupled with the temperature screen to estimate potential temperature. Vulnerability is determined considering the difference between potential view and the maximum allowable view that will maintain water temperature criteria. From this information, a map of potential water temperature in the watershed and the vulnerability is produced.

The basic steps of the stream temperature assessment are:

1. ***Map potential view-to-the-sky based on estimates from mature vegetation,***

2. ***Map maximum allowable view-to-the sky based on elevation/sky view relationship,***

3. ***Map reference temperature for each stream segment or riparian unit,***

4. ***Determine vulnerability to shade loss,***

Complete map products.

Steps:
Calculating potential and maximum allowable view-to-the-sky requires the use of a topographic map as a working map. Estimates of potential and maximum view are recorded on the map according to methods described in this section.

1. **Map potential view-to-the-sky based on mature or old growth forests.**

The first step in the temperature vulnerability analysis is to determine the view-to-the-sky that would likely occur under the assumption that fully mature forests populated the entire watershed. This establishes the minimum potential view-to-the-sky. The analyst estimates the potential view-to-the-sky assuming the potential height of older mature trees native to the site and vegetation density. Channels up to 20% gradient identified by the channel and riparian analysts are included in the assessment. Smaller or steeper channels not on the basemap can be assumed to have potential view-to-the-sky of 0.

If data on minimum view-to-the-sky is available from the area based on measurements of fully stocked and fully grown forest stands, then this may be used as a basis for this analysis. Many watersheds with past landuse or natural disturbance are likely to have vegetation on some or all stream segments that do not currently match these criteria. In the absence of reliable empirical relationships between potential view-to-the-sky and easy to determine watershed measures such as distance from divide or basin area, the analyst may estimate using hypotheses of channel dimensions and geometric characteristics of forest stands of appropriate species as described in the remainder of this section.

The following analysis demonstrates how to estimate view-to-the-sky directly from the geometry of the riparian setting. Calculating view-to-the-sky with the mathematical model requires knowledge of stream width between trees on either bank. If measured widths are unavailable, bankfull width can be used as a suitable surrogate. (For purposes of estimation, no attempt is made to include shade that may be provided by vegetation growing in mid-channel bars. Level 2 analysis could further investigate this effect).

Measurement of bankfull width is preferable. However, to extrapolate results to or from other watersheds, bankfull width may be estimated using hydraulic geometry relationships (Leopold et al. 1964, Dunne and Leopold 1978). Water depth may be estimated similarly. It may be assumed that channel width is a function of discharge of the form:

$$\text{Width} = aQ^{f} \tag{1}$$
$$\text{Depth} = bQ^{g} \tag{2}$$

where Q is discharge, and a and f are coefficients that may vary from watershed to watershed. Since Q increases with basin area, a similar form exists for estimating channel dimensions using basin area:

$$\text{Width} = bA^{m} \tag{3}$$
$$\text{Depth} = cA^{k} \tag{4}$$

This relationship, once established for the watershed, can be used to estimate channel width using basin area. To calibrate estimates, riparian and channel module analysts may be able to provide measured data from the watershed. Stream segments may be naturally wider or narrower than this general estimate, resulting in under- or overestimation of vulnerability. Local interactions between waterbody width and valley topography can be accounted for in field investigation.

To calculate view-to-the-sky, determine the angle, a (in degrees), from the horizontal formed by the wall of trees, and substitute into the formula:

$$\propto = \text{ArcCos}\,(w/\ \text{SQRT}\,(w^{2}+4h^{2})) \tag{5}$$

where w is the stream width and h is the height of the trees.

Calculate view-to-the-sky using angle ∝ using

$$\text{View-to-the-sky (\%)} = 100 - \frac{10}{9}\propto \qquad (6)$$

This equation was solved for a range of stream widths and potential tree heights in Figure G-1.

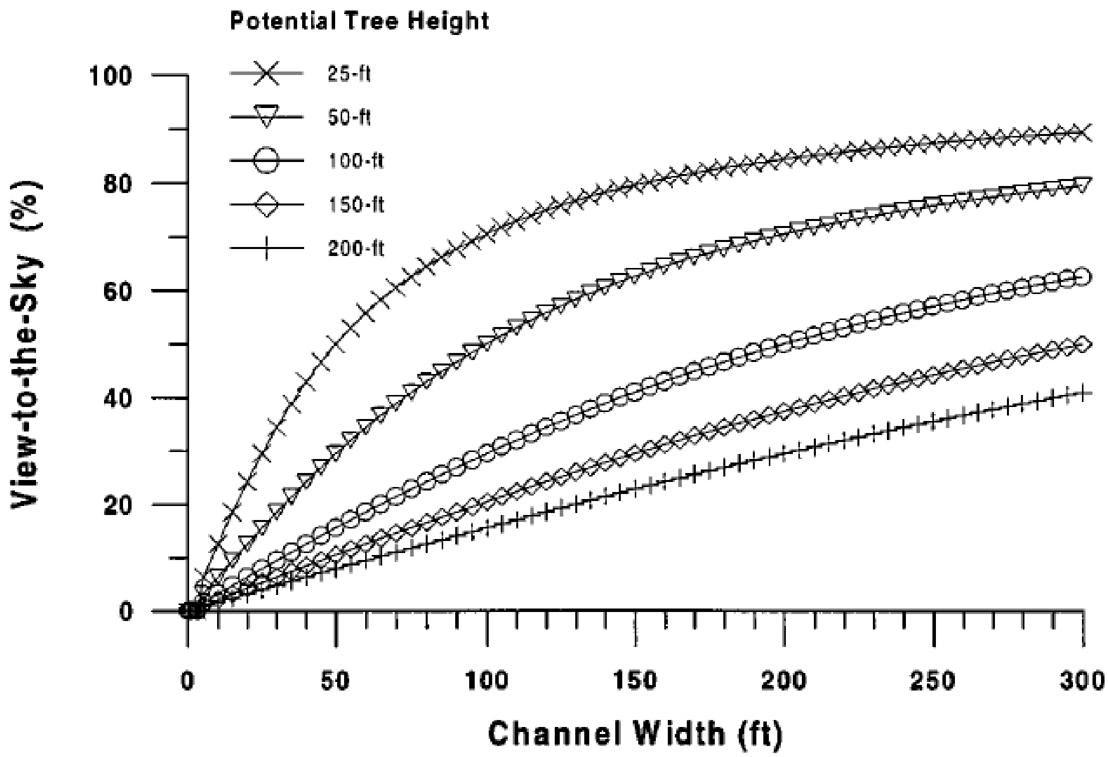


Figure G-1. Calculated view-to-the-sky in relation to potential tree height based on equation (6)

Several assumptions are made to determine potential view-to-the-sky calculations based on geometric relationships. Maximum potential height of native overstory species is assumed to be the height of blocking vegetation (h). Potential view-to-the-sky is determined by making the above calculations based on the site as it could be with mature vegetation (whether shrub or trees). The analyst must assume an appropriate height of the forest stand or shrub community that would occupy the site under historic natural conditions. The chosen height should be representative of vegetation that has reached mature height (potential height). Analysis of available riparian shade data from western Washington suggests that a height of 150-ft should be used in calculations for western Washington unless site data is available (see the Appendix attached at end of module).

Estimates may be improved by actual field measurement, including both change in potential tree height and an opacity factor. View-to-the-sky can be calculated by the same formula given above, but substituting effective tree height He for H. An additional correction may be needed if the trees are sparse. Use of an opacity factor should be based on field estimates from reference sites and should be ignored if these are not available. Opacity is already included in the recommendation of 150-ft potential tree height.

It is also assumed that blocking elements are the same on both sides of the stream. Analysts may alter estimates along stream systems where the assumptions can not be met. Bankfull stream width (w) is assumed to be the maximum distance between blocking elements on opposite banks.

Include the estimated potential view-to-the-sky on the working Temperature Vulnerability Map. An example is provided in Figure G-3.

2. **Map minimum potential view-to-the-sky based on the TFW temperature screen elevation/view relationship (see Tables G-8 and G-9).**

In this step, the analyst determines the minimum view necessary to maintain temperature within Washington water quality standards for annual maximum temperature. The analyst uses the relationship between view-to-the-sky and elevation based on empirical measures from rivers in Washington reported by Sullivan et al. (1990) and included in the Forest Practice Regulations (Title 222 WAC). Values for maximum allowable view-to-the-sky (S) are provided for western Washington in Table G-8 and eastern Washington in Table G-9. Note that the elevation zones for the AA and A standard are provided in the tables. The calculations for baseline temperature described in this section are adjusted relative to class AA standards. Therefore, use view-to-the-sky from the class AA elevation categories for constructing the reference temperature map.

The maximum allowable view-to-the-sky is recorded in 10% increments on the working temperature map based on change in elevation. Boundaries between the potential and allowable view will not necessarily overlap.

Table G-8. Maximum allowable view-to-sky for non-glacial streams in western Washington.

	Elevation Zones (feet)	
Maximum Allowable View-to-the-sky (%)	**Class AA DOE standard = 16.0° C**	**Class A DOE standard = 18.0° C**
>90	>3600	>2320
90+	3280-3600	1960-2320
80+	2960-3280	1640-1960
70+	2400-2960	1320-1640
60+	1960-2400	1000-1320
50+	1640-1960	680-1000
40+	1160-1640	440-680
30+	680-1160	120-440
20+	<680	<120

Table G-9. Maximum allowable view-to-sky for non-glacial streams in eastern Washington.

	Elevation Zones (feet)	
Maximum Allowable View-to-the-sky (%)	**Class AA DOE standard = 16.0° C**	**Class A DOE standard = 18.0° C**
>90	>4450	>3900
90+	4200-4450	3700-3900
80+	4000-4200	3450-3700
70+	3800-4000	3250-3450
60+	3600-3800	3050-3250
50+	3350-3600	2850-3050
40+	3200-3350	2600-2850
30+	2900-3200	2450-2600
20+	2750-2900	2200-2450
10+	<2750	<2200

3. **Determination of Reference Temperature.** In this step the analyst estimates the potential water temperature under mature vegetation conditions. This is accomplished by relating the maximum allowable view-to-the-sky with estimates of potential view with mature vegetation. Temperature is determined by comparing the difference in minimum and allowable view-to-the-sky to Figure G-3 :

$$D = V - S \qquad (7)$$

where D is the difference in view factors (%), V is the potential view-to-the-sky (%) and S is the maximum allowable view-to-the-sky (%) determined from the temperature screen in the previous step. These values have been plotted on the working temperature vulnerability map in previous steps. Calculation of D should be performed for each stream reach where either the potential view or the maximum allowable view changes.

To estimate the reference temperature, compare the calculated difference D to Figure G-2. Read the temperature from the line corresponding to D. The scale is based on the temperature screen observed relationships between view and temperature reported in Sullivan et al. (1990). This method is a first approximation for annual maximum water temperature and is not expected to be able to precisely predict the location where water quality exceedance is likely to occur. Other modeling techniques for estimating annual maximum temperature may be substituted (provide rationale and description of methods).

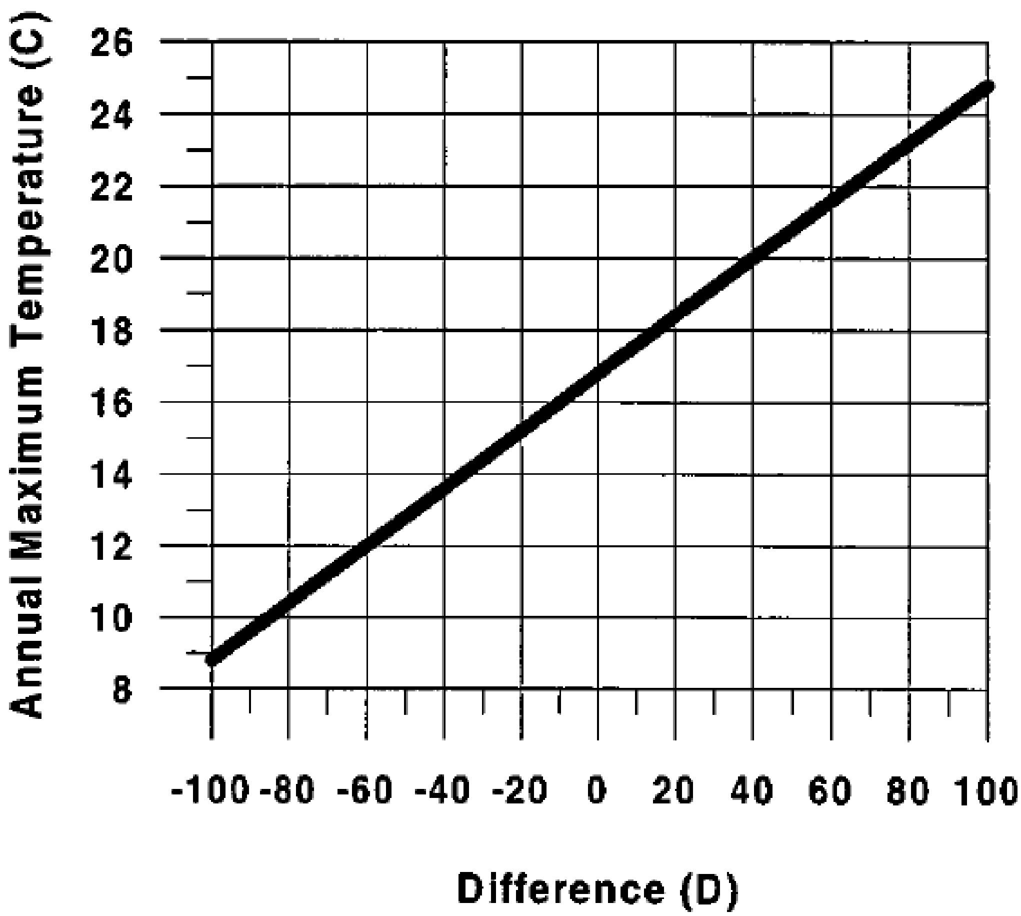


Figure G-2. Scale for comparing potential view to minimum view determined from the temperature screen to estimate reference temperature

Differences can range between -100 and +100 although most streams in Washington are likely to plot between -60 and +60 based on data from the TFW temperature study. This estimate suggests that maximum temperature may vary from 9-25 degrees C. in the portion of the basin affected by shade (Figure G-2). These values are close to the range or annual maximum temperature observed in Washington forested streams which typically fall between 10 and 25° C (Sullivan et al., 1990) as well the range of response to forest removal reported by Brown and Krygier (1970).

Using Figure G-3 and the values of potential and minimum view plotted on the working temperature map, the analyst creates a map that is a first approximation of potential water temperature in the WAU assuming mature forest (Figure G-3). This map may provide a useful comparison with current view-to-the-sky maps created by the riparian analyst from which a similar estimate of temperature at current view-to-the-sky can be calculated or if water temperature data is available.

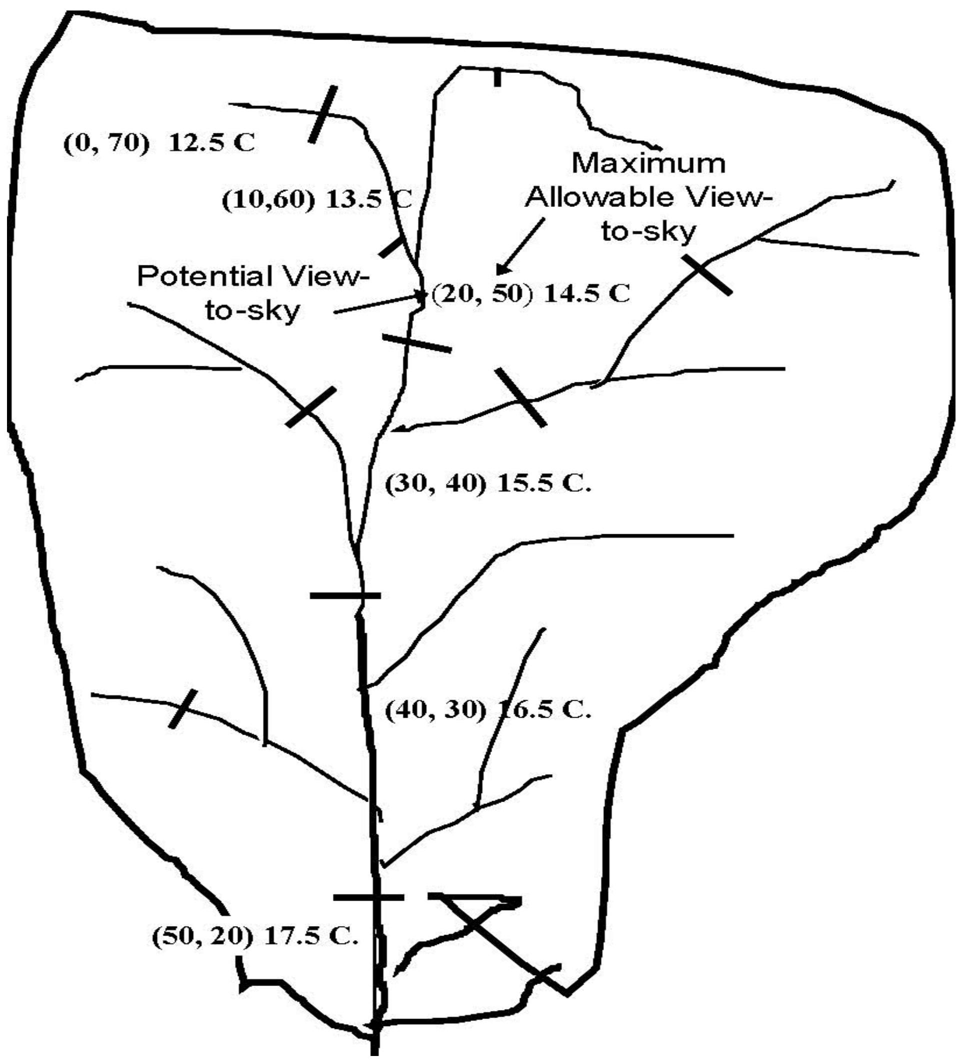


Figure G-3. Example of Reference Temperature Map (Map G-3)

4. **Determine Temperature Vulnerability**

The temperature of streams flowing during the warm summer months is vulnerable if shade removal is likely to result in exceedance of either the maximum or incremental water quality temperature criteria. All locations in the river system where the channel is wider than that associated with the potential view that resulted in D>+90 are probably very warm but are not vulnerable to removal of shade. All locations where D is less than +90 probably have some influence from streamside vegetation.

The vulnerability is determined from the scale provided in Figure G-4 using the view difference (D) and reference temperature determined in earlier steps. The diagram in Figure G-3 has been assigned vulnerability categories considering both the maximum and incremental criteria. These categories serve as guidance in selecting appropriate vulnerability based on likely response to shade removal. The analyst may further refine vulnerability based on specific location on the graph and local situations (provide justification for interpretation.) Effects of shade removal or addition and likely temperature response can be evaluated by moving up or down along the central line.

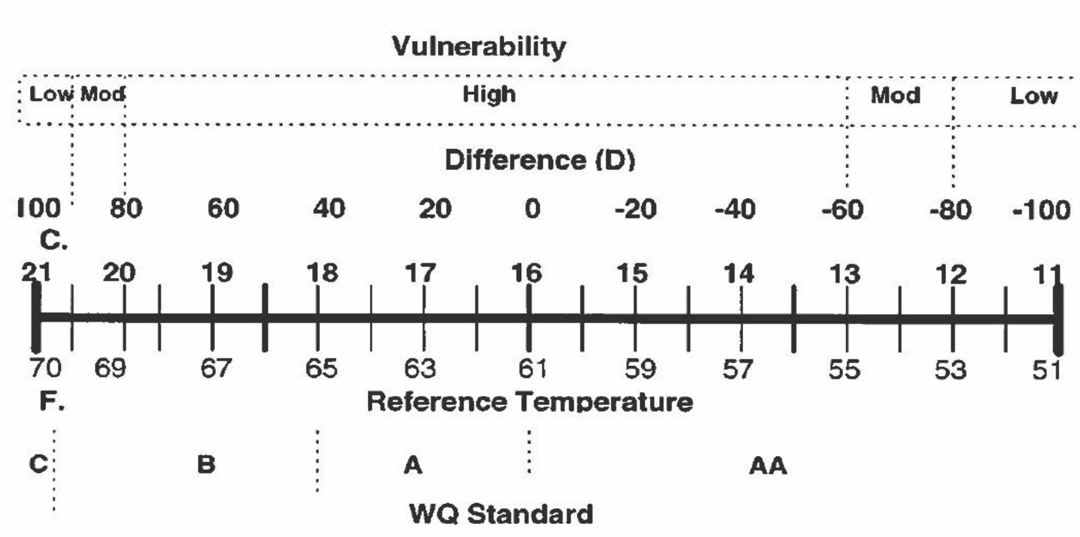


Figure G-4. Vulnerability determination is based on the scale at the top of the figure. Also marked at the temperature ranges associated with the DOE water type classification.

5. **Complete map products (Maps G-3 and G-4)**

The analyst shall begin to prepare a Water Temperature Vulnerability Map (Map G-4) which should include: potential view-to-the-sky, maximum allowable view-to-the-sky, vulnerability (high, moderate, low), achievable temperature based on the difference between potential and minimum required view, water quality classification (AA, A, B, C). Include locations where temperature has been monitored, if any. Any temperature sensitive public works (e.g., fish facilities) should also be located on this map. An example of the map product G-4 is provided in Figure G-5. Temperature vulnerability assessment for other waterbodies will be added to this map. Determinations should be recorded on the Stream Temperature Vulnerability Worksheet-Form G-3).

The potential temperature map can also be used by the analyst to evaluate the relationship between water quality standards currently assigned by the DOE by stream classification relative to the natural temperature patterns expected in the watershed based on vegetation and topographic analysis. Given that waterbodies were classified considering a variety of water quality conditions including fecal coliform, dissolved oxygen, temperature, and pH, there may be discrepancies between achievable and classified temperature.

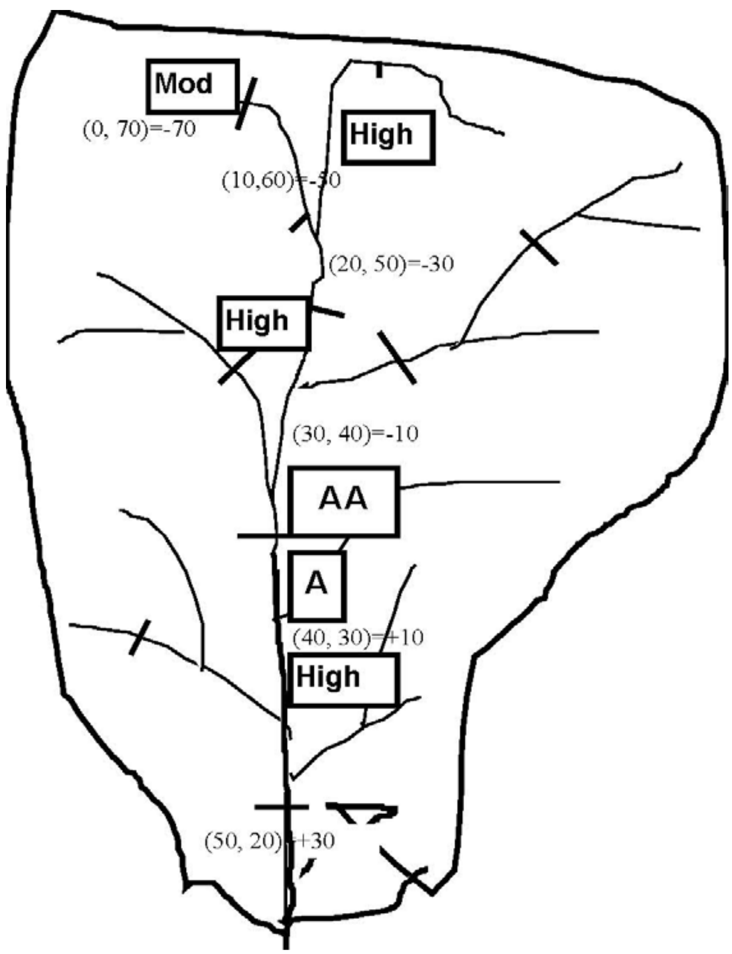


Figure G-5. Example of Temperature Vulnerability Map G-4.

Form G-3. Format for Stream Temperature Vulnerability Worksheet

Distance (mi.) or segment #	Channel Width (ft.)	Wetted Channel Depth (ft.)	Potential Sky-View (%)	Maximum Allowable Sky-View (%)	Current View-to-the-sky (%)	Potential Difference (%)	Current Difference (%)	Estimated Reference Temp (^oC)	Estimated Current Temp (^oC)	Measured Temp (C) if known	W.Q. Standard	Vulnerability Call

Temperature Vulnerability of Other Waterbodies

Water temperature in waterbodies other than streams is determined by the same heat transfer processes as streams. Lake size (and probably elevation) can be used as an effective screen for identifying where water temperature vulnerability to forest practices exists. The same geometric hypotheses described in detail in previous sections also apply to lakes and wetlands. However, these waterbodies were assumed to be round and the appropriate geometric calculations are based on spheres rather than lunes. The results of these calculations are provided in Figure G-6. Calculations assume 150-ft effective tree height and that the waterbody is round.

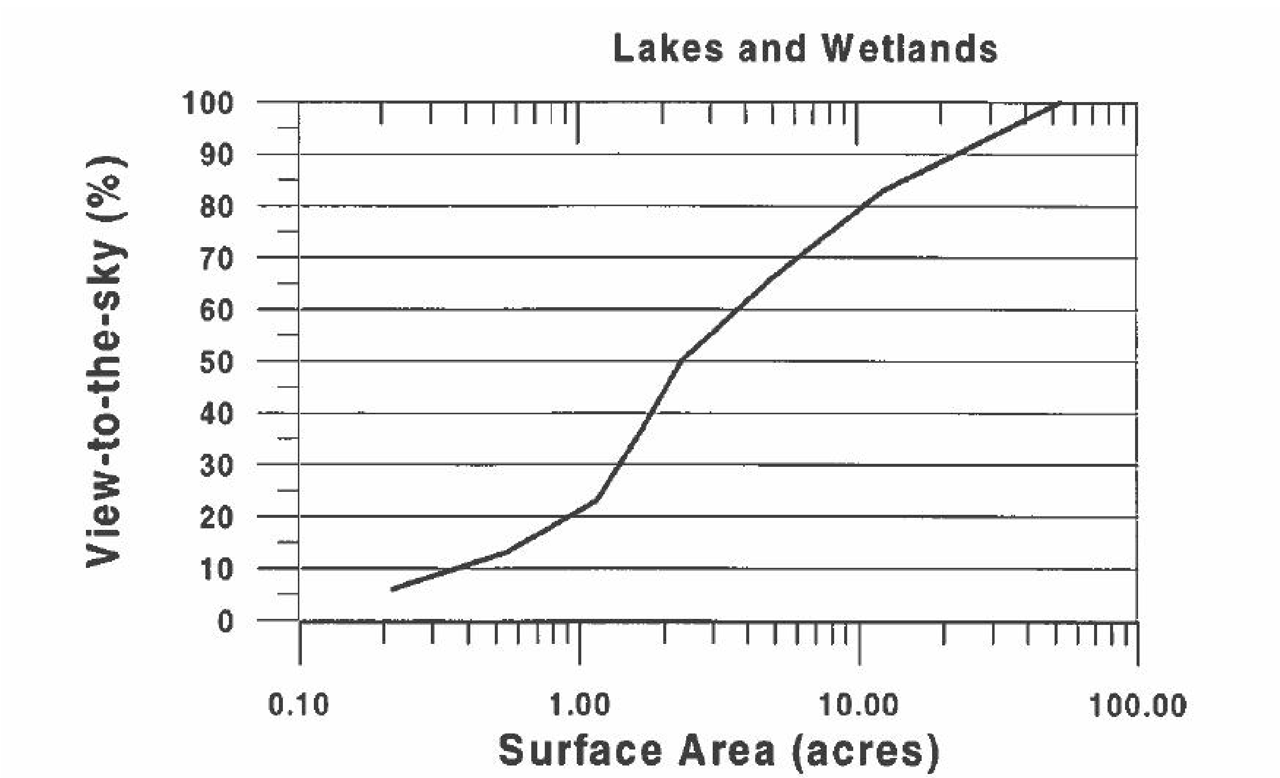


Figure G-6. Estimated view-to-the-sky as a function of surface area of waterbodies other than streams.

Standard Assessment: Assuming potential tree height, waterbodies less than 3 acres have high vulnerability to temperature effects from forest practices assuming waterbodies are close to round in shape. Waterbodies between 3 and 10 acre have moderate vulnerability. Larger waterbodies have low vulnerability.

Level 2 Assessment: Use native vegetation characteristics and waterbody dimensions to determine whether potential view-to-the-sky is less than 50% (moderate vulnerability) or less than 80% (low vulnerability.) The analyst may chose the appropriate geometric shape for the waterbody for use in calculating the hemisphere area blocked by vegetation. If the waterbody is relatively linear, the same calculations based on the lune shape where width is averaged for the waterbody may be used. If water temperature information is available for the waterbody, the analyst may wish to attempt to use the same method for determining vulnerability of the waterbody in a manner similar to that used for determining the vulnerability of the streams.

For wetlands whose water surface is below the ground surface but that discharge groundwater to streams, there may still be vulnerability to shade removal if the water table is near the surface during the months of July and August. Although soil and gravel is a relatively poor conductor of heat, the surface layers will experience diurnal fluctuation in response to solar radiation just as the water will (Chen at al.1995). Information on heat flux in streambed gravels was used to derive criteria in Table G-10 (Ringler and Hall 1975, Comer and Grenney 1977, and Sinokrot and Stefan, 1993). Use the following vulnerability determination for riverine connected wetlands with shallow water tables:

Table G-10. Vulnerability of Wetlands with Shallow Water Tables

Vulnerability	Criteria
High	Water table <8" (20cm) below the ground surface (July-August)
Moderate	Water table 8-15" (21-38 cm) below the ground surface (July-August)
Low	Water table >15" (38 cm) below the ground surface (July-August)

Water Supplies

Public works (water supplies and hatcheries in particular) have need for cool water and are likely to be vulnerable to temperature increases. Usually water suppliers will have information on temperature and a clear understanding of the temperature vulnerability. The water quality analyst will consult with the public works analyst to determine the temperature vulnerability of water supplies occurring in the watershed. It will be useful during Synthesis for the water quality analyst to determine the zone upstream of waterbodies that potentially affect water temperature. This distance will vary with stream size: the smaller the stream, the more local the zone of influence. For smaller streams (type 3), the zone upstream where shade removal can influence temperature at downstream locations is up to 2000-ft (600m). For type 1 and 2 streams the distance considered should be 5000 ft because of faster travel time and deeper water which responds more slowly to environmental conditions (Sullivan and Adams, 1990). For type 4 streams, the influence is not likely to extend more than 1000 feet. However, local stream conditions may vary the distance estimates depending on water depth, groundwater inputs, and velocity. Distances may be longer or shorter.

Level 2 Assessment

Estimates of water temperature based on Level I assessment rely primarily on generalized relationships between watershed, channel and vegetation characteristics. Although the temperature prediction model is expected to be an approximation of potential temperature, estimation may be improved by better quantification of variables included in the Level I method. For example, measurement of stream width and depth to determine the hydraulic geometry for the WAU is preferable to estimates based on data from other watersheds or regions. The Level I method uses width to calculate view-to-the-sky from assumed vegetation characteristics (this module) and current vegetation (riparian module) to estimate potential and current temperature. Variation in width due to natural or man-caused disturbance can be accounted for in estimation of temperature by altering view-to-the-sky appropriately. In addition, vegetation calculations assume dense (closed) stands of fully mature native vegetation. View factors may be modified with the use of an opacity factor to improve representation of potential or existing stands with species or density characteristics different than the assumed value. Significant blocking topography can be accounted for by increasing tree height according to hillslope gradient.

The simple temperature prediction model included in Level I assessment only accounts for view-to-the-sky, channel width, and elevation in estimating temperature. Although some provision for local variability in these factors can be achieved, other variables that are known to influence water temperature are not considered in the Level I method and these can be locally important in controlling temperature and may be affected in combination by changes in various input factors. If more precise definition of temperature is desired for vulnerability or hazard determination or cumulative effects analysis, the analyst should use a computer-based temperature model such as TEMPEST (Sullivan et al., 1990) where site factors can be more precisely accounted for. Basin models are not recommended at this time since they tend to predict poorly and have significant data requirements.

Finishing Temperature Assessment

1. ***Combine information about streams and lakes on the Working Temperature Vulnerability Assessment Map, (the existing shade will be added to the map by the riparian analyst).***

2. ***Produce Reference Temperature Map (G-3).***

3. ***Produce final stream Temperature Vulnerability Map (G-4).***

4. ***Notify riparian analyst if there are any special shade assessment needs to be completed prior to the synthesis phase of watershed analysis.***

5. ***Coordinate with channel and public works analysis to determine if there are any special assessment needs.***

Sediment Accretion in Wetlands

Scientific Background

Forest management can have both short and long-term effects on the production and routing of sediment to waterbodies. Road building, road use, yarding and removal of vegetation from hillslopes can affect erosion processes, including landslides and other rapid mass wasting processes, slumps and earth-flows, surface erosion, and channel bank erosion. The relative extent to which these processes account for forest practice-related sediment impacts to water quality varies among the different forested regions of Washington and locally within regions, depending on topographic, geologic and climatic conditions.

State water quality standards (Chapter 173-201A WAC) include both numeric and narrative (i.e. descriptive) criteria that apply to sediment-related impacts. Numeric criteria for turbidity prohibit an increase of 5 NTU, or 10% over background levels, whichever is greater. No numeric criteria exist for other characteristics of sediment.

The effects of coarse sedimentation are evaluated in the stream channel and fish habitat modules.

The purpose of this assessment is to determine whether forest practices are likely to increase the rate of both fine and coarse sediment accretion in wetlands, thereby impairing wetland functions. Primary assumptions include:

- the rate at which sediment is delivered and stored will influence the physical and biological properties of a wetland
- excessive accumulation of sediment in wetlands is detrimental, affecting resource characteristics and reducing valuable wetland functions such as water storage and discharge, energy dissipation, nutrient cycling, as well as habitat suitability
- the vulnerability of a wetland to sediment and concomittant reduction of functional values can be assessed by evaluating the likelihood that sediment will be delivered and stored by the wetland in excess of natural levels

- the chance that a wetland will receive sediments is dependent on topography, the degree of connection to the stream system that would transport sediments, soil type and extent of disturbance
- the vulnerability of a wetland increases as a wetland's effectiveness at trapping sediments increases because more sediments will be retained to affect existing functions

For the purposes of this assessment, it is assumed that sediment accretion beyond natural background rates may negatively affect existing wetland functions, and that wetlands are considered vulnerable to forest practices if management activities will significantly alter the amount of sediment routed to, and retained by, the wetland.

The ability of wetlands to store sediment varies significantly. There are some general properties that may be applied to all wetlands with respect to their ability to trap sediments. These properties are: water velocity, residence time, available sediment, and sediment base level as follows:

The *velocity* of water must be fast enough to transport sediment to the wetland and then slow enough through the wetland to allow the sediment to be deposited there.

The residence time of the water is the length of time it remains in the wetland. Generally, long residence times are necessary to allow the clay faction to settle out of the water column. As the residence time increases, so does the proportion of the sediment load that will be deposited in the wetland.

Available sediment refers to the amount of sediment that is transported to the wetland. If more sediment is delivered to the wetland than can be transported away, it will accumulate.

The *sediment base level* is the level above which there can be no deposition. As the level of the sediment-water interface approaches base level, vertical accretion rates diminish and deposits tend to accumulate horizontally where possible.

Vulnerability Assessment

The vulnerability of a wetland to sediment accumulation and associated reduction of functional values will be assessed by evaluating the likelihood that sediment will be delivered and stored by the wetland. Establishing the vulnerability of the wetland to sediment accretion requires an assessment of characteristics that determine the probability that sediments will reach the wetland and the effectiveness with which they are trapped by the wetlands in the WAU.

Probability assesses the chance that a wetland will receive sediment carried by streams and rivers from upstream locations in the watershed. The chance that a wetland will receive sediments from stream sources is dependent on the degree of connection to the stream or overland flow systems that would carry the sediments. The probability, and thus the vulnerability, increases as the connections between the wetland and stream increase because the wetland is "accessible" to sediment loads that are higher than "normal." Probability is assessed based on a wetland's position in the landscape as determined by its HGM subclass, site topography and hydrology.

Effectiveness assesses the capability of a wetland to store sediment. Two variables are important in assessing a wetland's effectiveness at trapping sediments: velocity of water through the wetland and the roughness of the surface. Two indicators of velocity are to be used: gradient and type of outlet. The indicator for roughness will be the extent of vegetation cover in the wetland.

Generally, the higher the probability and effectiveness, the higher the vulnerability to sediment filling. Table G-11 provides the decision matrix for assigning vulnerability ratings based on probability and effectiveness.

Table G-11. Vulnerability determination based on rating of probability and effectiveness

	EFFECTIVENESS		
PROBABILITY	**High**	**Moderate**	**Low**
High	High	High	moderate
Moderate	High	moderate	low
Low	moderate	Low	low

Level 1 Assessment

The information needed by the analyst to do a Level 1 assessment is the inventory base map of wetlands in the WAU and their HGM Subclass. At this point, the analyst establishes a general rating for the HGM Subclasses, relying upon remote sensing with very limited field verification. This first-level assessment is based on the probability of sediments reaching a wetland, as determined by its hydrogeomorphic classification, and ratings for effectiveness based on presumptions regarding the HGM classification. The following rationale is used for rating probability and effectiveness:

Riverine Flow-Through -Probability that sediments will reach the wetlands is High because the surface water connection to the stream carrying sediment will facilitate transport to the wetland. This is especially important during overbank flooding. The default for effectiveness is Moderate because the characteristics of effectiveness have not been determined.

Riverine Impounding -Probability that sediments will reach the wetland is High because the surface water connection to the stream carrying sediment will facilitate transport to the wetland. The default for effectiveness is High because sediment deposition occurs where water velocity rapidly slows as a result of constriction or increased cross-sectional area.

Depressional Flow-Through -The probability that sediments will reach the wetland is Low because sediments may only reach the wetland from surface runoff in the surrounding watershed. The rating is low because it is assumed that most of the sediments will be retained before they reach the wetland. The rating for effectiveness is Moderate because the velocity of water in the wetland is expected to be low regardless of other conditions. By definition, depressional wetlands are found in topographic depressions which by their geomorphic setting will collect and hold water. Depressional wetlands are effective traps for sediment because they have constricted outlets and pond (i.e. slow down) water.

Depressional Closed -The probability that sediments will reach the wetland is Low because sediments may only reach the wetland from surface runoff in the surrounding watershed. The rating is low because it is assumed that most of the sediments will be retained before they reach the wetland. The rating for effectiveness is High. Sediment retention in wetlands without outlets approaches 100 percent because flow is totally stopped.

Slope Connected -The probability that sediments will reach the wetland is Low because sediments will only reach the wetland by surface erosion from overland flows. These overland surface (sheet) flows tend to be low in volume because the catchment areas tend to be small. Most of the water in slope wetlands comes from groundwater seeps. The default for effectiveness is also Low because connected slope wetlands are usually found on steeper gradients where water velocities are higher. The presence of an outflow (connection) will also improve the transport of sediments out of the wetland, minimizing the effectiveness of the wetland at trapping sediments.

Slope Unconnected -The probability that sediments will reach the wetland is Low because sediments will only reach the wetland by surface erosion from overland flows. These overland surface (sheet) flows tend to be low in volume because the catchment areas tend to be small. Most of the water in slope wetlands comes from groundwater seeps. The default for effectiveness is Moderate because, although slope wetlands are usually found on steeper gradients where water velocities are higher, the absence of an outflow (connection), will improve sediment trapping in the wetland if there is any vegetation present.

Lacustrine Fringe -The probability that sediments will reach the wetland is Low because sediments in streams and rivers will be deposited in the lake before they reach the wetland. There is little chance that sediments will reach a lakeshore wetland. The only case where there is a significant chance of sediments reaching a wetland is if the sediment source is adjacent to the wetland. The default for effectiveness is Moderate because sediments in lakeshore wetlands are subject to resuspension by storms. Although lake-shore wetlands tend to have a dense cover of vegetation, water velocities may be significant during storms, and these may resuspend and disperse any new sediment deposits.

Tidal Saltwater Fringe -The probability that sediments will reach estuarine fringe wetlands is High because these wetlands are directly connected to the rivers and coastal currents carrying the sediments. The tidal inundation of wetlands occurs twice daily, thus increasing the chance that sediment bearing waters will reach the wetland. The default for effectiveness is Moderate because the estuarine fringes in saltwater tend to be more exposed. Storms in these location will tend to resuspend sediments, thus decreasing the effectiveness of the sediment trapping that occurs in the wetland.

Tidal Freshwater Fringe -The probability that sediments will reach fresh-water fringe wetlands is High because these wetlands are directly connected to rivers that transport sediments. The tidal inundation of wetlands occurs twice daily, thus increasing the chance that sediment bearing waters will reach the wetland. The default for effectiveness is also High because tidal freshwater fringe wetlands tend to be heavily vegetated and located in areas with very low water velocities. Much of the water fluctuation is vertical rather than horizontal.

Table G-12 summarizes the ratings for probability and effectiveness that are to be used in establishing level 1 vulnerability calls for HGM subclasses.

Table G-12. Level 1 Assessment: Ratings for Probability and Effectiveness of Sediment Retention

Wetland Hydrogeomorphic Subclass	Probability	Effectiveness
Riverine Flow-through	High	Moderate
Riverine Impounding	High	High
Depressional Flow-through	Low	Moderate
Depressional Closed	Low	High
Slope Connected	Low	Low
Slope Unconnected	Low	Moderate
Lacustrine Fringe	Low	Moderate
Tidal Saltwater Fringe	High	Moderate
Tidal Freshwater Fringe	High	High

Table G-13 displays the predicted vulnerability to sediments of wetlands in different hydrogeomorphic Subclasses for a Level 1 assessment based on Table G-12. The effectiveness of certain individual wetlands in trapping sediments may lead to calls other than those predicted by Table G-12. If a vulnerability call other than that predicted is made, the analysts should document the justification for this call.

Table G-13. Level 1 Assessment: Vulnerability Rating for Wetlands in Different Hydrogeomorphic Subclasses

High	Moderate	Low
Riverine Flow-through	Depressional Closed	Depressional Flow-through
Riverine Impounding		Slope Connected
Tidal Saltwater Fringe		Slope Unconnected
Tidal Freshwater Fringe		Lacustrine Fringe

If hydraulic connectivity of a wetland is affected by a road, the analyst will adjust the HGM class and vulnerability according to the situation.

Level 2 Assessment

For a Level 2 assessment, the general probability and effectiveness ratings used in the Level 1 assessment may be directly evaluated by the analyst for individual wetlands based on site specific characteristics.

For example, increased residence time generally results in more effective sediment removal. Water velocity decreases, and thus retention time increases, with decreasing slope. Therefore, riverine wetlands associated with lower stream gradients are more likely to perform sediment retention than those with steep gradients (Hupp, 1993).

To better understand stream power (transport capacity) and the routing capabilities of riverine wetlands present in the watershed, fieldwork with the stream channel analyst is recommended.

In addition, the effectiveness of individual wetlands in storing sediments may influence vulnerability calls derived from the Level 1 assessment.

Wetlands with constricted outlets are more likely to retain sediments than those with unconstricted outlets (Adamus, 1993). In addition to physical controls on wetlands outlets, beavers are also known to exert a widespread influence on the structure and dynamics of riverine valley connected wetlands (Naiman et al. 1988). A beaver dam may force channel flow into adjacent wetlands during floods. Studies of beaver-influenced streams in Quebec, Canada, recorded up to 6500 m^3 of sediment stored per dam (Naiman et al., 1986).

Sediment deposition is also greatly enhanced by wetland vegetation, which creates frictional resistance to water movement (increasing residence time) and limits resuspension by wind mixing. Wetlands with mostly open water are less likely to retain sediments than those that are extensively vegetated. Wetlands with dense vegetation (low vegetation-open water interspersion) are more likely to retain sediments that those with sparse vegetation. Table G-14 provides a decision matrix for rating the effectiveness of sediment trapping in riverine wetlands (based on Adamus, 1993).

Table G-14. Rating the Effectiveness of Sediment Trapping

	Roughness		
	Vegetation Cover		
Water Velocity & Constriction	**>66%**	**33-66%**	**0-33%**
low gradient <1% and constricted outlet	High	High	High
low gradient and outlet >1/3 width	High	High	Moderate
moderate gradient 1-5% and constricted outlet	High	Moderate	Moderate
moderate gradient and outlet >1/3 width	Moderate	Low	Low
high gradient >5% and constricted outlet	Moderate	Low	Low
high gradient and outlet >1.3 width	Low	Low	Low

Record the vulnerability on the wetlands assessment worksheet (Form G-1). Vulnerability of wetlands to sedimentation should be identified on Map G-5.

Nutrient Assessment

Scientific Background

Nitrogen (N) and phosphorus (P) are two nutrients that stimulate plant growth. The balance between available nitrogen and phosphorus in solution in the water column determine the primary productivity of waterbodies. Forested mountain streams of the Pacific Northwest are generally very low in both nitrogen and phosphorus, and primary productivity is often naturally low.

Forest streams of the Northwest commonly have very low background concentrations of N compounds, often less than 0.01 mg/L (MacDonald et al., 1991). Nitrogen export varies significantly during the year, reaching annual maximums in autumn with leaf fall. The presence of nitrogen-fixing plants in the riparian forest such as alder can significantly increase levels of dissolved nitrogen (NO_3) in stream runoff (Binkley and Brown, 1993).

Phosphorus is very tightly conserved within forest ecosystems (Salminen and Beschta, 1991). Mass balance calculations of phosphorus from forested watersheds indicate that substantial amounts of phosphorus are adsorbed to and carried by sediment. Fine-grained sediments are most important in phosphorus sorption due to their high proportion of surface area to volume (Meyer, 1979; Holton et al., 1988). The net effect of phosphorus sorption by stream sediments is to convert dissolved phosphorus to fine particulate phosphorus which is suspended during periods of high, turbulent flows. The majority of this phosphorus is contained within the mineral lattice of the sediment and is therefore unavailable for solution or biological uptake. Furthermore, sediment transport primarily occurs in the winter months, having a reduced significance for summertime phosphorus concentrations. However, the dynamics of phosphorus and sediment in stream systems of the Northwest have received relatively little attention (Salminen and Beschta, 1991).

In a review of 40 studies which collected phosphorus data, Salminen and Beschta (1991) report that background concentrations of total phosphorus for streams draining forested watersheds in the Northwest averaged 0.034 mg/L (range 0.005 to 0.090 mg/L) and mean concentrations of orthophosphorus averaged 0.012 mg/L (0.003 to 0.026 mg/L). The range of nitrogen and phosphorous concentrations is shown in Figure G-7.

Generally, the greater the concentration of growth nutrients, the greater the aquatic primary production. However, a critical atomic ratio of 16:1 nitrogen to phosphorus (approximately 7:1 mass ratio) can be used to estimate the nutrient limiting aquatic plant growth. If the ratio is less than 16:1 then nitrogen is considered the limiting nutrient. If the ratio is greater than 16:1, then P is considered limiting (MacDonald et al., 1991). The 16:1 line is shown on Figure

G-7. This relationship implies that if a waterbody is nitrogen-limited, then an increase in phosphorus will not increase primary production. Similarly, if the waterbody is phosphorus-limited, an increase in nitrogen will not affect it. In either case, the limiting nutrient deficit must be eliminated before aquatic production can increase.

The typical range of nitrogen and phosphorous concentrations observed in Pacific Northwest forest streams is shown on Figure G-7. It is evident that most are likely to be both low in primary productivity and nitrogen-limited.

Cutting of forests has been shown to increase NO_3 as much as 3-5 times for a relatively short-lived period following harvest (3-5 years) (Fredricksen et al., 1975; Sollins and McCorison, 1981), although severe burning has resulted in changes as much as 10 times higher. Numerous studies have shown that the absolute amount of nitrogen which enters a stream is still relatively small and that the risks of nitrate pollution from forest practices are low (Bisson et al., 1992; Fredricksen et al., 1975). Indeed, small additions of N or P to aquatic systems of the Northwest can often have beneficial effects enhancing primary and secondary productivity (Bisson et al., 1992; MacDonald et al., 1991). Fertilization is a possible source of short-term effects on nitrogen.

Soil erosion and input of organic matter are the primary mechanisms for increasing P levels in aquatic systems (MacDonald, 1991). Literature reviews concluded that forest practices in the Pacific Northwest are unlikely to substantially increase phosphate concentrations in aquatic systems (MacDonald et al., 1991; Salminen and Beschta, 1991; Wolf, 1992). Phosphorus is rarely applied as fertilizer in the Northwest because it is seldom considered to be limiting to forest growth (Gessel et al., 1979). The low nitrogen-phosphorus ratio in most forest stream systems suggests that changes in phosphorus loading with sedimentation are unlikely to have adverse effects on the aquatic productivity.

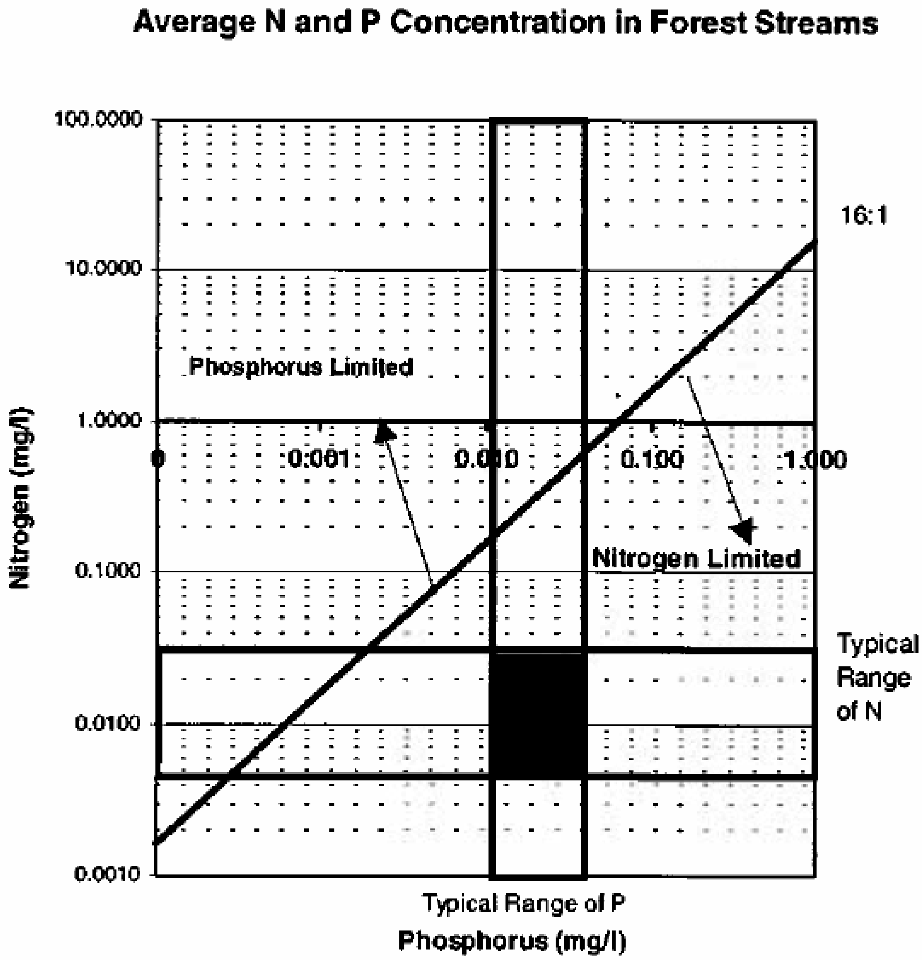


Figure G-7. Typical range of nitrogen and phosphorus concentrations among forest streams of the Pacific Northwest

Receiving waterbodies such as lakes and reservoirs serve as nutrient "sinks" and may accumulate nutrients. Often lakes have higher primary productivity, and may be more sensitive to nutrient loading from natural processes and forest practices than streams draining to them. Eutrophication is a condition in which the rate of primary productivity creates high levels of aquatic plant biomass leading to increases of aquatic fauna (secondary productivity) and changes in dissolved oxygen and pH. Phosphorus retention by lakes is dependent on lake volume, shape, and phosphorus inputs (Larsen and Mercier, 1976) and detention times. Birch et al., (1980) concluded that phosphorus increases from land use in watersheds draining to Lake Washington increased primary productivity of the lake. Lakes act as phosphorus traps, causing downstream decreases in expected phosphorus loads (Dillon and Kirchner, 1975).

It is common to classify lakes by trophic status encompassing a range of productivity from very low (oligotrophic) to very high (hypereutrophic) (Table

G-15). Some lakes are particularly vulnerable to elevated inputs of nutrients which can eutrophy a mesotrophic lake or exacerbate an already eutrophied lake condition. Excessive aquatic plant growth and nuisance algae can subsequently create diurnal fluctuations in dissolved oxygen and pH, and deplete dissolved oxygen when plants die. These conditions can lead to problems with fish and the aesthetics, odor, and taste of water. Lake basin morphology is an important factor controlling nutrient flux and trophic status. Wide, shallow, and warm lakes with long detention times favor plant growth (G. Ice, NCASI, 1994, pers. Comm.).

Table G-15. General Trophic Classification of Lakes and Reservoirs in Relation to Phosphorus, Nitrogen, Secchi Transparency, and Chlorophyll *a* (annual means and ranges)

Table modified from Vollenweider (1979).

	Trophic Levels			
Parameter	**Oligotrophic**	**Mesotrophic**	**Eutrophic**	**Hypereutrophic**
Total Phosphorus Range (mg m -3)	8.0 (3.0-17.7)	26.7 (10.9-95.6)	84.4 (16-386)	-- (750-1200)
Total Nitrogen Range (mg m -3)	661 (307-1630)	753 (361-1387)	1875 (393-6100)	-- --
Secchi Transparency Depth (m)	9.9 (5.4-28.3)	4.2 (1.5-8.1)	2.45 (0.8-7.0)	-- (0.4-0.5)
Chlorophyll *a* (mg m -3)	1.7 (0.3-4.5) <4ug/L*	4.7 (3-11) 4-10ug/L*	14.3 (3-78) >10ug/L*	-- --

*data from Welch (1980)

Oligotrophic = low nutrients and relatively stable dissolved oxygen concentrations (near saturation), favoring aquatic fauna over flora.

Mesotrophic = intermediate between the two.

Eutrophic = high nutrients and fluctuating dissolved oxygen concentrations with period of relatively low concentrations, favoring aquatic flora over fauna.

No explicit numeric criterion currently exists for nutrients in the state water quality standards (although these are being developed in the current triennial review of the water quality standards). Nevertheless, the vulnerability of waterbodies to increased nutrient loading resulting from forest practices is assessed relative to the propensity for nuisance aquatic growth. The vulnerability criterion used in this assessment is that the relative contribution of nutrients from forest practices shall not be routed to eutrophic lakes so as to prevent recovery or worsen the growth of vegetation; or the relative contribution of nutrients from forest practices shall not be routed to a mesotrophic lake which could elevate the trophic status to eutrophic. Streams are not considered vulnerable to changes in nutrient loading unless a receiving waterbody such as a lake or estuary is vulnerable. Wetlands, by definition, are naturally high in organic matter and nutrients, and small changes from forest practices do not harm essential wetland processes. Therefore, wetlands are not considered vulnerable to changes in nutrient loading with forest practices and are not assessed.

Nutrient Assessment Procedure

The first step of the assessment is to determine the trophic status of lakes and estuaries. If eutrophication exists, the limiting nutrient is identified and contributing streams are assessed for vulnerability to change in that parameter. If no vulnerability to lakes or estuaries is identified, then streams are not further assessed.

Lake Nutrient Vulnerability

The first step of the assessment is to determine the primary productivity status of lakes, and if present, estuaries and nearshore marine waters. The analyst determines the trophic status of lakes by considering their ability to retain nutrients, and their current condition.

Trophic Status. The water quality characteristics, productivity status, and land use effects of many lakes in the state have been studied by the DOE. The analyst should seek such information if it exists. The DOE 305(b) list is a source of information from some states. Scientific studies that support DOE listings may be available. Reports may provide a determination of productivity status, or data that can be compared to Table G-15 to establish whether the lake is oligotrophic, mesotrophic, or eutrophic.

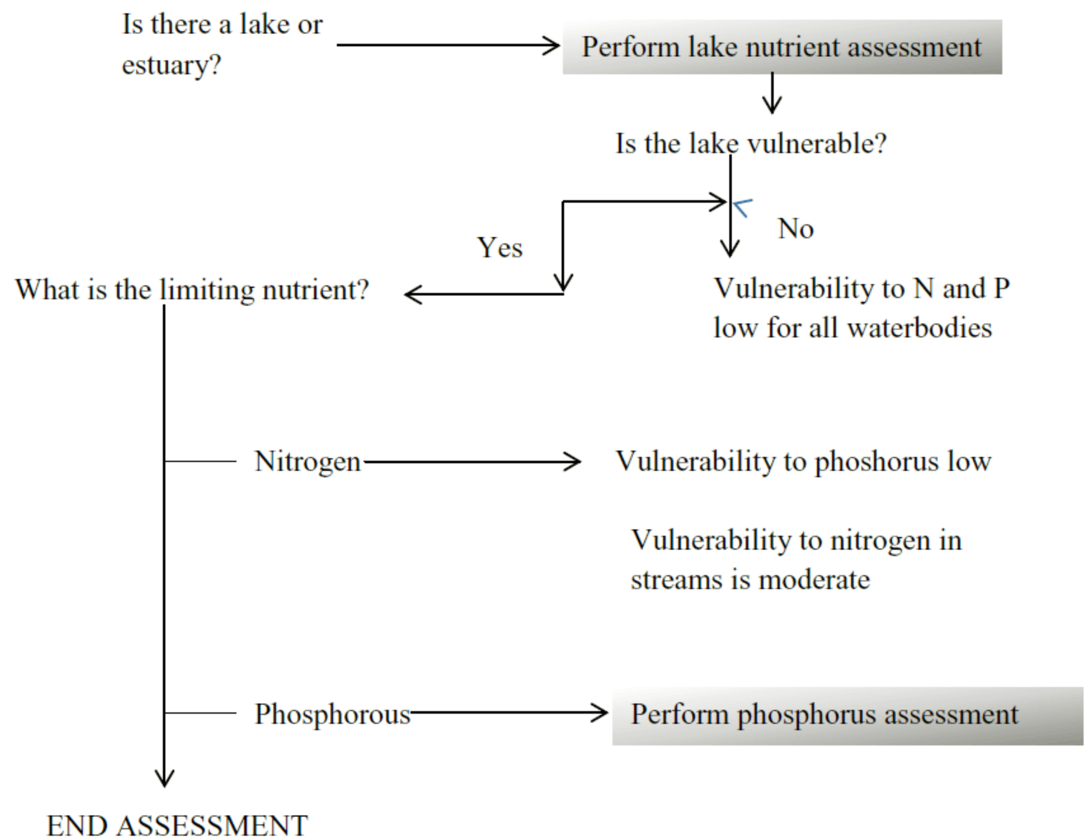


Figure G-8. Nutrient assessment flow chart.

In the absence of data, the analyst can estimate the productivity status using observation of aquatic plants within the lake. Generally, aerial photographs available via DNR will be of low reliability for observing submerged aquatic plants or algae blooms. Usually aquatic plants establish in the shallower portions of the lake. As deposition of sediment and organic matter from dying vegetation shallows the lake along the edges, the plant growth grows increasingly towards the deeper areas. The area of vegetation growth relative to surface area of the lake suggests the productivity status. A lake with little aquatic vegetation or algae along the edges is likely oligotrophic. Eutrophic lakes typically exhibit relatively high plant biomass and are often dominated by very few plant species. Recent summer aerial photographs can be used to evaluate whether portions of the lake are occupied by aquatic vegetation or algal blooms.

Vulnerability of lakes to nutrients depends on lake size relative to nutrient loading and detention time. Mean depth is regarded as the best single index of detention time and shows a general inverse correlation to productivity at all trophic levels among large lakes (Neumann, 1959). Therefore, the analyst can assess vulnerability using the mean depth and trophic state Table G-16.

Table G-16. Vulnerability Call for Adverse Levels of Limiting Nutrients in Lakes.

Trophic Status	Mean Lake Depth		
	Deep (>50 feet)	**Medium (20-50 feet)**	**Shallow (<20 feet)**
Oligotrophic	Low	Low	High
Mesotrophic	Moderate	Moderate	High
Eutrophic	Moderate	High	High

If the lake receives either a moderate or high vulnerability determination, the analyst determines the likely limiting nutrient.

Limiting Nutrient. We recognize that because of the complex functional interactions in lake ecosystems, the limiting factor concept needs to be applied with caution (Stumm and Morgan 1981). The evolution of appropriate nutrient ratios in fresh waters involves a complex series of interrelated biological, geological, and physical processes, including photosynthesis, the selection of species of algae that can fix atmospheric nitrogen, alkalinity, nutrient supplies and concentrations, rates of water renewal, and turbulence. It is beyond the scope of Watershed Analysis to adequately characterize lake or estuary nutrient dynamics and trophic response to nutrient loading. However, the concept applies to be consistent with the simplifications necessary to determine the likely response of lakes to forest practices.

We use the nitrogen and phosphorus ratio to establish whether nitrogen or phosphorous may be limiting phytoplankton. Based on steady state stoichiometry (Stumm and Morgan 1981). Lakes with N:P ratio greater than 16 are phosphorous limited, and less than 16 are nitrogen limited. If nutrient concentration data is available, the ratio can be calculated directly and should be used. In the absence of lake specific nutrient data, the analyst can assume that waterbodies in volcanic geology are nitrogen limited, and waterbodies in glacial and granitic geologies are phosphorus limited (Gregory et al., 1987; Thut and Haydu, 1971).

Stream Nutrient Vulnerability Assessment

The analyst will then evaluate the vulnerability of streams draining to the lake to determine whether forest practices are likely to cause adverse changes in nutrient loading.

Nitrogen

In nitrogen limited systems, concentrations of less than 0.3 mg/L nitrate-N will prevent eutrophication (Brooks et al., 1991; Cline 1973). Vulnerability is provided in Table G-17.

Table G-17. Vulnerability of water bodies to nitrate-N

Average Annual Concentration (mg/L)	Vulnerability
<.050	Low
0.05-0.10	Medium
0.1-0.3	High

Since the average nitrate-N concentration of forest streams is generally far below this level, the assumed vulnerability of streams is low and no assessment is required. There is no recommended method for estimating the concentration of nitrate-N in forest streams. If the analyst can determine the nitrate concentration, the vulnerability determination should reflect the above criteria.

Waterbodies determined to have moderate or high vulnerability to nitrate should be identified on Map G-6 (nutrient vulnerability map).

Phosphorus

To prevent eutrophication, the annual yield as indexed by the average annual concentration of total phosphates should not exceed 0.10 mg/L in streams (MacKenthun, 1973) or 0.05 mg/L in streams flowing to lakes and reservoirs (MacDonald et al., 1991).

The vulnerability of lakes to phosphorus from forest practices is driven by the mechanism of phosphorus bound to sediment. Vulnerability to phosphorus is determined based on sediment yield. The analyst should consult with the surface erosion analyst who develops an estimate of background sediment yield for sub-basins within the WAU.

Phosphorus yield has been approximated by multiplying suspended sediment yield by 0.001 (i.e., 0.1% phosphorus content) (Ahl, 1988). Though Ahl (1988) investigated streams primarily in Scandinavia, Salminen and Beschta (1991) indicated that this may represent a reasonable approximation of phosphorus composition based on a broad range of rock type data (Table G-18).

Table G-18. Phosphorus composition of rock types
(from Salminen and Beschta, 1991)

Rock Type	Phosphorus Composition (%)
Sedimentary	
Limestone	0.0201
Sandstones	0.0401
Shales	0.0801
Red Clay	0.1401
Sedimentary-mixed (mean)	0.0701
Igneous	
Rhyolite	0.0551
Granite	0.0871
Andesite	0.1231
Syenite	0.1331
Monzonite	0.1391
Diorite and Dacite	0.1441
Gabbro	0.1701
Basalt	0.2441
Igneous rock	0.1182
Igneous-plutonic (mean)	0.1343
Igneous-volcanic (mean)	0.1413

[1]Phosphorus composition values from Omernik (1977)
[2]Mean of the values given by Goldschmidt (1958) and Van Wazer (1961)
[3]Mean of plutonic or volcanic types listed above

a. **Determine P content of geology.** Based on the dominant rock type of the WAU, the analyst should determine the specific phosphorus composition from Table G-18.

b. **Calculate background P yield.** Using the estimated background fine sediment for the lake basin obtained from the surface erosion and mass wasting modules, assume that the fine sediment yield is suspended and multiply by the phosphorus concentration to approximate the total phosphorus yield (metric tonnes) to the lake.

Sediment Yield (tonnes/km2) x Area (km2) x P Content (%) = P Yield (tonnes) (10)

c. **Calculate mean annual runoff.** The analyst may use basin-specific gauge data, if available, or estimate the runoff based on records from an appropriate USGS station. The annual volume of runoff is reported by the USGS for water survey stations.

Report the total runoff in cubic meters of water.

d. **Calculate background average phosphorus concentration input to the lake.** Take approximated background phosphorus yield (tonnes) and divide by average annual runoff to yield the average P concentration (mg/ L)

$$\text{Background P conc. (mg/L)} = \frac{\text{background P yield (tonnes)} \times 10^{6}}{\text{average annual runoff } (m^{3})} \quad (7)$$

Make this calculation for each sub-basin within the watershed, and calculate an area-weighted mean annual P concentration.

Low vulnerability if estimated background P concentration is less than 0.025 mg/L.

Moderate vulnerability if estimated background P concentration is greater than 0.025 mg/L but less than 0.05 mg/L.

High vulnerability if estimated background P concentration is greater than 0.05 mg/L.

The above calculation was performed for the M. Santiam River in Oregon where phosphorous and sediment concentration has been measured for a number of years. Figure G-9 shows results of the above model computation compared with measured phosphorus yield.

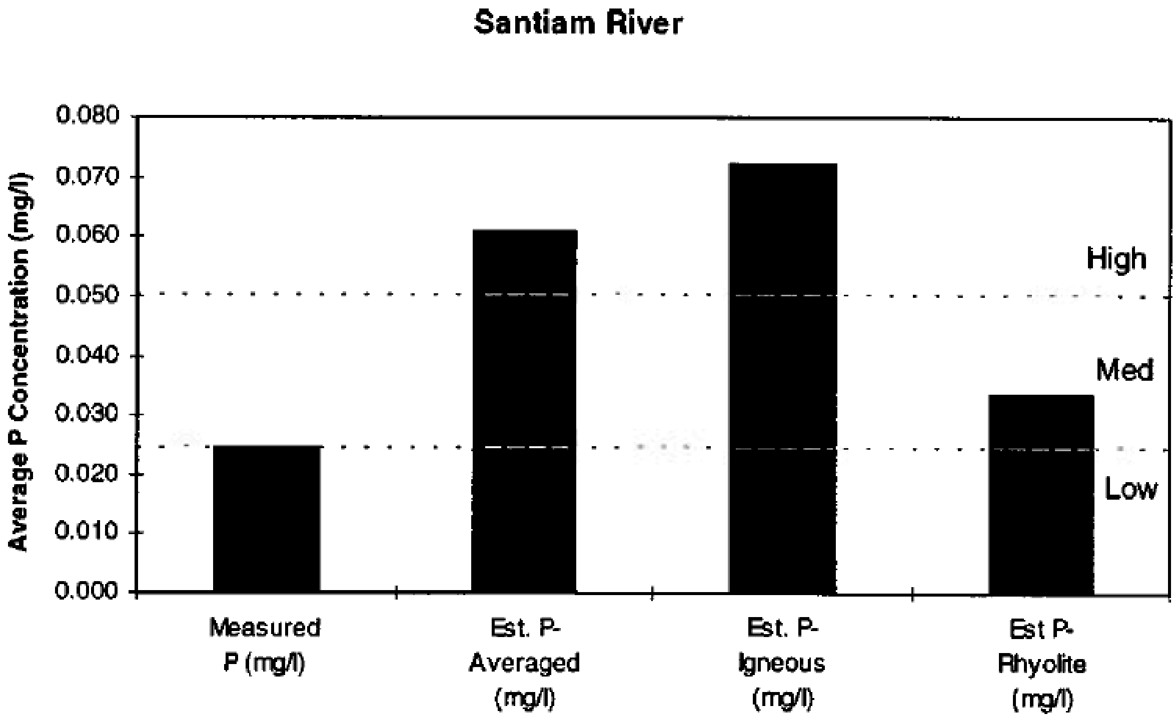


Figure G-9. An example of the phosphorous concentration calculation for the M. Santiam River, Oregon, where phosphorous, sediment, and flow have been measured for several years.

Modeled values using various geologic rock types are compared to measured values. Geology in the watershed is mixed.

The dominant rock type in the M. Santiam River basin is tuffaceous igneous and andesite. While the rhyolite estimate matches measured phosphorous reasonably well, assumptions associated with other rock types are sufficiently high that moderate or high vulnerability would have been identified where a low vulnerability exists. Therefore, while this analysis appears to provide a reasonable first order estimate of phosphorus yield based on geology, analysts must use caution in extrapolating the phosphorus content of surface materials.

Waterbodies determined to have moderate or high vulnerability to phosphorus should be identified on Map G-6 (Nutrient Vulnerability Map).

Dissolved Oxygen Assessment

Scientific Background

In general, most forest streams exhibit cool temperatures, rapid aeration rates, and relatively low biochemical oxygen demand (BOD). This typically allows streams to be at or close to saturation for dissolved oxygen (DO) (MacDonald et al., 1991), especially at the relatively high velocities and turbulence characteristic of streams in forested watersheds of the Northwest. By definition, wetlands include anoxic conditions and DO is naturally low.

Introduction of fine particulate organic matter to waterbodies can increase BOD and decrease DO. High background organic loading can naturally occur with soils rich in organic matter or be affected by forest management where loading of slash into streams has been extreme. This situation can further be exacerbated by high water temperatures (Figure G-10). A study in a Canadian forest stream found that fresh slash loaded to impound a low gradient (<1%) stream coupled with a low reaeration rate caused DO to drop to zero (Plamondon et al., 1982). The concentration of dissolved oxygen in water at saturation decreases with increasing temperature and can approach, if not exceed, the numeric criteria when ambient conditions are very warm (Figure G-10). Temperature is also important because it affects the rate at which organic matter is oxidized. Low DO may occur at any time of the year, but is most likely to occur during the warmest weather and lowest flows.

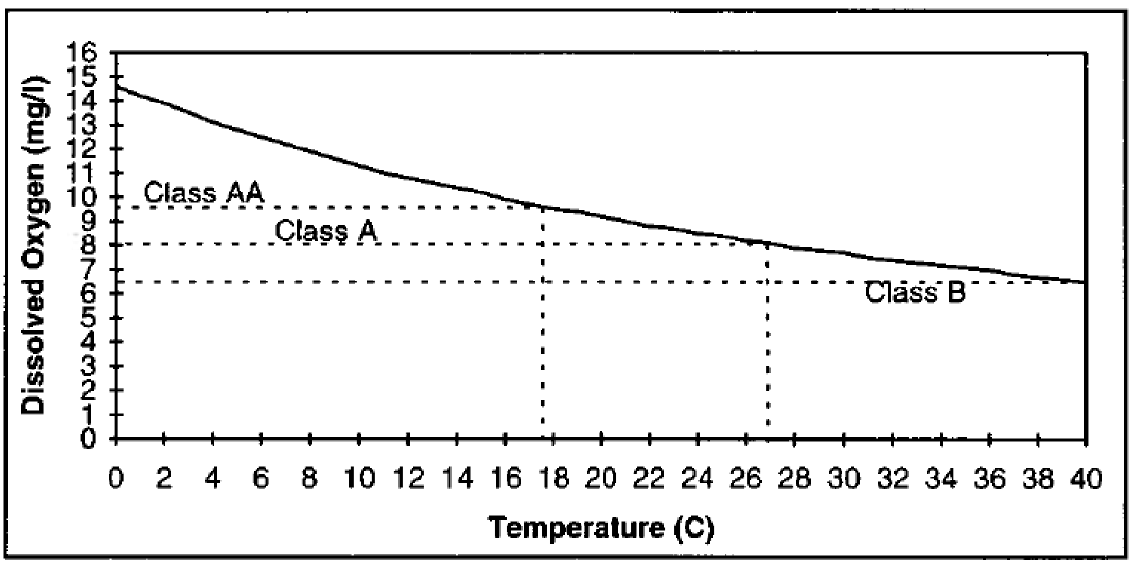


Figure G-10. Relationship of dissolved oxygen saturation (mg/L) in water to temperature (°C) at sea level assuming no reaeration

Streams are considered vulnerable to dissolved oxygen (DO) if forest practices cause the dissolved oxygen concentration to fall below the state water quality criteria provided in Table G-19.

Table G-19. Dissolved Oxygen Water Quality Standards

Class AA Waters	9.5 mg/L
Class A Waters	8.0 mg/L
Class B Waters	6.5 mg/L

One of the primary factors influencing the DO of streams is the reaeration rate which is determined by the velocity and turbulence of water as it flows through the system. Most forest streams have sufficient velocity and bed roughness that turbulence is more than sufficient to maintain a high concentration of DO in the water column, even under low summer flows and normal organic loading. Ice (1991) developed an equation to calculate reaeration based on reach-averaged stream characteristics:

$$K_2 = \frac{37 * W^{2/3} * S^{1/2} * g^{1/2} * Vmax^{7/8}}{Q^{2/3}} \qquad (8)$$

where:
W = active stream width (ft)
S = slope (ft/ft)
g = gravitational constant (32.2 ft/s^2)
Vmax = maximum velocity (ft/s)
Q = stream discharge (cfs)

where the aeration rate is adjusted for stream temperatures different than 20° C:

$$K_{2adj} = K_2 * (1.024)^{T-20} \qquad (9)$$

Streams are vulnerable to lowered DO when the reaeration rate coefficient (K2) is less than 10 day^{-1} (at 20°C). Note that the lower the water temperature, the lower the reaeration coefficient. Streams with reaeration rate coefficients greater than 10 day^{-1} can accept a high amount of BOD without significant oxygen depletion.

Most forest streams have low vulnerability to low DO because fine organic debris is generally low, and reaeration of flowing water is more than sufficient to maintain high levels of DO. Only streams with low reaeration rate coefficients will be vulnerable to markedly lowered DO. Most forest streams have high reaeration rates when calculated using the above equation. An example calculation is made using average data measured during the summer for the variables in the reaeration equation (reported in Sullivan et al., 1990). For example, at a distance 10 km (6 miles) downstream from watershed divide, the values of input parameters are:

Example Reaeration Calculation

Width (w)	= 13.12 ft	(4 m)
Velocity (v)	= 0.66 ft/s	(0.2 m/s)
Discharge (Q)	= 7 cfs	(0.2 cms)
Slope (S)	= 3%	

Substituting into the equation and solving:

K2 = 38.4 Adjusting for Temperature at 16.^{3o} C (61 F) : **K_{2adj} = 35.2**

This value is well above the threshold necessary for reaeration.

Current forest practices are not generally believed to input sufficiently large enough amounts of slash to cause management-induced depletion of DO through increases in BOD, except where DO is naturally low (Skaugset and Ice, 1989). Adverse depletion of DO, however, may occur when the following conditions are present (MacDonald et al., 1991; Ice, 1992; Ice, 1991):

- Very slow-moving, low gradient, warm streams with low discharge (i.e., low reaeration rates), including impounded wetlands, especially those formed by beaver; or
- Heavy inputs of fine organic debris to low-flow streams causing a large BOD, or naturally high concentrations of organics; or
- Warm, eutrophic waterbodies where high rates of photosynthesis and respiration cause diurnal fluctuations in DO (consuming O_2 without re-aeration). These conditions often accompany lake eutrophication; therefore nutrient analysis will suffice for lakes.

Dissolved Oxygen (DO) Assessment Procedure

The dissolved oxygen assessment involves screening the watershed for the presence of situations where streams are very slow-moving, loaded with organic matter, and potentially of high temperature (Figure G-11). Wetlands are assumed to have low DO since they often meet these criteria, even when contributing streams do not. In fact, wetlands are assumed to have a significant effect on DO for some distance downstream from a wetland outlet and may be a source of DO problems to aquatic life in streams. DO in lakes and estuaries and near-shore marine environments is assumed to be controlled by biological and physical processes within them, and are beyond the scope of this assessment. The DO of these waterbodies are assumed to have low vulnerability to forest practices.

The analyst will look for situations where streams are slow-moving, relatively deeper and low turbulence.

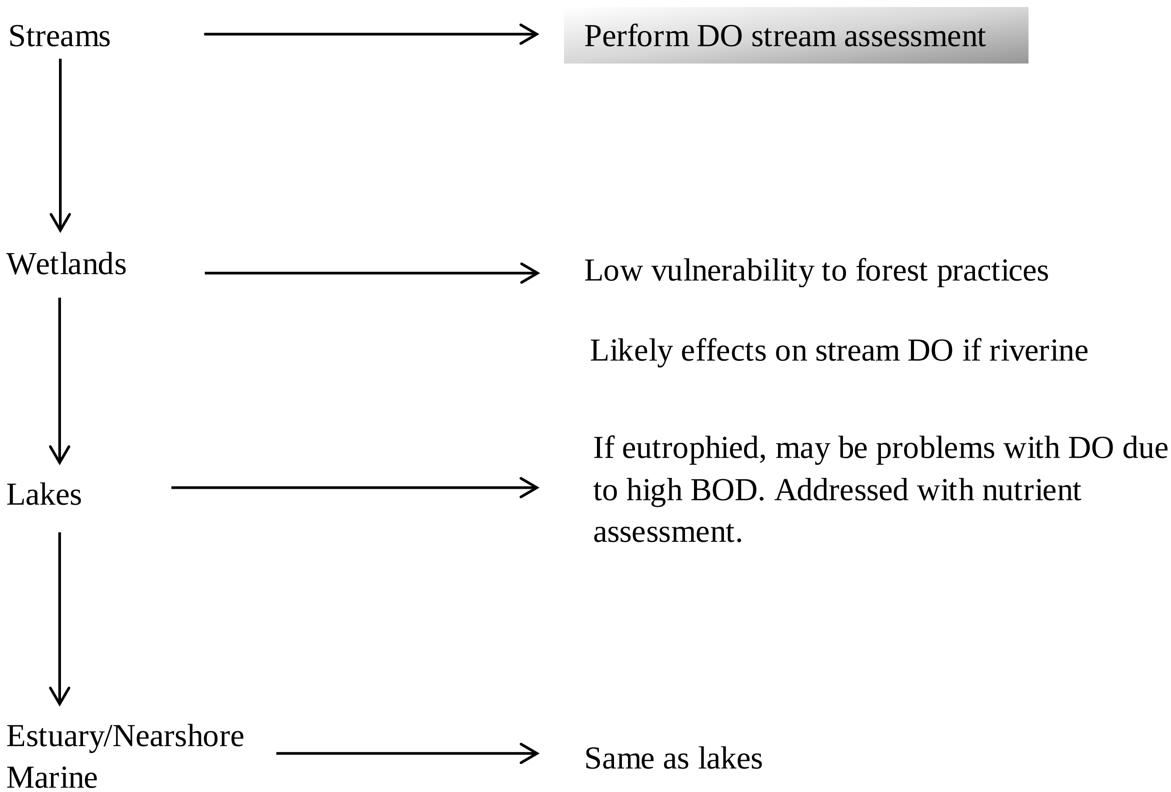


Figure G-11. Dissolved Oxygen Assessment Flow Chart

To simplify use of the reaeration equation (eq 8) for purposes of watershed analysis, we sought to determine flow conditions with low reaeration coefficients (k<10). To do so, solved eq 12 for a number of different combinations of the stream parameters (Q,v, w, s) to determine the factors to which reaeration are most sensitive. Although depth is not included in the equation, its influence can also be determined using the relationship:

$Q = v \times d \times w$

where Q is discharge, v is velocity, d is depth and w is width.

The reaeration coefficient is proportional to velocity and inversely proportional to depth. It is relatively insensitive to width. These relationships suggested a relationship between K and the ratio of v/d. We found that the ratio v/d was closely related to K over a wide range of values for parameters in equation 12 (Figure G-12.) Note that K approximately 20% lower when water temperature is

10º C compared to 20º C. Thus, the v/d ratio is a good indicator of reaeration coefficient K. Vulnerability to DO is shown on Figure G-12 where thresholds of K are 10 for high vulnerability and 20 for moderate vulnerability. (Vulnerability is based on the cooler temperature, since this value is more conservative, and the objective of management is to minimize temperature. However, the analyst may adjust the v/d ratio for appropriate temperature using equation 12 directly.

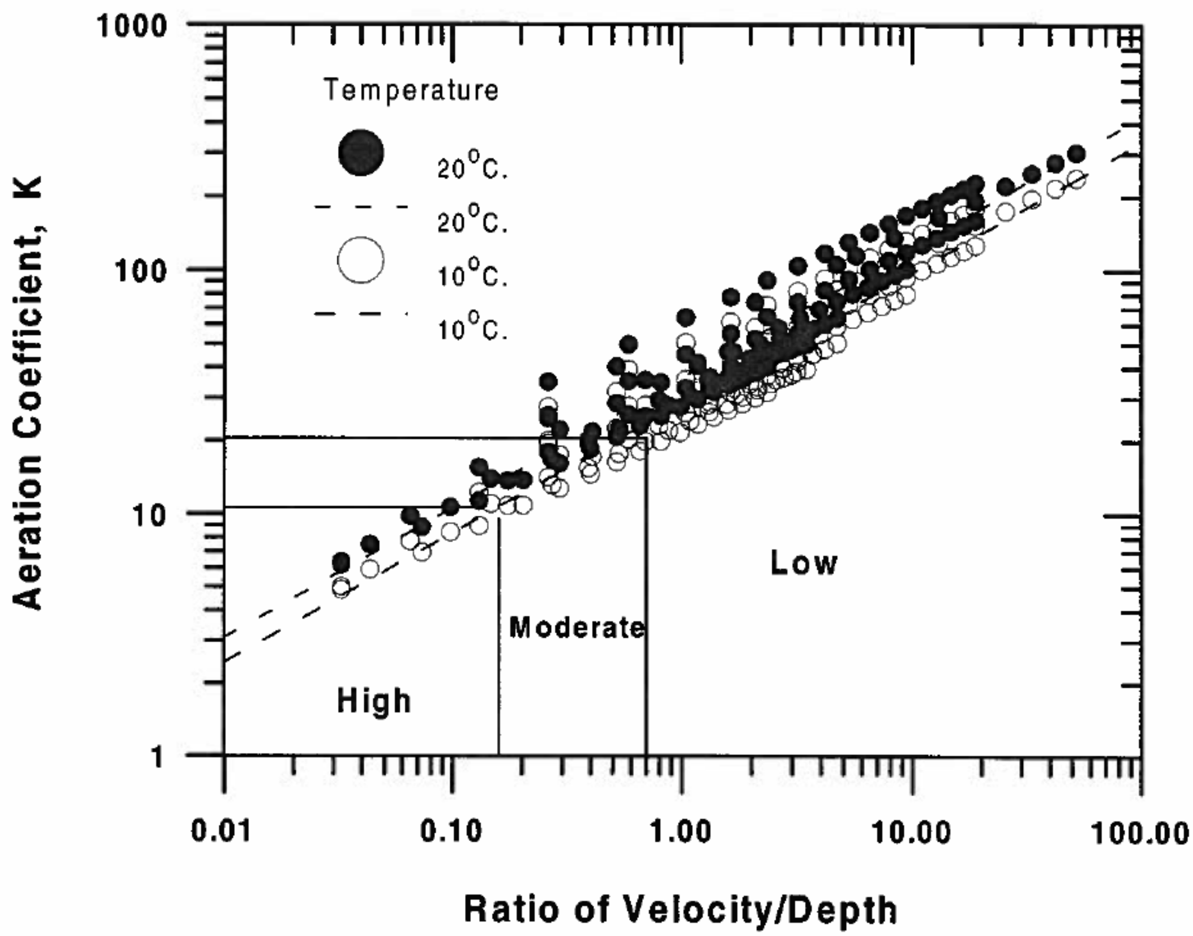


Figure G-12. Vulnerability of streams to low dissolved oxygen based on calculations of the reaeration coefficient (k) in relation to the ratio of velocity to depth

The threshold for **HIGH** vulnerability (K<10) occurs at v/d equal to 0.18. The threshold for MODERATE vulnerability (10<K<20) occurs at v/d equal to 0.7. For example, assuming average reach velocity of 25 cm/s, the average reach depth would need to be more than 140 cm for low reaeration and 36 cm for moderate reaeration. Low reaeration is usually associated with streams that are slower and deeper than most forest streams and this situation is not expected to occur frequently.

The analyst determines where very slow-moving, low gradient, warm streams with low discharge are located in the watershed, and whether fine organic debris has been loaded to these areas. Utilize the stream channel segment map produced in the Channel Module (Map E-1) for locations of all low discharge streams with less than 1% gradient. Low gradient streams are most likely to be sufficiently slow and deep to meet the above criteria. Stream segments associated with extensive riverine impounded wetlands should be included as these are likely to be the most likely situations naturally experiencing low DO due to low v/d ratios and high organic loading. In most forested watersheds, if a stream demonstrates any signs of turbulence (i.e., rippling of water surface to produce other than tranquil flow) it is probably well-aerated. To apply the relationships, both velocity and depth should be averaged over substantially long reach (>30 channel widths), and should be based on summer streamflow conditions.

Level 2 Assessment. In addition to the v/d relationship, high bed roughness can improve aeration by inducing turbulent mixing. To account for bed roughness that induces turbulence, the analyst calculates the relative submergence of the streambed, calculated as the ratio of the water depth relative to the average particle size of the streambed material (Figure G-13).

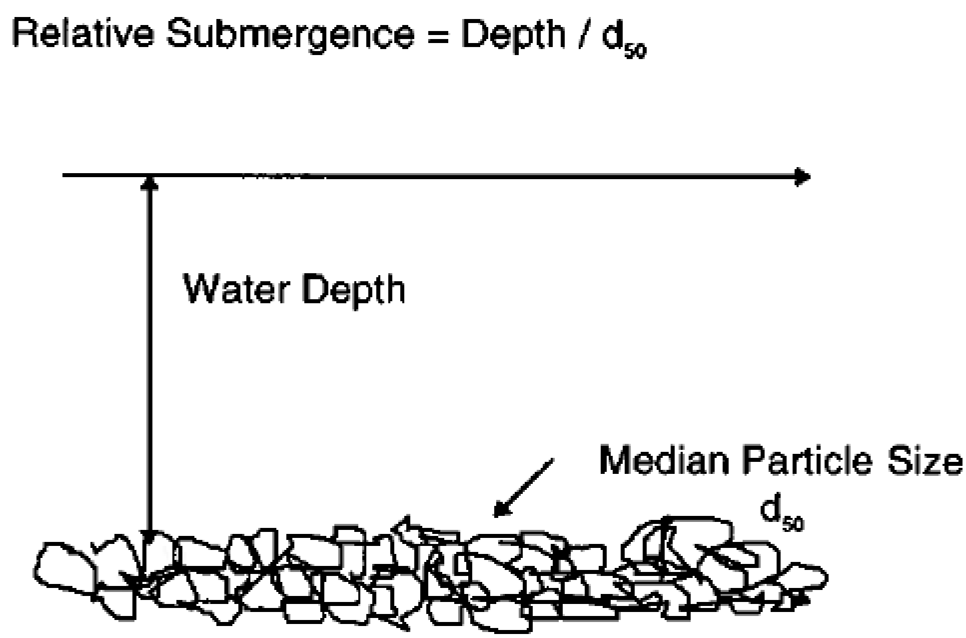


Figure G-13. Relative Submergence = Water Depth (mm) / Avg. Particle Size (mm)

(Consult the channel analyst for methods to determine the bed particle size).

Note: If a stream is greater than 1% and has any degree of turbulence, it is well above the critical reaeration rate coefficient. In contrast, very slow moving, low gradient streams may require calculation of the reaeration rate coefficient using equation 12.

The analyst will visit some stream segments to determine whether depth and velocity criteria are met. If segments are riverine wetlands, they may assume that velocity and depth criteria for vulnerability threshold are met.

Pay particular attention to identified stream reaches which may experience high temperatures exceeding the criteria, such as low elevation and/or low riparian shade. Temperature measurements may be helpful to determine this, but locations where riparian shade is below target are identified on the Riparian Shade Situation Map (Map D-4).

Vulnerability Determination
Situations of low reaeration coefficient are likely to occur where the velocity/ depth ratio is low and relative submergence is high. The analyst shall make the vulnerability call, according to Table G-20. Values of relative submergence greater than 10, coupled with velocity and depth combinations in Figure G-12 are conditions leading to high vulnerability of the stream to low levels of DO.

Table G-20. Vulnerability Criteria for Dissolved Oxygen

	Relative Submergence		
Vel-Depth Call	<3	3-10	>10
High	Mod	High	High
Medium	Low	Mod	Mod
Low	Low	Low	Low

Vulnerability can be increased if high organic loading exists. In addition, existing conditions of high water temperature may also increase the vulnerability identified in Table G-20, although this effect can be accounted for using the appropriate Figure G-12.

Level 2 DO Stream Assessment Procedure
The analyst may improve upon the estimate of reaeration coefficient by obtaining field measured data and solving equation 12 for each reach of interest. The vulnerability criteria are the same as for the standard assessment.

Lakes, Wetlands, and Estuaries
Lakes and estuaries may be vulnerable to adverse levels of DO resulting from runoff into lakes with poor reaeration rates, especially lakes that are thermally stratified during portions of the year. Low DO in lakes would likely be a

secondary effect of eutrophication resulting from nutrient loading. The vulnerability of lakes to nutrients is assessed above, and therefore DO will not be addressed directly.

Wetlands are likely to have low dissolved oxygen because of their high organic content, low velocities and deeper depths. However, forest practices are not likely to affect already low values and the dissolved oxygen of wetlands is considered to have low vulnerability to forest practices.

Waterbodies determined to have moderate or high vulnerability to Dissolved oxygen should be identified on Map G-7 (DO/pH vulnerability map).

Acidity and Alkalinity

Scientific Background

Generally pH is within 6.5 to 8.5, although watershed conditions may create some conditions that are naturally more acidic or alkaline than these conditions. For example, soils very high in organic content may have low pH, while very basic lithologies may produce soils with high alkalinity. Few studies have rigorously assessed the ability of forest practices to change water pH, but available data indicate that pH is not generally affected by forest practices (MacDonald et al., 1991). In many cases, the buffering capacity of the soil precludes forest practices from affecting stream pH (Stottlemeyer, 1987).

Streams are considered vulnerable to acidity or alkalinity if pH falls outside the range of the following state water quality criteria listed in Table G-21.

Table G-21. Water quality standards for pH

Class AA Waters	6.5 to 8.5 (+<0.2 units)
Class A and B Waters	6.5 to 8.5 (+<0.5 units)

All streams and waterbodies are assumed to have low vulnerability to pH. The presence of indicators sensitive to pH should trigger a Level 2 assessment to determine the source of pH and management effects.

One situation where pH may be naturally low is where streams are very rich in dissolved organic matter. This condition may occur on some soil types, and it can often be the case if there are wetlands or bogs as a source of stream water. The analyst should examine soil information for situations of high organic content, notably organically rich soils. Though not affected by forest practices, this condition could be important to fish habitat quality. The water quality analyst should inform the fish habitat analyst that low pH conditions may exist.

Waterbodies determined to have moderate or high vulnerability to pH should be identified on Map G-7 (DO/pH vulnerability map).

Use of Existing Water Quality Data

Although water quality vulnerability to forest practices is determined primarily by assessing potential based on watershed conditions, measured water quality data can be very helpful in determining whether hypothesized vulnerabilities are correct. If forest management “stressors” are present, that is, if past practices are already likely to have influenced a water quality parameter, data from the area can help the analyst evaluate the vulnerability determinations. Table G-22 helps to explain the likely situations that will occur when measured data is compared to modeled vulnerability.

Table G-22. Modifying vulnerability determinations based on available water quality data

		Observed Water Quality Parameter	
		Does Exceed	**Does Not Exceed**
Predicted Vulnerability	**Moderate or Low** (parameter within standard and not likely to exceed)	**Change to vulnerability to HIGH**	**CORRECT**
	High (parameter likely to exceed standard)	**CORRECT**	**Change vulnerability to MODERATE**

Several situations are possible. If vulnerability determinations match measured data results, then the module results would appear to be appropriate. If the measured data does not match the vulnerability determinations, than the vulnerability determinations should be changed to reflect the measured data according to Table G-22. When vulnerability determinations are changed, the rationale for doing so and an explanation for the deviation should be included in the module report.

A number of factors should be included in the analyst’s vulnerability assessment due to current condition before over-riding the vulnerability determinations developed in previous sections.

1. Are the type of forest practices present and of sufficient spatial effect to have affected water quality?
2. Are current water quality conditions a result of a legacy of past forest practices that are no longer in effect?
3. Are current water quality conditions a result of natural disturbances? If so, what is the link between the disturbance and water quality that caused exceedances?

4. Are other landuses affecting the water quality conditions?

After consideration of disturbance, forest practices and watershed factors, the analyst will change the vulnerability determinations as appropriate. The analyst will include a discussion of measured vs. modeled water quality and discuss disturbance and watershed factors that may have caused error in vulnerability determination from module criteria.

Finally, precise location of boundaries between waterbodies likely to be within standards and those exceeding cannot be guaranteed with the general methods provided in this module. For example, the location where predicted temperature changes from 16ºC to 17ºC will appear more exact on maps than the method is likely to be able to predict accurately but the boundary between the two has significant regulatory significance. Furthermore, there is likely to be some error in predicting maximum temperature with the temperature screen due to the range of annual variability in water temperature due to climatic influences (Sullivan et al., 1990). When measured data indicates water quality criteria are exceeded vulnerability should be adjusted. However, conclusions regarding the utility of the water quality module methods in predicting the direction and magnitude of change with forest practices can be aided by discussion of model performance relative to criteria in a spatial and temporal context.

Water Quality Assessment Report

The Water Quality Assessment Report organizes and presents results of the water quality assessment. The report is a compilation of key work products, maps and narrative summarizing interpretations. The report should describe the results of the analysis and any conclusions reached relative to the critical questions. While the Water Quality Assessment Report should be concise, it should be complete enough so that, together with the other module products, it provides the input necessary for the synthesis and prescription phases of Watershed Analysis where the information developed in the analysis modules is incorporated into land use decision-making.

The assessment report should include the following:

- Documentation of all information used in the assessment of conditions of waterbodies within the WAU. This includes aerial photos, maps, anecdotal information, and any other information used to characterize riparian conditions.
- A summary of the assessment results and vulnerability determinations for each water quality parameter.
- A description of any deviations from the standard methods and why the changes were necessary.
- A description of any additional analyses that were performed.

- A discussion of the analyst's confidence in the work products. Consider factors such as the amount, type, and quality of available information, extent of field data collection and observation, experience of the analyst, complexity of the terrain, availability and quality of aerial photographs and maps, and multiple lines of evidence for inferred changes.
- Answers to the critical questions presented at the beginning of the section. While it is not necessary to include this as a separate section, be sure that the critical questions are addressed somewhere in the report.

Maps

G-1 Waterbody map

G-2 Land use map

G-3 Reference temperature map

G-4 Temperature vulnerability Map

G-5 Sediment vulnerability map (if necessary)

G-65 Nutrient vulnerability map (if necessary)

G-7 DO and pH vulnerability (if necessary)

Summary Data

G-1 Wetlands assessment worksheet

G-2 Waterbody vulnerability determination worksheet

G-3 Temperature vulnerability worksheet

Water Quality Assessment Report

I. **Title page** with name of watershed analysis, name of module, level of analysis, signature of qualified analyst(s), and date

II. **Table of contents**

III. **Maps**
- Water body map (map G-1)
- Land use map (map G-2)
- Reference temperature map (map G-3)
- Temperature vulnerability map (map G-4)
- Sediment vulnerability map (map G-5), if map is necessary
- Nutrient vulnerability map (map G-6), if map is necessary
- DO and pH vulnerability (map G-7), if map is necessary

IV. **Summary Data**
- Wetlands assessment worksheet (form G-1)
- Water body vulnerability determination worksheet (form G-2)
- Temperature vulnerability worksheet (form G-3)

V. **Summary Text**
- Summary of assessment results and vulnerability determinations for each water-quality parameter
- Summary of all information used to document water-body conditions
- Description of any additional analyses that were performed
- Study methods, including description of sampling methods
- Descriptions of any deviations from the standard methods and why the changes were necessary
- Recommendations for Level 2 (at Level 1 only)
- Does module report address all critical questions?

VI. **Other Information (optional)**
- Monitoring strategies and design and implementation suggestions
- Learning resources (a.k.a., references, bibliography) section
- Acknowledgments section

Module Project Management

The module project management checklist is provided to assist the module leader and team members to schedule tasks and review interim and final module products. It is not a requirement of watershed analysis.

Table G-23. Water quality project task checklist

Project Tasks	Schedule	Review	Complete
Assemble start-up materials (e.g., mylar base mapAssemble start with WAU boundary and DNR hydro layer; soil survey, NWI maps, topo maps, aerial photos, 303(d) list, 305(b) report, available data)			
Start-up meeting-brief WQ team on process andStart intent. Schedule project tasks.			
Identify and map all waterbodies on mylar overlay (**Map G-1**) streams, lakes, wetlands, water: supplies, and nearshore marine/estuarine waters. Notify other analysts where waterbodies are so they can include in assessments.			
Develop **Land Use Map (Map G-2)**.			
Query ps/ws, surface erosion, and channel erosion module leaders for key information. Query outside data sources.			
Conduct Vulnerability Assessment. Produce worksheet and map products.			
Team meeting to review results and interpretations.			
Produce module assessment report.			

Information Provided to Other Analysts by Water Quality Analyst

After completion of the water quality assessment the analyst is prepared to participate in Synthesis with an understanding of the vulnerability of water quality in the waterbodies in the WAU and has identified input variables likely to require consideration in prescriptions. In the case of temperature and sediment there is abundant information on these input variables generated in other modules. The analyst may alert the riparian, surface erosion and mass wasting analysts of the vulnerability and location of specific water-bodies and water supplies if location specific analyses will be advisable. If nutrient vulnerability is identified, the analyst should alert the surface erosion analyst so that phosphorous input from soil erosion can be more carefully evaluated. If dissolved oxygen is found to be vulnerable, the water quality analyst should alert the fish habitat analyst since this information may be important in understanding aquatic habitat effects on fish, and the channel and riparian analysts so that they can identify the locations and sources of organic matter loading.

Acknowledgments

This module represents the work of many people over the course of many years. This version was written by Kate Sullivan, Jerry Gorsline, Karen Walters, Doug Rushton and Dave Parks. Previous versions of the module were written by Hans Ehlert, Steve Toth, Dave Parks and Fred Greef. Significant technical comments were provided by Iris Goodwin, Walt Megahan, George Ice, Jim Ryan, Jeff Light, Rob Plotnikoff, Jim Matthews, Ed Rashin, Ron Figlar-Barnes, Fran Wilshusen, Bruce Cleland, Dave Ragsdale, Sally Marquis, Mark Hunter, Curt Veldhuisen, Sandra Donnelly, Jerry Erickson and Lee Benda. Important policy input was provided by Marcy Golde, Julie Thompson, David Roberts, Dick Wallace, Stephen Bernath and Chris Kelly. Judith Holter and Nancy Charbonneau assisted in preparing the final version for the Forest Practices Board.

This version of the Water Quality Module was accepted as part of the Forest Practices Board Manual by the Forest Practices Board on March 25, 1997 and became effective June 20, 1997.

The current module represents a work in progress. Further revision of the manual and methods are required to maintain the technical viability and credibility of the water quality assessment procedure. Periodic revision and incorporation of new methods will be needed.

References

Adams, T.A. and K. **Sullivan.** 1990. The physics of forest stream heating: a simple model. Weyerhaeuser Technical Report. Weyerhaeuser Company, Tacoma, WA 98477

Adamus, P.R., E.J. **Clairain,** Jr., R.D. **Smith,** and R.E. **Young.** 1991. Wetland Evaluation Technique (WET); Volume 1: Literature Review and Evaluation Rationale. US Army Corps of Engineers. Waterways Experiment Station. WPR-DE-2.

Ahl, T. 1988. Background yield of phosphorus from drainage area and atmosphere: An empirical approach. Pages 35-44 in G. Persson and J. Jansson (eds.). Phosphorus in Freshwater Ecosystems, Hydrobiologia. 170:35-44.

Beschta, R.L., R.E. **Bilby,** G.W. **Brown,** L.B. **Holtby,** and T.D. **Hofstra.** 1987. Stream temperature and aquatic habitat: fisheries and forests interactions. Ed. E.O. Salo and T.W. Cundy, Proc. of a symposium held February 1986, University of Washington, Seattle, WA: 1991-232.

Beschta, R.L. and R.L. **Taylor.** 1988. Stream temperature increases and land use in a forested Oregon watershed. Wat. Resources Bull. 24: 19-25.

Binkley, D., and T.C. **Brown.** 1993. Management impacts on water quality of forests and rangelands. USFS Rocky Mtn. For. and Range Exp. Stn. GTR RM-239. 114p.

Birch, P.B., R.S. **Barnes,** D.E. **Spyridakis.** 1980. Recent sedimentation and its relationship with primary productivity in four western Washington lakes. Limnol. Oceanogr. 25(2): 240-247.

Bisson, P.A., G.G. **Ice,** C.J. **Perrin,** and R.E. **Bilby.** 1992. Effects of forest fertilization on water quality and aquatic resources in the Douglas-fir region. Pages 179-193 in Chappell, H.N., G.F. Weetman, and R.E. Miller. [eds]. Forest Fertilization: Sustaining and Improving Nutrition and Growth of Western Forests, Institute of Forest Resource Contrib. 72, Univ. Wash., Seattle.

Brinson, M.M. 1993. A hydrogeomorphic classification for wetlands. Tech. Rep. WRP-DE-4. US Army Corps Engineer, Waterways Expt. Stn., Vicksburg, MS. 101pp.

Brooks, K.N., P.F. **Folliott,** J.M. **Gregersen,** and J.L. **Thames.** 1991. Hydrology and the Management of Watersheds. Iowa State Univ. Press, Ames, 392p.

Brown. 1969. Predicting temperatures of small streams. Water Resources Res. 5(1):68-75.

Brown, G.W. and J.T .**Krygier.** 1970. Effects of clearcutting on stream temperature. Water Resources Res. 6(4):1133-1139.

Chen, J., J.F. **Franklin,** and T.A. **Spies.** 1995. Growing-season microclimatic gradients from clearcut edges into old-growth Douglas-fir forests. Ecological Applications 5(1): 74-86.

Cline, C. 1973. The effects of forest fertilization on the Tahuya River, Kitsap Peninsula, Washington. Washington State Dept. Ecology. 55p.

Comer, Larry E. and William J. **Grenney.** 1977. Heat transfer processes in the bed of a small stream. Water Research 11:743-744.

Cowardin, Lewis M., Virginia **Carter,** Francis C. **Golet** and Edward T. **LaRoe.** 1979. Classification of Wetlands and Deepwater Habitats of the United States. US Fish & Wildlife Service. Washington, DC.

Department of Ecology. 1992. Statewide water quality assessment (305 (b) report). Washington Department of Ecology, Olympia, WA. Pub. No. 92-04.

Department of Ecology. 1994. Water Quality in Washington State (Section 303(d) of the Federal Clean Water Act. Washington Department of Ecology, Olympia, WA. Pub. No. F-WQ-94-37.

Department of Ecology. 1996. Washington State Wetland Function Assessment Project. An Approach to Developing Methods to Assess the Performance of Washington's Wetlands. Publication No. 96-110. Olympia.

Department of Ecology. 1997. Profiles of wetland classes and subclasses for lowland Washington. 1/2/97 Unpublished Draft.

Deysher, L.E., and T.A. **Dean.** 1986. In situ recruitment of sporophytes of the giant kelp Macrocytis pyrifera: Effects of physical factors. J. Exp. Mar. Biol. Ecol. 103:41-63.

Dillon, P.J., and W.B. **Kichner.** 1975. The effects of geology and land use on the export of phosphorus from watersheds. Water Resources Res. 9:135-148.

Edinger, J.E., D.W. **Duttweiler,** and J.C. **Geyer.** 1968. The response of water temperature to meteorological conditions. Wat. Resources Res. 4: 1137-1143.

EPA. 1986. Quality criteria for water: 1986. USEPA, Off. Water Regulations and Standards. Washington, DC.

Fredricksen, R., D. **Moore,** and L. **Norris.** 1975. The impact of timber harvest, fertilization, and herbicide treatment on stream water quality in western Oregon and Washington. in B. Bernier and C. Winget (eds.) Forest Soils and Land Management. Laval University Press, Quebec, Canada. p.288-313.

Gessel, S.P., E.C. **Steinbrenner,** and R.E. **Miller.** 1979. Response of Northwest forests to elements other than nitrogen. Pages 29-36 in S.P. Gessel et al. (eds.). Forest Fertilization Conference. College of Forest Resources, University of Washington, Seattle, WA.

Goldschmidt, V.M. 1958. Geochemistry. Oxford University Press, London. 730pp.

Government Printing Office. 1996. Federal Register: August 16, 1996. Vol. 61, No. 160. Washington, DC

Gregory, S.V., G.A. **Lamberti,** D.C. **Erman,** K.V. **Koski,** M.L. **Murphy,** J.R. **Sedell.** 1987. Influence of forest practices on aquatic production. Pages 233-255 in Salo, E.O., Cundy, T.W. [eds]. Streamside Management: Forestry and Fishery Interactions. Institute of Forest Resource Contrib. 57, Univ. Wash., Seattle.

Henderson-Sellers, B. and A.M. **Davies.** 1989. Thermal stratification modeling for oceans and lakes. Ann. Rev. Numer. Fluid Mech. and Heat Transfer. 2: 86-156.

Holton, N., L. **Kamp-Nielsen,** and A.O. **Stuanes.** 1988. Phosphorus in soil, water, and sediment: An overview. Pages 19-34 in G. Persson and J. Jansson (eds.). Phosphorus in Freshwater Ecosystems, Hydrobiologia. 170:19-34.

Hupp, Cliff R., Michael D. **Woodside** and Thomas M. **Yanosky.** 1993. Sediment and Trace Element Trapping in a Forested Wetland, Chickahominy River, Virginia. Wetlands. Vol. 13, No. 2, Special Issue

Hynes, H.B. 1970. The Ecology of Running Waters. Liverpool University Press. Liverpool, UK.

Ice, G.G. 1991. Dissolved oxygen and woody debris: Detecting sensitive forest streams. Pages 333-346 in Air and Water Mass Transfer. ASCE Sept. 1990. New York, NY.

Ice, G.G. 1992. Example of a CWE assessment module: Dissolved oxygen effects on fish. Appendix A in Status of the NCASI Cumulative Watershed Effects Program and Methodology. June 1992. NCASI Tech. Bull. No. 634.

Larsen, D.P., and H.T. **Mercier.** 1976. Phosphorus retention capacity of lakes. J. Fish Res. Bd. Can. 33:1742-1750.

MacDonald, L.H., A.W. **Smart,** and R.C. **Wissmar.** 1991. Monitoring Guidelines to Evaluate Effects of Forestry Activities on Streams in the Pacific Northwest and Alaska. EPA 910/9-91-001. 166p.

MacKenthun, K.M. 1973. Toward a cleaner aquatic environment. USEPA. Washington, D.C.

Meyer, J.L. 1979. The role of sediments and bryophytes in phosphorus dynamics in a headwater stream ecosystem. Limnology and Oceanography. 24(2):365-375.

Mills, Anthony F. 1992. Heat transfer. Irwin Publishers, Homewood, Illinois. 888 pg.

Naiman, R.J., J.M. **Melillo,** and J.E. **Hobbie.** 1986. Ecosystem alteration of boreal forest streams by beaver (Castor canadensis). Ecology. 67(5):1254-1269.

Naiman, R.J., C.A. **Johnston,** and J. C. **Kelley.** 1988. Alteration of North American Streams by beaver. BioScience. 38(11):753-762.

Neumann, J. 1959. Maximum depth and average depth of lakes. J. Fish. Res. Bd. Can., 16:923-927.

Omernik, J.M. 1977. Nonpoint source - stream nutrient level relationships: A statewide study. Ecol. Res. Serv. 600/3-77-105. 150pp.

Phipps, J.B. 1986. Sediment trapping in northwest wetlands--The state of our understanding. Pages 25-30 in Wetland Functions, Rehabilitation and Creation in the Pacific Northwest: The state of our understanding. Washington Department of Ecology. Pub. No. 86-14.

Plamondon, A.P., A. **Gonzalez,** and Y. **Thomassin.** 1982. Pages 49-70 in Effects of logging on water quality: Comparison between two Quebec sites. Can. Hydrol. Symp.:82. Fredericton, NB, Canada.

Rice, R.M., and P.A. **Datzmann.** 1987. Sediment routing by debris flows. Pages 213-223 in Erosion and sedimentation in the Pacific Rim. Beschta, R.L., T. Blinn, G.E. Ice, and F.J. Swanson (eds.). IAHS Publication No. 165.

Richardson, C.J. 1994. Ecological functions and human values in wetlands: A framework for assessing forestry impacts. Wetlands. 14 (1):1-9.

Riekerk, H., D. **Neary,** and W.T. **Swank.** 1989. The magnitude of upland silviculture nonpoint source pollution in the South. Pages 8-18 in Hook, D.D., and R. Lea (eds.) Proceedings of the Symposium: The forested wetlands of the Southern United States; 1988 July 12-14; Orlando, FL. Gen. Tech. Rep. SE-50. Asheville, NC: US Department of Agriculture, Forest Service, SE For. Exp. Stn. 168pp.

Ringler, N. H. and J. D. **Hall.** 1975. Effects of logging on water temperature and dissolved oxygen in spawning beds. Trans. Amer. Fish. Soc. 1:111-121.

Salminen, E.M., and R.L. **Beschta.** 1991. Phosphorus and forest streams: the effects of environmental conditions and management activities. Oregon State University, Department of Forest Engineering. Corvallis, OR. 185p.

Shepard, J.P. 1994. Effects of forest management on surface water quality in wetland forests. Wetlands 14(1):18-26.

Skaugset, A., and G. **Ice.** 1989. Research on dissolved oxygen in steams. Pages C15-C30 in Abstracts to Presentations at the 1989 West Coast Regional Meeting. Nat'l Council of the Paper Industry for Air and Stream Improvement. Corvallis, OR.

Sinokrot, B.A. and H.G. **Stefan.** 1993. Stream temperature dynamics: measurements and modeling. Wat. Resources Res. 29: 2299-2312.

Sollins, P., and F.M. **McCorison.** 1981. Nitrogen and carbon solution chemistry of an old growth coniferous forest watershed before and after cutting. Water Resource. Res. 17(5):1409-1418.

Stottlemeyer, R. 1987. Natural and anthropic factors as determinants of long-term streamwater chemistry. Pages 86-94 in C.A. Troendle, M.R. Kaufmann, R.H. Hamre, and R.P. Winokur (tech. coord.). Proceedings of a Technical Conference: Management of Subalpine Forests: Building on 50 Years of Research, Silver Creek, CO. July 6-9, 1987. USDA For. Serv., Gen. Tech. Rep. RM-149. 253p.

Stumm, Werner and James J. **Morgan.** 1981. Aquatic chemistry--an introduction emphasizing chemical equilibria in natural waters. John Wiley and Sons, New York. 780 pp. 2nd ed.

Sullivan, K., J. **Tooley,** K. **Doughty,** J.E. **Caldwell,** and P. **Knudsen.** 1990. Evaluation of prediction models and characterization of stream temperature regimes in Washington. Timber/Fish/Wildlife Rep. No. TFW-WQ3-90-006. Washington Dept. Nat. Resources, Olympia, WA. 224pp.

Sullivan, K., and T.A. **Adams.** 1990. The physics of stream heating: (2) An analysis of temperature patterns in stream environments based on physical principles and field data. Weyerhaeuser Tech. Rep. 044-5002/89/2. Tacoma, WA. 54p.

Sullivan, M.A., and S.C. **Samis.** 1988. Assessment of acidification potential of selected lower mainland and Vancouver Island, British Colombia Streams. Can. Tech. Rep. Fish. Aquat. Sci. No. 1599. 106p.

Swanson, F.J., L.E. **Benda,** S.H. **Duncan,** G.E. **Grant,** W.F **Megahan,** L.M. **Reid,** and R.R. **Zimmer.** 1987. Mass failures and other processes of sediment production in Pacific Northwest forest landscapes. Pages 9-38 in E.O. Salo and T.W. Cundy (eds.), Streamside Management: Forestry and Fishery Interactions. Contr. no. 57, Institute of Forest Resources, Univ. Washington, Seattle, WA.

Theurer, F.D., K.A. **Voos,** and W.J. **Miller.** 1984. Instream water temperature model. Instream Flow Info. Paper No. 16, U.S.D.I. Fish and Wildlife Service FWS/OBS-84/15.

Thut, R.N. and E.P. **Haydu.** 1971 Effects of forest chemicals on aquatic life. Pages 159-171 in J.T. Krygier and J.D. Hall (eds.). Forest Land Uses and Stream Environment: Proceedings of a Symposium. Oregon State Univ., Corvallis, OR.

Van Wazer, J.R. 1961. Occurrence and mining. Pages 955-985 in J.R. Van Wazer (ed.) Phosphorus and its Compounds: Vol. II Technology, Biological Functions and Applications. Interscience Publishers, Inc., New York, NY.

Washington Administrative Code (WAC). 1992. Chapter 173-201A WAC, Water quality standards for surface waters of the state of Washington.

Washington Forest Practices Board (WFPB). 1993. Washington Forest Practices, Rules (WAC 222), Board Manual, and Forest Practices Act (RCW 76.09). Wash. DNR, For. Prac. Div., Olympia, WA.

Wolf, D.W. 1992. A literature review: Land use and nonpoint phosphorus pollution in the Tualatin Basin, Oregon. Oregon State University Extension Service and Oregon Water Resources Research Institute. Corvallis, OR. Special Rep. No. 898. 63p.

Water Quality Module Appendix

Background Discussion of Scientific Basis For Estimating the Effects of Watershed and Management Impacts on Water Temperature

Stream temperature has been widely studied and the physical processes controlling heat transfer are well understood. Most researchers have used an energy balance approach based on the physics of heat transfer to describe and predict changes in stream temperature. The six primary processes by which heat is transferred in aquatic environments are: 1) solar (short-wave) radiation, 2) radiation (long-wave) exchange with the sky and vegetation, 3) convection with the air, 4) evaporation, 5) conduction to the soil or streambed, and 6) advection from incoming water sources. Direct solar radiation is the primary source of energy for heating streams while reradiation of energy to the sky and vegetation and evaporation are the major sources of heat loss. Standing water undergoes the same heat transfer processes as streams. Most solar energy is absorbed in the upper 2 meters of water, depending upon opacity and other specific characteristics (Henderson-Sellers and Davies 1989). This portion of the water column is most subject to heating and cooling with solar radiation and heat exchange with the air. Thus all streams and wetlands and shallow lakes are affected by heat transfer processes described in this module.

The net energy balance, which is influenced by local environmental factors, determines the water temperature at a particular location at any particular time. Meteorological conditions averaged over the day explain daily maximum, mean, and minimum temperature (Edinger and Geyer, 1968). A thorough discussion of heat transfer mechanisms as they apply to forest streams can be found in Brown (1969), Theurer and others (1984), or Adams and Sullivan (1990).

Temperature of a waterbody seeks equilibrium with air temperature (Edinger et al., 1968) as both react to solar radiation with degree of adjustment primarily regulated by the local environmental factors of groundwater inflow, openness to the sky, relative humidity, and water depth (Adams and Sullivan, 1990). The combination of these factors at a site determines the energy balance and temperature.

Heat can be transported downstream with flowing water, although water temperature adjusts to local environmental conditions as it moves. If a stream flows from an open reach into a shaded reach, it will cool. Stream depth influences the rate of response (Brown 1969, Adams and Sullivan 1990, Sinokrot 1993). Very small, shallow streams respond rapidly, on the order of hundreds to a thousand feet. Deeper streams, including most fish-bearing streams, respond more slowly and the effect of the heating in the unshaded stream segment can be felt farther downstream, on the order of thousands of feet. When numerous less shaded reaches exist, there can be a downstream cumulative effect (Beschta and Taylor, 1988).

Table G-a1. Types of environmental variables affecting stream heating processes (from Sullivan et al. 1990).

GENERAL VARIABLE	EXAMPLE
GEOGRAPHY	latitude, longitude, elevation
CLIMATE	air temperature, relative humidy, wind velocity, cloudiness
STREAM CHANNEL CHARACTERISTICS	stream depth, width, velocity, substrate composition, water clarity
RIPARIAN OR TOPOGRAPHIC BLOCKING	sky-view (% shade), canopy density, vegetation height, crown radius, topographic angle

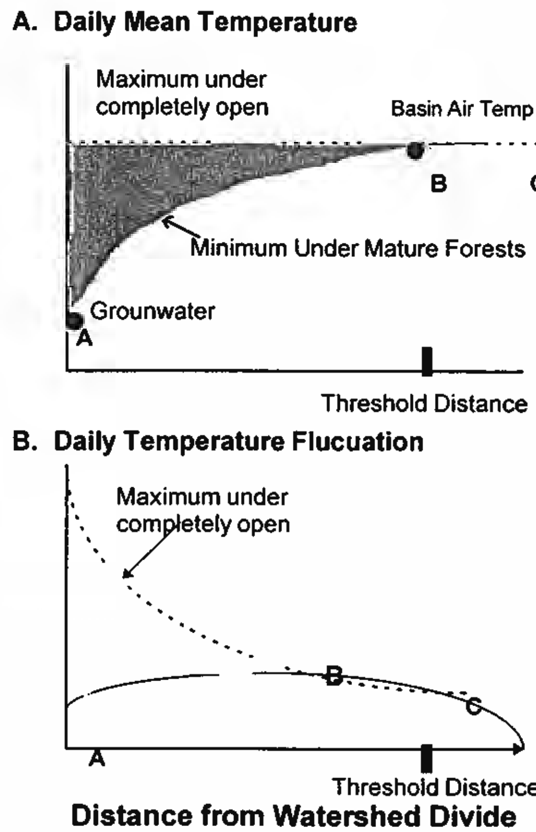
Temperature patterns within watersheds. Not all parameters are equally important for determining temperature regimes at all possible stream locations within the watershed. Rather, the relative importance of stream width, depth, shading, groundwater inflow, and air temperature in determing stream temperature tends to vary systematically by stream reach location within the watershed. Stream temperature tends to increase in the downstream direction from headwaters to lowlands, even under mature forest conditions. Expected stream temperature characteristics at a watershed scale are schematically presented in Figure G-a1 providing a conceptual framework for examining the interaction of these processes at both watershed- and stream reach-scales. This framework is thus helpful for understanding the use of reach-specific shade characteristics for estimating stream temperature as described in this module.

Figure G-a1 depicts *daily mean* temperatures and *daily fluctuations* in stream temperatures. Note that the methods in this module estimate the effects of changes in riparian vegetation at a stream-reach scale on the *annual maximum* temperature expected for that stream reach. This time-scale was selected because it was the basis of the temperature/elevation screen (Sullivan et al. 1990), and because the stream temperature characterizations produced by this module can then be related to Washington's annual water temperature standard. In addition, estimates of the annual maximum temperature permit some interpretation about stream temperatures at other time intervals (e.g., if daily fluctuations in stream temperature increase, the annual maximum temperature would, by definition, also increase). Ongoing research and data collection on stream temperature processes is expected to produce additional methods to estimate stream temperature at other spatial scales and time intervals.

At the watershed scale, the curve A-C of the upper graph can be thought of as a probable longitudinal profile of daily average stream temperature for any given stream within the basin. That is, the curve describes, in a qualitative way, the expected increase in temperature as the stream flows from point A to C (Theurer et al, 1984). The expected temperature at point A is determined primarily by the combined effects of the riparian canopy in providing shading and the effect of groundwater inflow in depressing stream temperatures below the local daily air temperatures (Sullivan and Adams, 1989). For high elevation, or groundwater-dominated streams such as those close to source, the likely maximum summer temperature can be expected to vary from about 8-10 deg. C (Sullivan and Adams, 1990). This lower curve from point A to B thus traces a "reference" temperature profile that could be expected for streams under fully shaded mature forests. The shape of this baseline temperature would be expected to vary as a function of basin air temperatures, groundwater inflow, and differences in natural vegetation (Sullivan and Adams, 1990).

Point B on the upper schematic represents that point along the stream where mean stream temperatures equilibrate primarily to local air temperatures. This point is also referred to as the "threshold distance" (Sullivan et. a. 1990). In practice, this threshold distance is that distance from the stream's origin where water temperature is primarily determined by air tempature.

Figure G-a1. Conceptual diagram of increasing temperature with distance downstream from watershed divide.



This tends to occur where the average stream depth is approximately 0.6-1.0 meters and shade is not measureable. Upstream of this threshold distance (point B), riparian shading significantly affects stream temperature, and determines: (1) the degree to which average stream temperatures are depressed below local daily average air temperatures; and (2) the range of the daily fluctuations in stream temperature (i.e., maximum and minimum stream temperatures)(Sullivan and Adams, 1989, which Coweeta studies?). Similarly, the dashed upper curve shows the expected daily mean stream temperature expected for reaches upstream of this threshold depth. This daily average maximum temperature corresponds closely to average daily basin air temperature. The hachured area between the upper and lower curves represents the increases in daily mean stream temperature associated with varying degrees of riparian canopy removal.

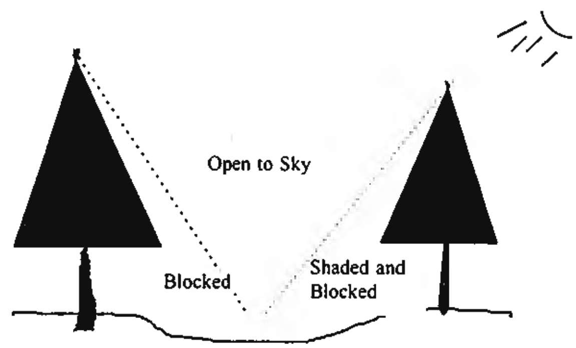
For the down-river point C, the maximum stream temperature is determined primarily by the basin air temperature. This is because low elevation, high-order streams tend to have: (1) relatively low contribution of groundwater to total streamflow; (2) stream widths that are too great for riparian vegetation to provide appreciable shading; and (3) stream depths sufficient to significantly dampen the daily stream response to solar heating (Theurer et al, 1984, Sullivan and Adams 1990). Stream temperatures that are raised above local air temperatures cool by reradiation, convection and evaporation processes, thus establishing a theoretical maximum stream temperature (Sullivan and Adams, 1990). Thus, at point C, the average stream temperature tends to equilibrate primarily to average air temperature.

The lower schematic portrays a similar longitudinal stream temperature profile from the perspective of daily fluctuations about the daily average temperature. For reaches upstream of the threshold distance, stream depth is a key parameter that determines how quickly the stream reach heats up, and how great the daily fluctuation in temperatures will be. As a general rule of thumb, the expected range in daily stream temperature fluctuations can be up to 75-80% of the daily fluctuation in local air temperatures (Sullivan and Adams 1990).

Assuming typical river valley formation, it appears that the portion of the watershed where vegetation has some effect on water temperature may lie within 50-60 km (31-37 miles) of the watershed divide in western Washington (Sullivan et al. 1990). Specific conditions within watersheds such as differences in valley form accompanying geologic substrate may alter the temperature profile and move the threshold for riparian vegetation influence up or downstream. Some valleys may be flatter or wider than average (e.g. glaciated terrain) and some may be steeper and deeper (e.g. incised or entrenched rivers). Elevation, vegetation, and summer air temperature differences may also make these relationships differ between watersheds east and west of the crest of the Cascade Mountains.

Determining shading effects of riparian vegetation. The waterbody's view-to-the-sky (the inverse of which is often inexactly referred to as "shade") (Adams and Sullivan, 1990) is a major environmental factor influencing stream temperature that can be affected by forest practices (Beschta et al. 1987). In the absense of riparian shade, water temperature will be near air temperature except where groundwater infow is significant. The proportion of the sky view that streamside vegetation can effectively block determines the proportion that water temperature will be depressed below air temperature.

Figure G-a2. Conceptual diagram of factors blocking radiation exchange and view-to-the sky.

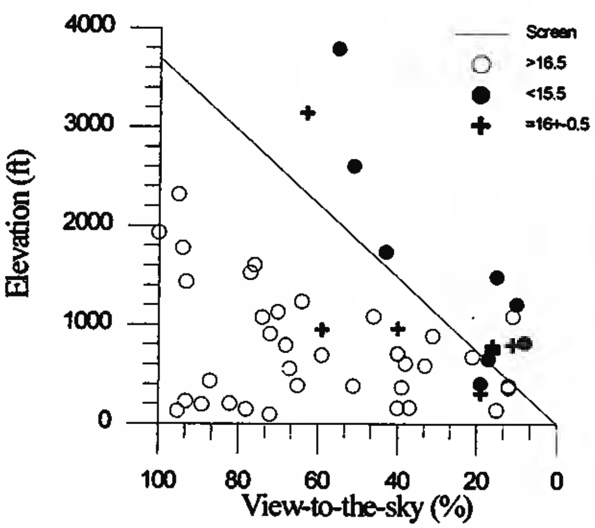


Blocking of in-coming and out-going radiation is determined by the height of streamside vegetation and topographic features within the overhead hemisphere that is the stream's "field of view" (Figure G-a2). The effect of blocking factors is very significant in small to moderate-sized forested streams, helping to maintain cool water temperature during warm summer months. Brown (1969) demonstrated that consideration of direct beam radiation to the stream surface is an important determinant of stream temperature response to solar input. Shade is a measure of the effects of incoming direct beam solar radiation. However, as a measure of heat exchange, it fails to adequately account for other important mechanisms that block outgoing radiation. Adams and Sullivan (1990) and Sullivan et al. (1990) used view-to-the-sky as a measure of blocking in modeling stream temperature with little or no loss of precision. There is some inaccuracy associated with using either view-to-the-sky or shade as a measure of factors that account for both incoming and outgoing radiation. Since view-to-the-sky is far easier to estimate than shade it is used in the calculations in this module. Treatment of the more complex elements of shade and solar angle as performed by Theurer et al. (1984) would not appreciably improve results (Sullivan et al. 1990).

The ability of vegetation to block incoming and outgoing radiation depends on its height relative to the width of the water body. Along very small streams almost any vegetation and streambanks themselves will provide shade, while tall trees and major topographic features are necessary for significant shading of larger rivers. Lakes are often too wide for any vegetation to be an effective control of water temperature. However, small or moderate-sized lakes may not be fully shaded but they may still be affected by the blocking of radiation by streamside vegetation. The maximum potential shade depends on the features of native vegetation.

View-to-the-sky and water temperature. An extensive study of temperature in Washington streams confirmed that watershed and landuse factors influenced water temperature consistent with previous research (Sullivan et al. 1990). Despite the complexities of site conditions on local control of temperature, the study was also able to identify a simple relationship between view-to-the-sky and elevation that could be used to predict the maximum allowable view-to-the-skythat would maintain temperature within water quality criteria for purposes of guiding riparian area management in state forest practice regulations. Referred to as the "temperature screen", the data and relationship is reproduced in Figure G-a3). Documentation of the basis of the simple model is provided in Sullivan et al., 1990, see chapters 6 and 7). Relationships for streams east and west of the Cascade Mountain divide have been adopted as the temperature screen by the Washington Forest Practices Board (WFPB, 1993) for use in prescribing shade requirements on a site-by-site basis.

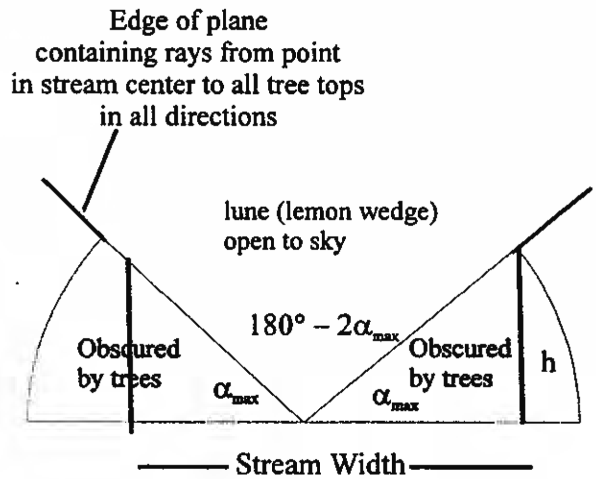
Figure G-a3. Temperature screen for westside plotted with original data from Sullivan et al. (1990). Included are 14 new data points from the Chehalis River.



Note that the screen isolates regions of the elevation/view relationships where annual maximum temperature falls above or below 16.0oC. The line was fitted by eye to best envelope the data. When sites are misclassified, the screen tends to specify more shade than necessary (it misses more low temperature sites than high temperature sites). Only one data point on Figure G-a3 is warmer than expected given the elevation and view-to-the-sky of the site. At low elevations, considerable shade is required to maintain low temperature, and the definition of the boundary is more muted. When comparing measured versus modeled results, analysts are reminded that the screen is a first order approximation of temperature adopted on the basis of ease of use and reasonable accuracy for prescribing forest practices.

Estimating view-to-the-sky based on vegetation. Vulnerability to heat input is determined by evaluating potential temperature based on fully mature streamside forest conditions and likelihood that forest management can reduce shade sufficiently to exceed temperature standards. Since forest managment has altered many riparian forests from old growth forest conditions, there is rarely data available for measuring fully shaded stream conditions. This module provides a method for estimating the openness of the stream based on geometry of the riparian setting in the absence of measured data.

Figure G-a4. Definition sketch of view-to-the-sky in two dimensions.



Geometric relationships can be applied to calculate the angle from the stream center to the top of the blocking elements. In two dimensions, the sky can be represented as an arc of 180¡, and view-to-the-sky is the fraction of the arc that is unobstructed (Figure G-a4). Essentially this is in a vertical plane perpendicular to the stream banks. The larger the angle without obstructions, the larger view-to-the-sky. For a given maximum vegetation height (tree or shrub as appropriate) and stream width, it is possible to calculate view-to-the-sky as the portion of the horizon not blocked by vegetation and topography.

(Figure G-a5). If the angle α is greater than the hillslope angle (λ), then the stream does not "see" trees beyond the first solid block of trees near the bank and α is the appropriate angle for estimating view-to-the-sky and the effects of topography can be ignored. If the nearstream angle is less than the hillslope angle, than the sideslopes provide more blocking than the streamside trees and topographic effects are significant. In this case, the hillslope angle λ is the appropriate angle to use for the calculations. Topography may be a significant factor reducing view-to-the-sky along stream segments that are moderately to tightly constrained.

Stream width affects view-to-the-sky by determining the location of the closest vegetation to the stream center, and thus the angle and proportion of the overhead hemisphere blocked (Figure G-a6). Small streams can be nearly completely shaded by overhanging trees or shrubs. Medium streams can be partially shaded by trees of suitable size. The largest streams get little shade from even the tallest trees. It should be noted that the view-to-the-sky is not dependent on the angle of the sun, which will vary during the year and with latitude. Using view-to-the-sky as the measure rather than shade allows estimates based on riparian geometry.

This 2-dimensional representation over-simplifies the surface area of the 3-dimensional hemisphere above the stream. View-to-the-sky is the fraction of a hemisphere centered over the stream which is unobstructed by vegetation or topography (Figure G-a7). The hemisphere extends from horizontal to vertical (0-90¡ of elevation), and around the compass (0-360¡ of azimuth). View-to-the-sky is therefore a 3 dimensional concept. There is an occluded plane that contains the line along the center of the corridor and the line formed by the top of the trees. The intersection of this plane and the celestial sphere is a great circle. The horizontal plane at the stream surface also intersects the celestial sphere forming a hemisphere which is the potential field of view of the water surface.

Topography can also affect the view-to-the sky Similarly, the same size tree can have very different effect on the view-to-the-sky depending on the stream width. Only on a perfectly flat landscape with no vegetation or topography is it possible to attain a view-to-the-sky of 100%.

Figure G-a5. Effects of stream width on view-to-the-sky.

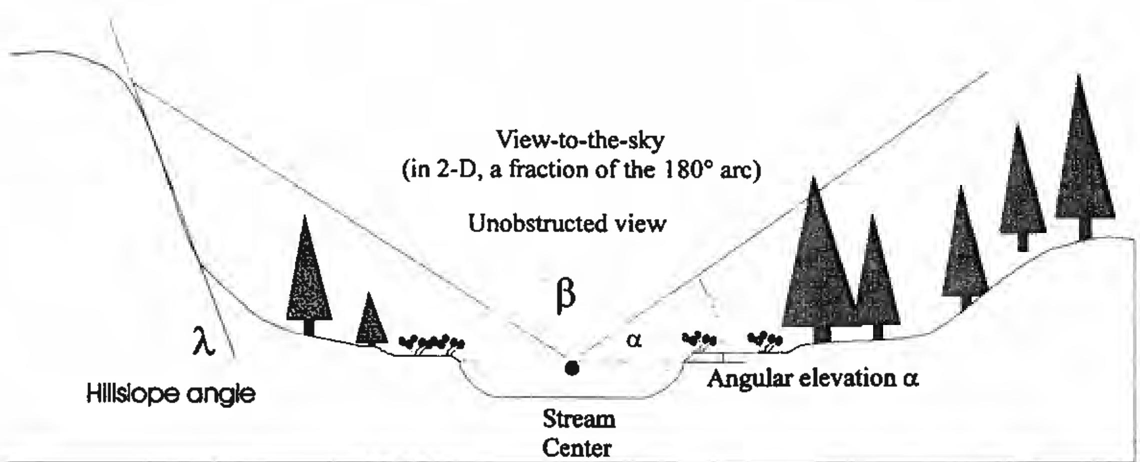


Figure G-a6. Effects of stream width on view-to-the-sky.

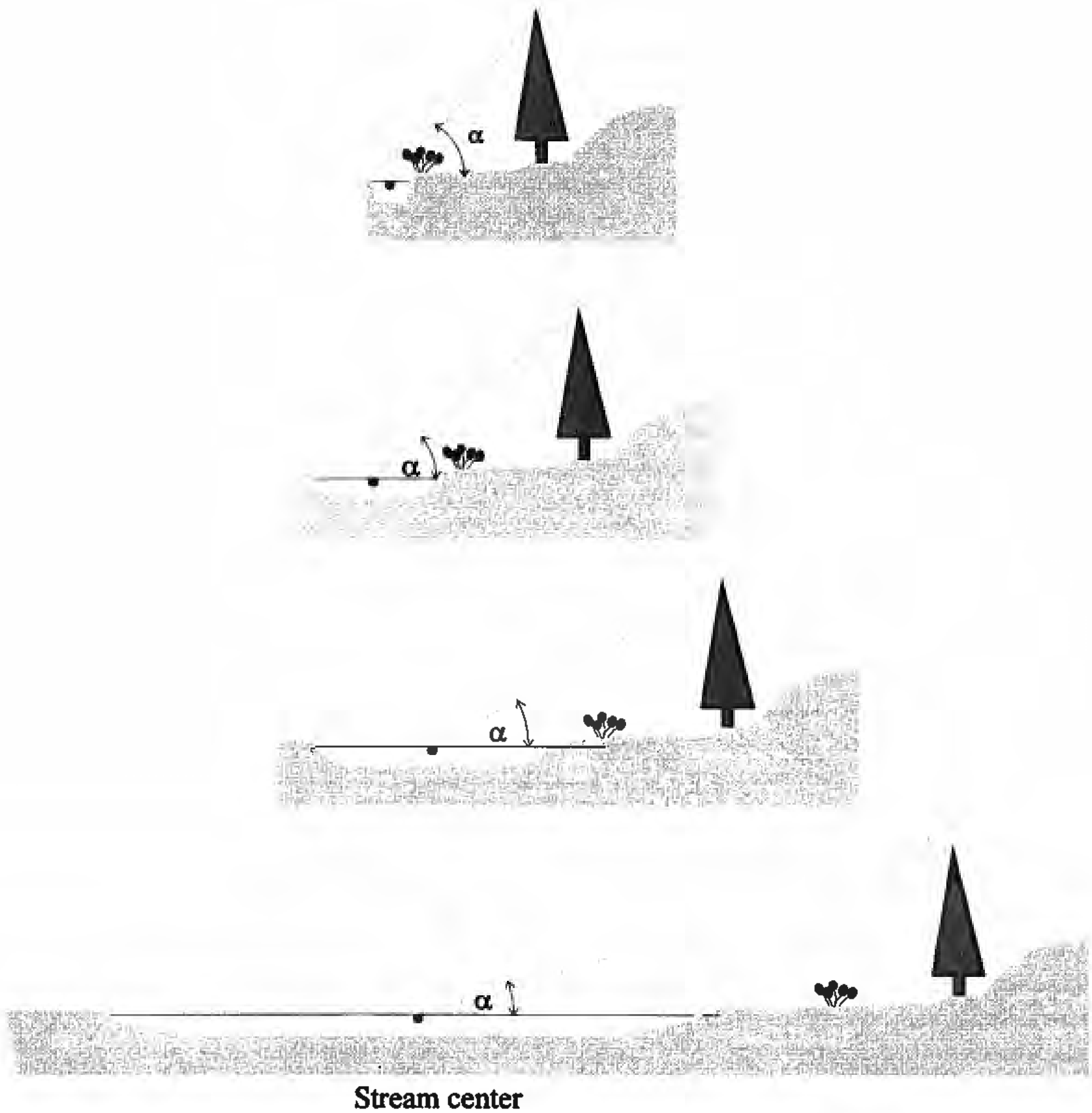
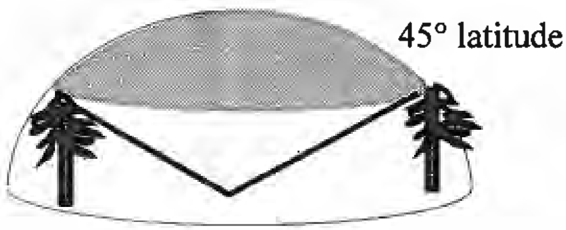


Figure G-a7. Three-dimensional representation of the sphere of view of a waterbody.



Consider the hemisphere in quadrants (Figure G-a8). On wider streams, quadrants facing the banks may have a considerable portion of the angular view blocked by vegetation, while quadrants facing up and downstream may be quite open. This geometry can have an important effect on estimations of view-to-the-sky in wider channels. The slice of sky viewed by the stream between two banks of trees is represented as the area of a geometric shaped termed a "lune" defined by the angle α (degrees) on a celestial sphere (Figure G-a4). To calculate view-to-the-sky, first determine the angle, α (in degrees) that is open above the stream (Figure G-a4). The angle α may be directly measured, or estimated from equation 1 based on the height of trees (h) and width of stream (w).

$$\alpha = \text{ArcCos}\,(w/\,\text{SQRT}\,(w^2+4h^2)) \quad (1)$$

The surface area (A) for the lune whose angle is α is:

$$A = (180-2\alpha/360)4\pi r^2 \quad (2)$$

$$= 2\pi r^2 - \frac{\pi r^2 \alpha}{45} \quad (3)$$

The calculation of view-to-the-sky involves dividing the surface area of the lune above the stream by the surface area of the entire horizon above the stream plane.

$$\text{View-to-the-sky } (\%) = \frac{(2\pi r^2 - \pi r^2 \alpha/45)100}{2\pi r^2} \quad (4)$$

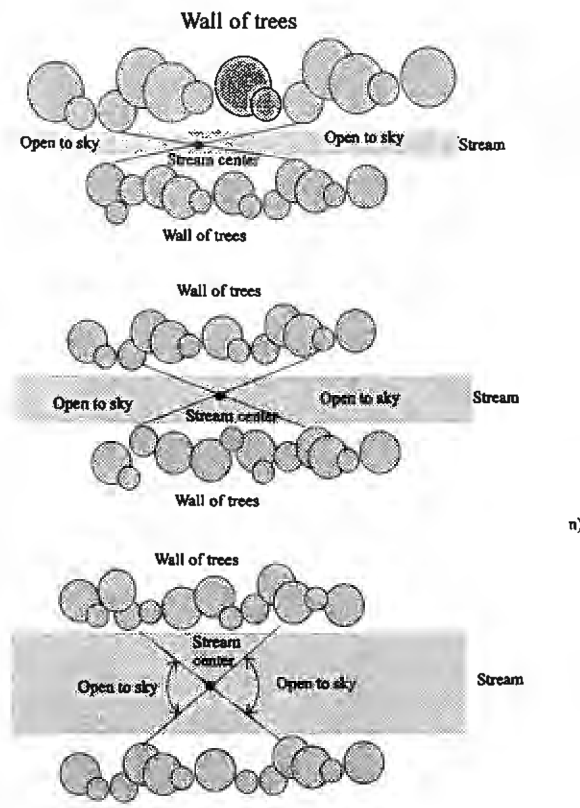


Figure G-a8 Conceptual diagram of the three-dimensional view-to-the-sky from the center of a straight reach of stream

Considering the horizon of view, and therefore r, as large, the radius cancels from the equation with division, making the area of the lune primarily dependent on the angle formed by the trees. This simplifies to

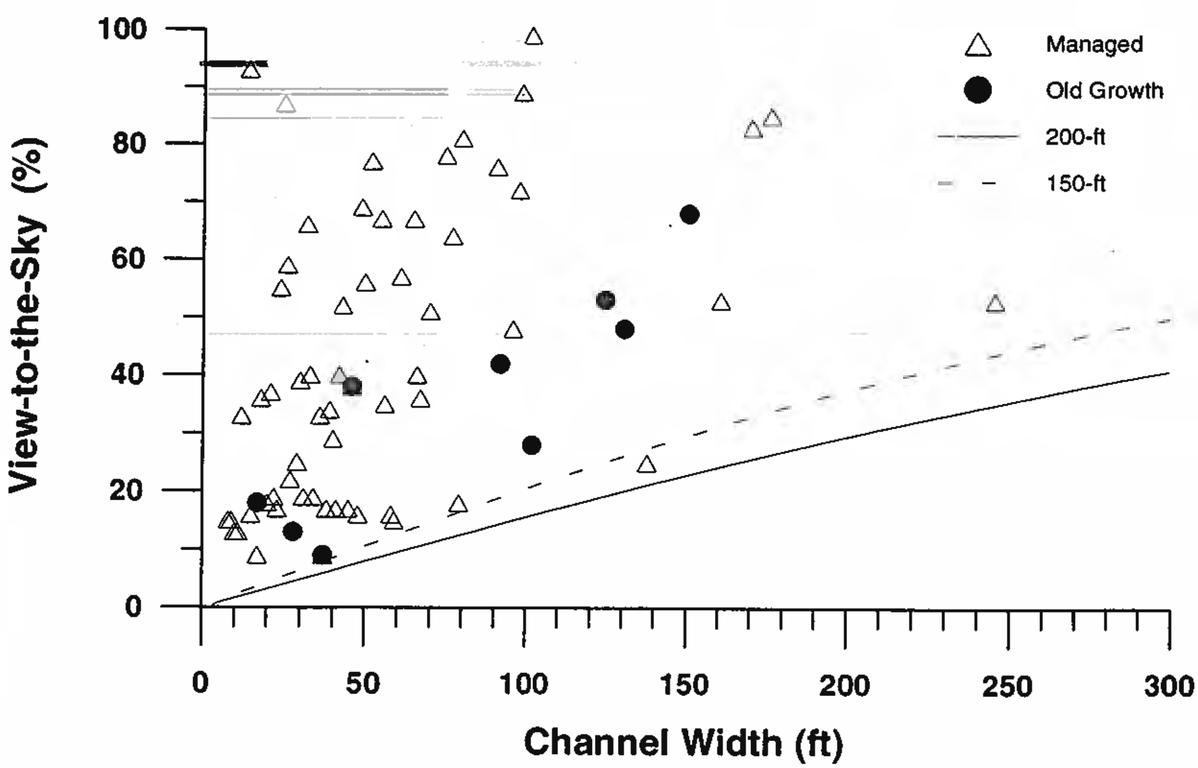
$$\text{View-to-the-sky } (\%) = 100 - \frac{10}{9}\alpha \quad (5)$$

Several assumptions underlie potential view-to-the-sky calculations based on geometric relationships. Maximum potential height of native overstory species is assumed to be the height of blocking vegetation (h). Potential view-to-the-sky is determined by making the above calculations based on the site as it could be with mature vegetation (whether shrubs or trees). The analyst must assume an appropriate height of the forest stand or shrub commuity that would occupy the site under historic natural conditions. It is also assumed that blocking elements are the same on both sides of the stream. Bankfull stream width (w) is assumed to be the maximum distance between blocking elements on opposite banks. Calculation of view-to-the-sky at the center of the stream is sufficient to adequately represent blocking effects. Although the sides of larger streams may be partially shaded while the center is represent blocking effects. Although the sides of larger streams may be partially shaded while the center is fully open, heat is rapidly mixed in the water column and the center of the stream is likely to adequately represent the average condition. Streams may meander. This characteristic will make little difference in estimates of view since small streams are nearly fully closed based on calculations regardless of channel pattern and the horizon effect on large streams is small.

Calculations of potential view-to-the-sky were performed via spreadsheet for bankfull widths ranging from 0 to 300 feet (Figure G-a9). Calculations assumed effective tree heights of 150 and 200 feet (shown as lines). Estimates of view-to-the-sky for old growth conifer forest conditions represent the minimum view-to-the-sky possible for each segment of a given stream width. Thus the calculated lines in Figure G-a9 should be minimums and all points should plot on or above the appropriate line for forest height. Streams that have had shade removed should plot somewhere between the minimum and 100% open.

The geometric model provides a minimum fit to the data as expected, including data from larger rivers (Figure G-a9). Although the maximum height modeled was 200-feet, view-to-the-sky in old growth forests appeared to have a best fit by assuming tree height of 150-feet or less, although trees in old growth or mature forest stands were undoubtedly taller than this. There may be several reasons why streams appear to be more open than calculations suggest. Note that the above formulation assumes a solid (impenetrable) wall of trees. In fact, real trees only partially obscure view-to-the-sky, especially in the upper portion of the canopy or if vegetation is not dense. In the calculations shown in Figure G-a9 there was no compensation for opacity of the upper portions of the forest stand. These results suggest that perhaps as much as 25% of the total tree height has a significant loss of opacity which was not accounted for in calculations. Thus, view-to-the-sky calculations using total tree height bias estimates of minimum view to lower values than probably naturally occur. It also appears that 150-ft or 75% total tree height is a better estimator of the blocking effect of mature conifers on the westside of the Cascades.

Figure G-a9. Calculated result of view-to-sky equations for effective height equal to 200-ft and 150-ft. Data from TFW sources for westside sites is also plotted tocompare to the vegetation calculations. Points labeled "managed" were collected by TFW cooperators along streams with various histories of logging in riparian areas. Sites labeled "Old Growth" were reported to be representative of old growth stand conditions. Lines are labeled according to tree height used in the calculation.

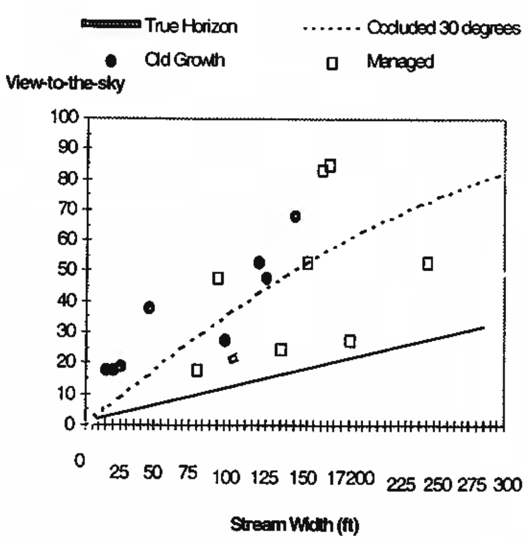


Conversely, the densiometer measuring instrument overestimates the openness of the stream. The convex mirror of the instrument is inset into the wood platform on which it is mounted. The emplacement of the mirror into the platform occludes nearly 30 degrees at the base of the mirror, thus seeing less of the horizon at the base than the stream would "see". Although an apparently small amount when gazing at the instrument, this portion represents a rather large area of the hemisphere above the stream. As much as 50% of the area of a hemisphere lies below 30 degrees on the horizon which would not be measured with the instrument. The larger the stream, the greater the effect on measured view.

However, overestimation of openness during measurement partially accounts for real differences in effectiveness of energy transfer around the celestial sphere. Energy exchange is not equal around the hemisphere: it reaches a maximum straight overhead and declines toward the horizon with the cosine of the angle according to Lambert's Law (Mills, 1992).

Algebraically solving for this factor in the above calculations for the lune illustrates the instrument bias (Figure G-a10). Note that the measured view of larger channels is more open to the sky than predicted by the equations (Figure G-a9). For larger streams, the calculated view appears to be more representative of the true condition, and is reasonably consistent with most observations. In reality, the effective view-to-the-sky lies somewhere between that calculated using equation 4 and that measured in the field by a spherical densiometer. This analysis uses the calcuated view recognizing that it underestimates the actual view-to-the-sky.

Figure G-a10. Calculated view -to-the-sky of 150-ft tall trees assuming horizon at the ground, and horizon at 30 degrees above the ground as measured by spherical densiometers. Also shown are data from Figure G-9 representing old growth sites and other sites with stream widths greater than 100 feet.



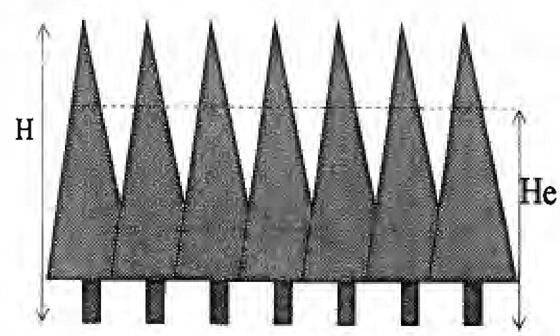
The stream's view of the hemisphere of the sky above it depends on the height and light filtering capacity of objects blocking that view. View-to-the-sky is therefore a function not only of the width of the stream but also of factors that control the height and density (Figure G-a11). To compensate for the gaps in vegetation cover, as viewed sideways from the stream, the analyst can take several steps which further improve the calculation. Since most trees are full in the mid-canopy, but less than opaque in the tree-tops, the analyst can translate that partial opacity into an effective tree height.

$$H_e = H * \% \text{ opacity} \quad (6)$$

A 120-foot Douglas-fir might be 70% opaque. The effective tree height would then be 84 feet

View-to-the-sky can be calculated by the same formula given above, but substituting effective tree height H_e for H. An additional correction may be needed if the trees are sparse, for example in east-side situations where there are substantial gaps between trees. Use of an opacity factor should be based on field estimates from reference sites and should be ignored if these are not available.

Figure G-a11. Conceptual view of opacity factor accounting for openness of stand.



He = effective tree height
H = total tree height

Estimated temperature based on view-to-the-sky. Data on which the temperature screen was developed from the TFW temperature study (Sullivan et. al. 1991) was used to develop a relationship between view-to-the-sky and maximum temperature. In Figure G-a3, the line representing the temperature screen approximates the relationship between elevation and view-to-the-sky where water temperature is equal to 16°C. Conceptually, the distance each point is away from the line for a given elevation should reflect the distance temperature is likely to vary from the reference. Thus, the difference between existing or potential view-to-the-sky and the screen reference view-to-the-sky can be translated to water temperature as shown in Figure G-a12.

The TFW temperature study provided a rule of thumb estimate that 10% change in view-to-the-sky results in 0.6°C (1°F). Analysis of Figure G-a12 allows recalibration of this relationship to 0.7 °C (1.3°F). The relationship plotted in Figure G-a12 was reformatted for ease of use in water quality module calculations in Figure G-a13.

This approach to calculating maximum temperature has better predictive capability than linear regression of view-to-the-sky and temperature (R^2=.34). The method can be easily applied at the watershed scale using potential or existing view-to-the-sky. The analysis should provide a generalized perspective of temperature at that scale, although it is probably imprecise in locating exact temperature profiles.

Results suggest that this simple approach to estimating water temperature should provide a first approximatation of annual maximum temperature at the watershed scale. There is scatter in the relationship (Figure G-a12) and the water quality analyst should use care in interpreting modeled results in comparison with measured results. Since the model works reasonably well for explaining measured temperature patterns in relation to riparian vegetation, it should provide reasonable estimates of modeled temperature based on estimates of potential view calculated from riparian geometry.

Figure G-a12. Annual maximum temperature in relation to the Difference in view-to-the-sky between potential and allowable based on the temperature screen.

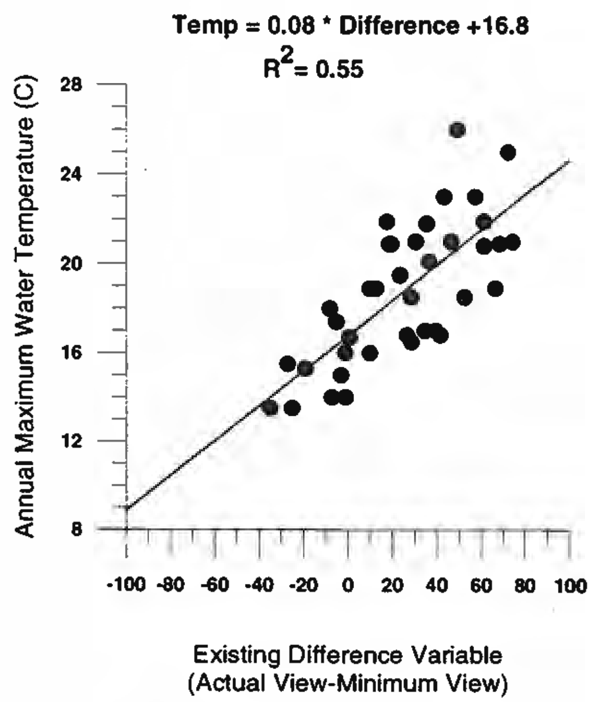
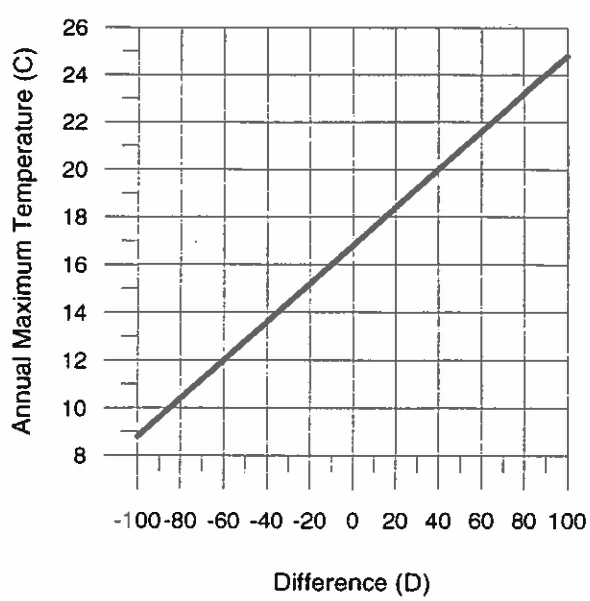


Figure G-a13. Simple model for predicting annual maximum temperature in western Washington based on view-to-the-sky and elevation.



Water Quality Module Appendix

Profiles Of Wetland Classes And Subclasses For Lowland Washington (Draft, Department of Ecology 3/97)

Class: Riverine

Riverine wetlands occur in floodplains and riparian corridors in association with stream or river channels. They lie in the active floodplain of a river, and have important hydrologic links to the water dynamics of the river or stream. The distinguishing characteristic of riverine wetlands in Washington State is that they are frequently flooded by overbank flow from the stream or river. The flooding waters are a major environmental factor that structures the ecosystem in these wetlands. Wetlands that may lie in floodplains but are not frequently flooded are not classified as riverine.

Surface and shallow subsurface water movement in most Riverine wetlands is from the valley sides toward the stream channel, from the stream channel toward the adjacent floodplain and downstream during overbank events. Additional water sources may be groundwater discharge from surficial aquifers, overland flow from adjacent uplands and tributaries, and precipitation.

Water leaves Riverine wetlands by surface flow returning to the river or stream channel after flooding or a rain event. The wetlands also may lose subsurface water by subsurface discharge to the channel (called interflow), movement of water to deeper groundwater through permeable geologic formations, and evapotranspiration.

Many Riverine valley wetlands are associated with rivers that are very dynamic. Their proximity to the river facilitates the rapid transfer of floodwaters in and out of the wetland, and the import and export of sediments. These wetlands are subject to frequent flood disturbances that may reset the "successional clock." The dominant vegetation in these wetlands may be reprensetative of any of the seral stages possible; from early successional, emergent species, to late successional forest species. Near the headwaters of streams and rivers, Riverine valley wetlands are often replaced by depressional or slope wetlands, where the channel (bed) and bank disappear, and overbank flooding grades into surface or groundwater inundation. In headwaters, the dominant source of water becomes surface runoff or groundwater seepage. For the purposes of classifying wetlands, wetlands that show evidence of frequent overbank floodingeven if from an intermittent stream, are considered to be in the class Riverine.

The downstream extent of riverine wetlands is where they normally intergrade with estuarine fringe wetlands. According to the hydrogeomorphic classification, the riverine class is dominated by unidirectional flows (Brinson 1993, Brinson et al. 1995). The interface with estuarine fringe occurs where the dominant hydrodynamics change to bidirectional flows, tidal, flows (Brinson et al 1995). This interface has been significantly modified in western Washington by diking. Many wetlands that were once freshwater tidal (a subclass of estuarine fringe in Washington) are now either Riverine or Depressional (depending on the frequency of flooding).

Riverine wetlands normally extend perpendicular from the stream or river channel to the edge of the area that is frequently flooded (also known as active floodplain). Wetlands in large floodplains that are found outside the areas frequently flooded, and in landscapes with great topographic relief and steep hydrostatic gradients may function more like slope or depressional wetlands because the water regime is dominated by groundwater sources (see discussion in Brinson et al. 1995).

Field Characteristics for Riverine Wetlands in Washington State: The operative characteristic of Riverine wetlands in Washington State is that of being "frequently flooded" by overbank flows. The assessment teams and technical committee, however, decided that this characteristic could only be determined from field indicators. The water regime of Washington's wetlands have enough variability between dry and wet years that a frequency of flooding (e.g. flooded at least once every two years) could not be used. The field indicators that are to be used to classify a wetland as riverine are still being developed.

Subclass: Flow-through

Riverine Flow-through wetlands are those that do not retain surface water significantly longer than the duration of a flood event. Water tends to flow through the wetland rather than pond in the wetland. Usually the water does not remain in the wetland more than several days after the surrounding landscape is drained. Soil saturation, however, may be maintained by groundwater seepage from valley walls. Flow-through wetlands usually have evidence of active erosion and deposition and have a dynamic, fluctuating hydroperiod that closely matches that of the stream or river.

The wetlands in this subclass tend to be found in, or adjacent to, the active channel of a river or larger stream. They may be the vegetated bars in the active channel or form on recent alluvial deposits along the sides of the channel or within the channel.

Field characteristics of Riverine Flow-through Wetlands for Western Washington: has a less dense herbaceous understory and commonly contains stinging nettle contains deciduous shrubs and trees (conifers less likely) the soils are more coarse and have higher mineral content than those found in the Impounding subclass the vegetation tends to be less diverse than in the Impounding subclass. This profile will be expanded to include descriptions of how wetlands in this subclass performs the 16 functions after reference data are collected during the field calibration of the models.

Subclass: Impounding

Riverine Impounding wetlands are those that retain surface water significantly longer than the duration of a flood event. Impounding wetlands tend to hold water longer than a week after a flood event. These wetlands are found within a topographic depression on the valley floor or in areas where natural or man-made barriers to downstream flow occur. The depressions may be filled with sediments or organic deposits. The critical characteristic, however, is that these wetlands retain flood waters after an event longer than the surrounding landscape. The impounding wetlands often have no outlet, or a constricted outlet, and have a hydroperiod that is less dynamic than that found in the adjacent stream, river, or "flow-through" wetland in the same valley. Most of the Impounding riverine wetlands are in the less dynamic parts of the floodplain; often on floodplain terraces or in old oxbows. Many may have peat accumulations that have become isolated from the usual riverine processes, and they are subjected to long durations of saturation from surface or groundwater sources. Riverine processes will dominate only during the flooding event, though the groundwater levels may be controlled by water levels in the hyporheic zone through hydrostatic processes.

Many wetlands in lowland Washington fall into this subclass because their surface water connections have been reduced by dikes or roads. These wetlands at one time did not retain floodwaters longer than the actual flooding event, but now do so because of some blockage.

Field characteristics of Riverine Impounding wetlands for western Washington: more herbaceous understory and commonly contains skunk cabbage aquatic vasculars are frequently present if there is a forested component, may contain conifers contains finer soils which may have a higher organic content vegetation tends to be more diverse than in Flow-through wetlands.

This profile will be expanded to include descriptions of how wetlands in this subclass performs the 16 functions after reference data are collected during the field calibration of the models.

Class: Depressional

Depressional wetlands occur in topographic depressions, that exhibit a closed contour interval(s) on three sides and elevations that are lower than the surrounding landscape. The shape of depressional wetlands vary, but in all cases, the movement of surface water and shallow subsurface water from at least three cardinal directions in the surrounding landscape is toward the point of lowest elevation in the depression. The movement of surface water in depressional wetlands is also vertical (up and down). Depressional wetlands may be isolated with no surface water inflow or outflow through a defined channel, or they may have permanent or intermittent, surface water inflow or outflow in defined channels, that connects them to other surface waters or wetlands. Streams draining into a wetland may modify the topographic contours of the depression where they enter or exit the wetland. Depressional wetlands with channels or streams differ from riverine wetlands in that their ecosystem is not significantly modified by riverine flooding events.. Headwater wetlands would be classified as depressional because overbank flooding is not a major ecological "driver".

Depressional wetlands may lose water through intermittent or perennial drainage from an outlet, by evapotranspiration, and flow into the groundwater at times when they are not receiving discharge from groundwater.

The Flow-through and Closed subclasses have very similar positions in the landscape that do not warrant separate geomorphic profiles. Differences between the subclasses are based on the functions they perform. The geomorphic characteristics of depressional wetlands in lowland western Washington are as follows:

1. Depressional wetlands in lowland western Washington are found in the following geomorphic settings; 1) Former kettleholes left by receding glaciers, 2) in depressions on top of clay lenses in glacial outwash, such as the area between Olympia and the Chehalis River, 3) headwaters of lowland streams, 4) alluvial terraces

above the existing floodplains, and 5) depressions in glacial till.

2. Many depressional wetlands have well developed peat deposits because the outflow, if it exists, is above the base of the depression. Thus, organic matter will tend to collect.

Field Characteristics for Washington State: Depressional wetlands in the lowlands of western Washington lie in topographic depressions where the slope on at least three sides above the wetland is greater than 1%, and that are not within the active floodplain of a stream or river. There may be a stream going through the wetland, but if so it is not the major source of physical energy to the system.

The topographic depressions that characterize the position of this class in the landscape can be very small with only slight differences in elevation between the wetland and surrounding uplands. Some depressional wetlands are found on relatively flat surfaces. They are formed in depressions that exit in soils with low permeability such as glacial till plain.

Very small wetlands found in surface depressions with only a 1-3 foot topographic relief may be difficult to classify. If such small wetlands form a mosaic on a landscape that is flat it may be more appropriate to classify them as a single wetland in the "Flats" class if the only source of water to the wetland is precipitation. If the wetland receives a significant amount of its water from a surrounding contributing basin, however slight the topographic relief, it would be classified as a Depressional wetland. A Flats wetland, on the other hand, receives its water by direct precipitation over the area within the wetland only.

Subclass: Flow-through

Depressional Flow-through wetlands are those that have a surface water outflow to a stream or river that eventually discharges into the ocean for at least part of the year. Inflow may be from surface water flowing down from the surrounding topographic relief, from an intermittent or permanent stream(s), or from groundwater.

This profile will be expanded to include descriptions of how wetlands in this subclass performs the 16 functions after reference data are collected during the field calibration of the models.

Subclass: Closed

Depressional Closed wetlands are those that have no surface water outflow to channels, streams, or rivers. Closed depressional wetlands may have surface water inflow but no outflow through a defined channel.

This profile will be expanded to include descriptions of how wetlands in this subclass performs the 16 functions after reference data are collected during the field calibration of the models.

Class: Slope

Slope wetlands occur on hill or valley slopes. Elevation gradients may range from steep hillsides to slight slopes. Principal water sources are usually groundwater seepage and precipitation. Slope wetlands may occur in nearly flat landscapes if groundwater discharge is a dominant source of water and there is flow in one direction. The movement of surface and shallow subsurface water is perpendicular to topographic contour lines. Slope wetlands are distinguished from the riverine wetland class by the lack of a defined topographic valley with observable features of bed and bank. Slope wetlands may develop channels but the channels serve only to convey water away from the slope wetland.

Field characteristics for Washington State: Slope wetlands in Washington are found on hillsides or at the edge of hill where they grade into a river valley. They are identified by the fact that: 1) they are on a slope, even if very gradual), 2) they lack closed contours and cannot store surface water, and 3) they have no obvious surface water inflows such as streams or channels.

Subclass: Slope Connected

Slope wetlands with a surface water connection, at least periodically, to an intermittent or perennial stream or other surface water body connected to a stream or river that discharges into the ocean.

Subclass: Slope Unconnected

Slope wetlands isolated from streams or surface waters.

Class: Flats

Flats wetlands occur in topographically flat areas that are hydrologically isolated from surrounding groundwater or surface water. The main source of water in these wetlands is precipitation. They receive virtually no groundwater discharge which distinguishes them from depressional and slope wetlands. The DOE Technical Committee decided that for Washington there was no need to create two separate classes for Flats as proposed in the current HMG documentation. "Flats" wetlands are not very common in the state, and the committee judged that both organic and mineral flats found in the state perform the same functions and do not need to be separated. The DOE team developing the models for the flats, however, may decide that further divisions are necessary.

Class Lacustrine Fringe

Lacustrine fringe wetlands occur at the margin of topographic depressions in which fresh surface water is greater than 2 meters deep. They are found along the edges of bodies of water such as lakes. The dominant surface water movement in fringe wetlands has a bi-directional horizontal component due to winds or currents, but there may also be a corresponding up and down vertical component resulting from seiches, wind, or seasonal water fluctuations.

Field characteristics for Washington State: Lacustrine fringe wetlands are those adjacent to bodies of freshwater that are at least two meters deep with no evidence of water flow in one direction. Some wetlands may be adjacent to rivers that are more than two meters deep but these would be classified as riverine because there is measurable flow in one direction.

No subclasses are proposed for the Lacustrine Fringe class in Washington State.

Class: Estuarine Fringe

Estuarine fringe wetlands occur at the margin of topographic depressions in which marine waters are greater than 2 meters deep. They are found along the coasts and in river mouths to the extent of tidal influence. The dominant source of water is from the ocean or river. The one unifying characteristic of this class is hydrodynamic. All estuarine fringe wetlands are have water flows dominated by tidal influences with water depths controlled by the tidal cycles.

Subclass: Estuarine Saltwater Fringe

Estuarine fringe wetlands in which the dominant water flows have salinities that are higher than 0.5 parts per thousand.

Subclass Estuarine Freshwater Fringe

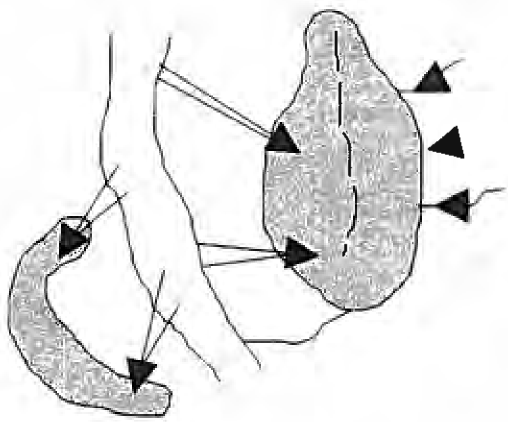
Estuarine fringe wetlands in which the dominant water flows are tidal but freshwater, with salinities below 0.5 parts per thousand.

HGM CLASSIFICATION FOR WASHINGTON

RIVERINE

flooded frequently by river: "Frequently" to be determined by field indicators

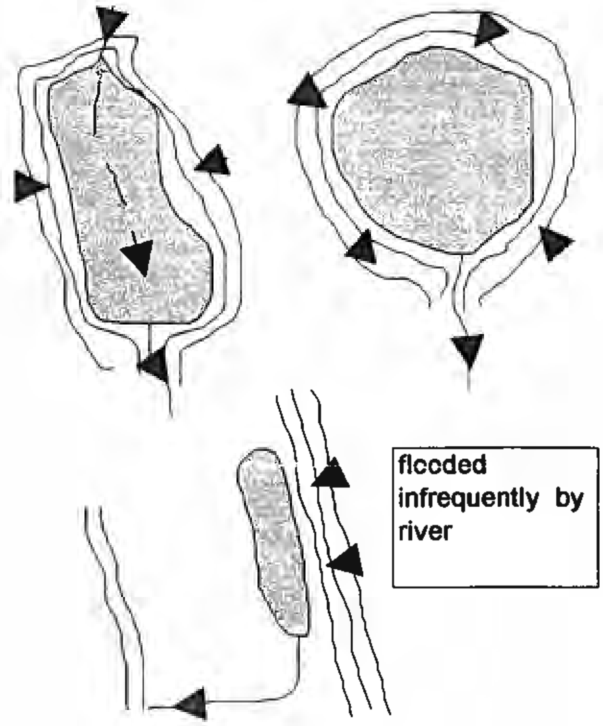
Impounding



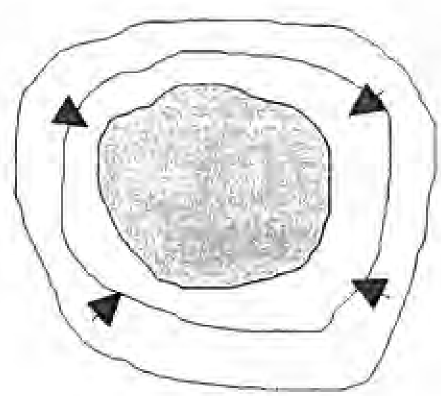
Flow-through

DEPRESSIONAL

Flow-through



Closed



Linkage Between Water Temperature and Watershed Conditions--Making Vulnerability Calls

Prior to the synthesis steps that involve all of the assessment modules, the water quality analyst will consider watershed factors other than riparian vegetation that may affect the vulnerability of streams to temperature change. The water quality analyst will work with other analysts and the products they developed from the hydrology, mass wasting, channel, riparian and fish habitat modules, as well as ancillary data on fisheries resources, to develop an integrated assessment of the likely effects of forest practices on stream temperature and other water quality parameters. The following steps describe the general process by which several module assessments are used to create the water temperature vulnerabilities. It is important to bear in mind that water quality issues not covered in this manual may arise. The analysts must rely on the data describing the situation and their knowledge of watersheds and water quality to create vulnerability calls.

The initial determination of water temperature vulnerability is based on estimates of potential and minimum allowable view-to-the-sky as it is influenced by riparian vegetation and topographic blocking. The method described in the water quality module is based on simplified approaches for stream temperature prediction that neglect important watershed factors other than riparian vegetation that can influence temperature including stream depth, channel width, groundwater inflow and air temperature (Sullivan and Adams, 1990).

Additional impacts on water temperature vulnerability are considered by the watershed assessment in this section. Natural or management-caused conditions may exist in the WAU that increase or decrease the temperature vulnerability. Table 1 lists a number of conditions related to potential changes in key environmental variables. These include the effect of natural variability or anthropogenically caused differences in channel, flow, climatic, or riparian vegetation variables, potential shade loss, relative to the assumptions on which initial vulnerability determinations are made. Criteria for identifying when differences are sufficient to consider potential effects on temperature are provided. These are based on sensitivity analysis of the effect of environmental variables on temperature found in the TFW evaluation of temperature prediction (Sullivan et al. 1990) and Sullivan and Adams (1990). The percentages provided in Table 1 are intended as guidance on conditions likely to cause significant deviation in temperature. Analysts should consider other conditions than those specified when necessary.

In addition, the presence of biologically sensitive organisms may alter vulnerability based on beneficial uses or may suggest characteristics of temperature other than the annual maximum temperature should be considered. The watershed assessment team determines whether watershed conditions exist that may require revision of temperature vulnerability. They will document conditions and modify vulnerability calls accordingly.

Similarly, the initial determination of shade hazard (likelihood of reduced shade from forest practices) is based on potential and current view-to-the-sky. Factors that may influence hazard calls for shade loss include stand characteristics that are naturally sparser than expected for the forest type, or narrowly confined canyons where topography provides additional shade. Hazard may also be increased in the region of the stream where riparian shade is important in maintaining water temperature by immediately adjacent upstream reaches that have reduced shade. Water may flow into the downstream reach at warmer temperatures than expected. The rate at which water may cool as it travels in the downstream reach depends on stream depth and the difference between actual and expected water temperature based on environmental conditions within the downstream reach. The shallower the stream or the larger the difference in water temperature, the more rapid the response.

Primary Factors Influencing Vulnerability to Temperature Change

Key Environmental Variable	Watershed Condition	Situation	Criteria for recognizing situation	Temperature Effect	Possible Change in Vulnerability
Riparian Shade	Forest stand composition	• tree species that do not achieve expected heights	• Native vegetation less than 150 ft west side,	• warmer	• decrease
Riparian Shade	Channel width	• wider than expected (sedimentation) • wider than expected (wetlands) • narrower than expected (canyons)	• more than 50% increase in channel width • more than 50% increase in channel width • more than 50% decrease in channel width	• warmer • warmer • cooler	• increase • increase • decrease
Stream Depth	Channel morphology	• shallower than expected (sedimentation)	• reduction of stream depth of 50% or more	• warmer	• increase
Stream Depth	Low flow withdrawals	• shallower than expected (loss of flow)	• reduction of stream depth of 50% or more	• warmer	• increase
Groundwater	Rate of Groundwater Inflow	• More than expected (usually occurs at geologic discontinities, e.g. waterfalls) • Less than expected (losing reaches)	• Determine locally	• cooler • warmer	• decrease • increase
Air Temperature	Forest stand composition	• Hardwood stands have slightly higher air temperature than conifer stands	• Mature hardwood dominated stands	• slightly warmer	• increase if near 16C
Beneficial Uses	• Differences in life history requirements of fish species • Sensitive fish stocks	• Presence of species most sensitive to temperatures other than those related to the annual summer maxima • Presence of species or stocks with heightened sensitivity to selected maximum value	• Migrating/holding chinook or summer steelhead • Sockeye or kokanee habitats • Depressed or critical fish stocks Bull trout	• need cool temperatures for long duration • Need cooler temperature than 16C	• increase • increase

Factors Influencing Hazard to Shade Removal

Key Environmental Variable	Watershed Condition	Situation	Criteria for Recognizing Situation	Shade Effect	Potential Change in Hazard Call
Riparian Shade	Forest stand composition	• less dense stands with high opacity	• Opacity factor described in WQ module is greater than 30%	• less than expected	• could increase or decrease depending on position in watershed
Riparian Shade	Existing shade level upstream of segment of concern	• significant shade loss in adjacent upstream segments within zone of influence can result in higher temperatures entering segment of interest	• Current shade level more than 30% below minimum shade in zone 200 channel widths upstream in watershed area where shade influences temperature	• need more than minimum to prevent adverse temperature impacts	• increase if within zones where shade influences temperature

Water Quality Module Appendix

Background Discussion of Scientific Basis For Estimating the Effects of Watershed and Management Impacts on Water Temperature

Stream temperature has been widely studied and the physical processes controlling heat transfer are well understood. Most researchers have used an energy balance approach based on the physics of heat transfer to describe and predict changes in stream temperature. The six primary processes by which heat is transferred in aquatic environments are: 1) solar (short-wave) radiation, 2) radiation (long-wave) exchange with the sky and vegetation, 3) convection with the air, 4) evaporation, 5) conduction to the soil or streambed, and 6) advection from incoming water sources. Direct solar radiation is the primary source of energy for heating streams while reradiation of energy to the sky and vegetation and evaporation are the major sources of heat loss. Standing water undergoes the same heat transfer processes as streams. Most solar energy is absorbed in the upper 2 meters of water, depending upon opacity and other specific characteristics (Henderson-Sellers and Davies 1989). This portion of the water column is most subject to heating and cooling with solar radiation and heat exchange with the air. Thus all streams and wetlands and shallow lakes are affected by heat transfer processes described in this module.

The net energy balance, which is influenced by local environmental factors, determines the water temperature at a particular location at any particular time. Meteorological conditions averaged over the day explain daily maximum, mean, and minimum temperature (Edinger and Geyer, 1968). A thorough discussion of heat transfer mechanisms as they apply to forest streams can be found in Brown (1969), Theurer and others (1984), or Adams and Sullivan (1990).

Temperature of a waterbody seeks equilibrium with air temperature (Edinger et al., 1968) as both react to solar radiation with degree of adjustment primarily regulated by the local environmental factors of groundwater inflow, openness to the sky, relative humidity, and water depth (Adams and Sullivan, 1990). The combination of these factors at a site determines the energy balance and temperature.

Heat can be transported downstream with flowing water, although water temperature adjusts to local environmental conditions as it moves. If a stream flows from an open reach into a shaded reach, it will cool. Stream depth influences the rate of response (Brown 1969, Adams and Sullivan 1990, Sinokrot 1993). Very small, shallow streams respond rapidly, on the order of hundreds to a thousand feet. Deeper streams, including most fish-bearing streams, respond more slowly and the effect of the heating in the unshaded stream segment can be felt farther downstream, on the order of thousands of feet. When numerous less shaded reaches exist, there can be a downstream cumulative effect (Beschta and Taylor, 1988).

Table G-a1. Types of environmental variables affecting stream heating processes (from Sullivan et al. 1990).

GENERAL VARIABLE	EXAMPLE
GEOGRAPHY	latitude, longitude, elevation
CLIMATE	air temperature, relative humidy, wind velocity, cloudiness
STREAM CHANNEL CHARACTERISTICS	stream depth, width, velocity, substrate composition, water clarity
RIPARIAN OR TOPOGRAPHIC BLOCKING	sky-view (% shade), canopy density, vegetation height, crown radius, topographic angle

<u>Temperature patterns within watersheds</u>. Not all parameters are equally important for determining temperature regimes at all possible stream locations within the watershed. Rather, the relative importance of stream width, depth, shading, groundwater inflow, and air temperature in determing stream temperature tends to vary systematically by stream reach location within the watershed. Stream temperature tends to increase in the downstream direction from headwaters to lowlands, even under mature forest conditions. Expected stream

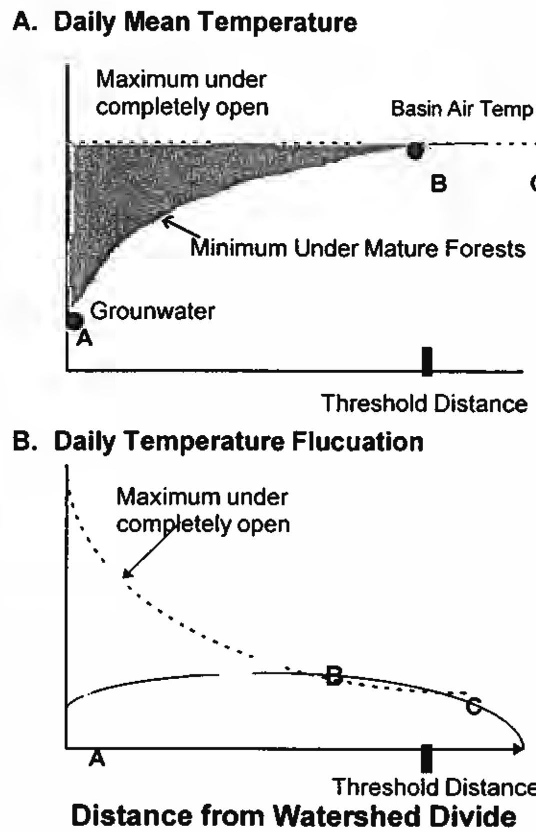
temperature characteristics at a watershed scale are schematically presented in Figure G-a1 providing a conceptual framework for examining the interaction of these processes at both watershed- and stream reach-scales. This framework is thus helpful for understanding the use of reach-specific shade characteristics for estimating stream temperature as described in this module.

Figure G-a1 depicts *daily mean* temperatures and *daily fluctuations* in stream temperatures. Note that the methods in this module estimate the effects of changes in riparian vegetation at a stream-reach scale on the *annual maximum* temperature expected for that stream reach. This time-scale was selected because it was the basis of the temperature/elevation screen (Sullivan et al. 1990), and because the stream temperature characterizations produced by this module can then be related to Washington's annual water temperature standard. In addition, estimates of the annual maximum temperature permit some interpretation about stream temperatures at other time intervals (e.g., if daily fluctuations in stream temperature increase, the annual maximum temperature would, by definition, also increase). Ongoing research and data collection on stream temperature processes is expected to produce additional methods to estimate stream temperature at other spatial scales and time intervals.

At the watershed scale, the curve A-C of the upper graph can be thought of as a probable longitudinal profile of daily average stream temperature for any given stream within the basin. That is, the curve describes, in a qualitative way, the expected increase in temperature as the stream flows from point A to C (Theurer et al, 1984). The expected temperature at point A is determined primarily by the combined effects of the riparian canopy in providing shading and the effect of groundwater inflow in depressing stream temperatures below the local daily air temperatures (Sullivan and Adams, 1989). For high elevation, or groundwater-dominated streams such as those close to source, the likely maximum summer temperature can be expected to vary from about 8-10 deg. C (Sullivan and Adams, 1990). This lower curve from point A to B thus traces a "reference" temperature profile that could be expected for streams under fully shaded mature forests. The shape of this baseline temperature would be expected to vary as a function of basin air temperatures, groundwater inflow, and differences in natural vegetation (Sullivan and Adams, 1990).

Point B on the upper schematic represents that point along the stream where mean stream temperatures equilibrate primarily to local air temperatures. This point is also referred to as the "threshold distance" (Sullivan et. a. 1990). In practice, this threshold distance is that distance from the stream's origin where water temperature is primarily determined by air tempature.

Figure G-a1. Conceptual diagram of increasing temperature with distance downstream from watershed divide.



This tends to occur where the average stream depth is approximately 0.6-1.0 meters and shade is not measureable. Upstream of this threshold distance (point B), riparian shading significantly affects stream temperature, and determines: (1) the degree to which average stream temperatures are depressed below local daily average air temperatures; and (2) the range of the daily fluctuations in stream temperature (i.e., maximum and minimum stream temperatures)(Sullivan and Adams, 1989, which Coweeta studies?). Similarly, the dashed upper curve shows the expected daily mean stream temperature expected for reaches upstream of this threshold depth. This daily average maximum temperature corresponds closely to average daily basin air temperature. The hachured area between the upper and lower curves represents the increases in daily mean stream temperature associated with varying degrees of riparian canopy removal.

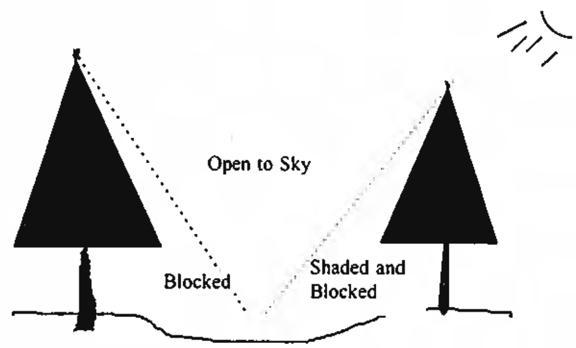
For the down-river point C, the maximum stream temperature is determined primarily by the basin air temperature. This is because low elevation, high-order streams tend to have: (1) relatively low contribution of groundwater to total streamflow; (2) stream widths that are too great for riparian vegetation to provide appreciable shading; and (3) stream depths sufficient to significantly dampen the daily stream response to solar heating (Theurer et al, 1984, Sullivan and Adams 1990). Stream temperatures that are raised above local air temperatures cool by reradiation, convection and evaporation processes, thus establishing a theoretical maximum stream temperature (Sullivan and Adams, 1990). Thus, at point C, the average stream temperature tends to equilibrate primarily to average air temperature.

The lower schematic portrays a similar longitudinal stream temperature profile from the perspective of daily fluctuations about the daily average temperature. For reaches upstream of the threshold distance, stream depth is a key parameter that determines how quickly the stream reach heats up, and how great the daily fluctuation in temperatures will be. As a general rule of thumb, the expected range in daily stream temperature fluctuations can be up to 75-80% of the daily fluctuation in local air temperatures (Sullivan and Adams 1990).

Assuming typical river valley formation, it appears that the portion of the watershed where vegetation has some effect on water temperature may lie within 50-60 km (31-37 miles) of the watershed divide in western Washington (Sullivan et al. 1990). Specific conditions within watersheds such as differences in valley form accompanying geologic substrate may alter the temperature profile and move the threshold for riparian vegetation influence up or downstream. Some valleys may be flatter or wider than average (e.g. glaciated terrain) and some may be steeper and deeper (e.g. incised or entrenched rivers). Elevation, vegetation, and summer air temperature differences may also make these relationships differ between watersheds east and west of the crest of the Cascade Mountains.

Determining shading effects of riparian vegetation. The waterbody's view-to-the-sky (the inverse of which is often inexactly referred to as "shade") (Adams and Sullivan, 1990) is a major environmental factor influencing stream temperature that can be affected by forest practices (Beschta et al. 1987). In the absense of riparian shade, water temperature will be near air temperature except where groundwater infow is significant. The proportion of the sky view that streamside vegetation can effectively block determines the proportion that water temperature will be depressed below air temperature.

Figure G-a2. Conceptual diagram of factors blocking radiation exchange and view-to-the sky.

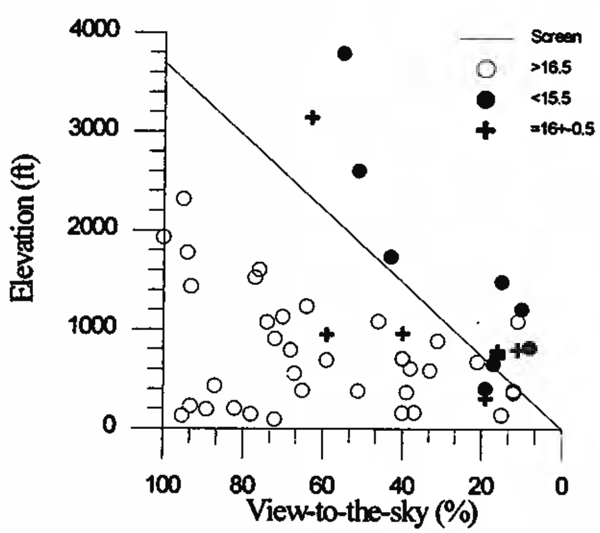


Blocking of in-coming and out-going radiation is determined by the height of streamside vegetation and topographic features within the overhead hemisphere that is the stream's "field of view" (Figure G-a2). The effect of blocking factors is very significant in small to moderate-sized forested streams, helping to maintain cool water temperature during warm summer months. Brown (1969) demonstrated that consideration of direct beam radiation to the stream surface is an important determinant of stream temperature response to solar input. Shade is a measure of the effects of incoming direct beam solar radiation. However, as a measure of heat exchange, it fails to adequately account for other important mechanisms that block outgoing radiation. Adams and Sullivan (1990) and Sullivan et al. (1990) used view-to-the-sky as a measure of blocking in modeling stream temperature with little or no loss of precision. There is some inaccuracy associated with using either view-to-the-sky or shade as a measure of factors that account for both incoming and outgoing radiation. Since view-to-the-sky is far easier to estimate than shade it is used in the calculations in this module. Treatment of the more complex elements of shade and solar angle as performed by Theurer et al. (1984) would not appreciably improve results (Sullivan et al. 1990).

The ability of vegetation to block incoming and outgoing radiation depends on its height relative to the width of the water body. Along very small streams almost any vegetation and streambanks themselves will provide shade, while tall trees and major topographic features are necessary for significant shading of larger rivers. Lakes are often too wide for any vegetation to be an effective control of water temperature. However, small or moderate-sized lakes may not be fully shaded but they may still be affected by the blocking of radiation by streamside vegetation. The maximum potential shade depends on the features of native vegetation.

View-to-the-sky and water temperature. An extensive study of temperature in Washington streams confirmed that watershed and landuse factors influenced water temperature consistent with previous research (Sullivan et al. 1990). Despite the complexities of site conditions on local control of temperature, the study was also able to identify a simple relationship between view-to-the-sky and elevation that could be used to predict the maximum allowable view-to-the-sky that would maintain temperature within water quality criteria for purposes of guiding riparian area management in state forest practice regulations. Referred to as the "temperature screen", the data and relationship is reproduced in Figure G-a3). Documentation of the basis of the simple model is provided in Sullivan et al., 1990, see chapters 6 and 7). Relationships for streams east and west of the Cascade Mountain divide have been adopted as the temperature screen by the Washington Forest Practices Board (WFPB, 1993) for use in prescribing shade requirements on a site-by-site basis.

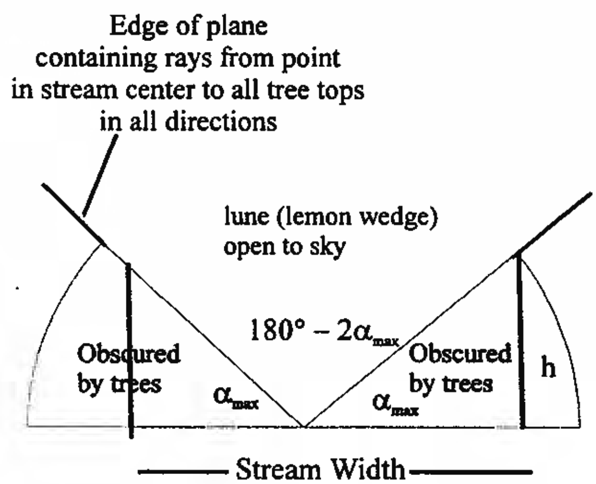
Figure G-a3. Temperature screen for westside plotted with original data from Sullivan et al. (1990). Included are 14 new data points from the Chehalis River.



Note that the screen isolates regions of the elevation/view relationships where annual maximum temperature falls above or below 16.0oC. The line was fitted by eye to best envelope the data. When sites are misclassified, the screen tends to specify more shade than necessary (it misses more low temperature sites than high temperature sites). Only one data point on Figure G-a3 is warmer than expected given the elevation and view-to-the-sky of the site. At low elevations, considerable shade is required to maintain low temperature, and the definition of the boundary is more muted. When comparing measured versus modeled results, analysts are reminded that the screen is a first order approximation of temperature adopted on the basis of ease of use and reasonable accuracy for prescribing forest practices.

Estimating view-to-the-sky based on vegetation. Vulnerability to heat input is determined by evaluating potential temperature based on fully mature streamside forest conditions and likelihood that forest management can reduce shade sufficiently to exceed temperature standards. Since forest managment has altered many riparian forests from old growth forest conditions, there is rarely data available for measuring fully shaded stream conditions. This module provides a method for estimating the openness of the stream based on geometry of the riparian setting in the absence of measured data.

Figure G-a4. Definition sketch of view-to-the-sky in two dimensions.



Geometric relationships can be applied to calculate the angle from the stream center to the top of the blocking elements. In two dimensions, the sky can be represented as an arc of 180¡, and view-to-the-sky is the fraction of the arc that is unobstructed (Figure G-a4). Essentially this is in a vertical plane perpendicular to the stream banks. The larger the angle without obstructions, the larger view-to-the-sky. For a given maximum vegetation height (tree or shrub as appropriate) and stream width, it is possible to calculate view-to-the-sky as the portion of the horizon not blocked by vegetation and topography.

(Figure G-a5). If the angle α is greater than the hillslope angle (λ), then the stream does not "see" trees beyond the first solid block of trees near the bank and α is the appropriate angle for estimating view-to-the-sky and the effects of topography can be ignored. If the nearstream angle is less than the hillslope angle, than the sideslopes provide more blocking than the streamside trees and topographic effects are significant. In this case, the hillslope angle λ is the appropriate angle to use for the calculations. Topography may be a significant factor reducing view-to-the-sky along stream segments that are moderately to tightly constrained.

Stream width affects view-to-the-sky by determining the location of the closest vegetation to the stream center, and thus the angle and proportion of the overhead hemisphere blocked (Figure G-a6). Small streams can be nearly completely shaded by overhanging trees or shrubs. Medium streams can be partially shaded by trees of suitable size. The largest streams get little shade from even the tallest trees. It should be noted that the view-to-the-sky is not dependent on the angle of the sun, which will vary during the year and with latitude. Using view-to-the-sky as the measure rather than shade allows estimates based on riparian geometry.

This 2-dimensional representation over-simplifies the surface area of the 3-dimensional hemisphere above the stream. View-to-the-sky is the fraction of a hemisphere centered over the stream which is unobstructed by vegetation or topography (Figure G-a7). The hemisphere extends from horizontal to vertical (0-90¡ of elevation), and around the compass (0-360¡ of azimuth). View-to-the-sky is therefore a 3 dimensional concept. There is an occluded plane that contains the line along the center of the corridor and the line formed by the top of the trees. The intersection of this plane and the celestial sphere is a great circle. The horizontal plane at the stream surface also intersects the celestial sphere forming a hemisphere which is the potential field of view of the water surface.

Topography can also affect the view-to-the sky Similarly, the same size tree can have very different effect on the view-to-the-sky depending on the stream width. Only on a perfectly flat landscape with no vegetation or topography is it possible to attain a view-to-the-sky of 100%.

Figure G-a5. Effects of stream width on view-to-the-sky.

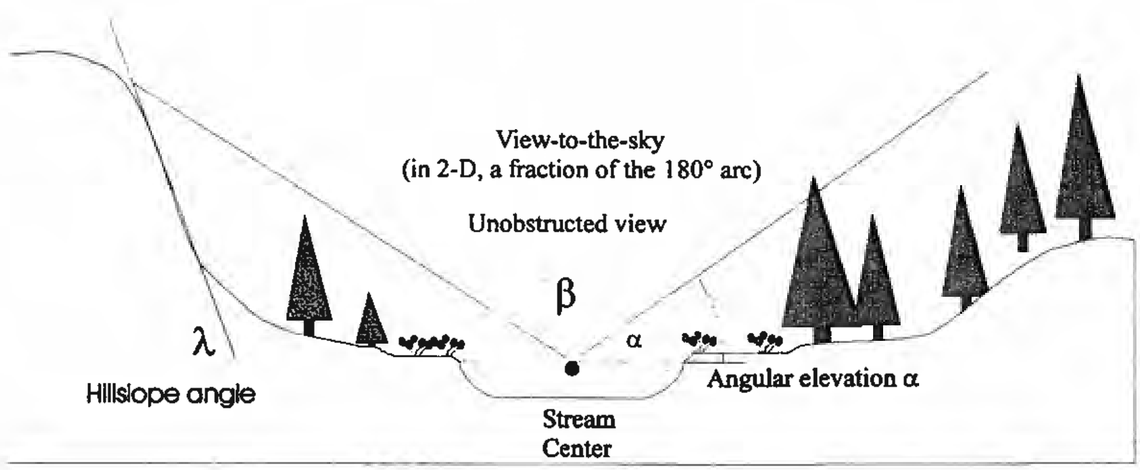


Figure G-a6. Effects of stream width on view-to-the-sky.

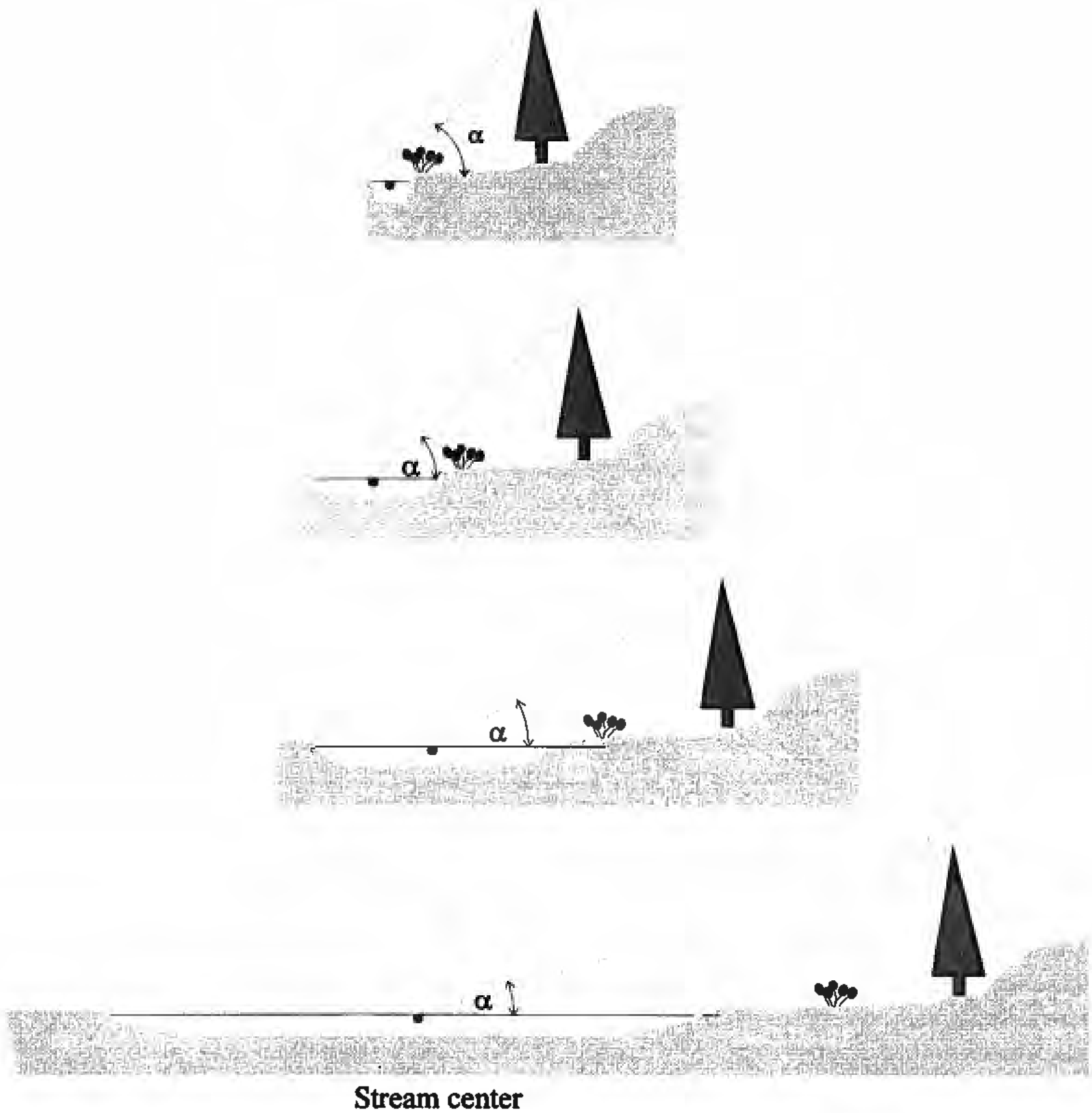
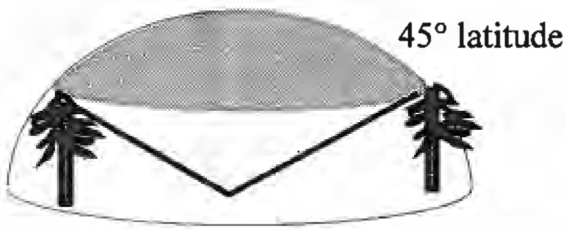


Figure G-a7. Three-dimensional representation of the sphere of view of a waterbody.



Consider the hemisphere in quadrants (Figure G-a8). On wider streams, quadrants facing the banks may have a considerable portion of the angular view blocked by vegetation, while quadrants facing up and downstream may be quite open. This geometry can have an important effect on estimations of view-to-the-sky in wider channels. The slice of sky viewed by the stream between two banks of trees is represented as the area of a geometric shaped termed a "lune" defined by the angle α (degrees) on a celestial sphere (Figure G-a4). To calculate view-to-the-sky, first determine the angle, α (in degrees) that is open above the stream (Figure G-a4). The angle α may be directly measured, or estimated from equation 1 based on the height of trees (h) and width of stream (w).

$$\alpha = \text{ArcCos}\,(w/\ \text{SQRT}\,(w^2+4h^2)) \qquad (1)$$

The surface area (A) for the lune whose angle is α is:

$$A = (180 - 2\alpha/360)4\pi r^2 \qquad (2)$$

$$= 2\pi r^2 - \frac{\pi r^2 \alpha}{45} \qquad (3)$$

The calculation of view-to-the-sky involves dividing the surface area of the lune above the stream by the surface area of the entire horizon above the stream plane.

$$\text{View-to-the-sky (\%)} = \frac{(2\pi r^2 - \pi r^2 \alpha/45)100}{2\pi r^2} \qquad (4)$$

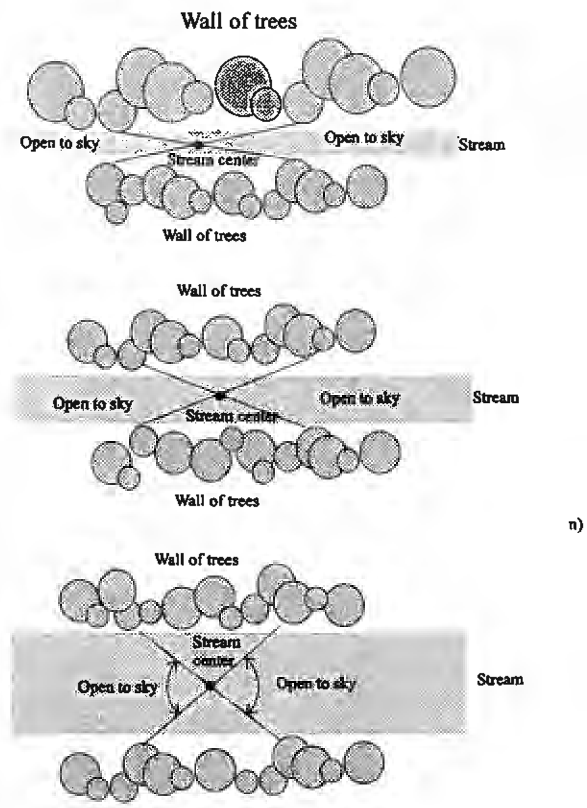


Figure G-a8 Conceptual diagram of the three-dimensional view-to-the-sky from the center of a straight reach of stream

Considering the horizon of view, and therefore r, as large, the radius cancels from the equation with division, making the area of the lune primarily dependent on the angle formed by the trees. This simplifies to

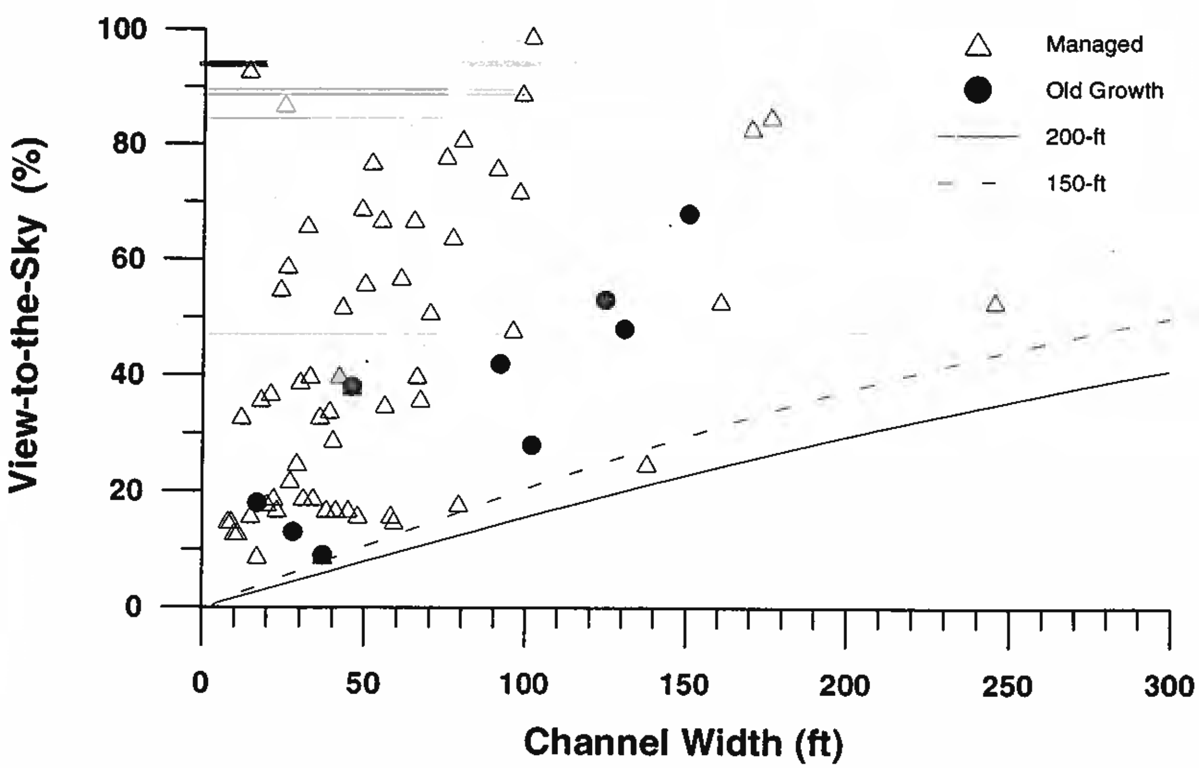
$$\text{View-to-the-sky (\%)} = 100 - \frac{10}{9}\alpha \qquad (5)$$

Several assumptions underlie potential view-to-the-sky calculations based on geometric relationships. Maximum potential height of native overstory species is assumed to be the height of blocking vegetation (h). Potential view-to-the-sky is determined by making the above calculations based on the site as it could be with mature vegetation (whether shrubs or trees). The analyst must assume an appropriate height of the forest stand or shrub commuity that would occupy the site under historic natural conditions. It is also assumed that blocking elements are the same on both sides of the stream. Bankfull stream width (w) is assumed to be the maximum distance between blocking elements on opposite banks. Calculation of view-to-the-sky at the center of the stream is sufficient to adequately represent blocking effects. Although the sides of larger streams may be partially shaded while the center is represent blocking effects. Although the sides of larger streams may be partially shaded while the center is fully open, heat is rapidly mixed in the water column and the center of the stream is likely to adequately represent the average condition. Streams may meander. This characteristic will make little difference in estimates of view since small streams are nearly fully closed based on calculations regardless of channel pattern and the horizon effect on large streams is small.

Calculations of potential view-to-the-sky were performed via spreadsheet for bankfull widths ranging from 0 to 300 feet (Figure G-a9). Calculations assumed effective tree heights of 150 and 200 feet (shown as lines). Estimates of view-to-the-sky for old growth conifer forest conditions represent the minimum view-to-the-sky possible for each segment of a given stream width. Thus the calculated lines in Figure G-a9 should be minimums and all points should plot on or above the appropriate line for forest height. Streams that have had shade removed should plot somewhere between the minimum and 100% open.

The geometric model provides a minimum fit to the data as expected, including data from larger rivers (Figure G-a9). Although the maximum height modeled was 200-feet, view-to-the-sky in old growth forests appeared to have a best fit by assuming tree height of 150-feet or less, although trees in old growth or mature forest stands were undoubtedly taller than this. There may be several reasons why streams appear to be more open than calculations suggest. Note that the above formulation assumes a solid (impenetrable) wall of trees. In fact, real trees only partially obscure view-to-the-sky, especially in the upper portion of the canopy or if vegetation is not dense. In the calculations shown in Figure G-a9 there was no compensation for opacity of the upper portions of the forest stand. These results suggest that perhaps as much as 25% of the total tree height has a significant loss of opacity which was not accounted for in calculations. Thus, view-to-the-sky calculations using total tree height bias estimates of minimum view to lower values than probably naturally occur. It also appears that 150-ft or 75% total tree height is a better estimator of the blocking effect of mature conifers on the westside of the Cascades.

Figure G-a9. Calculated result of view-to-sky equations for effective height equal to 200-ft and 150-ft. Data from TFW sources for westside sites is also plotted tocompare to the vegetation calculations. Points labeled "managed" were collected by TFW cooperators along streams with various histories of logging in riparian areas. Sites labeled "Old Growth" were reported to be representative of old growth stand conditions. Lines are labeled according to tree height used in the calculation.

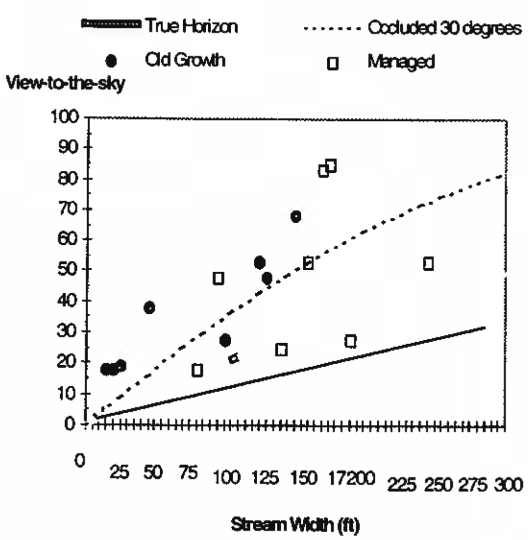


Conversely, the densiometer measuring instrument overestimates the openness of the stream. The convex mirror of the instrument is inset into the wood platform on which it is mounted. The emplacement of the mirror into the platform occludes nearly 30 degrees at the base of the mirror, thus seeing less of the horizon at the base than the stream would "see". Although an apparently small amount when gazing at the instrument, this portion represents a rather large area of the hemisphere above the stream. As much as 50% of the area of a hemisphere lies below 30 degrees on the horizon which would not be measured with the instrument. The larger the stream, the greater the effect on measured view.

However, overestimation of openness during measurement partially accounts for real differences in effectiveness of energy transfer around the celestial sphere. Energy exchange is not equal around the hemisphere: it reaches a maximum straight overhead and declines toward the horizon with the cosine of the angle according to Lambert's Law (Mills, 1992).

Algebraically solving for this factor in the above calculations for the lune illustrates the instrument bias (Figure G-a10). Note that the measured view of larger channels is more open to the sky than predicted by the equations (Figure G-a9). For larger streams, the calculated view appears to be more representative of the true condition, and is reasonably consistent with most observations. In reality, the effective view-to-the-sky lies somewhere between that calculated using equation 4 and that measured in the field by a spherical densiometer. This analysis uses the calcuated view recognizing that it underestimates the actual view-to-the-sky.

Figure G-a10. Calculated view -to-the-sky of 150-ft tall trees assuming horizon at the ground, and horizon at 30 degrees above the ground as measured by spherical densiometers. Also shown are data from Figure G-9 representing old growth sites and other sites with stream widths greater than 100 feet.



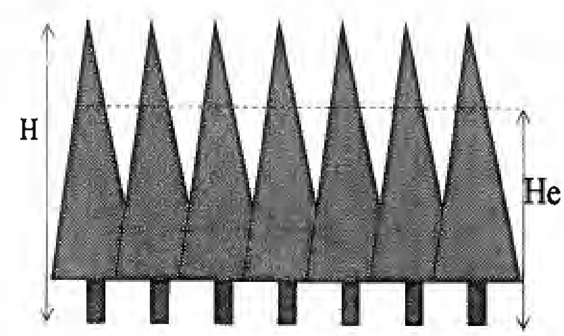
The stream's view of the hemisphere of the sky above it depends on the height and light filtering capacity of objects blocking that view. View-to-the-sky is therefore a function not only of the width of the stream but also of factors that control the height and density (Figure G-a11). To compensate for the gaps in vegetation cover, as viewed sideways from the stream, the analyst can take several steps which further improve the calculation. Since most trees are full in the mid-canopy, but less than opaque in the tree-tops, the analyst can translate that partial opacity into an effective tree height.

$$H_e = H * \% \text{ opacity} \qquad (6)$$

A 120-foot Douglas-fir might be 70% opaque. The effective tree height would then be 84 feet

View-to-the-sky can be calculated by the same formula given above, but substituting effective tree height H_e for H. An additional correction may be needed if the trees are sparse, for example in east-side situations where there are substantial gaps between trees. Use of an opacity factor should be based on field estimates from reference sites and should be ignored if these are not available.

Figure G-a11. Conceptual view of opacity factor accounting for openness of stand.



He = effective tree height
H = total tree height

Estimated temperature based on view-to-the-sky. Data on which the temperature screen was developed from the TFW temperature study (Sullivan et. al. 1991) was used to develop a relationship between view-to-the-sky and maximum temperature. In Figure G-a3, the line representing the temperature screen approximates the relationship between elevation and view-to-the-sky where water temperature is equal to 16°C. Conceptually, the distance each point is away from the line for a given elevation should reflect the distance temperature is likely to vary from the reference. Thus, the difference between existing or potential view-to-the-sky and the screen reference view-to-the-sky can be translated to water temperature as shown in Figure G-a12.

The TFW temperature study provided a rule of thumb estimate that 10% change in view-to-the-sky results in 0.6°C (1°F). Analysis of Figure G-a12 allows recalibration of this relationship to 0.7 °C (1.3°F). The relationship plotted in Figure G-a12 was reformatted for ease of use in water quality module calculations in Figure G-a13.

This approach to calculating maximum temperature has better predictive capability than linear regression of view-to-the-sky and temperature (R^2=.34). The method can be easily applied at the watershed scale using potential or existing view-to-the-sky. The analysis should provide a generalized perspective of temperature at that scale, although it is probably imprecise in locating exact temperature profiles.

Results suggest that this simple approach to estimating water temperature should provide a first approximatation of annual maximum temperature at the watershed scale. There is scatter in the relationship (Figure G-a12) and the water quality analyst should use care in interpreting modeled results in comparison with measured results. Since the model works reasonably well for explaining measured temperature patterns in relation to riparian vegetation, it should provide reasonable estimates of modeled temperature based on estimates of potential view calculated from riparian geometry.

Figure G-a12. Annual maximum temperature in relation to the Difference in view-to-the-sky between potential and allowable based on the temperature screen.

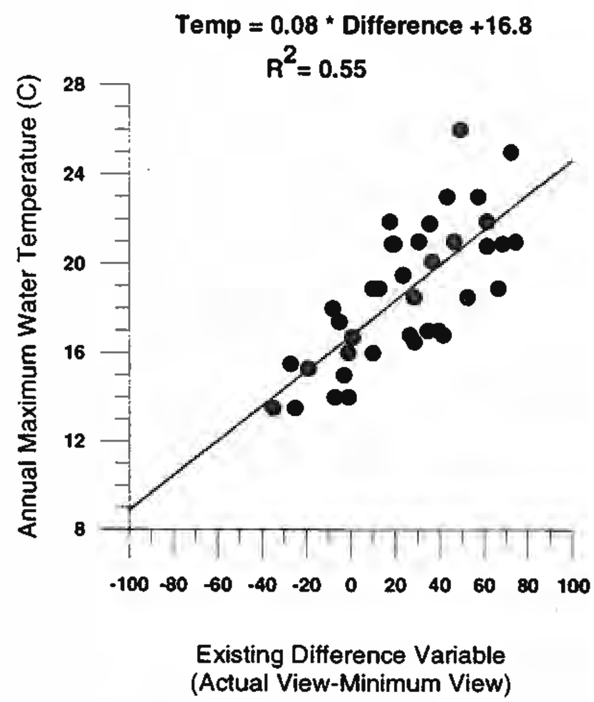
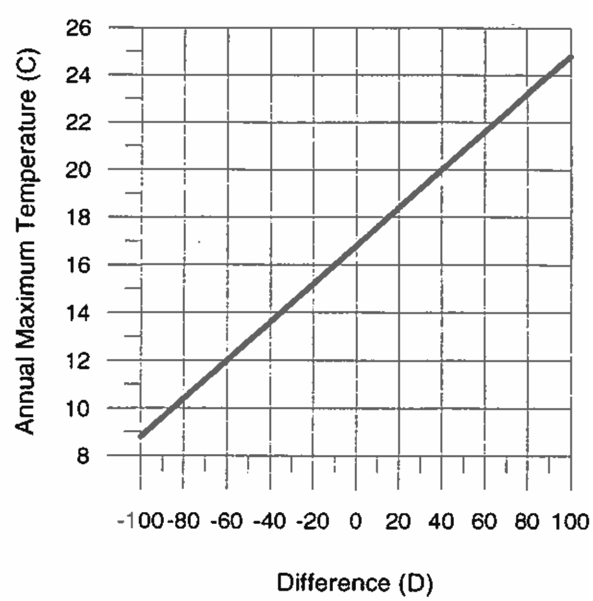


Figure G-a13. Simple model for predicting annual maximum temperature in western Washington based on view-to-the-sky and elevation.



Water Quality Module Appendix

Profiles Of Wetland Classes And Subclasses For Lowland Washington (Draft, Department of Ecology 3/97)

Class: Riverine

Riverine wetlands occur in floodplains and riparian corridors in association with stream or river channels. They lie in the active floodplain of a river, and have important hydrologic links to the water dynamics of the river or stream. The distinguishing characteristic of riverine wetlands in Washington State is that they are frequently flooded by overbank flow from the stream or river. The flooding waters are a major environmental factor that structures the ecosystem in these wetlands. Wetlands that may lie in floodplains but are not frequently flooded are not classified as riverine.

Surface and shallow subsurface water movement in most Riverine wetlands is from the valley sides toward the stream channel, from the stream channel toward the adjacent floodplain and downstream during overbank events. Additional water sources may be groundwater discharge from surficial aquifers, overland flow from adjacent uplands and tributaries, and precipitation.

Water leaves Riverine wetlands by surface flow returning to the river or stream channel after flooding or a rain event. The wetlands also may lose subsurface water by subsurface discharge to the channel (called interflow), movement of water to deeper groundwater through permeable geologic formations, and evapotranspiration.

Many Riverine valley wetlands are associated with rivers that are very dynamic. Their proximity to the river facilitates the rapid transfer of floodwaters in and out of the wetland, and the import and export of sediments. These wetlands are subject to frequent flood disturbances that may reset the "successional clock." The dominant vegetation in these wetlands may be reprensetative of any of the seral stages possible; from early successional, emergent species, to late successional forest species. Near the headwaters of streams and rivers, Riverine valley wetlands are often replaced by depressional or slope wetlands, where the channel (bed) and bank disappear, and overbank flooding grades into surface or groundwater inundation. In headwaters, the dominant source of water becomes surface runoff or groundwater seepage. For the purposes of classifying wetlands, wetlands that show evidence of frequent overbank floodingeven if from an intermittent stream, are considered to be in the class Riverine.

The downstream extent of riverine wetlands is where they normally intergrade with estuarine fringe wetlands. According to the hydrogeomorphic classification, the riverine class is dominated by unidirectional flows (Brinson 1993, Brinson et al. 1995). The interface with estuarine fringe occurs where the dominant hydrodynamics change to bidirectional flows, tidal, flows (Brinson et al 1995). This interface has been significantly modified in western Washington by diking. Many wetlands that were once freshwater tidal (a subclass of estuarine fringe in Washington) are now either Riverine or Depressional (depending on the frequency of flooding).

Riverine wetlands normally extend perpendicular from the stream or river channel to the edge of the area that is frequently flooded (also known as active floodplain). Wetlands in large floodplains that are found outside the areas frequently flooded, and in landscapes with great topographic relief and steep hydrostatic gradients may function more like slope or depressional wetlands because the water regime is dominated by groundwater sources (see discussion in Brinson et al. 1995).

Field Characteristics for Riverine Wetlands in Washington State: The operative characteristic of Riverine wetlands in Washington State is that of being "frequently flooded" by overbank flows. The assessment teams and technical committee, however, decided that this characteristic could only be determined from field indicators. The water regime of Washington's wetlands have enough variability between dry and wet years that a frequency of flooding (e.g. flooded at least once every two years) could not be used. The field indicators that are to be used to classify a wetland as riverine are still being developed.

Subclass: Flow-through

Riverine Flow-through wetlands are those that do not retain surface water significantly longer than the duration of a flood event. Water tends to flow through the wetland rather than pond in the wetland. Usually the water does not remain in the wetland more than several days after the surrounding landscape is drained. Soil saturation, however, may be maintained by groundwater seepage from valley walls. Flow-through wetlands usually have evidence of active erosion and deposition and have a dynamic, fluctuating hydroperiod that closely matches that of the stream or river.

The wetlands in this subclass tend to be found in, or adjacent to, the active channel of a river or larger stream. They may be the vegetated bars in the active channel or form on recent alluvial deposits along the sides of the channel or within the channel.

Field characteristics of Riverine Flow-through Wetlands for Western Washington: has a less dense herbaceous understory and commonly contains stinging nettle contains deciduous shrubs and trees (conifers less likely) the soils are more coarse and have higher mineral content than those found in the Impounding subclass the vegetation tends to be less diverse than in the Impounding subclass. This profile will be expanded to include descriptions of how wetlands in this subclass performs the 16 functions after reference data are collected during the field calibration of the models.

Subclass: Impounding

Riverine Impounding wetlands are those that retain surface water significantly longer than the duration of a flood event. Impounding wetlands tend to hold water longer than a week after a flood event. These wetlands are found within a topographic depression on the valley floor or in areas where natural or man-made barriers to downstream flow occur. The depressions may be filled with sediments or organic deposits. The critical characteristic, however, is that these wetlands retain flood waters after an event longer than the surrounding landscape. The impounding wetlands often have no outlet, or a constricted outlet, and have a hydroperiod that is less dynamic than that found in the adjacent stream, river, or "flow-through" wetland in the same valley. Most of the Impounding riverine wetlands are in the less dynamic parts of the floodplain; often on floodplain terraces or in old oxbows. Many may have peat accumulations that have become isolated from the usual riverine processes, and they are subjected to long durations of saturation from surface or groundwater sources. Riverine processes will dominate only during the flooding event, though the groundwater levels may be controlled by water levels in the hyporheic zone through hydrostatic processes.

Many wetlands in lowland Washington fall into this subclass because their surface water connections have been reduced by dikes or roads. These wetlands at one time did not retain floodwaters longer than the actual flooding event, but now do so because of some blockage.

Field characteristics of Riverine Impounding wetlands for western Washington: more herbaceous understory and commonly contains skunk cabbage aquatic vasculars are frequently present if there is a forested component, may contain conifers contains finer soils which may have a higher organic content vegetation tends to be more diverse than in Flow-through wetlands.

This profile will be expanded to include descriptions of how wetlands in this subclass performs the 16 functions after reference data are collected during the field calibration of the models.

Class: Depressional

Depressional wetlands occur in topographic depressions, that exhibit a closed contour interval(s) on three sides and elevations that are lower than the surrounding landscape. The shape of depressional wetlands vary, but in all cases, the movement of surface water and shallow subsurface water from at least three cardinal directions in the surrounding landscape is toward the point of lowest elevation in the depression. The movement of surface water in depressional wetlands is also vertical (up and down). Depressional wetlands may be isolated with no surface water inflow or outflow through a defined channel, or they may have permanent or intermittent, surface water inflow or outflow in defined channels, that connects them to other surface waters or wetlands. Streams draining into a wetland may modify the topographic contours of the depression where they enter or exit the wetland. Depressional wetlands with channels or streams differ from riverine wetlands in that their ecosystem is not significantly modified by riverine flooding events.. Headwater wetlands would be classified as depressional because overbank flooding is not a major ecological "driver".

Depressional wetlands may lose water through intermittent or perennial drainage from an outlet, by evapotranspiration, and flow into the groundwater at times when they are not receiving discharge from groundwater.

The Flow-through and Closed subclasses have very similar positions in the landscape that do not warrant separate geomorphic profiles. Differences between the subclasses are based on the functions they perform. The geomorphic characteristics of depressional wetlands in lowland western Washington are as follows:

1. Depressional wetlands in lowland western Washington are found in the following geomorphic settings; 1) Former kettleholes left by receding glaciers, 2) in depressions on top of clay lenses in glacial outwash, such as the area between Olympia and the Chehalis River, 3) headwaters of lowland streams, 4) alluvial terraces

above the existing floodplains, and 5) depressions in glacial till.

2. Many depressional wetlands have well developed peat deposits because the outflow, if it exists, is above the base of the depression. Thus, organic matter will tend to collect.

Field Characteristics for Washington State: Depressional wetlands in the lowlands of western Washington lie in topographic depressions where the slope on at least three sides above the wetland is greater than 1%, and that are not within the active floodplain of a stream or river. There may be a stream going through the wetland, but if so it is not the major source of physical energy to the system.

The topographic depressions that characterize the position of this class in the landscape can be very small with only slight differences in elevation between the wetland and surrounding uplands. Some depressional wetlands are found on relatively flat surfaces. They are formed in depressions that exit in soils with low permeability such as glacial till plain.

Very small wetlands found in surface depressions with only a 1-3 foot topographic relief may be difficult to classify. If such small wetlands form a mosaic on a landscape that is flat it may be more appropriate to classify them as a single wetland in the "Flats" class if the only source of water to the wetland is precipitation. If the wetland receives a significant amount of its water from a surrounding contributing basin, however slight the topographic relief, it would be classified as a Depressional wetland. A Flats wetland, on the other hand, receives its water by direct precipitation over the area within the wetland only.

Subclass: Flow-through

Depressional Flow-through wetlands are those that have a surface water outflow to a stream or river that eventually discharges into the ocean for at least part of the year. Inflow may be from surface water flowing down from the surrounding topographic relief, from an intermittent or permanent stream(s), or from groundwater.

This profile will be expanded to include descriptions of how wetlands in this subclass performs the 16 functions after reference data are collected during the field calibration of the models.

Subclass: Closed

Depressional Closed wetlands are those that have no surface water outflow to channels, streams, or rivers. Closed depressional wetlands may have surface water inflow but no outflow through a defined channel.

This profile will be expanded to include descriptions of how wetlands in this subclass performs the 16 functions after reference data are collected during the field calibration of the models.

Class: Slope

Slope wetlands occur on hill or valley slopes. Elevation gradients may range from steep hillsides to slight slopes. Principal water sources are usually groundwater seepage and precipitation. Slope wetlands may occur in nearly flat landscapes if groundwater discharge is a dominant source of water and there is flow in one direction. The movement of surface and shallow subsurface water is perpendicular to topographic contour lines. Slope wetlands are distinguished from the riverine wetland class by the lack of a defined topographic valley with observable features of bed and bank. Slope wetlands may develop channels but the channels serve only to convey water away from the slope wetland.

Field characteristics for Washington State: Slope wetlands in Washington are found on hillsides or at the edge of hill where they grade into a river valley. They are identified by the fact that: 1) they are on a slope, even if very gradual), 2) they lack closed contours and cannot store surface water, and 3) they have no obvious surface water inflows such as streams or channels.

Subclass: Slope Connected

Slope wetlands with a surface water connection, at least periodically, to an intermittent or perennial stream or other surface water body connected to a stream or river that discharges into the ocean.

Subclass: Slope Unconnected

Slope wetlands isolated from streams or surface waters.

Class: Flats

Flats wetlands occur in topographically flat areas that are hydrologically isolated from surrounding groundwater or surface water. The main source of water in these wetlands is precipitation. They receive virtually no groundwater discharge which distinguishes them from depressional and slope wetlands. The DOE Technical Committee decided that for Washington there was no need to create two separate classes for Flats as proposed in the current HMG documentation. "Flats" wetlands are not very common in the state, and the committee judged that both organic and mineral flats found in the state perform the same functions and do not need to be separated. The DOE team developing the models for the flats, however, may decide that further divisions are necessary.

Class Lacustrine Fringe

Lacustrine fringe wetlands occur at the margin of topographic depressions in which fresh surface water is greater than 2 meters deep. They are found along the edges of bodies of water such as lakes. The dominant surface water movement in fringe wetlands has a bi-directional horizontal component due to winds or currents, but there may also be a corresponding up and down vertical component resulting from seiches, wind, or seasonal water fluctuations.

Field characteristics for Washington State: Lacustrine fringe wetlands are those adjacent to bodies of freshwater that are at least two meters deep with no evidence of water flow in one direction. Some wetlands may be adjacent to rivers that are more than two meters deep but these would be classified as riverine because there is measurable flow in one direction.

No subclasses are proposed for the Lacustrine Fringe class in Washington State.

Class: Estuarine Fringe

Estuarine fringe wetlands occur at the margin of topographic depressions in which marine waters are greater than 2 meters deep. They are found along the coasts and in river mouths to the extent of tidal influence. The dominant source of water is from the ocean or river. The one unifying characteristic of this class is hydrodynamic. All estuarine fringe wetlands are have water flows dominated by tidal influences with water depths controlled by the tidal cycles.

Subclass: Estuarine Saltwater Fringe

Estuarine fringe wetlands in which the dominant water flows have salinities that are higher than 0.5 parts per thousand.

Subclass Estuarine Freshwater Fringe

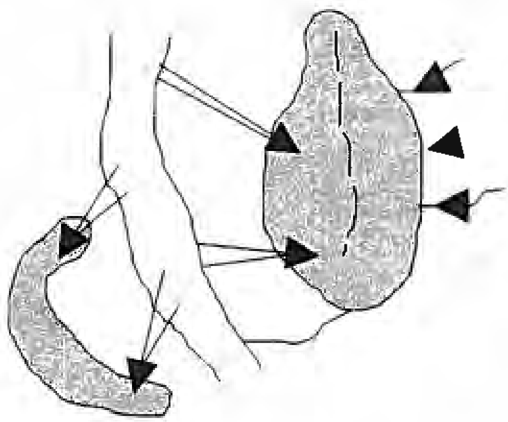
Estuarine fringe wetlands in which the dominant water flows are tidal but freshwater, with salinities below 0.5 parts per thousand.

HGM CLASSIFICATION FOR WASHINGTON

RIVERINE

flooded frequently by river: "Frequently" to be determined by field indicators

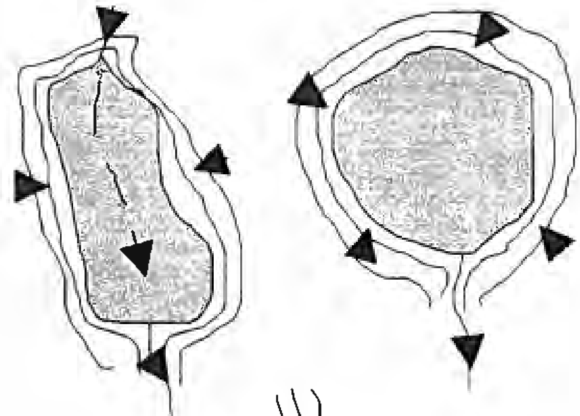
Impounding

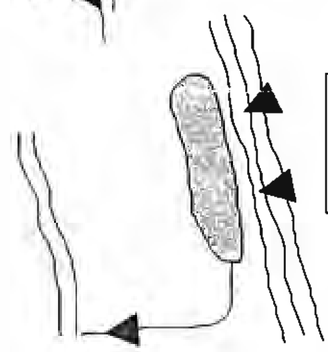


Flow-through

DEPRESSIONAL

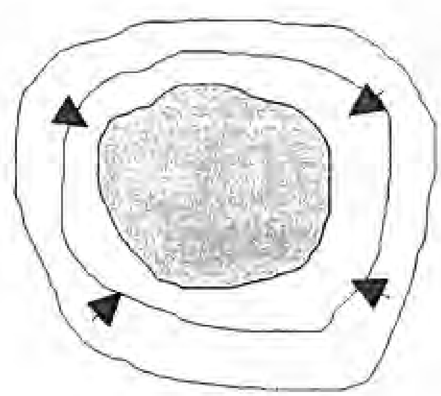
Flow-through





flooded infrequently by river

Closed



Linkage Between Water Temperature and Watershed Conditions--Making Vulnerability Calls

Prior to the synthesis steps that involve all of the assessment modules, the water quality analyst will consider watershed factors other than riparian vegetation that may affect the vulnerability of streams to temperature change. The water quality analyst will work with other analysts and the products they developed from the hydrology, mass wasting, channel, riparian and fish habitat modules, as well as ancillary data on fisheries resources, to develop an integrated assessment of the likely effects of forest practices on stream temperature and other water quality parameters. The following steps describe the general process by which several module assessments are used to create the water temperature vulnerabilities. It is important to bear in mind that water quality issues not covered in this manual may arise. The analysts must rely on the data describing the situation and their knowledge of watersheds and water quality to create vulnerability calls.

The initial determination of water temperature vulnerability is based on estimates of potential and minimum allowable view-to-the-sky as it is influenced by riparian vegetation and topographic blocking. The method described in the water quality module is based on simplified approaches for stream temperature prediction that neglect important watershed factors other than riparian vegetation that can influence temperature including stream depth, channel width, groundwater inflow and air temperature (Sullivan and Adams, 1990).

Additional impacts on water temperature vulnerability are considered by the watershed assessment in this section. Natural or management-caused conditions may exist in the WAU that increase or decrease the temperature vulnerability. Table 1 lists a number of conditions related to potential changes in key environmental variables. These include the effect of natural variability or anthropogenically caused differences in channel, flow, climatic, or riparian vegetation variables, potential shade loss, relative to the assumptions on which initial vulnerability determinations are made. Criteria for identifying when differences are sufficient to consider potential effects on temperature are provided. These are based on sensitivity analysis of the effect of environmental variables on temperature found in the TFW evaluation of temperature prediction (Sullivan et al. 1990) and Sullivan and Adams (1990). The percentages provided in Table 1 are intended as guidance on conditions likely to cause significant deviation in temperature. Analysts should consider other conditions than those specified when necessary.

In addition, the presence of biologically sensitive organisms may alter vulnerability based on beneficial uses or may suggest characteristics of temperature other than the annual maximum temperature should be considered. The watershed assessment team determines whether watershed conditions exist that may require revision of temperature vulnerability. They will document conditions and modify vulnerability calls accordingly.

Similarly, the initial determination of shade hazard (likelihood of reduced shade from forest practices) is based on potential and current view-to-the-sky. Factors that may influence hazard calls for shade loss include stand characteristics that are naturally sparser than expected for the forest type, or narrowly confined canyons where topography provides additional shade. Hazard may also be increased in the region of the stream where riparian shade is important in maintaining water temperature by immediately adjacent upstream reaches that have reduced shade. Water may flow into the downstream reach at warmer temperatures than expected. The rate at which water may cool as it travels in the downstream reach depends on stream depth and the difference between actual and expected water temperature based on environmental conditions within the downstream reach. The shallower the stream or the larger the difference in water temperature, the more rapid the response.

Primary Factors Influencing Vulnerability to Temperature Change

Key Environmental Variable	Watershed Condition	Situation	Criteria for recognizing situation	Temperature Effect	Possible Change in Vulnerability
Riparian Shade	Forest stand composition	• tree species that do not achieve expected heights	• Native vegetation less than 150 ft west side,	• warmer	• decrease
Riparian Shade	Channel width	• wider than expected (sedimentation) • wider than expected (wetlands) • narrower than expected (canyons)	• more than 50% increase in channel width • more than 50% increase in channel width • more than 50% decrease in channel width	• warmer • warmer • cooler	• increase • increase • decrease
Stream Depth	Channel morphology	• shallower than expected (sedimentation)	• reduction of stream depth of 50% or more	• warmer	• increase
Stream Depth	Low flow withdrawals	• shallower than expected (loss of flow)	• reduction of stream depth of 50% or more	• warmer	• increase
Groundwater	Rate of Groundwater Inflow	• More than expected (usually occurs at geologic discontinities, e.g. waterfalls) • Less than expected (losing reaches)	• Determine locally	• cooler • warmer	• decrease • increase
Air Temperature	Forest stand composition	• Hardwood stands have slightly higher air temperature than conifer stands	• Mature hardwood dominated stands	• slightly warmer	• increase if near 16C
Beneficial Uses	• Differences in life history requirements of fish species • Sensitive fish stocks	• Presence of species most sensitive to temperatures other than those related to the annual summer maxima • Presence of species or stocks with heightened sensitivity to selected maximum value	• Migrating/holding chinook or summer steelhead • Sockeye or kokanee habitats • Depressed or critical fish stocks Bull trout	• need cool temperatures for long duration • Need cooler temperature than 16C	• increase • increase

Factors Influencing Hazard to Shade Removal

Key Environmental Variable	Watershed Condition	Situation	Criteria for Recognizing Situation	Shade Effect	Potential Change in Hazard Call
Riparian Shade	Forest stand composition	• less dense stands with high opacity	• Opacity factor described in WQ module is greater than 30%	• less than expected	• could increase or decrease depending on position in watershed
Riparian Shade	Existing shade level upstream of segment of concern	• significant shade loss in adjacent upstream segments within zone of influence can result in higher temperatures entering segment of interest	• Current shade level more than 30% below minimum shade in zone 200 channel widths upstream in watershed area where shade influences temperature	• need more than minimum to prevent adverse temperature impacts	• increase if within zones where shade influences temperature

APPENDIX H
Water Supply / Public Works Assessment Module

Table of Contents

Introduction

Many watersheds provide water used for irrigation, domestic use, fish hatcheries, etc. In addition, public roads, bridges, parks, and other capital improvements are present in many watersheds. Watershed processes such as mass wasting, surface erosion, rain-on-snow-events, etc., can impact water supplies and public works. Most commonly, water supplies are impacted by processes that change water quality in streams, rivers, and lakes. Surface erosion-related increases in turbidity or nutrient releases following timber harvest are two possible examples of watershed processes impacting water quality. By contrast, public works are most commonly impacted by changes in peak flows that lead to flood damage. For example, timber harvest could decrease hydrologic maturity in a watershed, leading to increased peak flows that damage bridges. Certain public works are also sensitive to mass wasting, to changes in stream-borne sediment loads, or to leave trees.

The Level 1 module is an office-based procedure that identifies water supply sources and the location and type of public works in the watershed. The vulnerability of these resources is assessed using information such as location on floodplain, water quality requirements, etc. Level 2 methods utilize the data collected in Level 1, but require field visits and additional data analysis to further refine estimates of sensitivity. Methods for water supply and public works are presented separately below. Figure H-1 summarizes the steps used in these procedures.

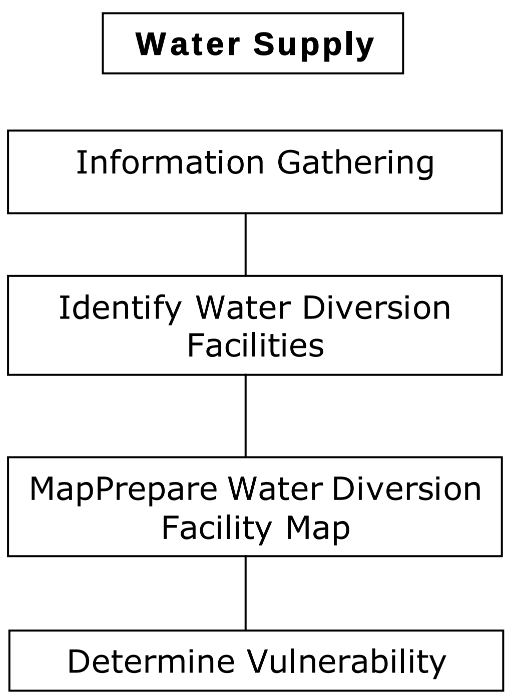


Figure H-1: Water supply assessment flow chart.

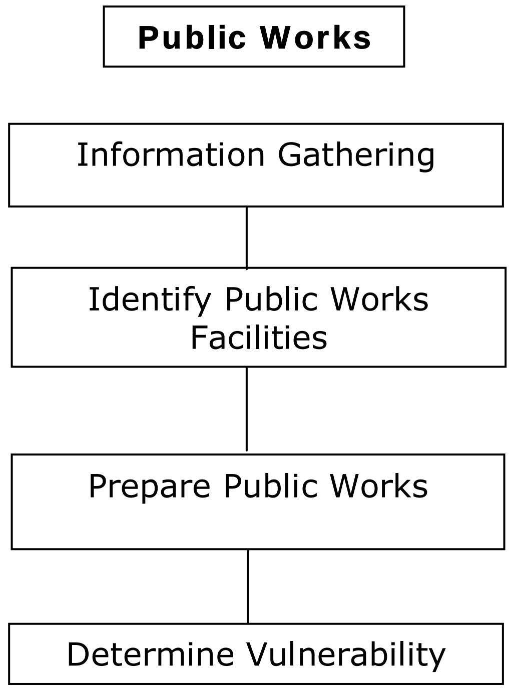


Figure H-2: Public works assessment flow chart

Water Supply Procedures

Critical Questions

Is water being diverted out of the watershed?

Are there irrigation diversions?

Are there domestic water supply diversions?

Are there other diversions?

If water supply diversions exist, then:

Is the water diversion sensitive to changes in one or more of the five input variables? (Consider both the physical structure and the water being diverted.)

Is it sensitive to fine sediment inputs?

Is it sensitive to coarse sediment inputs?

Is it sensitive to increased water temperatures?

Is it sensitive to changes in peak or base flows?

Is it sensitive to nutrient inputs?

Level 1 Assessment

The Level 1 assessment uses interviews, topographic maps, and aerial photos to identify the location and type of water diversion facilities present in the watershed. If diversion facilities are present, the water quality requirements of these diversions are used to determine sensitivity to changes in each of five input variables: fine sediment, coarse sediment, water temperature, flow changes, and nutrient inputs. Results of the analysis are presented as a graphical overlay supplemented by analysis reports for each diversion facility.

Objectives

1. Identify the location of all water supply diversions.
2. Classify diversions according to use (e.g., irrigation).
3. Use diversion type to determine sensitivity to each of the five input variables.

Qualifications

Skills

Mapping and aerial photography interpretation.

Assumptions

- Water quality requirements for diversions are determined by the type of water use (e.g., irrigation).

Information Gathering

The following information sources are needed for the interpretive steps of this module.

Maps

USGS topographic maps (WAU Base Map).

Photographs

Aerial photographs of the stream-bearing portion of the watershed. Obtain the most current photos available.

Personal and first-hand knowledge of the area

- Conduct interviews with appropriate resource managers to acquire local knowledge. Conduct interviews using Form H-1 Interviews focus on the location of diversion facilities, how the diverted water is used, and the sensitivity of the diversion to various potential impacts. Interviews are also used to determine if diversions of water originating in the watershed occur outside the analysis area (i.e., in downstream reaches outside of the WAU). State Departments of Wildlife, Fisheries, Ecology, and Natural Resources may have staff with experience in the watershed. Additional contacts are irrigation districts, the Soil Conservation Service, municipal water offices, and county planning agencies.

- If the drainage is within the usual and accustomed area of any federally recognized treaty tribes, contact these tribes to determine appropriate resource management personnel.
- Consult DNR’s GIS ownership coverage or the county assessor’s office to determine ownership information on any diversion facilities. Contact and interview these owners.

Analysis Procedure

Steps

Identify Water Diversion Facilities

- Review USGS topographic maps. Look along stream network for dashed lines labeled "aqueduct" or "pipeline." Alternately, look for offshoots of the main channel labeled "aqueduct" or "canal" These offshoots will often be straight, narrow channels that rapidly move away from the main channel. Many diversions will originate near the base of dams.
- Look for facilities labeled "hatchery" along the stream network.
- Aerial photos can be examined to identify diversions or diversion facilities that may have been installed since the USGS maps were printed.
- If no diversion facilities are noted in maps, photos, or in interviews, then the watershed has no sensitivity with respect to water supply, and the analysis is completed.

Prepare Water Diversion Facility Map

If any diversion facilities are located, then prepare an acetate overlay of the watershed base map. Identify the location of any diversions. An example is illustrated in Figure H-3.

Determine Water Supply Facility Vulnerability

Review each water supply diversion and decide if the primary use is for irrigation, domestic supply, fish hatchery, power generation, or other.

For each of the diversions identified in the base map overlay, list the vulnerability to each of the input variables (see Figure H-3 Label this overlay as Map H-1 Water Supply Vulnerability.

Table H-1: Water Supply Facility Vulnerability Table

Diversion	**Input Variable**				
Type	**Fine Sediment**	**Coarse Sediment**	**Water Temp.**	**Flows Peak/Base**	**Nutrient Input**
Irrigation	Low	High	Low	High/High	Low
Domestic	High	High	Low	High/High	High
Power Generation	High	High	Low	Low/High	Low
Hatchery	High	High	High	High/High	High
Other*					

Use this table to assess the vulnerability of each diversion facility to the five input variables.

Calls from this table can be modified based on interviews and personal information. The basis for such modification must be documented on Form H-2. Modifications to calls would most likely be based on the design of the diversion facility. For example, water supplies taken from reservoirs may be insensitive to peak flows due to storage capacity of the reservoir. In contrast, streamside canals and aqueducts could be very sensitive to peak flows.

*Other diversion types must be analyzed using project specific information.

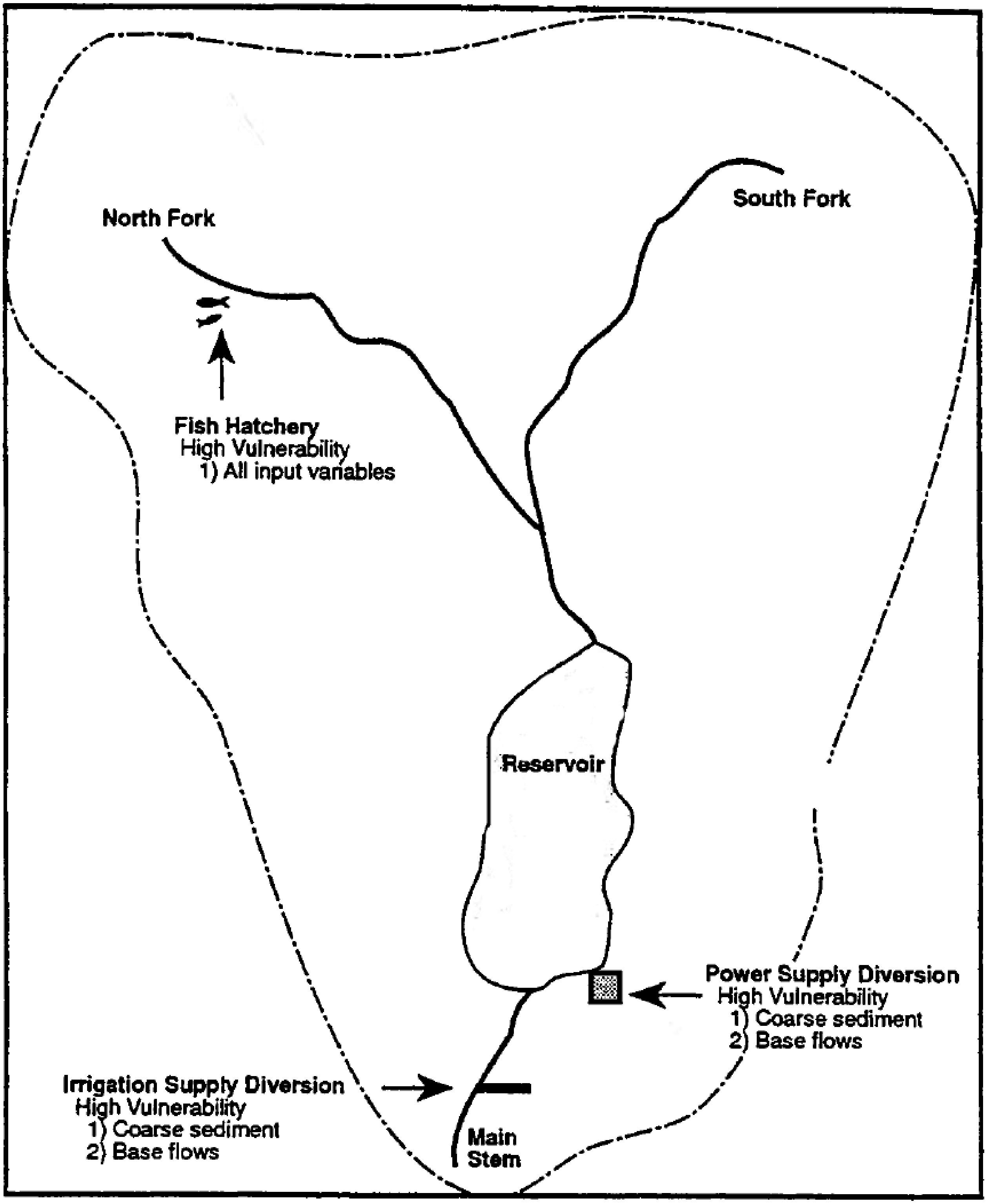


Figure H-3: Examples of vulnerability

Note: Map symbology will be provided at training

Public Works Procedures

Critical Questions

What public works are present in the watershed?

What public works are sensitive to changes in one or more of the three input variables?

Which are sensitive to peak flow changes?

Which are sensitive to mass-wasting events?

Which are sensitive to coarse sediment inputs?

Level 1 Assessment

The Level 1 assessment utilizes interviews, topographic maps, and aerial photos to identify the location and type of public works present in the watershed. The location and/or type of facilities present are then used to determine vulnerability to changes in each of three variables: peak flows, mass wasting, and coarse sediment. Sensitivity for one category of public works, power lines, is assessed separately by evaluating the potential for damage from wind throw trees. Results of the analysis are presented as a graphical overlay of the WAU base map.

Objectives

1. Identify the location of all public works.

2. Use location and type of public work to determine vulnerability to each of the three input variables.

Qualifications

Skills

Mapping and aerial photography interpretation.

Assumptions

- Vulnerability of public works to peak flow changes can be determined from position on the floodplain.
- Vulnerability of public works to mass wasting can be determined from position relative to impact areas identified in the mass-wasting module.
- Vulnerability of public works to coarse sediment inputs can be determined by the type of public work being analyzed.

Information Gathering

Maps

- USGS topographic maps (WAU Base Map).
- Federal Emergency Management Agency (FEMA) flood hazard maps.
- Soil survey maps. (Available at Photo & Map Sales or DNR Info. Management.

Photographs

Aerial photographs of the watershed - obtain the most current photos available.

Personal and first-hand knowledge of the area

Conduct interviews with state and county transportation departments or other appropriate entities (e.g., U.S. Forest Service, private landowners) to obtain information on roads and bridges in the watershed. If dams, power lines, railroad lines, parks, or other public works are present, conduct interviews with individuals familiar with these facilities. Use Form H-3 for all interviews.

Analysis Procedure

Steps Identify Public Works Facilities

Review USGS maps and aerial photos to identify the locations of public works. Common public works include:

- Roads
- Bridges
- Power Lines and Structures
- Railroad Lines
- Pipelines
- Fish Hatcheries
- Parks
- Buildings

Prepare Public Works Map

Prepare an acetate overlay of the WAU base map. Identify the location and type of all public works in the watershed. An example is illustrated in Figure H-4.

Determine Public Work Vulnerability

Assess the vulnerability of these resources to changes in peak flow as follows:

Review FEMA flood hazard maps to identify the 50-year and 100-year flood-plains. If FEMA maps are not available, contact the emergency management division of the county sheriff's office or the county surface water management division to obtain floodplain information.

Identify those public works located on the 50-year or 100-year floodplains.

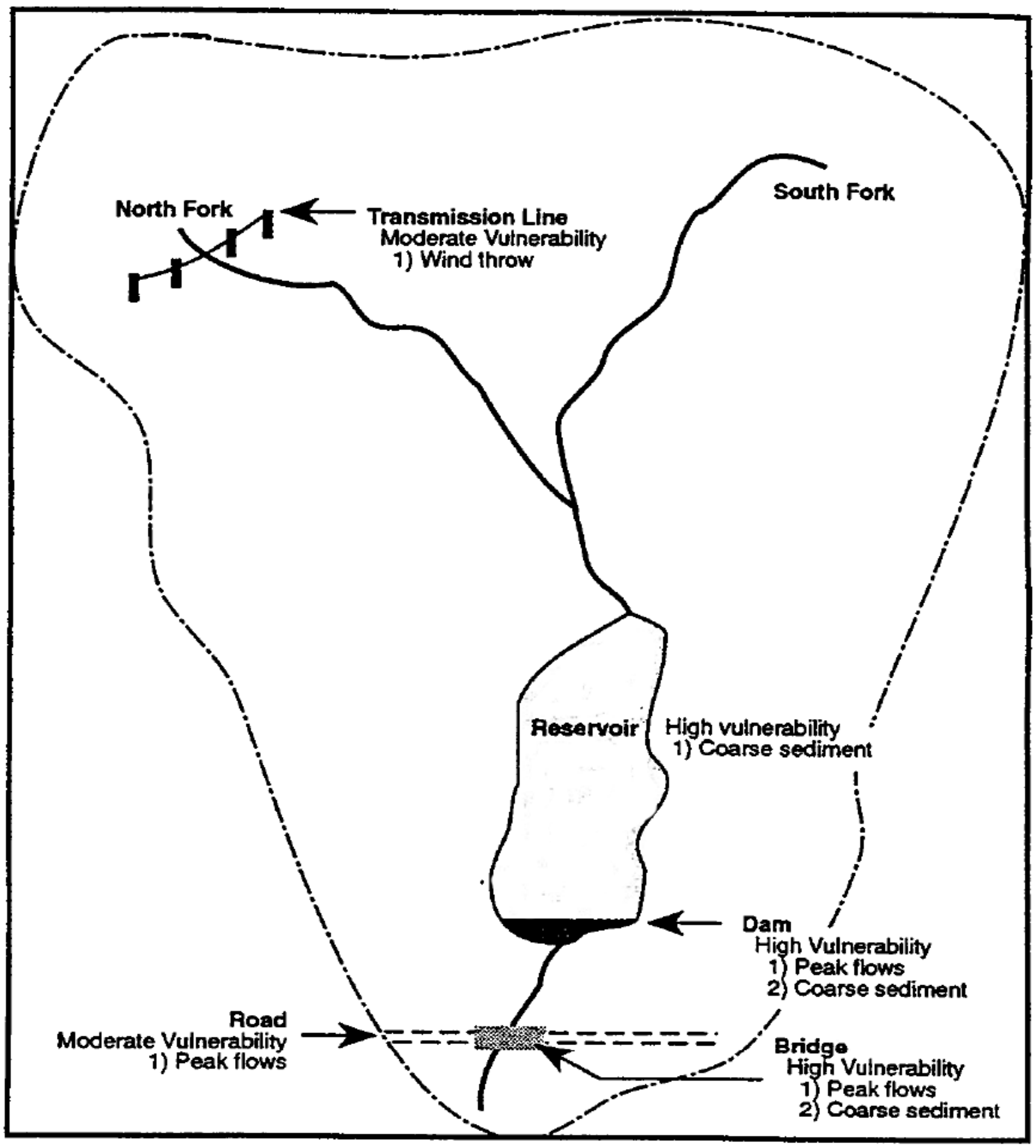


Figure H-4: Examples of vulnerability

Note: Map symbology will be provided at training.

Assign a vulnerability for each facility to peak flow changes using the following table:

Table H-2: Vulnerability of public works to peak flow changes.

Located on 100-year Floodplain?	**Located on 50-year Floodplain?**	**Vulnerability to Peak Flow** Changes
N	N	Low
Y	N	Moderate
Y	Y	High

For each of the public works identified in the base map overlay, list the vulnerability to changes in peak flow. Label this overlay as "Map H-2 Public Works Vulnerability."

Assess the vulnerability of each public work to mass wasting as follows:

Review the landslide potential map prepared as part of the mass-wasting module. Identify areas of high and moderate potential.

Determine which, if any, of the public resources are downslope of high and moderate mass-wasting potential areas.

Assign a vulnerability for each facility to mass wasting using the following table:

Table H-3: Vulnerability of Public Works to Mass Wasting

Downslope of Moderate Hazard Area	**Downslope of High Hazard Area?**	**Vulnerability to Mass Wasting**
N	N	Low
Y	N	Moderate
Y	Y	High

For each of the public works identified in the base map overlay, list the vulnerability to changes in mass wasting.

The vulnerability of public works to coarse sediment is assumed in Level 1 to depend on the type of facility being analyzed. For example, coarse sediment inputs can result in channel filling and widening. Consequently, bridges and roads running along floodplains are more sensitive to coarse sediment than public works located away from stream channels. The following table identifies sensitivity to coarse sediment for several types of public works. Individual calls can be modified using project specific information if available. The basis for modifying calls must be recorded on Form H-4.

Table H-4: Vulnerability of public works to coarse sediment

Public Work	Vulnerability to Coarse Sediment
Bridges over streams	High
Other bridges	Low
Floodplain roads	High
Other roads	Low
Reservoirs/lakes	High
Streamside parks/buildings	High

Use the above table to assign a vulnerability for each public work to coarse sediment.

For each of the public works identified in the base map overlay, list the vulnerability to coarse sediment (see Figure H-4).

Assess the vulnerability of power line facilities to wind throw as follows:

- Use aerial photos to determine the distance between transmission lines and any trees along the right-of-way.
- Use results from the riparian function module's analysis of tree maturity to assign vegetation into one of three maturity classes: young, mature, or old.
- Use the following table to determine power line vulnerability to hazard trees.

Table H-5: Power line vulnerability to hazard trees

Tree Maturity	Distance to Treeline		
	<100 ft.	100'-150'	>150'
Young	L	L	L
Mature	H	M	L
Old	H	H	L

The probability of wind throw increases when trees along the right-of-way are confined to buffer strips. Review of the site with utility related foresters is recommended.

Power lines or line segments identified as being subject to a moderate or high potential impact should be identified in the base map overlay (see Figure H-4).

Water Supply / Public Works Assessment Report

I. Title page with name of watershed analysis, name of module, level of analysis, signature of qualified analyst(s), and date

II. Table of contents

III. Maps
- Water supply vulnerability (map H-1)
- Public works vulnerability map (map H-2)

IV. Summary Data
- Water supply assessment interview (form H-1)
- Water supply assessment modification of vulnerability call (form H-2)
- Public works assessment interview (form H-3)
- Public works assessment modification of vulnerability call (form H-4)

V. Summary Text
- Watershed overview
- Summary of water-diversion types, locations, and vulnerabilities to input variables
- Summary of public-works types, locations, and vulnerabilities to input variables
- Descriptions of any deviations from the standard methods and why the changes were necessary
- Discussion of analyst's confidence in work products
- Does module report address all critical questions?

VI. VI. Other Information (optional)
- Monitoring strategies and design and implementation suggestions
- Learning resources (a.k.a., references, bibliography) section
- Acknowledgments section

Form H-1: Water supply assessment Interview

Person Interviewed ____________________ Representing _________________

Address ____________________________ Date Interviewed _______________

Phone #

Specific experience in watershed being analyzed? (Y/N)

If yes, detail.

Are water supply diversions present?
Where are the diversions located?

What is diverted water used for?

Is diversion sensitive to fine sediment inputs?

Is diversion sensitive to coarse sediment inputs?

Is diversion sensitive to temperature increases?

Is diversion sensitive to changes in flow?

Is diversion sensitive to nutrient inputs?

Are any fish hatcheries located in the watershed?

Are there any diversions of water from this watershed in areas downstream of the WAU?

Form H-2: Water supply assessment

Modification of Vulnerability Call

Diversion ____________________ Input Variable ___________________________

Vulnerability Assigned in Table H3 _______________________________________

Modified Vulnerability Rating ____

Basis for Modification

Form H-3: Public works assessment interview

Person Interviewed ___________________ Representing ____________________

Address ___________________________ Date Interviewed ___________________

Phone #

Specific experience in watershed being analyzed? (Y/N)

If yes, detail

What public works is interviewee familiar with?

Where are the public works located?

Are the public works being used/maintained?

Are they sensitive to changes in peak flows?

Are they sensitive to mass wasting?

Are they sensitive to coarse sediment inputs?

Are unstable soils or hazard trees located along power lines or structures?

Form H-4: Public works assessment

Modification of Vulnerability Call

Public Work ___________________ Input Variable _______________________

Vulnerability Assigned in Table H4 _____________

Modified Vulnerability Rating __________________

Basis for Modification

APPENDIX I
Routing Assessment Module

Table of Contents

Introduction

Many physical processes operate simultaneously within a watershed. They deliver material or energy such as water, sediment, woody debris, nutrients and heat from the surrounding landscape and atmosphere to the stream system. Watershed conditions dictate the rate of materials transfer to the stream system, and changes in their input rates raise many of the concerns associated with forest management activities. As these materials and energy are processed, stored, or transported downstream, they influence channel morphology and the suitability of streams for fish habitat and water quality.

Watersheds and the series of stream segments in a drainage system are linked systems. Materials, once introduced to the stream, are transferred from segment to segment or are stored in and released from segments episodically as a function of water flow regimes and sediment transport capacities of segments. In this module, only the fluvial transport of materials are considered; other transport processes, such as debris flows, are treated as sediment-generating processes. See the Mass-Wasting Module.

Coupling the rate of input with transport and storage within a stream system will be critical elements of relating stream characteristics with basin-wide erosion or hydrologic processes. For example, sediment budgets need to be coupled with estimates of transport and indices of channel response. Although detailed accounting of sediment or water budgets are probably not possible in all watersheds, more qualitative or general estimates are still of value. They provide some discrimination of the significance of potential changes. Adjustment of channels to moving material will reflect both amounts introduced upstream as well as locally.

Critical Questions

Critical questions addressed by this module are:

Is the potential impact (sediment or peak flow) transported or routed to the indicator segment of concern?

Is the amount of material or energy transported to the segment sufficient to cause a significant change in channel or habitat conditions?

Answers to the following second order questions will help determine if the potential impact is routed to the indicator segment.

Is the segment directly or indirectly linked to the potential impact source?

Is the potential impact active or inactive?

Is there evidence of an effect from the potential impact?

Can potential impacts be routed to segment?

Level l and 2 Analysis

This module is designed to address questions concerning the linking or routing of sediment and peak flow impacts from hillslope processes to stream segments. The module is a subroutine of synthesis; therefore it is not performed during the hillslope process and resource assessment phase of watershed analysis. Information needed to perform the routing assessment is derived from the modules. All required information, however may not be available from the Level l analysis. In some cases, answers to specific questions (e.g., downstream transport efficiency) will most likely require Level 2 channel analysis.

Qualifications

Analyst qualifications required to perform the routing assessment are equivalent to the skills, education, and experience required for the channel assessment.

Analysis Procedure

The routing assessment is performed for the indicator areas selected for synthesis. Only segments that have resource characteristics vulnerable to one or more of the potential hillslope impacts (i.e., fine sediment, coarse sediment, or peak flows) are evaluated.

Linkages between each potential hillslope hazards and vulnerable resource characteristics are examined by answering a set of questions. The questions are organized in a logical stepwise format (Figures I-1 and I-2). Decision criteria for each impact variable are used to determine the appropriate response to each question (Tables I-1 to I-3). Responses to each question and the specific criterion (if more than one applies) are recorded on Worksheet I-1.

The routing analysis is performed for each potential impact and each indicator area where routing is in question. The hillslope impact area closest to the indicator area is evaluated first. Additional hillslope areas that may impact upstream vulnerable resource characteristics are evaluated sequentially. The process continues until all impact areas that may be linked to a specific indicator area are examined. If evidence of effect is used to confirm delivery of an impact from more than one hillslope impact area there is a possibility that there is unequal contribution from each area. In these cases, the magnitude of the effect from each impact area needs to be weighed against the signal from observed effects to determine if a routing connection exists.

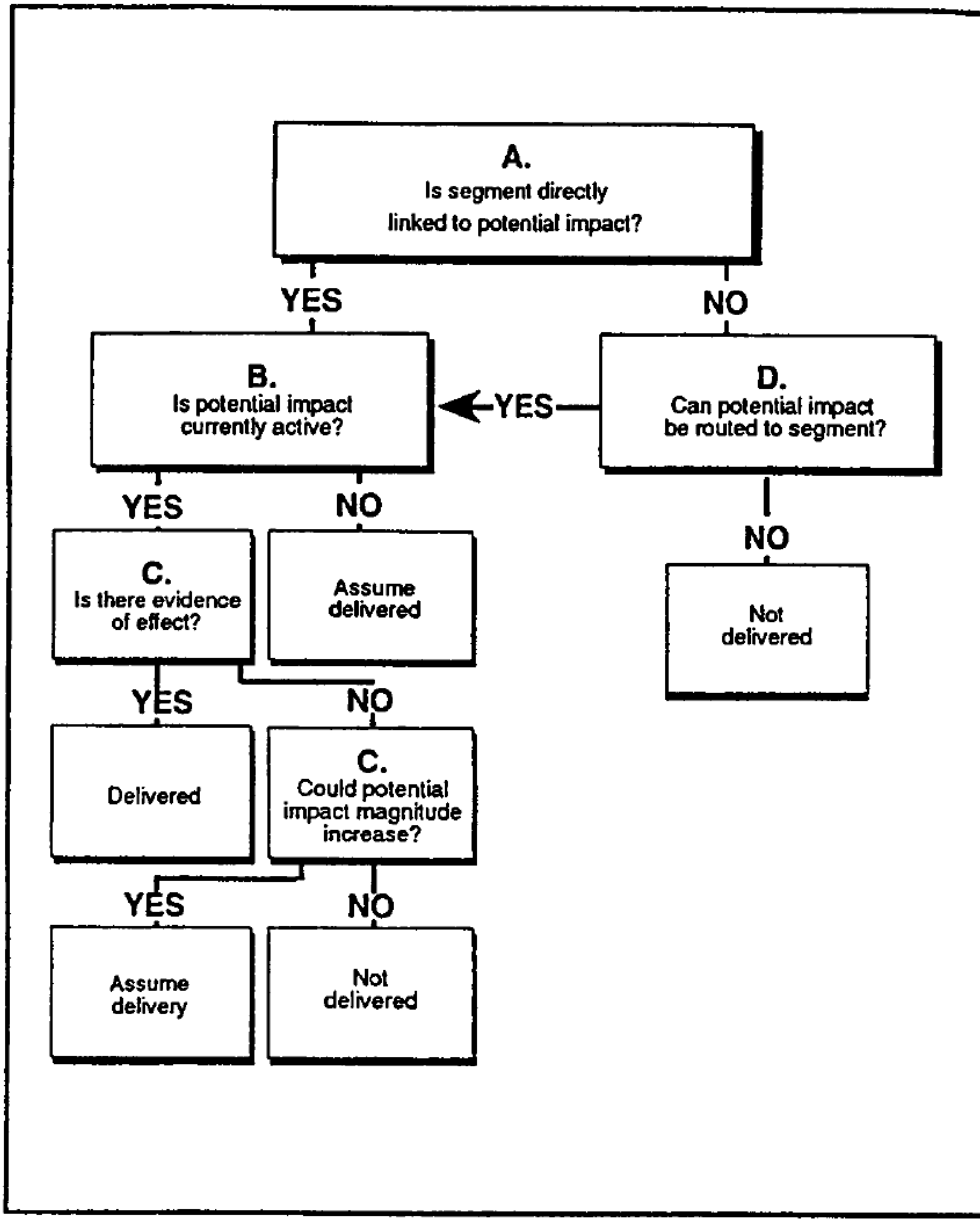


Figure I-1: Fine and coarse sediment routing analysis.

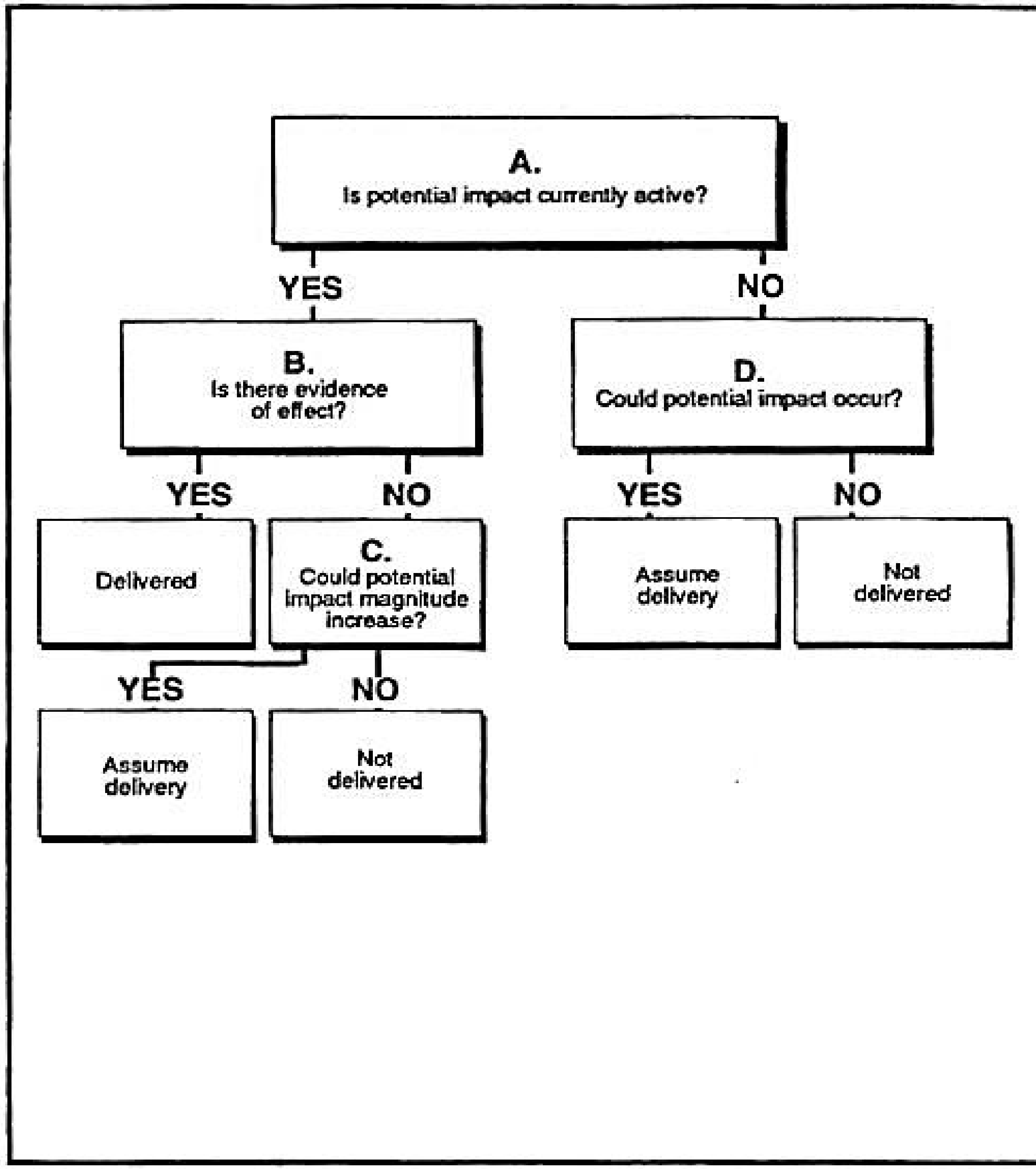


Figure I-2: Peak flow routing analysis.

Table I-1: Decision criteria for fine sediment routing analysis

Question	Response	Criteria
A. Is segment directly linked to potential impact?	Yes	Potential impact immediately adjacent to segment
	No	Potential impact not adjacent to segment
B. Is potential impact active?	Yes	Mass wasting events, or hillslope surface erosion, or road surface erosion currently generating fine sediment
	No	Mass wasting potential impacts, or hillslope surface erosion potential impacts, or road surface erosion potential impacts not generating fine sediment
C. Is there evidence of fine sediment effect?	Yes	• Spawning gravel fines rated as fair or poor • No stream bed armoring • Sand in stream bed • Decreased pool capacity • Channel module sensitivity • rating medium or high
	No	None of the above
D. Can potential impact be routed to segment?	Yes	• Intervening stream channel • conducive to transport of fine sediment • Sediment flushing flows likely • Upstream sediment storage capacity saturated
	No	• Upstream sediment storage available and inputs attenuated • Sediment flushing flows unlikely

Table I-2: Decision criteria for coarse sediment routing analysis

Question	Response	Criteria
A. Is segment directly linked to potential impact?	Yes	Potential impact immediately adjacent to segment
	No	Potential impact not adjacent to segment
B. B. Is potential impact active?	Yes	Mass wasting event generating coarse sediment
	No	Mass wasting event not generating coarse sediment
C. Is there evidence of fine sediment effect?	Yes	• No stream bed armoring • Decreased pool capacity • Channel module sensitivity rating medium or high • Channel widening
	No	None of the above
D. Can potential impact be routed to segment?	Yes	• Intervening stream channel conducive to transport of coarse sediment • Sediment flushing flows likely • Upstream sediment storage capacity saturated
	No	• Upstream sediment storage available and inputs attenuated • Sediment flushing flows unlikely

Table I-3: Decision criteria for peak flow routing analysis

Question	Response	Criteria
A. Is potential impact active?	Yes	• Moderate or high peak flow impact potential rating for the sub-basin
	No	• Low peak flow impact potential rating
B. Is there evidence of effect?	Yes	• Bank cutting obvious • Evidence of recent bed mobility • Bed armoring • Small particles only present on bars • Evidence of redd scouring
	No	None of the above
C. Could potential impact increase?	Yes	• Hydrologic maturity of vegetation could be decreased by timber harvest
	No	• Hydrologic immaturity is at maximum
D. Could hazard occur?	Yes	• Timber harvest could increase peak flow impact potential rating to moderate or high
	No	• Not possible to increase peak flow impact potential rating above low

Worksheet I-1: Record of routing decisions linking hillslope potential impacts to stream segments

River Basin ____________ Date ____________ Page _____ of _____

WAU ____________ Analyst ____________

Impact / Vulnerability Variable	Indicator Segment Number	Hillslope Impact Area			Routing Response and Criteria			
		Map Number	Unit Number	Rating	A	B	C	D

APPENDIX J
Cultural Resources Module

Table of Contents

INTRODUCTION

Using this methodology in a formal watershed analysis or as a stand-alone process - This module is designed to provide a methodology for performing cultural resource (CR) assessment as part of a watershed analysis. It discusses the steps, techniques and methods for carrying out such a study. Watershed analysis (WSA) is a formal assessment of an entire Watershed Administrative Unit (WAU). However, this module can also be used as a "standalone" reference guide for research, inventory or assessment of cultural resources outside of a formal WSA. Four uses of the module are outlined below, only the first of which pertains to a formal WSA.

1. ***Using this methodology in a formal watershed analysis:*** In WSA, this module is an interdisciplinary team-based process for defining CR sensitivities through assessment of existing and potential hazards and their effects on CR vulnerabilities. Voluntary management strategies are then proposed and chosen, based on information generated in the resource assessment. Disturbance of archeological sites, or Native American cairns, graves or glyptic records is regulated under state archeological and historic preservation laws. The Office of Archaeological and Historic Preservation (OAHP) must be consulted prior to the disturbance of these sites.

   It is important to maximize participation by all those affected by a cultural resource module in order to realize the full potential of the analysis and resulting products. A good faith effort is necessary to ensure that all affected parties have an opportunity to contribute to the assessment and add to the solutions anticipated in the module. Tribal participation is necessary but may vary in degree from providing consultation to being the module leader. Throughout the module process, the initiator of the watershed analysis should facilitate tribal participation by accomplishing at least the following:

   - Ongoing neighborly efforts to inform and involve affected parties,
   - Timely notification of meetings and other related processes, and
   - Adequate notice of final decision-making processes.

2. ***Using this methodology in a cultural resource assessment of a property larger or smaller than a WAU:*** Cultural resources can also be assessed as part of a formal (i.e., following WSA protocols) or stand-alone review of a property that does not confine itself to the boundaries of a single WAU. For example, an assessment of a park, reservation or private landholding could review CRs and some or all of the other resources. Depending upon the project and objective, the methodology presented in this module can be followed without deviation or simply consulted regarding techniques for CR data collection and assessment.

3. ***Using aspects of this methodology in consultations relating to a Forest Practices Application (FPA) for a property that may include cultural resources.*** There is information in this module that may be useful to landowners and tribes when an FPA proposes activities in an area that contains identified tribal cultural resources. In such a case, the step by step methodology for WSA presented in the body of this CR module is not called for, but the organized approach and methods in the module may be helpful in leading to a cooperative solution.

4. ***Using aspects of this methodology for research with the objective of producing an inventory of cultural resources in a property, traditional tribal territory or other geographic area.*** Tribes, historical societies and other groups recognize the need to compile cultural resource inventories. If the objective of a research project is limited to compiling a complete inventory of CRs, this module contains various sections that present and explain discovery procedures (e.g., interview and archival research), record keeping and collation of data. It is also useful to have data on the current condition of CRs, as well. Thus, the sections on assessment may be useful, as well.

The methodology of cultural resource assessment – In WSA, all CR assessments follow a pattern similar to that of the other modules in this manual. Cultural resource assessment involves the following steps and processes, shown in Figure 1 below:

- Startup
- Resource assessment (research and inventory)
- Synthesis: Assessment of condition, hazards and vulnerability
- Management strategies process
- Wrapup

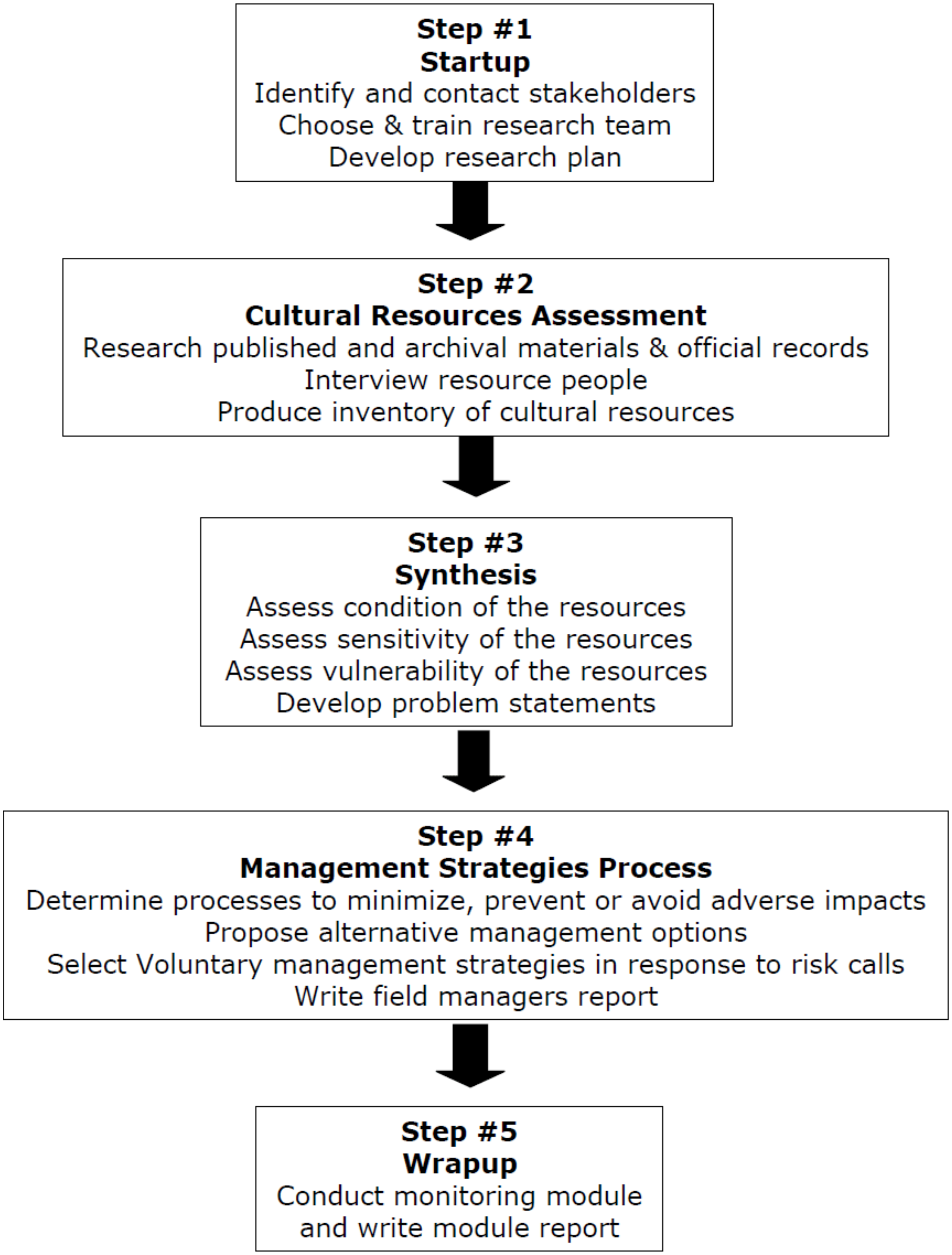


Figure J-1: Methodology of Cultural Resource Assessment

Watershed analysis is a process of inquiry involving interdisciplinary investigations of the potential adverse effects of land management activities on some resources in a basin. In watershed analysis, all of the module teams do resource inventory and initial assessment, identifying areas of resource sensitivity. This is followed by a synthesis stage of inter-team consultation in which the effects of land use activities and ecological processes on vulnerable resources, called causal mechanisms, are catalogued. The condition and vulnerability of those sensitive resources are used to produce rule calls (or "risk calls" in CR assessment) for determining appropriate management actions over space and time. The next stage is the prescription process (or "management strategy process" for CRs), carried out largely by a team of field managers, to determine agreed upon approaches to minimize, prevent or avoid adverse impacts. The final stage is wrap-up, in which monitoring responsibilities are specified and set up and the final report is compiled. Cultural resource assessment, as one of the components in WSA, involves the same steps and activities. However CR assessment differs significantly from the other modules in WSA.

A short glossary of terms reflecting the non-regulatory nature of cultural resource assessments in watershed analysis – The WSA rules and manual use terminology with very specific meanings and connotation. The specific language of the other modules in this manual, which are physical science based and regulatory, differs from that of this cultural resource module, which is social science based and largely non-regulatory (i.e., voluntary). For that reason, we include this short comparative glossary of watershed analysis usage in the physical science modules and the equivalent cultural resource module terms.

Physical Resource Modules	Cultural Resource Module
Physical science based data	Social science based data
Largely quantitative evidence	Largely qualitative evidence
Rule call	Risk call
Regulatory measures	Voluntary measures
Prescriptions	Management strategies

In contrast to the prescriptions resulting from the other modules of a WSA, management strategies intended to be employed by landowners in response to cultural resource sensitivities are generally dependent on voluntary cooperation. This is not to suggest that there are not any laws and regulations that apply to cultural resources. Disturbance of archeological sites, or Native American cairns, graves or glyptic records is regulated under state archeological and historic preservation laws. The Office of Archeology and Historic Preservation (OAHP) must be consulted prior to the disturbance of these sites. Forest practice activities that have the potential to disturb any of these sites or other recorded archaeological or historic sites are subject to detailed scrutiny under the State Environmental Policy Act. Furthermore, the Forest Practices Rules require that activities on lands which contain cultural resources identified as of interest by an affected tribe require a 30-day review period and a mandatory meeting between the landowner or operator and the tribe with the objective of agreeing on a plan for protecting the cultural values.

Nature of cultural resource assessment – For the purpose of this module, cultural resources may be broadly defined as historic sites, traditional places, traditional materials and archaeological resources of cultural value: the sites of historic things and events, places where traditional activities happen, the locations of traditional foods and materials and archaeological remains. The term cultural resource assessment actually refers specifically to the inventory and assessment of the CRs contained within a watershed (or within a property, when this module is being used as a stand-alone methodology). However, CR assessment is also regularly used with reference to the entire process of identifying, assessing damage or risk and developing management strategies to protect cultural resources. CR assessment provides the basis for discussions that build cooperation and trust among the various parties that produce and use the cultural resources report. While the objective of cultural resource assessment is the protection and management of resources that have value to people of Washington state, the stewardship responsibilities and management objectives of landowners and land managers are of equal importance in successfully completing this module. Thorough and precise assessment can provide the basis for informed, sensitive negotiation and agreements that protect unique and valued cultural resources.

Qualitative nature of cultural resource data – Information gathered in a cultural resource module differs significantly from the statistics and test results on which all of the other modules of this manual are based. At the inventory level, cultural resource investigations primarily draw on qualitative data, which refers to personal history accounts, observational reports, traditional narratives, ethnic traditions and conclusions based on value judgments. Statistics and test results are called quantitative data since they are based on numbers, and they are considered by those with an experimental bias to be "more scientific". In fact, qualitative data are the basis of much social science research; that is, they are "social-scientific" and are a reliable body of information on which to base decisions derived from cultural resource inventories.

Qualitative data may be supported by other types of research data. For instance, a historic home site that old people remember hearing about and which, although no longer extant, is mentioned in traditional stories, may also be indicated by archaeological evidence and mention of remains at a precise location in an early surveyor's logbook (two types of "hard data" supporting the qualitative evidence or "soft data"). The fact of this different, qualitative basis of evidence does not mean that cultural resource inventories are less reliable, replicable or respectable than the conclusions of the other watershed analysis teams. They are simply based on different data, often the only evidence available. This difference in data has occasionally resulted in the perception that cultural resource data is not relevant to the rigorously scientific conduct of watershed analysis. Experience has shown that this is not the case. Cultural resource sites are presumed to be actual locations, the existence and value of which is supported by qualitative evidence.

Qualifications of Cultural Resource Assessment Team – Cultural resource inventories and assessments require precise, complete data collection, rigorous and objective assessment, and skillful communications. These requirements are necessary because CR assessments may become the basis for far-reaching decisions. A CR module provides a lasting record of tribal and non-tribal cultural resources sites within the area of concern. CR assessments provide a benchmark for future comparison and can be the basis for management practices that have consequential implications. Finally, cultural resources are valued and emotion laden, often associated with tribal or community identity. For that reason, the assessment phase of the CR module must include expertise in both archaeology and cultural anthropology. Depending on the resources identified in assessment, the management strategy phase must include expertise in archaeology and/or cultural anthropology. It is also suggested that those performing CR assessments or supervising the CR modules have the following qualifications:

- Expertise in documentary research, interview and transcription.
- Training in the social sciences sufficient to recognize and discuss the social or cultural basis for resource findings.
- Familiarity with the appropriate federal and state laws, regulations and policies relating to forest practices, DNR watershed analyses and the treatment of cultural resources.
- Access to information or input as needed from skilled researchers in the areas of forestry, hydrology, soil science, geology, geomorphology, fisheries, botany, ecology and vertebrate biology.

It saves a great deal of time if the CR investigator is already aware of the community and area history or tribal ethnography before starting the project.

Principles underlying cultural resource analyses - This CR methodology module has the following assumptions:

1. The purpose of CR assessment is to provide a basis of information to be used in developing voluntary measures for the protection and management of Washington's significant cultural resources, in particular those located on state, private and non-federal forestlands. Note that there are existing laws

and regulations that pertain to archaeological sites and tribal cairns, graves and glyptic records.

2. The qualities of cultural resources should be preserved for future generations through protection, restoration or recording of physical historic evidence and protecting opportunities to access and benefit from traditional use of forest resources.
3. Cultural Resource inventories and assessments, if used cooperatively with sensitivity for the values and objectives of all parties, can be used to develop management strategies and agreements that protect those unique and valued cultural properties and respect the goals and concerns of all.

These principles will be re-articulated below, directed specifically at the particular concerns of tribal and non-tribal communities and their cultural resources.

ASSESSMENT OF CULTURAL RESOURCES

Assessing tribal and non-tribal cultural resources in the same watershed analysis project – Many WAUs include both tribal and non-tribal cultural resources. When this is the case, it is usual for the inventory and assessment of all cultural resources, tribal and non-tribal, to be carried out at the same time. Both types of CRs need to be assessed or the WSA is not complete. Although different experts can be used, it is most efficient and effective to have a single CR team and produce a unified module, even though tribal and non-tribal CRs may be treated separately.

Organizing and conducting a cultural resource assessment- The beginning phases of a CR module for WSA involve startup, team building, and preliminary gathering of assessment information. Even before startup begins, a face-to-face pre-meeting between tribal representatives and landowners can serve to clarify expectations and set up lines of communication that lead to cooperation and mutually acceptable management strategies. For information on contacting tribes, call the Department of Natural Resources forest practices program in the DNR region where the module is to be used.

Startup - Whether the cultural resource assessment is part of a formal watershed analysis or a stand-alone assessment of CRs in a property, the start-up process is the same. It involves team building and, if necessary, new learning or training. It includes collecting maps, video, audio, imagery and other available data and extant sources of information on the area included in the WSA or stand-alone process. Consultation between landowners and other stakeholders is important at this stage. It is important to identify all stakeholders concerned and to hold one or more meetings in which the process of CR assessment can be clarified and developed for further action (i.e., resource assessments, synthesis, handoff, management strategies) and evaluation. Startup is a time to exchange opinions about the makeup and conduct of the CR team.

Memoranda of understanding have been identified as a preferred pathway by landowners and tribes for managing cultural resources. Landowners, land managers and tribes are encouraged to develop a memorandum of understanding (MOU) either prior to conducting and/or upon completion of the WSA or stand-alone process. A pre-process MOU could document the stakeholders cooperative process and commitments in finding mutually beneficial solutions; while an outcome based MOU could incorporate the CR management strategies and provide for resolution of issues not within the scope of the WSA.

Level 1 and Level 2 analyses - Watershed analysis is usually initiated by landowners or the DNR or both. The initiator can choose either Level 1 Analysis (map based without a high degree of detail) or Level 2 Analysis (field based assessment that may even go beyond methods described in the manual if there are lingering questions). The choice of level is based on various issues such as how long the initiator expects the analysis will actually take, how urgent the need for the finished assessment, or what degree of detail is warranted. There are no time limits when using the CR module as a stand-alone process. It may be practical, however, to establish a time line as part of setting expectations for the assessment and resulting management strategies.

Team building – The size and composition of the CR assessment team is an important issue. The resource assessment team could profitably include representation by the various stakeholders. This is a research unit, though, and investigators should be chosen on the basis of objectivity, skill and experience. If there has been no previous review of CRs in the area of concern, a researcher with appropriate credentials should be included in the assessment team. In a WSA, the CR team should be included in the process from the beginning so the members understand the assessment process.

Tribal groups should distinguish between a cultural resource panel of tribal members and the CR assessment team. The elders and other informed tribal members and leaders have an important role in the research process, but they are subject matter experts or consultants. The assessment team is the group that conducts the interviews, transcribes and collates the data provided by those resource people. Team members may also conduct library and archival research. Sometimes the tribe already has a long-term relationship with an anthropologist or archaeologist who has a working relationship with elders based on trust. Such a professional, in addition to having researched the history, language, traditional lifeways, mythology and beliefs of the people, usually has other useful skills such as technical communications (e.g., writing, editing, information design and retrieval). Tribal officials may subsequently serve as representatives on the field managers team at the management strategy stage.

If the CR assessment is conducted as a stand-alone investigation (not part of a WSA project), in which case the CR team is not working with other assessment teams, consider inviting a biologist or forester who is aware of tribal priorities onto the team. By the time the CR assessment is completed, it may be helpful to have stakeholder representatives participate in the synthesis process. Effective resource assessment teams are generally small enough to meet around a table; and they are made up of informed, skilled people who are prepared to discuss and compromise in order to protect both the tribal cultural resources and the landowners' interests within the area being considered.

New learning or special training should not be necessary if the CR assessment team is chosen with care, being careful to include qualified team members.

Evaluation of cultural resources - The special expertise of Indian tribes is recognized when assessing properties to which they attach religious and cultural significance. Only the tribe(s) can make that evaluation. Non-tribal cultural resources and most archaeological sites should be assessed using predetermined criteria such as the criteria for eligibility for the National Register of Historic Places. The National Register criteria are based on the quality and significance in American history of architecture, archeology, engineering, and culture as present in districts, sites, buildings, structures, and objects. To qualify, these features must possess integrity of location, design, setting, materials, workmanship, feeling, and association that:

1. Are associated with events that have made a significant contribution to the broad patterns of our history; or
2. Are associated with the lives of significant persons in our past; or
3. Embody the distinctive characteristics of a type, period, or method of construction, or that represent the work of a master, or that possess high artistic values, or that represent a significant and distinguishable entity whose components may lack individual distinction; or
4. Have yielded or may be likely to yield, information important in history or prehistory.

Further information can be obtained from National Register Bulletin #15, "How to Apply the National Register Criteria for Evaluation, 1991".

Record keeping - All materials should be copied and labeled, and the information abstracted from it kept in organized files, notebooks and computer files. The CR assessment is, in part, a process of organizing data so that generalizations and conclusions become apparent. Therefore, investigators should be organized, using a classified, arranged storage system for data and copies of source materials. Also, a properly organized assessment is replicable.

That means that another investigator should be able to review the data and records of a resource assessment or re-do it and come up with the same conclusions. In order for someone to re-examine the project's database it has to be organized understandably. A by-product of CR assessment is often a tribal archives. Tribal input should be sought to decide whether and to what extent CR data should be treated and stored as confidential.

Maps, locations and GIS – Maps are both an important tool and a valuable product of CR assessment. Locations must be drawn onto maps, and exact coordinates are easy to determine with a hand-held GPS (global positioning system) receiver, a satellite based scheme that provides the coordinates of the location (latitude and longitude) in which the person holding the receiver is standing. Since maps of the various resources of the area under study are among the deliverables of a watershed analysis, it is important to determine exact coordinates that will allow the CR sites to be integrated into the geographic information system (GIS). This is a digital system in which site spatial data (site coordinates) and attributes (data collected in the field, interview and all other sources) are captured and databases storing attribute and spatial data are created and manipulated and maps that include the sites and information are drawn by computer and printed on large format printers. Because each of the module teams will produce maps, as a general rule a formal WA will have budgetary allowance and contractual arrangements to do the GIS input, programming (if necessary), database queries, and output (See discussion of GIS, Startup section).

Confidentiality under the Public Disclosure Act - State law provides that certain records in the government's possession are exempt from public inspection and copying. For cultural resources, this applies to "Records, maps, or other information identifying the location of archaeological sites in order to avoid the looting and depredation of such sites" (Chapter 42.17.310 (1)(k)). All other CR's revealed and documented as part of the WSA CR module are subject to public disclosure. All module development teams should endeavor to protect tribal CR's by including as little detail as possible regarding the nature and location of individual CR's in documents.

Cultural versus community-social based assessment information - Cultural and community-social based values are not always distinctive from one another, and are often intermixed in the information generated through interview and/or other assessment techniques.

The cultural resources module is intended to distinguish cultural from community-social oriented information, and emphasize only the cultural. Any or all community-social based assessment data or information that is identified as a result of cultural resources module assessment efforts could be acknowledged and summarized. Summaries of a community-social oriented assessment information that are produced may be discussed within the assessment findings as additional information and be available for potential consideration or strategic response.

Tribal cultural resources

The nature of tribal cultural resources (TCR) – Tribal cultural resources symbolize the traditional heritage and modern-day living culture of Native American people. These resources are the sites, food, medicines and materials of traditional tribal lifeways. Many of these resources are non-renewable and are vital to the peoples that depend upon them. Tribal cultural resources, as an example, include archaeological sites and relics, settlements and campsites, spiritual and sacred sites, and traditional subsistence grounds (see detailed discussion of tribal cultural resources under Data needs below). This is a general definition of tribal cultural resources that applies to most Native American peoples, but specific cultural resources vary from tribe to tribe, nation to nation, reflecting the individuality of each tribe and nation. It is because of this individuality that consultation with each tribe regarding their specific cultural resource protection requirements is important and necessary if cooperation is to flourish.

The features of a successful TCR assessment - The objective of this module is to provide a guide for successfully producing an inventory, assessment, and set of voluntary management strategies that can serve as the basis for the stakeholders in a landscape area (e.g., watershed, land-use conversion area, or logging unit) to negotiate management decisions that protect tribal cultural resources. Thus, an effective assessment of a watershed that includes tribal cultural resources will, to the extent possible, have the following features:

1. A successful TCR assessment will establish and maintain communication between forest landowners and land managers and Native People. TCR assessment may foster trust, communication and relationship building among stakeholders.
2. Since it is presumably impossible to conduct an effective TCR assessment without input from the tribe or tribes that have cultural interests in the area of concern, the most efficient and productive means of producing the TCR inventory is to have tribal representatives on the assessment team or to put the TCR assessment in the hands of the tribe. Tribal representatives should also be present during synthesis and the development of regulatory WSA prescriptions and TCR management strategies.
3. A complete TCR assessment will include archaeological sites (but does not require an archaeological survey nor replace the potential need for one). It may also include sufficient information to allow the identification of historic properties eligible for listing on the National Register of Historic Places.

4. Once an inventory of TCRs has been prepared and an assessment of their condition, their sensitivity to hazards, and the activities and processes that may affect their condition has been made, participants will negotiate management strategies that reflect mutual respect for tribal cultural resources and the economic objectives and stewardship responsibilities of the landowners.
5. The participating stakeholders in a successful TCR assessment will maintain trust and accord while protecting the privacy, security and confidentiality of TCRs, according to tribal wishes. Recognizing that some TCRs may be considered so sacred and irreplaceable that their existence will never be revealed to non-members, sensitive negotiations will determine tribal wishes and attempt to accommodate them.
6. The successful TCR assessment may foster trust, communication and relationship building between tribes and landowners and land managers that results in memorandum of understanding that document their resolve to cooperate in finding solutions to site-specific problems. Such a programmatic agreement could profitably be concluded between stakeholders as a result of the TCR process, resolving to find cooperative, mutually beneficial outcomes rather than impasses.

The tribe's decision on confidentiality – In some instances, tribes have decided to keep the location of all or some of their TCRs confidential. There are a number of reasons for this. Some feel that by preparing an inventory of their cultural resource sites, they are inviting voyeurs to spy on ritual sites and "pothunters" with their metal detectors and shovels to despoil historic locations looking for trophies. In fact, there have been instances of petroglyphs being defaced, burial caves plundered and vandalism. Other tribal councils and officials have decided that their TCR sites are so closely associated with their tribal heritage and their group identity that it is an issue of membership-privilege to maintain secrecy about the details of their common past and traditions. Whatever the reason for withholding the facts and locations of their TCRs, tribes have a right to do so. However, it does make protection of those sites more difficult to propose and negotiate. For the most part, divulging the location of TCRs is a matter of trust. Tribes that elect to maintain secrecy or invoke total or partial confidentiality (e.g., only maintain confidentiality about their ceremonial, ritual and burial sites) should be prepared to work with landowners to find alternative solutions to meet the landowner's goals as closely as possible while protecting TCR confidentiality. It is, of course, a responsibility of landowners and other stakeholders to inspire trust that they and their employees will respect the contents and privacy of sensitive TCRs.

Critical questions - The first step in cultural resource assessment is to decide a small set of general questions that focus the investigation. These questions are an evaluative metric to use in checking that the project is on course and consistent with the objectives of watershed analysis or a stand-alone investigation. The critical questions are also an explicit statement of topics for readers to use in orienting their expectations at the beginning of the TCR report. Critical questions can differ depending upon the watershed or area of interest. Here is a set similar to those that have been used in several TCR assessments:

1. What resources are of cultural significance (or are "critical resources") in the area of concern and where are they located?
2. What are the historical conditions of the cultural resources?
3. What are the current conditions of the cultural resources and what are the trends?
4. What are the causes of any changes between historical and current conditions?
5. What are the vulnerabilities of each TCR and to what is it vulnerable?

The answers to this set of questions represent a concise statement of the knowledge that is the goal of each stage of the tribal cultural resource assessment. In order to answer these questions and establish what the tribal critical TCR actually are, TCR interviews and investigations should seek answers to these questions. All cultural resources are valued. But some are important, "critical resources". The special expertise of Indian tribes is recognized when assessing the cultural properties to which they attach religious and cultural significance.

The inventory of tribal cultural resources - An inventory of cultural resources is the next stage in a TCR assessment and attempts to answer the first of the critical questions. Many stand-alone investigations will have a TCR inventory as their objective. For that reason, this module provides information for the techniques and methods of investigating and inventorying tribal cultural resources. A completed inventory is, in itself, a considerable achievement. It is a notable compilation of tribal heritage. Often it is the first time a tribe has ever compiled a site registry. In some cases, stand-alone TCR inventories limit themselves to a listing of the resources and their locations without emphasizing the condition of those resources or the mechanisms impacting them.

In a formal WSA, however, the inventory includes all the data necessary for synthesis. Only the first five of the following seven steps may be necessary for a basic TCR inventory as a stand-alone process, though participants may want to complete the last two steps as well. A TCR assessment for a formal WSA requires all the following steps:

1. Identify references to previous and current traditional artifacts, sites, use areas, resource locations and other sites of tribal interest. These are cultural resources.
2. List and annotate each TCR with traditional native name, English name, known information and data about use.

3. If possible, visit ("ground truth") each of the sites, i.e., visit each TCR location, noting the surroundings, dimensions, landmarks, condition, issues of archaeological interest or evidence of use, plant life, and map coordinates (of the corners if the site is more than 30' in diameter). Photographs or slides of each site are useful, especially if pictures will make clear that the resource is being impacted by a natural hazard or one resulting from forest practices.
4. Produce an initial draft map. Number the sites progressively (e.g., headwaters to mouth of the river). Note them on a clean map. Make sure all information is in your database file. For watershed analysis, use an official base map and label it Map J-1 Tribal Cultural Resources. This draft map is the property of the tribe and should not be formally submitted to the DNR making it subject to public disclosure, thereby not protecting the tribe's confidentiality.
5. In consultation with tribal representatives, decide whether there are confidentiality concerns regarding any of the sites, and/or what overall significance is assigned to the cultural resource feature by the tribe.
6. Produce an official, finalized cultural resource base map for use in subsequent required steps.
7. Identify sensitive tribal cultural resources.

- *Data needs: tribal cultural resources* – In terms of the basic purpose of TCR assessment one of the most important aspects of the undertaking is to determine the existence, location and details of those sites. In order to do this, complete data are a necessity. Some of this information may have been accumulated previously and be available already in Indian agency annals, tribal records, ethnographic publications or archaeological reports, and prior tribal and public surveys of cultural resources. A checklist for data needs within the area of concern includes documentation of tribal knowledge, history, cultural relevance, location, description and condition of the following:

1. Archaeological resources, which include artifacts and the relics and extant evidence of traditional native lifeways. Many locations may already be registered with OAHP.
2. Traditional (pre-contact and representing continuing tribal culture and lifeways up to the present) settlement and activity sites: village sites, homesites, campsites and trading sites, pathways, fords, named places, navigational and boundary markers; also, traditional grounds for hunting, fishing, trapping, food foraging, material gathering; and manufacture, gaming, ritual, ceremonial, burial, mythic, legendary and folkloric sites. Larger areas include battlegrounds, activity landscapes, and maintained prairies.
3. Traditional materials and subsistence foods: materials used in traditional tribal medicines, weaving and basketry, tools and weapons, carvings large

and small, sacred objects and building construction; also subsistence foodstuffs: animals, birds, fish, beachlife, and edible plants.

4. Historic (i.e., post-contact and historic tribal sites or locations and structures of non-tribal settlement of interest to Native people: reservations, trading posts, forts, lumber mills, canneries, churches, schoolhouses, inns and hotels, stores, homesteads, settler cabins, barns, corrals, gardens, early roadways and bridges, and shipwreck sites.

No listing of tribal cultural resource types is exhaustive, so investigators should be alert to particular tribe-specific TCRs in the area under consideration. Investigators should bear in mind that the absence of data indicating TCRs in earlier surveys of a watershed or property may only reflect a flawed or inadequate work plan. The traditional TCRs of many tribal groups have been studied various times over the years, including ethnographic descriptions, archaeological surveys and the reports prepared for the US Court of Claims in the 1950s. While these earlier studies contain valuable information regarding tribal use of resources and traditional sites, they may be incomplete and probably do not include present-day information. The sites discussed in each previous study should be collated and checked for completeness with knowledgeable tribal members. Interviewees should represent a cross-section of the community, including people of various ages, interests, activities and experience within the watershed or property being inventoried and assessed.

- *Data needs: physical environment* – In order to assess hazards and vulnerability of the cultural resources, it is important to have the following:
  1. Large scale maps of the watershed or property (see Startup section, p. 14).
  2. Existing basin, forest, or regional natural resource overviews, studies and statistics (available from other teams in a formal WSA).
  3. Input from knowledgeable fieldworkers who are acquainted with the area and have had field experience in it. This would be provided by other teams at synthesis in a formal WSA or available from local resource managers in a stand-alone assessment.

- *Investigative techniques and discovery procedures* – All investigations need to be rigorous, complete and ethical. Any TCR assessment project may be the only or last opportunity to learn what there is to know about the history of a particular area, and the best chance to put a tribe's cultural resources on record. Therefore, TCR researchers have an obligation to check their sources exhaustively and honestly. Most TCR data come from documentary research and interviews.

Documentary research – Research involves a great deal of searching for materials and reading. Often tribes do not have accessible copies of archival documents, books, articles, reports and other publications relating to their history, culture and traditional territory. There are bibliographies that list publications about each tribal group (a good place to start is with the tribal sketch in the Smithsonian Handbook of North American Indians.) This is an important phase of the project. If no one on the team has done archival research, the team may wish to hire a professional researcher or anthropologist. A tribal member can accompany the researcher and, in the process, get on-the-job research training.

Interviews – Interviews with knowledgeable elders and tribal members who know and use the territory under review are a valuable source of information. Suggestions for interviews: These sessions should be audio recorded using either tape or digital recorders. Some groups prefer to document interviews by video recording, but it is impractical to transcribe from video, so voice recording should be done as well. If interviewing in a home, turn off the television and move to an area without background noise; sit at a table if possible; check the recorder before arriving and bring an extension cord, extra batteries and tapes; place the microphone within 3’ of the consultant’s mouth. Make a list of questions before going to the interview but don’t feel bound by it. Try, wherever possible, to use open ended questions such as, “How did you learn so much about our traditional territory?” or “What basket materials have you collected and where?” Try not to interrupt your informant unless the answers have become repetitious or wandered from the topic. Don’t tire the subject by interviewing continuously without a break. It is important to have the interviewee sign a release at the beginning of the interview, attesting that the person knows why (s) he is being interviewed and is doing so voluntarily. Label the tape or digital record. Transcribe it as soon as possible (a rule of thumb for transcription of time, converting audio files to word processor files is 90 minutes transcription time per 60 minutes of raw audio). It is usual for research projects to pay interviewees.

Forms J-1 and J-2 are WSA forms for obtaining information from interviews. For a standalone process, the forms may be used or another system to accurately and consistently capture and record that information can be used.

Form J-1 Interview Release Form for Tribal Cultural Resources
WATERSHED ANALYSIS PROJECT

I, ______________________________ give my consent to be interviewed by a member of the cultural resources research team of the watershed analysis project. I understand that my participation is important, but voluntary, and that I can, at any time, ask for the interview to be stopped.

I give __ , **do not give** __ my consent to have this interview tape recorded. I understand that I have the right to review the tape recordings or transcripts of those tapes before the content of the interview is finalized.

I understand that the information that I give will be treated with respect and confidentiality based on my own expressed desires and the decision of appointed tribal officials as to what should be made public.

I understand that the information that I give will be used in compiling an inventory of tribal cultural heritage sites and resources. The interview is considered an expression of tribal heritage and will be treated with respect.

Interviewee Name ____

Interviewee Signature ____

Interview Place ____

Date ____

Interviewer Signature ____________________________________

Witness Signature ____________________________________

Form J-2 Interview Format Form for Tribal Cultural Resources

WATERSHED ANALYSIS PROJECT

Start the interview

After having the release form signed, start the taped interview with:

> This is an interview with __*(name of interviewee)*__ on __*(date)*__.
> The interview is being conducted by __*(name of interviewer)*__.
> This is Tape One, Side One.

Introductory questions

Please tell us how old you are, where you were born and grew up. Who were your parents? Who raised you? Where did you go to school? What type of jobs have you had? Tribal membership?

We are interested in traditional places and tribal heritage things in the watershed of the __*(name of the river)*__. Is there a native name for the river or area? Is this area in the traditional land of your people? According to tribal tradition did your tribe share rights to this land with any other tribe? Are there tribal stories about how the people came to own, inhabit and use this territory? Details?

Could you tell us how you know about this area? Have you traveled in it? Did your elders tell you about it? Who knows more about it than you do?

Geographic features – Are there native names for the rivers, creeks, mountains or other geographic features of the area?

Critical resources - What would you say are the most important traditional foods and materials that are taken from this area? Do or did you or the people fish anywhere in the area? Hunt? Collect Food? Collect materials? Collect medicines? [Based on the answers, see specific questions below.]

Fish – What types of fish are caught in the watershed? Is it an important resource? Where exactly are they caught? At what time of year? What type of fishing gear is used? Who else is well informed about past and present fishing in this area?

Was fishing different in earlier times? Were there weirs or other types of fishtraps in use? Were there family ownership rights to particular grounds? How were rights to those sites passed from generation to generation?

Are there fish camps along the watercourse? What preservation activities are practiced at the sites (drying, smoking, canning)? Are there rituals relating to fishing or fish? Are there traditional stories about how fish came to be in this area or about the origin of any aspect of fishing? Are there stories of especially successful fishermen in the area? What is the reason for their good luck? Is there a "fisherman's spirit society" in the culture. [And other questions that come up based on things that are said in the conversation]

Hunting – What do people hunt for in the watershed (animals, birds/native names)? Is it an important resource? What are the most important types of game? Where do people hunt? At what time of year? How do they hunt? Any trapping? Are the animals used for anything besides food (fur, hides, horns and bones, sinews)? Who else is well informed about hunting in this area?

Was hunting different in earlier times? How about deadfalls, pitfalls, snares, spring snares, traps, bow and arrow, spears, clubs, game drives. Were dogs used in traditional times?

Are there hunting camps in the area? Is the meat dried or smoked in camp? Are there rituals related to hunting? Are there places those rituals are done? Are there traditional stories about the origin of the animals or about hunting in ancient times? Are there stories of especially successful hunters in the area? What is the reason for their luck? Is there a "hunter's spirit society" in the culture? [And other questions based on things that come up in the conversation].

Collecting food – What foods are collected in the area: roots, berries, sprouts, other edibles, mushrooms? eggs? What are the most important of these foods? What are the native names? What are the most important of these foods? Are these native foods still eaten at home/tribal dinners/ritual events? How are they prepared? Where are the places that each is gathered? What are the native names of those places? Are there camps for berry picking or other foraging in the area?

Was collecting different years ago? How has it changed? Were edibles preserved in different ways in the past? Are there traditional stories about the origin of edible plants or about collecting food in the old days? [And other questions based on things that come up in the conversation].

Collecting materials - What materials are still gathered in this area: types of wood, weaving materials, household materials, raw materials for dyes and other uses, medicines, ceremonial plants? What are the native names for each? Are any of them considered to be especially important "critical" resources? Where were they collected in the area? What are the native names of those places? Are there CMTs (culturally modified trees) in the area? Are there sites used by non-tribal people to collect materials, either with or without permit? Details?

Settlement sites – Are there campsites, trapper's cabin or shack sites, traditional house or village sites, historic house sites or old homesteads in the area? Are there traditional trading sites, gaming areas, maintained prairies or other landscape areas. Are there places where canoe logs were roughed out or other traditional manufacturing done? What is known about them? Native names? Are or were there paths that lead through the area?

Traditional use sites – Are there sites that are special for rituals, ceremonies, sweat bath or bathing, spirit quest sites or puberty enclosures, previous burial sites, courting or picnic places? Details? Native names? Are there caves in the area that were used for storage or other purposes?

Historical ecology – Have any changes in environmental conditions had critical impacts on tribal cultural resource protection or management needs? Are there any specific environmental conditions that are critical for tribal cultural resource protection and management?

Artifact locations - Are there any archaeological locations that have not previously been mentioned in the area? Are there any known or suspected midden areas with shell or bone deposits? Do you know of any petroglyphs, rock drawings? Culturally modified features of any type? Relics (e.g., fish trap posts, house depression sites or house posts, drying rack poles)? Artifact find sites (fireplace remains with heat-cracked rocks, lithic flakes, arrowheads, worked stones for grinding or weights, bone tools, beads)?

Mythic and supernatural sites – Are there places where the events of traditional stories took place which have not yet been mentioned? Are there places where mythic beings or creatures, personal guardian spirits or other spirit beings can be contacted or expected to be. Are the traditional homes of the ancestors of animals, the winds, the great natural beings (e.g., Rainbow, Thunderbird) in this area? Is the entrance to the underworld or underground river or other ghost trail traditionally thought to be in this area? Native names for each place?

Historic locations – Are there any places in the area which have not been mentioned that are used by non-tribal people for any purpose? Can you think of any places where things happened in the area that we have not yet mentioned: tribal battles or raids, previous logging, fires, famous visitors, notorious incidents, anecdotal occurrences.

Named sites – Can you think of any other places that have names in the area, for example names for sections of the river or places along the watercourse, navigational points, halfway points, boundaries or borders, remembered places that have come to be named?

Other____

____
____
____

Identifying sensitive tribal cultural resources, contributing natural or human causes and resource vulnerabilities - The TCR team should prepare for synthesis by noting particular examples of cultural resources within the investigation area that have been impacted by terrestrial (hillslope) or fluvial (stream) processes, forest practices and other natural or human causes or that are considered to be at risk of damage or threatened. Each of the WSA module teams will be preparing a similar assessment list for the purpose of creating causal mechanism reports (CMR) during synthesis for hand off to the field managers team. An example organizer for tribal cultural resources follows as Figure J-2.

Process	Input or Effect	TCR Impacted by Watershed Processes	Importance & Vulnerability
Process: Timber harvest Location: XYZ	Change in native vegetation patterns	Location, quantity and existence of native plants, tribal resources traditionally gathered at point X	*Importance:* *Vulnerability:*
Process: Timber harvest Location: ABC	Disturbs the site of mythic and ritual locations	Traditional site of mythic occurrence (point B), which is traditionally used as a ritual location by tribal members.	*Importance:* *Vulnerability:*
Process: Timber harvest Location: DEF	Cuts down cedar trees	Traditional (CMT locations at point D) and contemporary cedar bark collection sites at points D and F.	*Importance:* *Vulnerability:*
Process: Road building Location: TUV	Provides access to vehicles and visitors	Ritual site at point V, traditionally used for rites requiring isolation and privacy.	*Importance:* *Vulnerability:*
Process: Road building Location: GHI	Disturbs the ground and native vegetation.	Traditional medicine foraging site at points H and I	*Importance:* *Vulnerability:*
Process: Foraging by floral gathering teams Location: Through-out watershed	Over-harvest sensitive tribal key resources in limited supply	Bear grass areas traditionally exploited by tribal weavers at points A, C, G, I, P, R, and Y have already been destroyed and plant populations at other confidential sites are endangered	*Importance:* *Vulnerability:*

Figure J-2: An Example of an Organizer Relating Common Management and Natural Physical Processes to Tribal Cultural Resource Impacts

Note that assessments should include statements of high, mid, or low importance and vulnerability of the TCRs. These are subjective tribal evaluations of the importance they attach to the sensitive resources and the degree to which they feel the TCR is threatened by the causal mechanism (e.g., forest practice). Each tribe may evaluate their resources differently, according to their own perspective and values. The high, mid, low evaluations can be used in calculating a “risk call”.

Form J-3 Tribal Cultural Resource Assessment Form

WATERSHED ANALYSIS PROJECT (Required Form)

Process	Input or Effect	TCR Impacted by Watershed Processes	TCR Importance & Vulnerability
Process: *Location:*			*Importance:* *Vulnerability:*
Process: *Location:*			*Importance:* *Vulnerability:*
Process: *Location:*			*Importance:* *Vulnerability:*
Process: *Location:*			*Importance:* *Vulnerability:*
Process: *Location:*			*Importance:* *Vulnerability:*
Process: *Location:*			*Importance:* *Vulnerability:*

Non-tribal Cultural Resources

Introduction - This section of the Cultural Resources Module provides a step-by-step guide to protecting Washington's non-tribal cultural resources (NTCR). The DNR Watershed Analysis manual is a handbook for researching, inventorying, evaluating risk and developing management strategies as a process of resource assessment applicable to whole watersheds or as a stand-alone methodology for assessments of sub-watershed sized properties. There is some inevitable overlap and repetition involved in the separate treatment of tribal cultural resources above. However, the issues of non-tribal resources are distinct and profitably discussed separately through the assessment phase of the process. After assessment, non-tribal and tribal cultural resources are merged for synthesis and the development of management strategies.

The nature of non-tribal cultural resources – Non-tribal cultural resources include archaeological and historic sites of importance and interest to all people. In many cases, inventories of these resources have not been completed and this assessment process is an opportunity to investigate the history of an area of concern. Some unique and special sites are eligible for listing on the National Register of Historic Places in a process initiated through the state Office of Archaeology and Historic Preservation (OAHP). Other significant archaeological and historic sites can be recorded by OAHP triggering additional environmental review of forest practices on or near these sites. Some features and sites may not carry the significance for protective status but are valuable as part of recorded history. Like tribal cultural resources, the assessment of historic and archeological resources and measures for their protection and management should emphasize the importance of cooperation and mutual understanding.

There is, of course, no clear delineation between tribal and non-tribal CRs, since members of tribal groups use and identify with many post-European settlement historic and archeological values and many non-Native Americans consider Native cultural issues to be part of the community's common heritage. Often the inventories of tribal and non-tribal resources include overlapping locations of interest.

The features of a successful non-tribal cultural resources assessment – As part of a WSA, a non-tribal cultural resources assessment will provide the basis for informed and amicable protection and management of Washington's cultural resources. Thus, an effective analysis that includes non-tribal cultural resources will, to the extent possible, have the following features:

1. A successful NTCR assessment will establish and maintain communication between forest landowners and land managers, communities and interested parties. NTCR assessment may foster trust, communication and relationship building among stakeholders.

2. A complete NTCR assessment will include archaeological sites (but does not require an archaeological survey nor replace the potential need for one). It may also include sufficient information to allow the identification of historic properties eligible for listing on the National Register of Historic Places.
3. Once an inventory of NTCRs has been prepared and an assessment of their condition, their sensitivity to hazards, and the activities and processes that may affect their condition has been made, participants will negotiate management strategies that reflect mutual respect for cultural resources and the economic objectives and stewardship responsibilities of the landowners.

Critical questions - After the organizational activities of Startup, before actual investigation begins it is essential to formulate a small set of general questions that focus the investigation. These questions are an evaluative metric to use in checking that the project is on course and consistent with the objectives of watershed analysis or a stand-alone investigation. These critical questions differ depending upon the watershed or area of interest. Examples of critical questions for non-tribal cultural resources are essentially the same as those for tribal cultural resources:

1. What resources are of cultural significance (or are “critical resources”) in the area of concern and where are they located?
2. What are the historical conditions of the cultural resources?
3. What are the current conditions of the cultural resources and what are the trends?
4. What are the causes of any changes between historical and current conditions?
5. What are the vulnerabilities of each NTCR and to what is it vulnerable?

The answers to that set of questions represent a concise statement of the knowledge that is the goal of each stage of the watershed analysis. The critical questions allow investigations to focus on critical cultural resources, critically sensitive conditions and critical impacts. This allows synthesis and the management strategy phase to focus on appropriate protection plans for valued and at risk NTCRs. Non-tribal cultural resources and most archeological sites should be assessed using predetermined criteria such as the criteria for eligibility for the National Register of Historic Places. The National Register criteria are based on the quality and significance in American history of architecture, archeology, engineering, and culture as present in districts, sites, buildings, structures, and objects. To qualify, these features must possess integrity of location, design, setting, materials, workmanship, feeling, and association that:

1. Are associated with events that have made a significant contribution to the broad patterns of our history; or
2. Are associated with the lives of significant persons in our past; or
3. Embody the distinctive characteristics of a type, period, or method of construction, or that represent the work of a master, or that possess high

artistic values, or that represent a significant and distinguishable entity whose components may lack individual distinction; or
4. Have yielded or may be likely to yield, information important in history or prehistory.

Further information can be obtained from National Register Bulletin #15, "How to Apply the National Register Criteria for Evaluation, 1991".

Inventory of non-tribal cultural resources - An NTCR inventory attempts to answer the first of the critical questions. Many stand-alone investigations will have a CR inventory as their objective.

- In a formal WSA, the inventory includes all the data necessary for synthesis in order to interact with information from the other modules.
- Identify documentary references to sites that qualify as NTCRs. Interview knowledgeable community members regarding historical sites and associated lore and data.
- A site visit to each NTCR location will allow investigation of current condition and details of location, dimensions, landmarks, plant life, and map coordinates and a chance to photograph the site. Photos may help clarify if the resource is being impacted by a natural hazard or has the potential to be impacted by forest practices.
- Organize the listing, number the sites and mark them on the map, including sufficient information for GIS documentation. When part of a WSA, use official base map labeled J-2 non-tribal cultural resources.
- Identify sensitive NTCRs and contributing natural processes or forest practices and resource vulnerabilities.

Data needs - Cultural resources are identified through consultation with OAHP and other research. Existing basin, forest or regional cultural resource plans and assessments are useful starting places. Site-specific NTCR information and assessments may have already been carried out. Tribal CR inventories within and around the area of concern may also be available. Local, county and state historical society records and archives are an important resource that may include previous published and manuscript CR reports. Large scale maps of the watershed or property are crucial (see Startup section). The CR team may also have access to existing basin, forest, or regional natural resource overviews, studies and statistics, available from other teams in a formal WSA. Also provided by other teams at synthesis in a formal WSA (or available from local resource managers in a stand-alone assessment) is input from knowledgeable fieldworkers who are acquainted with the area.

Identifying sensitive non-tribal cultural resources - Assessment establishes the links between processes, human-caused or natural, and the impacts on cultural resources. For example, assessment could identify human-caused processes such as forest practices (timber harvest or road building), or recreation practices (artifact collecting). Examples of natural processes are weathering, vegetation growth, wild fire and stream bank erosion. The chart below contains examples of issues that may be considered in cultural resource assessment in WSA.

During formal watershed analysis, the "importance and vulnerability" ratings in the far right column are tentatively established by the CR assessment team and become the starting point for the synthesis process. During the WSA synthesis process, the effects and resource impacts on cultural resources are reviewed by the other assessment teams and the vulnerability calls are likely to be improved or refined. In a stand-alone process, the assessment form can be used through an abbreviated synthesis process.

Process	**Input or Effect**	**NTCR Impacted by Watershed Processes**	**Importance & Vulnerability**
Process: Timber Harvest Location: XYZ	Physical damage from log yarding	Above ground evidence of a trappers cabin circa 1945	*Importance:* *Vulnerability:*
Process: Natural stream bank erosion Location:	Washing out bridge supports	Abandoned county road bridge circa 1923	*Importance:* *Vulnerability:*
Process: Road construction Location:	Obliteration of physical evidence	A segment of the Oregon Trail circa 1860	*Importance:* *Vulnerability:*
Process: Weathering and vandalism Location:	Physical deterioration	Shay locomotive 1921	*Importance:* *Vulnerability:*

Figure J-3: An Example of an Organizer Relating Common Management and Natural Physical Processes to Non-Tribal Cultural Resource Impacts

Form J-4 Non-tribal Cultural Resource Assessment Form

WATERSHED ANALYSIS PROJECT (required form)

Process	Input or Effect	TCR impacted by watershed processes	TCR Importance & Vulnerability
Process: Location:			*Importance:* *Vulnerability:*
Process: Location:			*Importance:* *Vulnerability:*
Process: Location:			*Importance:* *Vulnerability:*
Process: Location:			*Importance:* *Vulnerability:*
Process: Location:			*Importance:* *Vulnerability:*
Process: Location:			*Importance:* *Vulnerability:*
Process: Location:			*Importance:* *Vulnerability:*

SYNTHESIS

Introduction - After a WSA assessment of resource conditions, the tribal and non-tribal CR assessment team is prepared to join with assessment team members of other modules for an interdisciplinary activity known as synthesis. The synthesis process brings together the understanding and insights from the assessment phase of the project through a lively and collaborative series of discussions of findings, challenges of interpretations, consideration of resource hazards and vulnerabilities, and shared insights from synergies among assessment team members. The two goals of synthesis include: (1) descriptions of resource conditions and sensitivity (vulnerability), and (2) discussions of causal mechanisms (i.e., land use practice and watershed processes affecting resource vulnerability). Synthesis establishes the degree of hazard and level of risk to resources for which prescriptions or management strategies must be considered. At this point in a watershed analysis, it is important to distinguish between the public resources that are addressed in the regulatory context of the rule matrix that establishes a standard of performance for prescriptions, in contrast to cultural resources that are included in a non-regulatory context of risk calls and consensus among the field managers team that establishes voluntary management strategies. While archaeological resources have protection and management standards set in law, the protection of other cultural resources assessed under this module are dependent on the voluntary implementation of the management strategies as well as other cooperative measures developed between landowners, land managers and affected tribes.

For the most part, the teams are looking at the cumulative effects of forest practices on hillslopes, wetlands, and channel corridors, as processors of inputs of sediment, wood, water, and heat. So, with regard to CRs, synthesis considers how tribal CRs such as fish, resource grounds, traditional use site and mythic/spiritual sites might be influenced by road building, use and maintenance, timber harvest, fire suppression/rehabilitation, tree planting, and stand treatments.

The input of the CR assessment team assists the other modules assessment teams in understanding the linkages of hillslope processes to CR vulnerabilities, but the presence of a CR should not necessarily influence rule calls made for the regulated public resources considered under other modules. Some cultural values like harvestable populations of fish may benefit directly from prescriptions later developed to meet the regulatory standards of watershed analysis. Others, like plant resources, may benefit indirectly through protection of riparian or wetland areas. And still others may benefit from timber set asides or public access restrictions.

Risk calls based on cultural resource vulnerability - The use of the rule matrix is required for other WSA modules. However, the rule matrix, as used with the physical science based and regulatory modules is inappropriate to use with cultural resources for the following reasons: (a) the rule matrix establishes regulatory rather than voluntary responses, and (b) the decisions on cultural resource protection and management are based on a subjective judgment of the importance of a cultural resource (the social value of a site) and its vulnerability to physical processes rather than an empirically testable resources vulnerability rating and measurable adverse change and deliverability of the rule matrix.

The risk call is based on CR vulnerability and CR importance. The risk call, whether attained using a risk matrix or not, is developed in consultation with the watershed analysis assessment teams. Where confidentiality is a concern for a particular CR, risk calls for the CR are derived from consultation and concurrence among the cultural resource assessment team and appropriate tribal representatives. Mutually acceptable voluntary management strategies to protect sensitive tribal and other CRs may be suggested as the issues arise in the assessment phase, including during synthesis. The structured approach of a matrix can be used if it is revised and re-labeled "risk call" (rather than rule call) and is used to provide a sense of the perceived urgency of the risk to the cultural resources. The adapted risk matrix and an example are included in Attachment 1.

The causal mechanism report – The watershed analysis assessment report is actually a compilation of intermediate reports, most of which were produced during the resource assessment and synthesis. The causal mechanism report form (Form J-5), produced as a result of synthesis and used in writing management strategies, includes a statement of the hazard ("situation statement") and a causal mechanism summary statement ("Triggering Mechanism statement") and the risk call. The form also includes a place for notation of supporting information regarding the resource affected and the sources of the information.

Form J-5 Causal Mechanism Report for Cultural Resources

Watershed Analysis Project (required form)

WAU:_________________ **Resource Sensitivity Number**________________

Location:____

Situation Sentence:____

____

____

Triggering Mechanism:____

____

____

____

Risk Call for Management Strategy:_________________________________

Additional Comments:____

____

____

PROCESS FOR DEVELOPING MANAGEMENT STRATEGIES

The role of management strategies and cooperative agreements - This stage of watershed analysis follows the assessment teams' synthesis process and is conducted by the field managers team, including the tribe(s) involved, using the causal mechanism reports as the basis for proposing management strategies. The chart below characterizes the process as it applies to cultural resources. Regulatory prescriptions for the other modules are replaced by voluntary management strategies for cultural resources since solutions are by cooperative agreement between affected tribe(s) and landowners. Note that there are existing laws and regulations pertaining to disturbance of archaeological sites and cairns, graves and glyptic records (chapters 27.44 and 27.53 RCW) so OAHP is consulted on these management strategies. Figure 4 shows how the WSA prescription process is used working out CR management strategies.

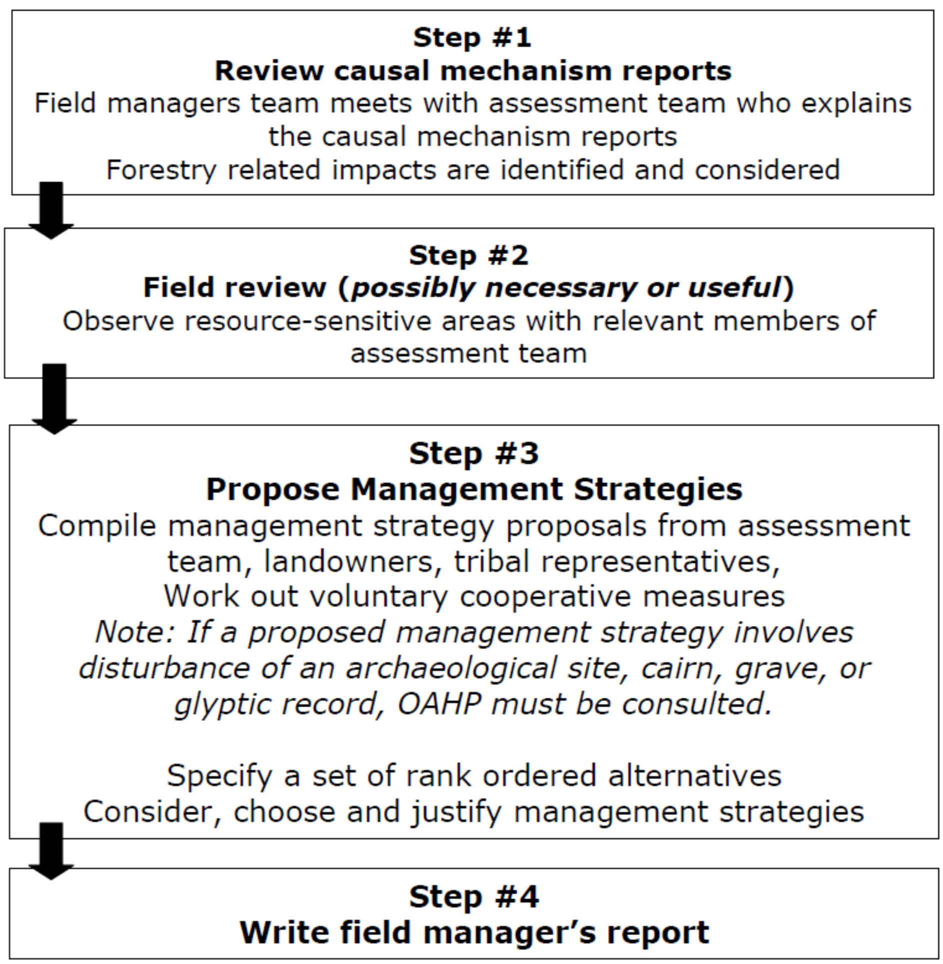


Figure 4: Working out Management Strategies for Cultural Resources

The field managers team - In watershed analyses, the prescription and management strategy writing process is performed by a team of field managers, including landowners and the affected tribes involved in the watershed. Their role is to develop management options to protect or allow the recovery of resources by measures that minimize or prevent or avoid the risks identified in the assessment. The field managers team may or may not be members of the assessment teams that conducted the research that produced the inventory and assessment. In a watershed analysis or in an investigation not associated with a full WSA, it may be largely the same group that performs all of the CR assessment; or, in tribal CR projects, the tribe can produce the inventory and then tribal representatives can meet with a group that may include specialists, DNR officials and landowners for the assessment and management strategy phase. It is useful for the field managers team to assemble early enough so that they can observe the synthesis sessions to better understand the results of the assessment process.

Use of the causal mechanism reports – The field managers team meets with the assessment team to understand the resource sensitive areas identified in the causal mechanism reports. Impacts that are caused by non-forestry related issues should be identified. The assessment team will have identified various causal mechanisms. In these cases and in mixed-use areas, the field managers team will clarify which aspects or impacts are forestry-related and develop prescriptions only for those that are forestry-related. Impacts that are not forestry-related should be referred in the final report to the proper jurisdictional authorities. Impacts to cultural resources that are probably related to previous or anticipated forestry activities are identified for consideration. Thus, this initial review process is to identify the causes of problems, linking resource effects to existing or potential hazards. In cases where the probable cause is forestry, the intent is to identify CRs that have been damaged or should be considered for protection, enhancement, restoration or monitoring.

Clarification, discussion and negotiation characterize the entire management strategy process. There are various alternatives for responding to sensitive cultural resources, and the team is encouraged, wherever possible, to suggest two or more alternative series of actions to address each of the issues identified in the causal mechanism reports. Finding solutions is a process, rather than a judgment handed down. It is important that the field manager’s team understand the values and traditions that relate to tribal cultural resources, so tribal representatives on the prescription and management strategy team should be prepared, within the context of confidentiality and trust, to discuss sensitive CRs.

Field review – Although information gathered and developed during assessment is generally the basis for the prescription process in WSA, field review by members of the field managers team and appropriate members of the assessment team may be deemed useful for clarification in some cases. On-site inspection may help elucidate and simplify issues. For instance, field visits may help clarify whether CR concerns are site-specific or area-wide. It may also be a venue for productive discussion of voluntary or cooperative actions. Sometimes inspection allows the group to generate various options to address the processes and issues identified in the causal mechanism report, alternatives that may even go beyond prevention to restoration. It also sometimes allows the team to identify those alternatives that may not reasonably be expected to work. The field review is not simply a tour of inspection, but a part of the process of considering mutually acceptable management strategies.

Writing management strategies – Management strategies for cultural resources must be reasonably designed to respond to the problematic resource issue. OAHP is consulted whenever an archaeological site, cairn, grave or glyptic record is involved. The assessment team may propose workable alternatives for each of the forestry-related issues or problems identified. Furthermore, each landowner in the watershed is entitled to submit draft management strategies to the team. For tribal cultural resources, the most successful resource management strategies have generally arisen in voluntary agreements, such as MOUs, between tribes, landowners and land managers. Management strategies need to be clearly stated and complete, including time frames for operations and monitoring provisions.

Types of management strategies – Management strategies are discussed in the context of the causal mechanism reports and utilizing the expertise of the field managers team.   Ideally, a number of alternative strategies will be considered for each area of resource sensitivity. For example:

1. Relating to timber harvest: alternative methods of harvest (e.g., even–age or uneven-age or designated skid trails), harvest limitations, timing of harvest activities, wet weather restrictions, buffers, possibility of postponing or modifying harvest.
2. Relating to road construction: changing location to avoid CRs or minimize clearing width to reduce impact;
3. Relating to road use and maintenance: regulating frequency or timing of use, access or activities, surface treatment to protect cultural resources in place and revegetation of disturbed ground with native plants of cultural significance.
4. Relating to vegetation management: plant trees of cultural significance, retaining native vegetation, limit non-Indian gathering.

For each of the forestry issues outlined above, modification of forest practices activity is an alternative strategy. Cooperative and mutual consideration of management strategies that recognize landowner objectives as well as tribal sentiments lead to creative problem solving and is essential for the process of working out mutually satisfying, management strategies.

The discussions and evaluations of alternative management strategies will result in the selection of appropriate management strategies for most of the problems and sensitive CR issues identified by the assessment team in the causal mechanism reports. This may not be the case for every site or resource as the subjective nature of tribal cultural resources creates issues that vary from case to case. For instance, it is impossible to measure supernatural and mythic sites or calculate the degree to which forest practices represent a danger to those resources. The most effective way to handle questions that relate to values, cultural expectations and customary appropriateness is through discussions characterized by trust and the attempt to reach mutually satisfactory outcomes.

Sufficient rationale to explain the choice of management strategy should be appended to the prescription and management strategy report. This evidence should, with regard to both tribal and non-tribal CRs, reasonably demonstrate that the management strategy will adequately address the specific processes and issues identified in the causal mechanism report. Explanations of the logic of the management strategy and examples of successful management strategies from past operations are helpful.

Reaching consensus - The goal of the field managers team is consensus on management strategies. The conduct of the CR module has been based on a relationship of trust and mutual respect that has developed through the process. This relationship should assist the field managers team in reaching consensus decisions on CR management strategies.

The management strategies will be considered agreed upon when:

1. The tribes, landowners, and land managers on the field managers team that are affected by a management strategy for a tribal cultural resource identified in the assessment agree upon the management strategy proposed for that tribal cultural resource, and
2. OAHP agrees that the management strategies adequately protect tribal and non-tribal sites registered on the OAHP archaeological and historic sites database and all resources that require mandatory protection under chapters 27.44 and 27.53 RCW.

If the field managers team is having difficulty reaching consensus, the following process, in the order given, is recommended to help resolve the issues.

1. Contact the assessment team for additional information, clarification and input.
2. Assign a small 'subgroup' that includes one representative from the tribe(s), landowner(s) or land manager(s) and DNR to develop options and a recommendation.
3. Contact people previously involved in a successful CR module development.

4. Elevate to higher authority in the respective organizations (policy level and tribal council level).
5. Engage a mediator.

The field managers team report – For a formal WSA, the field managers team will compile the management strategies for each causal mechanism report situation and document this on the Management Strategy Report, Form J-6. Maps and drawings may be helpful as appendices. These forms become part of the final report for the watershed analysis so tribal representatives must be consulted to assure that these public documents do not compromise the confidentiality of a tribal cultural resource. At the request of the tribe, OAHP may review the plan. For a stand-alone process, the form can be useful or another format can be used.

Form J-6 Field Managers Team Cultural Resources Management Strategy Report

Watershed Analysis Process (required form)

WAU: _____________________**Resource Sensitivity Number:** _______

Location: ____

Situation Sentence (from causal mechanism report):

____

____

____

Triggering Mechanism (from causal mechanism report):

____

____

____

____

Risk Call for Management Response (from causal mechanism report):

____

Additional Comments: ____

____

____

Voluntary Management Strategy[1]**:** ________________________________

____

____

Rationale: ____

[1] Consult with and obtain agreement from the Office of Archaeology and Historic Preservation for management strategies involving tribal and non-tribal sites registered on the OAHP archaeological and historic sites database and all resources that require mandatory protection under chapters 27.44 and 27.53 RCW.

Alternate Management Options: ____________________________________

____

____

____

Rationale: ____

____

____

Time Frame for Implementation: __________________________________

Management Strategy Determination:
The tribes, landowners, and land managers on the field managers team that are affected by a management strategy for a cultural resource – and where applicable, OAHP – agree upon the management strategy proposed for that cultural resource.

Tribe(s):
Agree ☐

Landowner(s) and /or Land Manager(s):
Agree ☐

Office of Archaeology and Historic Preservation (OAHP) *(see footnote 1)*:
Agree ☐

WRAP UP

Once the entire watershed analysis is completed, there is one last task in which the complete watershed analysis team generally participates: developing the monitoring module. Cultural resources should also be considered during development of the monitoring module. The need for monitoring should also be evaluated when the cultural resources module is deployed as a stand-alone.

At this point, tribal representatives, land managers and landowners can establish MOUs or other formal arrangements. MOUs have been identified as a preferred pathway by landowners, land managers and tribes for protecting cultural resources on forestland. Landowners, land managers and tribes are encouraged to develop an MOU upon completion of the WSA or stand-alone process. An outcome based MOU could incorporate the CR management strategies and provides for resolution of issues not within the scope of the WSA and continuing contact regarding issues resolved or left to be discussed and arranged at some future point.

Attachment 1 An alternative method for guiding the development of management strategies

Resource Importance	Resource Vulnerability (Likelihood of Adverse Change): L	M	H
L	Low risk, standard practices	Low risk, standard practices	Moderate risk Minimize impacts
M	Low risk, standard practices	Moderate risk Minimize impacts	High Risk Prevent or avoid impacts
H	Low risk, standard practices	High Risk Prevent or avoid impacts	High Risk Prevent or avoid impacts

Figure J-5 Matrix Used to Produce Management Response (Risk Call) For a Given Cultural Resources Location Problem Statement

As an example, in the case of a CR such as the site of a historic post office, now barren and overgrown, in an area scheduled for forest practices, the synthesis process would consider (a) whether the resource importance would be low, medium or high, and (b) whether the likelihood of adverse change due to logging would be low, medium or high. These are subjective valuations. But, if CR assessment team suggests that public sentiment feels the resource importance is medium and the likelihood of adverse change as a result of forest practice is low, the risk call would be "low risk", i.e., that standard management practice would probably not adversely affect the site. Again, it must be remembered that this method of calculations is used to assist in the calculation of impacts to subjectively evaluated resources and that management strategies are a voluntary response best worked out in mutual cooperation.

Attachment 2 Cultural resources module report checklist

DNR will use the following criteria to determine if the cultural resources module has been completed as part of a forest practices watershed analysis.

Assessment

- Were the CR assessment team leader(s) qualified?
- Were the appropriate tribes involved in both the CR WSA teams and assessment interviews?
- Was the assessment process complete?
  1. Maps
     Map J-1: Tribal cultural resources (except those intentionally excluded due to tribal confidentiality concerns)
     Map J-2: Non-tribal cultural resources
  2. Summary Data
     Form J-3 Tribal Cultural Resources Assessment Form
     Form J-4 Non-Tribal Cultural Resources Assessment Form
     Form J-5 Causal Mechanism Reports
- Was a peer review performed on the assessment report?

Management Strategies

- Were the cultural resources management strategy team leader(s) qualified?
- Were the appropriate tribes involved in the management strategy process?
- Was the management strategy process complete?

  Form J-6 is written for each cultural resources causal mechanism report and the tribes, landowners, and land managers affected by the management strategy, and OAHP if applicable, confirm on Form J-6 that:

  1. The tribes, landowners, and land managers on the field managers team that are affected by a management strategy for a tribal cultural resource agree upon the management strategy proposed for that tribal cultural resource, and

  2. OAHP agrees that the management strategies adequately protect tribal and non-tribal sites registered on the OAHP archaeological and historic sites database and all resources that require mandatory protection under chapters 27.44 and 27.53 RCW.

Appendix K
Mass Wasting Prescription Reanalysis Module

Table of Contents

Introduction

This appendix describes the processes, as required in WAC 222-22-090(4), to keep watershed analysis mass wasting prescriptions current. Part 1 describes the Department of Natural Resources (DNR) process for review of approved watershed analysis (WSA) to determine if a reanalysis of mass wasting prescriptions is necessary. Part 2 describes the reanalysis process for mass wasting prescriptions.

Part 1 Review Process

The forest practices rules in WAC 222-22-090(4) and (6) direct DNR to perform reviews of approved watershed analyses to determine if reanalysis is required to maintain or update mass wasting prescriptions. Completing the following two steps will determine when a WSA is subject to mass wasting prescription reanalysis:

1. DNR will clarify and collect data for each of the following elements for each Watershed Administrative Unit (WAU) within a WSA. Using these data the DNR will conduct a review to determine the need for reanalysis of mass wasting prescriptions.
   - Verify that mass wasting prescriptions (road construction and harvest) exist for the watershed;
   - Determine if recent significant storm events have impacted any WAU(s);
   - Determine if the frequency of current landslides as compared to past landslides have increased, then using current mass wasting inventories determine the potential for slides to threaten public safety;
   - Determine the level of significant forest management activities planned in the WSA based on the number of approved and proposed Forest Practices Applications (FPAs) per WAU;
   - Determine if previous reanalyses have been completed, and
   - Determine the degree of local stakeholder concerns within the WSA area.

2. DNR will, when determining a watershed reanalysis is required, notify all landowners with 10 percent or more ownership of the nonfederal forest lands within any WAU within the WSA that may be subject to a reanalysis. Upon notification, these landowners will need to determine and notify DNR with which option they want to select:
   - Volunteer to sponsor the mass wasting prescriptions reanalysis process. Sponsors provide funding and facilitation, and provide staff, including a qualified expert (QE), to conduct the assessment; or
   - Volunteer to be a participant in the reanalysis process by providing staff with relevant geologic expertise, or
   - Request DNR to withdraw the existing mass wasting prescriptions and agree to use the forest practices rule-identified landforms (WAC

222-16-50 (1)(d)(i)(A-E)) and the associated avoidance/mitigation strategy.

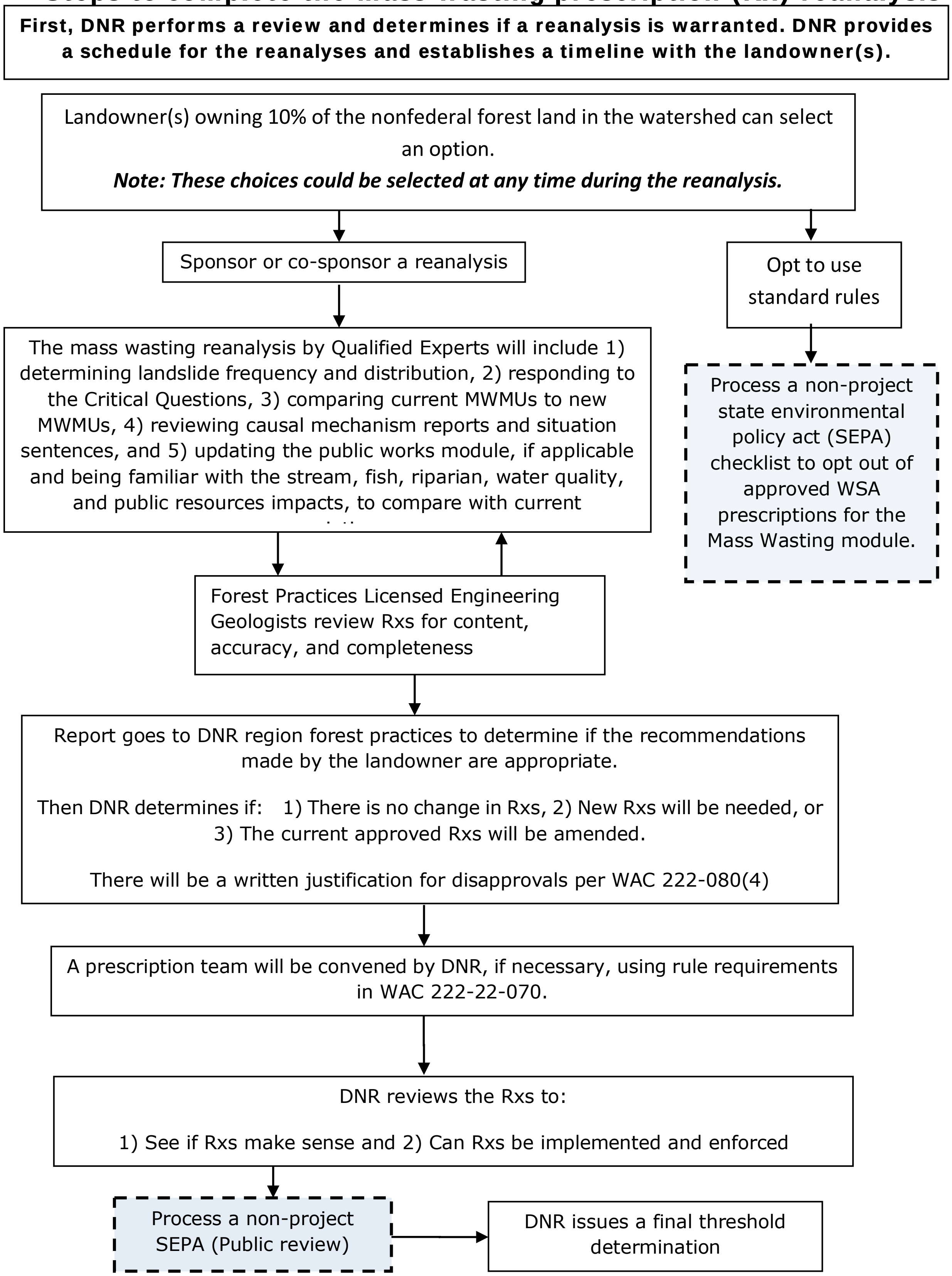
When steps 1 and 2 are completed and the landowner(s) chooses to conduct mass wasting prescription reanalysis, DNR will prioritize and schedule dates for completion of all WSA requiring mass wasting prescription reanalysis. Staggering reanalyses schedules for landowners of multiple watershed analyses will be considered in order to offset economic hardship.

Part 2 Reanalysis of Mass Wasting Prescriptions

The steps to complete a reanalysis of the mass wasting prescriptions within a WSA include many of the processes applied in Appendix A, *Mass Wasting Resource Assessment* of this board manual, found at http://www.dnr.wa.gov/Publications/fp_wsa_manual_appa.pdf.; and incorporates elements of the Landslide Hazard Zonation (LHZ) project protocols, found at http://www.dnr.wa.gov/Publications/fp_lhz_protocol_v2_1_final.pdf to help in the finalization of mass wasting map unit (MWMU) boundaries and revised or new prescriptions.

An overview of the reanalysis process is shown in flowchart 1 below. The mass wasting reanalysis is conducted using aerial photographs, maps, and field observations. Based on the collection of information and the answers to critical questions, qualified experts interpret the mass wasting processes observed within the WSA. The reanalysis uses the standard mass wasting assessment method developed for Appendix A, *Mass Wasting Resource Assessment*.

Flowchart 1
Steps to complete the mass wasting prescription (Rx) reanalysis



Background

Mass wasting is a natural process that occurs in most forested basins in the Pacific Northwest. Certain forest management activities can accelerate mass wasting processes. Because the various slope processes generate widely variable amounts of sediment under different sets of conditions, qualified experts and specialists must identify specific associations between land use and landslides; then distinguish among the types and rates of processes that are active in a basin to accurately evaluate the mass wasting hazard potential. Evaluation of forest management activities in the context of terrain characteristics provides the best guidance in developing appropriate management prescriptions for reducing the potential for mass wasting.

Four types of mass wasting commonly occur on forested slopes: shallow-rapid landslides, debris flows *of various magnitude*, large-persistent deep-seated landslides, and small-sporadic deep-seated landslides. Shallow-rapid landslides (also known as, debris slides, debris avalanches, or planar landslides) commonly occur on steep slopes where soil overlies a more cohesive material (for example, bedrock or glacial till). Soil thickness is typically small compared to slope length or the length of the landslide. Debris in the slide moves quickly down slope and commonly breaks apart to form a debris avalanche. Shallow-rapid landslides typically occur in convergent areas where topography concentrates subsurface drainage (Sidle and others, 1985), and may deliver sediment to streams and damage roads. Susceptibility of an area to shallow-rapid landslides is affected by steepness of slope, saturation of soil, and loss of root strength. Forest management activities can increase the occurrence of shallow-rapid landslides by altering these conditions; however, only a small portion (typically a few percent or less) of the landscape actually fails following timber harvest (Ice, 1985).

A debris torrent contains a slurry that is 70-80 percent solids consisting of soil, rock, vegetation and water that can travel miles from its point of initiation. This highly mobile slurry typically flows in confined mountain channels with typical deposition reaches occurring with channel slope less than 35 degrees (70 percent) and tributary junction angles greater than 70 degrees. Debris torrents form when landslide materials liquefy concurrently with, or immediately after the initial slope failure. As the debris torrent moves through first- and second-order channels, the volume of material may be increased by several orders of magnitude over initial slide volume, enabling debris torrents to become more destructive the further they travel. Debris torrent initiation is generally confined to steep, colluvium-filled first and second-order channels; debris torrents can, however, deposit large volumes of unsorted sediment and organic debris in streams of any order, typically at tributary junctions (Benda, 1990) or on alluvial debris fans. Hence, debris torrents increase suspended sediment loading that can contribute sediment locally at the site of deposition and further downstream, depositing fine sediment in spawning gravels, causing secondary erosion of valley walls, and damaging structures, impairing water quality and fish habitat at considerable distances from their points of initiation (Eisbacher and Clague, 1984).

Landslides and debris torrents that are deposited in narrow valley floors can create temporary dams that quickly impound water, creating small lakes. Failure of these dams can lead to extreme floods, referred to as landslide dam-break floods that can be up to two orders of magnitude greater in peak discharge than normal runoff floods. Such floods have caused extensive downstream erosion and sedimentation along entire stream segments throughout the mountainous regions of the state. Dam-break floods may also be triggered by the build-up and failure of logging slash in steep, first- and second-order streams (typically Type N waters) in managed forests. These dam break floods can cause slope failure of the valley walls (landslides) due to rapid loss of hydraulic head during the dam break process, The dam break floods, similar to debris torrents, can cause damage to structures, and/or destroy or affect fish habitat located at a considerable distance from their point of initiation.

Deep-seated landslides occur in response to strong seismic shaking, geologic weakness, or channel incision. Climatic changes, ranging from major (such as glacial-interglacial transitions), to intermediate (runs of several wet years), to short-term (extreme storm precipitation) can also trigger or accelerate deep-seated landslides. The failure plane is below the colluvial layer and commonly cuts through two or more strata. These slides may persist in the landscape for a few years or centuries; in any case, debris is typically supplied from the margins of the features to a channel. The stream itself can be the cause of chronic movement, if it periodically excavates the toe of a large slide mass.

Small-sporadic deep-seated landslides that move periodically can be triggered at irregular time intervals (by storms or earth movement), and can decay to the point where they are indiscernible in the landscape. Movement of deep-seated landslides is hydrologically controlled (at least in part), so land use can influence movement in certain situations. Excessive routing and infiltration as a result of road runoff could be routed to potentially unstable slopes.

The time scale (relative or absolute) of landslide activity in a basin is important to understanding the sediment mass balance of a watershed. Landslide events may occur on a return interval of one or two years, decades, centuries, or even millennia. While the smaller, more frequent events may cause the fresh scars seen on the landscape, the larger, infrequent events are probably the real shapers of the landscape. Both types of landslides are influential in their impact on physical resources. In a natural, unmanaged forested basin, the dynamic replenishment of material to the channels by landslide activity is essential to the diversity and health of the ecosystem.

Not all landslides deposit sediment directly in streams; sediments may be deposited on flood plains, glacial or alluvial terraces, or foot slopes, without reaching a stream. However, as basin area increases, the cumulative probability of either one small landslide entering a stream or one small failure triggering a debris torrent with catastrophic impact on habitat conditions increases.

Reanalysis Process

This section describes the reanalysis process for mass wasting prescriptions. When landowner(s) commit to sponsor a reanalysis to retain their approved watershed analysis, DNR will:

1. Determine the geographic area(s) to be reanalyzed.
2. Determine the degree of expertise required for the team conducting the reanalysis.
3. Provide necessary training for module(s) being reanalyzed.
4. Establish a timeline for the reanalysis. DNR will work with individual forest landowners who are sponsoring or participating in each reanalysis to consider appropriate schedules.
5. Provide start-up products. Many of the needed products are available at DNR's geo-spatial data website at: http://www.dnr.wa.gov/BusinessPermits/Topics/ForestPracticesApplications/Pages/fp_gis_spatial_data.aspx.Start-up products will include:
    a. 1:12,000 scale base map, with official WAU boundaries. Map will also show elevation contours, streams, roads, section, township and range information, and known landslides; federal and tribal lands will be delineated. All maps will use the same coordinate scale. DNR will provide map standards. Note: Although federal and tribal lands will not be mapped as part of this project, any unstable slope data that is available for adjoining lands will be provided.
    b. A map with all landslides from the current watershed analysis landslide inventories along with digital data for MWMUs.
    c. DNR Slope Stability (SLPSTAB) data.
    d. Geologic maps: DNR's Division of Geology & Earth Resources (DGER) maps at 1:100,000 (or larger) scale. Use the latest 1:100,000 maps or local detailed geology maps. See DGER indices to geologic mapping (Manson 1984, 1994, 1995 or county bibliographies).
    e. DNR Geographic Information System (GIS) also contains digital data on hydrology, forest roads and other information that may prove useful.

f. Soil maps are available at http://www.wa.nrcs.usda.gov/programs/soil_survey.html
g. DNR may have digital data on precipitation zones, forest roads and canopy/core density of vegetation from DNR Information Technology Division.

If a qualified expert is familiar with ArcGIS, the process of "heads-up digitizing" will allow the creation of landslide polygons within GIS while using an orthophoto or other base. On-screen digitizing is an interactive process in which a map is created using previously digitized scanned information such as base photography or LiDAR data. This method of geo-coding is commonly called heads-up digitizing because the attention of the user is focused on the computer screen, and not on a digitizing tablet. This technique may be used to trace features from a scanned map or image to create new layers or themes. On-screen digitizing may also be employed in an editing session where there is enough information on the screen to accurately add new features without a reference image or map.

The qualified expert should add to their base map all public roads, public water intakes, bridges, gravel pits and/or quarries that may have been constructed since the completion date of the current approved watershed analysis in regard to impacts to infrastructure. The addition of private forest roads would also be welcomed, especially if these roads are implicated in recent mass wasting events.

Qualified Expert Qualifications
The mass wasting reanalysis must be conducted by a qualified expert which is defined in WAC 222-10-030(5) as "a person licensed under chapter 18.220 RCW as either an engineering geologists or as a hydrogeologist (if the site warrants hydrologist expertise), with 3 years of field experience in the evaluation of relevant problems in the forested lands."

The qualified expert must also possess knowledge of hill slope processes (including erosion, transport, and deposition) and their relationship to forest management activities. Skill in aerial photo interpretation, landform analysis, and recognition of mass-movement features (including shallow-rapid landslides, debris torrents, and deep-seated landslides) in a variety of geomorphic settings is necessary.

Reanalysis Mass Wasting Checklist

It is recommended that qualified experts utilize the mass wasting assessment checklist, below, as a guide during their watershed mass wasting prescription reanalysis.

Form K-2 Mass Wasting Assessment Checklist

(Board Manual Section 11, Appendix A)

This may be revised by Qualified Expert and DNR if needed.

Task	Scheduled	Completed	Reviewed
Assemble startup materials:			
Official WAU base map **(DNR may supply these)**			
Aerial photographs **(landowner provides)**			
LiDAR if available			
Orthophotos **(DNR may supply these)**			
Geology maps **(DNR website)**			
Soil maps **(DNR website)**			
Topographic maps **(DNR website or landowner)**			
Products			
Landslide inventory			
Aerial photo inventory			
Complete Form K-1			
Record onto Map K-1 Landslide Inventory Map			
Field reconnaissance			
Compare rates and distribution of landslides to existing Mass Wasting Map Unit(MWMUs)			
Answer the Critical Questions			
Determine if new MWMUs are needed			
Formulate tentative new MWMUs			
(MWMU)s Designations			
MWMU descriptions (Form K-3)			
Mass Wasting Summary Table (Form K-4)			
Delineate MWMU polygons on Map K-2 MWMU map			
Summary Report			
Causal mechanism for the new MWMUs, if any			
Present information for the prescription team			
Be available to respond to the prescription team questions			

Reanalysis Area

DNR determines the geographic areas within the WAU(s) in the WSA where the reanalysis will be conducted on forest lands. The forest practices rules in WAC 222-16-010 define forest land as "all land which is capable of supporting a merchantable stand of timber and is not being actively used for a use which is incompatible with timber growing. Forest land does not include agricultural land that is or was enrolled in the conservation reserve enhancement program by contract if such agricultural land was historically used for agricultural purposes and the landowner intends to continue to use the land for agricultural purposes in the future. For small forest landowner road maintenance and abandonment planning only, the term "forest land" excludes the following:

1. Residential home sites. A residential home site may be up to five acres in size, and must have an existing structure in use as a residence;

2. Crop fields, orchards, vineyards, pastures, feedlots, fish pens, and the land on which appurtenances necessary to the production, preparation, or sale of crops, fruit, dairy products, fish, and livestock exist."

Reanalysis Process Initiation

1. The first step in reanalysis is an inventory by the qualified experts of all landslides that have occurred in the watershed since the completion date of the current approved WSA. The underlying assumption for this approach is that many of the activities that trigger mass wasting events have been conducted in the past in some or all of the areas sharing similar geomorphic characteristics (i.e., experiments). These prior "experiments" can be used to infer future erosion response.

2. Determine the potential for mass wasting by comparing the rate of past and current landslides and associating the occurrence of landslides with terrain or geologic controls and features (landforms). These associations form the basis for the mapping of MWMUs in the watershed. The MWMUs are then drawn for each area with similar landslide characteristics and land use associations. These mechanisms are the specific geomorphic processes that appear to contribute to mass wasting (i.e., increased pore water pressure, over-steepened or over-loaded slopes, excess water drainage, etc.). Unique units are described if the mass wasting processes are similar (i.e., shallow debris flow), but the triggering mechanisms are different (i.e., roads versus loss of root strength on hill slopes). Many of the MWMUs identified during the initial watershed analysis process are now the rule-identified landforms found in WAC 222-22-16-050 (1)(d)(i), and described in Board Manual Section 16, *Guidelines for Evaluating Potentially Unstable Slopes and Landforms*.

The key to the inventory and mapping of MWMUs is the use of time-series aerial photography. The photographs should be as chronologically extensive as possible. The following factors should be considered when choosing which photo years to analyze:

- Use at least two sets of photos since the last set of photos used for the current approved watershed analysis.
- If available, use photo sets that will show landscape response to storms. For example, major storms occurred in some areas in 2007 and 2009; use photo series immediately post-dating these events.
- If possible, use photos that best show exposed bare-ground conditions (for example, recently harvested areas) this will be especially useful for landform mapping.
- If available, use at least one set of high altitude photos (1:60,000), these will assist in identifying large deep-seated landslides.
- Choose a range of photo scales to analyze. Photographs at about 1:12,000 to 1:16,000 scale are best for detection of small features; scales of 1:24,000, 1:40,000, and 1:62,500 cover more area with fewer photographs, and are better for terrain evaluation, but provide reduced resolution. Color photographs are preferred because they allow detection of subtle differences in tone of soil and types of vegetation; however, they are more expensive and produced less often.
- National Agriculture Imagery Program (NAIP) color orthophotos (for both 2006 and 2009) are available from DNR for the entire state.
- Use LiDAR, if available, for identifying rule-identified landforms, convergent topography, more precise remote gradient determinations, and deep-seated landslides.

3. Assess and rate the potential for delivery from mass wasting events of sediment and debris to streams within the watershed. For this assessment, qualified experts will apply the process in Appendix A, *Mass Wasting Resource Assessment* to their updated information to rate the potential for delivery of debris and sediment to streams by mass wasting for geographic zones of the basin. These ratings are applied to the "likelihood of adverse change and deliverability" axis of the cumulative effects rule matrix.

   Table 1, from WAC 222-22-050(2)(d) outlines how to assess areas of resource sensitivity. Resource vulnerability may not need to be addressed in the reanalysis because resource vulnerabilities have already been identified in the current approved watershed analysis. However, the reanalysis should address the likelihood of adverse change and potential sediment deliverability as a result of the updated landslide inventory.

Table 1 (From WAC 222-22-050 (2)(d))
Rule matrix to use to assess areas of resource sensitivity.

		Likelihood of Adverse Change and Deliverability		
		Low	**Moderate**	**High**
Resource Vulnerability	**Low**	Standard rules	Standard rules	Standard rules
	Mod	Standard rules	Response: Minimize	Response: Prevent or avoid
	High	Standard rules	Response: Prevent or avoid	Response: Prevent or avoid

See Synthesis at http://www.dnr.wa.gov/ResearchScience/Topics/WatershedAnalysis/Pages/fp_watershed_analysis_manual.aspx for more details of the rule matrix.

When comparing the relative sources of sediment within a basin, attention should be given to the sources, rates and time scale at which various processes contribute sedimentation.

4. Determine if the current mass wasting prescriptions were properly implemented by landowners before the qualified expert determinats if current mass wasting prescriptions are identifying the landforms and slope processes that are occurring. To accomplish this, the qualified expert should examine a representative set of FPAs in the steep topographic areas of the WAU to determine if the FPAs and forest practices rules were followed as approved. Critical Question #9 below may be useful in deciding if the implementation of the prescriptions caused an unrelated outcome that may indicate the mass wasting prescriptions have not been effective.

   The relationships between forest land use activities and landslide processes are to be identified as accurately as possible. A comparison of past forest land use to recent land use and the frequency of landslides associated with each is a key aspect of the mass wasting prescription reanalysis.

   Within watershed analysis areas, FPAs with approved WSA mass wasting prescriptions are not classified as Class IV-special. This is because mass wasting prescriptions applied to timber harvest, or construction of roads landings, gravel pits, rock quarries, or spoil disposal areas, on potentially unstable slopes or landforms are designed to reduce the potential to deliver sediment or debris to a public resource or threaten public safety.

Public resources are defined in WAC 222-16-010 as water, or capital improvements of the state. Potential for delivery exists when three conditions are met:

- An impact is likely to occur;
- The magnitude or size of the impact is sufficient to have a significant adverse effect on the resource characteristic; and
- The impact is likely to be delivered to a stream segment.

Critical Questions

The following critical questions are specifically designed to be answered during the reanalysis process to help landowners determine if current mass wasting prescriptions are identifying the landforms and slope processes that are occurring in the WAU.

The reanalysis critical questions are provided below.

1. Are there any newly identified areas of the landscape that are susceptible to high landslide frequencies (i.e., areas not previously mapped or identified as MWMUs[1])?
2. What is the distribution of new landslides throughout the landscape; are they found in existing MWMUs? on rule identified landforms?, or in new locations within the watershed?

3. Are forest management activities associated with landslide activity?

4. Can a determination be provided to analyze those slopes for which prescriptions were followed but the slopes failed compared with those slopes that were covered under the same prescriptions but did not fail?

5. Have the prescriptions been properly implemented? The methodology for answering this question is outlined in steps a through d below:
    a. Review a random subset of ≥10 year old FPAs using aerial photos and if possible, field review to evaluate and verify the efficacy of potentially unstable landform buffers;
    b. Conduct an aerial photo, LiDAR, and if necessary, field review to determine if potentially unstable slopes in MWMUs were identified;
    c. Compare landslide locations to areas of buffered MWMUs;

[1] Note that new landslides may occur in areas that match the criteria of existing mass wasting map units (MWMUs), but were not mapped due to small size or because forest cover previously obscured their presence. This question specifically asks the Qualified Expert to identify terrain or landform types not defined in the current approved watershed analysis as MWMUs, but are now recognized as potentially subject to high spatial landslide frequencies (high landslide densities).

d. Determine landuse associations for landslides that occurred outside of MWMUs.

6. How does the distribution of new landslides compare to the distribution of landslides at the time the WSA was approved; are the new landslides on existing MWMUs or not?

7. What, if any, new types of landslides have been discovered since the time the current approved mass wasting analysis was completed? What landuses are associated with these landslides?

8. Have the newly inventoried landslides delivered sediment to public resources?

9. How does the rate of new landslides compare to the initial rate of landslides present when the watershed analysis was first approved, for example, how does the percentage of new landslides by forest landuse (e.g., 'road-related') compare to those inventoried in the current watershed analysis?

The conclusion to the answers of these questions will help determine if there are observed changes in landslide frequency or distribution and will be used to support any recommended changes to the mass wasting avoidance strategy, if necessary.

Assumptions

A number of fundamental assumptions and requirements underlie the approach developed for reanalysis. The most fundamental requirement is that reanalysis be based on the best available scientific information and techniques. Thus, the reanalysis module methods are designed to change as new methods are developed. The underlying assumptions and reanalysis framework on the other hand are not. Rather, assumptions dictate a rigorous, yet flexible framework for reanalysis. Assumptions for completing the reanalysis include:

- Delivery to typed waters will affect water quality or fish;
- Landslides are occurring in the current approved WSA locations;
- Fish are located at the same locations as in the current approved watershed analysis;
- The current approved watershed analysis fish and/or channel module analyses have probably not changed to the point that would affect the mass wasting reanalysis; and
- The public works module will be revisited to include new infrastructure, if applicable.

Technology and knowledge of mass wasting processes have improved since the completion of the original watershed analysis. These advances include:

- Aerial photographs and LiDAR that can be used to interpret and document the history of land use and mass movement in a basin. Although some features are obscured by vegetation, most landslides of significant size (1000 square yards) can be identified on aerial photos, as can the tracks of debris torrents and dam-break floods. The prescription reanalysis is not to identify a complete census of landslides in the watershed by intensive field reconnaissance, but a percentage (~10%) of the landslides must be field verified.
- Identification and spatial distribution of existing mass-movement features that can be used to predict the likelihood of future instability. Areas prone to these processes can be mapped based on physical characteristics, as interpreted from aerial photographs, LiDAR, topographic maps, and geologic maps.
- Although most landslides are partly caused by natural processes or events, in most cases, the initiation or acceleration of mass movement can be attributed either to natural conditions or to forest practices. Mass-movement features associated in time and space with logging or road activities are assumed to be caused by forest practices activities with the exception of very large storm events that are known to have occurred. Improperly constructed and maintained gravel pits and material waste sites can also trigger landslides.

It is feasible to extrapolate from one sub-basin to another having similar characteristics, based on information obtained from maps and aerial photos.

Landslide Inventory

The purpose of the landslide inventory is to collect information that will aid in understanding the distribution, timing, and relative size of landslides in the basin that would be useful in creating MWMUs. The primary intent of mass wasting reanalysis is to evaluate and map the potential for delivery of mass wasting hazards for use in the synthesis and prescriptions modules.

The qualified expert should review the existing landslide inventory and attribute tables before reviewing new photos in order to know where most slides would be expected. Existing landslides that have been reactivated may or may not be easy to identify when the reanalysis is conducted. Examine the aerial photographs in stereo (begin with earliest years to most recent) to identify landslides, debris torrents, and other erosion features to map the mass wasting features. The geo-spatial data sets that are available on the DNR website contain a landslide inventory http://www.dnr.wa.gov/BusinessPermits/Topics/ForestPracticesAppl ications/Pages/fp_gis_spatial_data.aspx . The DNR landslide inventory contains landslides from approved watershed analyses and from some LHZ projects. The attribute tables can be compared to determine if landslides on more recent photos are new or just reactivated. Using this data will resolve double counting of existing landslides that were mapped in the current approved mass wasting modules. Transfer the features into a GIS based data layer (Map K-1: Landslide Inventory) placed on the WAU base map.

The process of on-screen digitizing is similar to conventional digitizing. Rather than using a digitizer and a cursor, the user is able to create the map layer on the screen with the mouse and typically with referenced information as a background, see http://www.ncgia.ucsb.edu/cctp/units/unit14/14.html for more information on this process.

Assign an identification number to each landslide. The identification system will be established for each watershed area as there is a naming convention in place, see below. DNR will provide a distinct geographic identifier for each landslide in the inventory. This will enable users of this reanalysis to correlate landslides between maps, inventory lists, and text.

The system explained will be used for the reanalysis. A standard map projection for GIS will be required for any GIS submitted products. On the form, arrange the observations by smaller sub-basins (as defined by the current approved watershed analysis) beginning at the upstream end of the watershed. Organization of the inventory in this manner, combined with recording the appearance and size of landslides by air photo dates (see below), allows the qualified expert to understand the spatial distribution and possible timing of mass wasting downstream through the basin.

Landslide Identification Information

The attributes below marked with an asterisk are required on the form, others can be added if available.

Landslide unique ID number

This will be automatically assigned in the GIS entry process. DNR will give each landslide an identification number that will be unique in the statewide inventory system.

Landslide identification number*

The landslide identification number is assigned by the qualified expert while performing the inventory. This number should be unique for each landslide within a study area. If the watershed you are working on already has a numbering convention, continue that convention to be consistent within the WAU.

Location

Landslides will be entered in ArcGIS by the landowner qualified expert and the information will be sent to DNR for inclusion in the landslide inventory for the unique watershed. The elevation of the headscarp is usually close to the initiation location unless you have other information. Determinations of the initiation location may be useful for research or for critical questions.

Landslide description and attributes*

DS=debris slide	was shallow rapid landslide(s) in current approved watershed analysis manual
DF=debris flow	was shallow rapid landslide(s) in current approved watershed analysis manual
DA=debris avalanche	was shallow rapid landslide(s) in current approved watershed analysis manual?
SA = snow avalanche	was shallow rapid landslide(s) in current approved watershed analysis manual?
DT = debris torrent	was the same in current approved watershed analysis manual?
RF/T = rock falls/ topples	was not in current approved watershed analysis
LPDS = large persistent deep-seated	was the same in current approved watershed analysis
SSDS = small sporadic deep-seated	was the same in current approved watershed analysis
EF = earthflow	was not in current approved watershed analysis

Definitions of shallow rapid landslides:

1. Debris Slide: A shallow landslide that forms from the disaggregation of materials on a steep slope, involving the rapid movement of the soil and regolith over bedrock. This category includes those types of landslides also known as shallow-rapid, soil slips, and debris avalanches in Washington State's watershed analysis method, per this Board Manual. The lack of significant water differentiates a debris slide from a debris flow.

2. Debris Flow: A shallow landslide that flows within a channel formed either by the valley walls of a low-order tributary or by levees of its own making. It consists of soil and water with varying quantities of woody debris and is characterized by channelized flow, and often has a long run-out path. This category may include those events referred to as mud flows, debris torrents, hyper-concentrated slurries, and landslide dam-break floods.

3. Debris Avalanche: The rapid and unusually sudden sliding and flowage of incoherent, unsorted, mixtures of soil and weathered bedrock that is not contained within a confined channel.

4. Rock Slides (Jackson, 1997): A slide involving a downward and usually sudden and rapid movement of newly detached segments of bedrock sliding or slipping over an inclined surface of weakness, as a surface of bedding, jointing, or faulting, or other pre-existing structural feature.

5. Rock Topples and Falls: Shallow topples and falls consist of the individual blocks of soil or rock that becomes detached from a steep slope and descend through the air by falling, bouncing, or rolling before coming to rest on gentler slopes. Soil topples and falls tend to disintegrate whereas rock topples and falls do not. Repeated topples and falls lead to soil blocks forming a convex colluvial foot-slope and rock blocks forming talus (includes all forms of topple and fall that cannot be identified as deep-seated). These may contribute to deep-seated landslide activity by loading at the headscarp.

6. Snow Avalanche: Failure within or at the base of the snow pack of alpine areas that results in the rapid down-slope movement of snow, woody debris, and minor surface sediment to the base of the slope. The avalanche path results in an elongate area devoid of timber in the alpine and subalpine areas and fan-shaped deposits of rock and wood at the base of the slope.

Definitions of deep-seated landslides:

Large deep-seated landslides are those in which most of the area of the slide plane or failure zone lies below the maximum rooting depth of forest trees, to depths from several to hundreds of meters (Washington Forest Practices Board, 2002). Deep-seated landslides involve glacial deposits, deep regolith, weathered rock, and/or bedrock, as well as surficial, pedogenic soil. As used here, deep-seated landslides include large (acres to hundreds of acres) slope landslides associated with geologic materials and structures.

These landslides are commonly associated with geologic weakness and may be triggered by seismic shaking or channel incision. Climatic changes, ranging from major (e.g., glacial-interglacial transitions), to intermediate (runs of several wet years), to short-term events (extreme storm precipitation which may be coupled with antecedent moisture, hydrologic loading of the slope (e.g., road drainage), added weight at the head scarp, modification of the toe slope, etc.) may also trigger or accelerate deep-seated landslides. These landslides are defined as:

1. Large persistent deep-seated landslides: Commonly slump earthflows involving large area of hillside; found in natural and managed landscapes, recognizable over long periods of time, and almost without exception predate land use.

2. Small sporadic deep-seated landslides: Commonly smaller slumps that can be triggered at irregular time intervals (by storms or earth movements) and can decay to the point they are indiscernible.

3. Earthflows: A mass movement landform and process characterized by down slope translation of solid and weathered rock over a discrete basal shear surface (landslide) within well-defined lateral boundaries. The basal shear surface is more or less parallel with the ground surface in the down slope portion of the flow, which terminates in a lobe like form. Overall, a little or no rotation of the slide mass occurs during displacement, although, in the vicinity of the crown scarp, minor initial rotation is usually observed in a series of slump blocks (Jackson, 1997).

The qualified expert will summarize all deep-seated landslides according to these characteristics:

- Active/recent;
- Dormant-distinct;
- Dormant-indistinct;
- Rotational;
- Translational;
- Combination.

Certainty*

D = Definite: the qualified expert is certain that this is a Landslide.

P = Probable: the qualified expert is not sure, but it is probable that this is a landslide.

Q = Questionable: the qualified expert is not certain that this is a landslide, but is including it for completeness of the inventory, these landslides will not be in the GIS spatial data. The focus will be on field verification.

A variety of factors govern the certainty with which a qualified expert can remotely identify a landslide including ground cover, age and size of landslides, the scale, aspect, or lighting conditions of an aerial photograph. These are intended to be qualitative statements as to the certainty the qualified expert has that the observed feature is a landslide. Landslides with a "questionable" designation will not be used in the landslide hazard calculations, but are included to note that the qualified expert did observe the feature. Additionally, on the first set of photos or LiDAR, the qualified expert should only map and tabulate those landslides for which they are sure is a landslide and that the landslide occurred shortly before the time the photo was taken, as there is no way to 'age date' the landslide. On the west side of the state it is common for landslide scars to re-vegetate within 15 years and there is little evidence of the failure decades afterwards (unless it is greater than ~ 5000 square yards). The assignment of relative certainty should guide field verification. 'Questionable' and 'probable' calls should be given the highest priority to resolve in the field. Older or re-vegetated features may be difficult to see on subsequent aerial photos, but may still be identifiable on the ground.

ID Date*
Year of initiation of the landslide: Note the date (or flight number) of the aerial photograph set in the column heading on Form K-1; arrange the flights from oldest (left column) to most recent (right column), preserving the last column for features that initiated after the latest photos (i.e., identified in the field).

LS Size* area in square yards, using GIS mapping tools to estimate
Record the approximate area of the slide in the column corresponding to the photo set being examined. If you are using heads-up digitizing it will be easy to measure the area of the landslide.

1 = very small (1 to 100 square yards)
2 = small (101 to 500 square yards)
3 = medium (501 to 2000 square yards)
4 = large (2001 to 5000 square yards)
5 = very large (greater than 5000 square yards)

Slope Shape (lateral curvature)*
1 = convergent
2 = convergent to planar
3 = planar
4 = planar to divergent
5 = divergent

Slope at initiation zone* - field data is always best
- Using LiDAR

DNR may be able to provide a GIS-based process to allow the user to define a polygon at the head of the landslide (initiation area) that will average the slope.

- GIS-derived slope (percent) at initiation zone*

Using digital elevation model (DEM) data, average the slope gradient within a polygon at the initiation area of the landslide.

Land use (at initiation zone)
Gravel pit or quarry
CC = clear cut
MT = mature timber
RR = road
OR = orphan road*
AR = abandoned road*
L = landing
AR = agricultural road
A = agriculture
USB = unstable slope buffer
*Use RMAP information if available

We differentiated harvest unit from mature timber. If the initiation location is on or obviously from a road or unstable buffer, use those land use categories.

Age class of trees (2009 at initiation zone)
0 to 5, 5 to 20, 20 to 50, and 50+ years
The ambiguity associated with the duplication of ages between classes is deliberate because not all specific age classes are known. If definitive ages are known, use those.

Delivery to a public resource*
Public resources per WAC 222-16-010 are defined as water, fish, and wildlife and in addition mean capital improvements of the state or its political subdivisions.

If Yes, identify the resource:
Stream (F or N)
Infrastructure that may include bridges, roads, houses, and public water intakes, etc.

If No, identify the location as forest floor, field, or private forest road, etc.
Indeterminate (Ind) means that the qualified expert could not see if there was delivery to a public resource.

<u>Identifying existing MMWU in GIS (screening tool)*</u>
Use the number of the MWMU from the current approved watershed analysis hazard zone from the DNR GIS spatial database for this entry.

Is the landslide associated with a "Rule-Identified Landform" as listed in WAC 22-16-050?*
Input information is: Yes/No/Non FP Rules Land/tribal/other.

<u>Type of Landform*</u>
Remote landform assessment cannot determine if a landform is a rule–identified feature with certainty. Note the information if a landform is a field-verified, rule–identified landform

IG = inner gorge

BH = bedrock hollow

CH = convergent headwall

Toes of DSLS, and

OM = outside edges of meander bends edges along high terraces or valley walls

Ind = indeterminate

Stream erosion = natural or storm-related if possible to discern

<u>Cautionary comment</u>
DEMs and LiDAR gradients may not be conclusive for determining rule-identified gradients. It is not feasible to field verify every rule-identified landform as stated in WAC 222-16-050(1)(d)(i) using remote sensing methods. For example, if there is a convergent headwall and the DEM-derived gradient is 70 percent it may not be a rule-identified landform. However, studies such as Dragovich, 1993 determined that DEM-derived gradients may be off by 10 to 15 percent. If the DEM-derived gradient is close to 80 percent or the LiDAR-derived gradient is 74 percent and greater it is acceptable to make a professional call that you are confident there is a rule-identified landform.

<u>Comments</u>
Add any information that may be valuable for the particular landslide.

Other optional attributes for discussion:

- Geology
- Soils (perhaps engineering properties)
- Timber yarding impacts
- Specific road practices
    - Sidecast
    - Plugged culvert

- o Water concentration

Field Reconnaissance to Determine Land Use Associations and Contributing Factors

The qualified experts should perform a field inspection of the basin to resolve major uncertainties regarding:

a. The physical conditions associated with landsliding, and the particular characteristics that should be used in establishing the MWMUs;
b. Inferred land use associated with landslides (e.g., road sidecast, undersized culverts);
c. Delivery of sediment to streams, public works, etc.; and
d. Extrapolation of map units to lesser-known areas.

An intermediate decision point to-choose an option

Upon completion of the landslide inventory three situations may occur:

1. It is readily apparent that the majority of the landslides occur in locations that are similar to the current approved mass wasting analysis and the MWMU descriptions, processes, and land use are similar. You may not have to create new MWMUs. Your choices are:
    a. If there are non-specific prescriptions for these MWMUs, review the critical questions and determine if the reanalysis will change the MWMU prescriptions. If not, terminate the review at this point and choose the option to use standard rules; there will be no operational change for the process of addressing potentially unstable slopes in the watershed. Notify DNR and begin a non-project SEPA.
    b. If the prescriptions are specific and a change is needed, then proceed with the rest of the reanalysis.

2. If the landslides do not correlate to the same landforms as in the current analysis and you can identify new MWMUs (potentially unstable landforms) then you may have the choice of creating new mass wasting prescriptions and continuing with the reanalysis.

3. Decide if selecting the standard rules would be the more protective option.

MWMU Development and Mapping

Before creating new MWMUs the qualified expert should determine if the existing MWMUs can incorporate the landscape in areas of high landslide densities. Landslides that occur in high hazard MWMUs are typically where landslides are predicted to occur. Refer to the existing MWMU descriptions in your watersheds to see if the characteristics of the landslides you are observing seem to be like the descriptions of the landslides that were used to create any of the existing MWMUs. If you have LiDAR you may be finding landforms (that are or are not representative of existing MWMUs) that were difficult to detect with aerial photography alone. Recent aerial photography can also expose landforms in clear-cuts or burned areas. Look at the following characteristics to help in the decision to create new MWMUs.

- Landslide processes and landslides densities
- Slope gradients and landforms
- Bedrock types and structures
- Surficial materials

The reanalysis is partitioned into map units, based on physical characteristics contributing to landslide activity, and the potential for landslide sediment to enter streams or affect other public resources that have been clearly delineated.

- Inspect the landslide inventory data and map and note the geologic and geomorphic factors associated with each mass wasting feature type. What new mass wasting features are present in the basin and how are they distributed?
- If there are landslides that do not seem to be associated with any of the characteristics of the other MWMUs, try to define similarities among your newly inventoried landslides.
- The new MWMUs should have areas of terrain having similar physical characteristics and mass-movement behavior. (Do not differentiate map units based on the presence or absence of management activities at this point. Landscape sensitivity to management practices is evaluated in the hazard ratings).

In addition, each MWMU should be unique with respect to at least one of the following: landform, process, density, and delivery.

The number and nature of map units designated in a watershed will depend on the geomorphic complexity of the basin. Although the qualified expert is free to design MWMUs appropriate to the area being examined, there must be consistency in the character of the individual map units that comprise each new MWMU types (particularly among adjacent basins). For guidance, see Rib and Liang, 1978; Fiksdal and Brunengo, 1981; Varnes 1984; Sidle, et al., 1985; Howes and Kenk, 1988; Chatwin, et al., 1991.

Create a new GIS layer that outlines the map units and add the new MWMUs to the MWMU map (Map K-2 Mass Wasting Potential). Label the MWMUs by number; for units with multiple polygons, include a polygon number for each (e.g., 3-1, 3-2, etc.).

Summarize information on each MWMU into a concise summary form (see Form K-3, Mass Wasting Map Unit Description Form). Write a brief description of the physical characteristics, mass movement history and behavior, sediment delivery characteristics, and associations with forest practices for each new MWMU. Descriptions should be as quantitative and objective as possible.

Form K-3 Mass Wasting Map Unit Description Form

(From Board Manual Section 11, Appendix A and Landslide Hazard Zonation Protocol, 2006)

Form K-3	Mass Wasting Reanalysis Map Unit Description Form
MWMU Number	#1
Description	Steep (>65%) relatively planar slopes adjacent to stream channels
Materials	Shallow permeable soils, containing both colluvium and glacial sediments mantling competent but fractured andesitic bedrock
Landform	Example: Inner gorge : a narrow inset V-shaped valley characterized by steepening of slope gradient above stream channels, with more or less distinct break in gradient between the relatively planer inner gorge slope and the lower gradient hillslope above. Relief of the inner gorges (measured from the slope break) varied between about 30 to 150 feet. The inner gorge slope typically runs directly to the active stream channel.
Slope/ Slope shape	>65% (33 degrees) measured on site, convex, concave, planar, or mixed
Lithology	Geologic Units and/or soils
Elevation	600 ft to 3800 ft
Total area	~ 5 % of the total WAU acres
Mass Wasting Process	10 road-related shallow rapid landslides: 5 side cast landslides, 3 fill landslides all at stream crossings, 2 down slope shallow rapid landslides associated with concentrated surface water discharge from roads. 6 non-road-related landslides: 5 in clearcut harvest units (each of which was less than 20 years old), 1 in mature forest with not previous harvest
Landslide Density	Optional: 1 landslide per 269 acres observed over the 30 year record (0.08 landslides per square mile per year)
Forest Practices Sensitivity	High sensitivity to road construction activities, Moderate sensitivity to harvest
Mass Wasting	Moderate , there is a potential for landslides under forest

Potential	practices and road construction
Delivery potential	High
Delivery criteria used	Steep slopes adjacent to stream channels (no intervening low gradient areas for deposition), historical delivery observed
Hazard Potential Rating	Moderate to high
Trigger mechanisms	Roads: failures of sidecast material placed on slopes > 65% Fill landslides at stream crossing. Road washouts at stream crossings may result from plugged culverts. Discharge of surface water on to steep slopes. Harvest: Increased landslide rates are associated with clearcut harvests within inner gorges.
Confidence	High confidence that the potential hazard rating for the MWMU is high, landslides occurred in naturally and managed stands. Low confidence however that the entire area mapped as MWMU 1 is unstable. Inner gorges are often very narrow and may be obscured on aerial photos b full forest canopy. The final determination as to whether or not any particular slope falls within MWMU1 depends upon actual field conditions and should be based upon the description given above.
Comments	Example: Timber harvest may also affect slope hydrology in a manner that could increase the potential for mass wasting. For example, snow accumulations (and water equivalent) in clear cuts are commonly deeper than under forest canopy.

Distributions and types of existing landslides are important in designating the MWMUs. If many slides were located adjacent to the main stream channel in an inner gorge, the gorge could be identified as a separate map unit. In many places, shallow landslides are associated with the toes or headscarps of large slump-earthflows; thus, deep-seated slides (or specific parts of them) could be defined as map units. Note whether mass wasting features are persistent sources of sediment, either from continued enlargement, active earth-flows, or surface erosion of landslide scars.

Tabulate, for each MWMU, the number of features (by type) associated with various land use activities (on Form K-4 Mass Wasting Reanalysis Summary Table).

Extrapolate map units and descriptions to other areas. When appropriate, the qualified expert can extend the MWMUs to areas having no photographic record, or areas that have not been intensely affected by harvesting or road building. This allows extrapolation of the predictive mass wasting potential ratings as well.

Form K-4 Mass Wasting Reanalysis Summary Table
(From Board Manual Section 11, Appendix A Mass Wasting)

Activity or land use	Landslide Process							
	Shallow Un-Dif	Debris Slide	Debris Flow	Debris Avalanche	DSLS	Rock Fall /Topple	Snow Avalanche	Totals
Gravel Pit or Quarry								
Clear cut								
Partial Cut								
Mature Timber								
Road								
Stream Crossing								
Orphan Road								
Abandoned Road								
Landing								
Agricultural Road								
Agriculture								
Unstable Slope Buffer								

Mass Wasting Hazard Potential Ratings for New MWMUs

The landslide hazard zonation protocol to determine low, moderate, and high hazards is more quantitative than the process used in the current approved watershed analysis module. The following criteria will be used:

- The landslide frequency rate reflects the total number of landslides per unit area of landform normalized for the period since the earliest set of photography was acquired (typically, sometime during the 1970s.) The normalized numbers, which are small fractions, are then multiplied by one million and rounded in order to provide the nearest whole numbers. The landslide area rate for delivery includes only those landslides having "definite" or "probable" certainty for delivery, which is why it is important to resolve those landslides inventoried as 'probable' or 'questionable' through field verification.

- Areas or landform polygons with matching or similar characteristics (i.e., descriptors) within a landscape that have not been subject to forest practices, or are not covered by a reasonable photographic record, are not used in the calculation of landslide area and landslide frequency rates, although the hazard mapping is extrapolated to these areas. If these areas were included, the predictive value of the method would be reduced because the apparent instability per unit area would be biased by an obscuring canopy in areas of mature forest. After the rates have been assigned, the same rating is given to all new landforms with matching characteristics.

Table K-4. Calculating Landslide Area Rates with hypothetical examples (using an example of 50 years from the Landslide Hazard Zonation Protocols, 2006)

Landforms	Landform 1	Landform 2	Landform 3	Landform 1	WAU
Landform Area (acres)	100,000	10,000	1000	100	111,100
Number of "Delivering" Landslides	250	300	200	20	770
Landslide Frequency Rate (# of Landslides/landform area/years) x 10^6	50	600	4,000	6,667	139

Table K-5. Qualitative ratings equivalency of Landslide Frequency for a period of 50 years.

Qualitative Ratings (for a 50 year time span)	**Landslide Frequency Rate**
Low	< 100
Moderate	100 to 199
High	200 to 999

Developing Overall Hazard Ratings

Assign a low, moderate, or high rating to the landform based on Table K-5. Put these values into Table K-5 to develop the overall hazard rating in consideration of the additional criteria listed below. These results will provide the basis for comparison among watersheds throughout the state (Excerpted from the LHZ project protocol 11/30/2006 Version 2.1 30 of 50).

<u>Using landslide frequency rates for assigning overall hazard ratings</u>
Except for rule-identified landforms, most overall hazard ratings will be assigned on the basis of the semi-quantitative hazard ratings. The current guidelines for the landslide frequency are based on twenty-seven landforms analyzed as Priority II Watersheds under the LHZ project (Lingley, 2004a, b; Wegmann, 2004), on the data used to define rule-identified landforms.

Landslide frequency rate values are converted to qualitative ratings using Table K-4 and these are entered into Table K-5 to generate overall hazard ratings. While this method provides a better means of comparing watersheds in different parts of Washington, users should keep in mind that overall hazard ratings derived from this method are estimations only. This should be restated in each summary report. (Note: These semi-quantitative guidelines may be modified in the future.)

For an inference to be valid, the known area and the unmapped area must be comparable in materials, landforms, and (to the extent known) landslide types. Important characteristics that should be similar include all of those used to define the known MWMU, especially:

- Slope form and gradient;
- Bedrock and soil/surficial material types;
- Elevation, climatic zone; and
- Vegetation type.

The greater the similarity of these characteristics between the known and unknown areas, the greater the confidence will be in the extrapolation of hazard ratings. If there are large differences between the areas, extrapolation should not be attempted and indeterminate ratings should be assigned to the unmapped or unknown area.

Ratings of the potential hazard of landslide debris or sediment to be delivered to streams and other public resources are assigned to the MWMUs. The ratings are determined on the basis of occurrence of landslides in the past (recognized in the current approved landslide inventory and the landslide inventory created for the reanalysis). There are often relationships among forest practices and landslide occurrence and the likelihood that debris or sediment will be delivered to sensitive locations or waters (mass wasting map unit descriptions, Form K-2). Each element is part of the rating.

Consider the following factors when making hazard ratings:

- What is the natural potential for mass wasting processes?
- Are the mass wasting processes associated with forest practices?
- What is the potential for sediment to be delivered to streams or other waters?

The ratings address the most likely sediment sources in the watersheds, some basins may not contain a MWMU with a high hazard rating while others may not include any low ratings.

Hazard-potential ratings for mass wasting are derived from both mass wasting potential and delivery potential. Both components of the rating should be included in the MWMU description form with appropriate justification, evidence, and confidence addressed.

Indicate the ratings for hazard potential assigned to the MWMUs. It may be desirable to designate MWMUs on the current approved 1:24,000 map in color for use by the prescription teams. All polygons should be clearly labeled with the MWMU and hazard shading.
Comments need to include the following:

- Complexity of the basin;
- Extent of field-checking and accessibility to basin;
- Scale and range of aerial photograph coverage and length of record;
- Quality and quantity of other information;
- Additions to or deviations from standard methods; and
- Skill level of the qualified expert.

Mass Wasting Reanalysis Assessment Template

I. **Title page** with name of current approved watershed analysis, name of module, level of analysis, signature of qualified qualified expert(s), and date. All forms listed below can be found in Appendix A, *Mass Wasting Resource Assessment*.

II. **Table of contents**

III. **Maps**

- Mass wasting landslide inventory (Map K-1)
- New MWMUs and hazard potential ratings (Map K-2)

IV. Summary Data

- Mass wasting summary table (Form K-4)
- Mass wasting inventory data (Form K-5 to be distributed by DNR)
- New MWMU description form (Form K-3)

V. New mass wasting map units

- Description:
- Materials:
- Landform:
- Slope: Elevation:
- Total Area:
- MW Processes:
- Non-road-related Landslide Density: (optional)
- Forest Practice Sensitivity:
- MW Potential:
- Delivery Potential:
- Delivery Criteria Used:
- Hazard Potential Rating:
- Trigger Mechanism(s):
- Confidence:
- Comments:

VI. Summary Text

- Answer all the critical questions for the reanalysis
- Check to make sure that the report addresses all critical questions
- Summaries of reanalysis and results
- Descriptions of MWMUs
- Description and explanation of mass wasting potential ratings
- Statement on trigger mechanisms
- Statement of the author's confidence level in the analysis and results

Acknowledgments

References from the current approved watershed analysis mass wasting module

Benda, L., and T. W. **Cundy**. 1990. Predicting deposition of debris flows in mountain channels. Canadian Geotechnical Journal. v. 27, pp. 409-417.

Chatwin, S. C., D. E. **Howes**, J. W. **Schwab**, and D. N. **Swanson**, 1991, A guide for management of landslide-prone terrain in the Pacific Northwest. British Columbia Ministry of Forests, Land Management Handbook 18, 212 p.

Coho, C., and S. J. **Burges**, 1994, Dam-Break Floods in Low Order Mountain Channels of the Pacific Northwest, Water Resources Series Technical Report No. 138, Dept. of Civil Engineering, Univ. of Washington, Seattle, TFW-SH9-91-001, 23 p.

Costa, J. E., and R. L. **Schuster**, 1988, The formation and failure of natural dams. Geol. Society of America Bulletin, v. 100.7, pp. 1054-68.

Dietrich, W. E. and **Dunne**, T., 1978, Sediment budget for a small catchment in mountainous terrain: Z. Geomorphology Supplement 29, pp. 191-206.

Eisbacher, G. H., and J. J. **Clague**. 1984. Destructive mass movements in high mountains: hazards and management. Geologic Survey of Canada, pp. 8-16, 230 p.

Fiksdal, A. J., and M. J. **Brunengo**, 1981, Forest slope stability project, phase II. Wash. Dept. of Ecology, Technical Report 81-14, 62 p.

Howes, D. E., 1987, A terrain evaluation method for predicting terrain susceptible to post-logging landslide activity - a case study from the Coast Mountains of British Columbia. British Columbia Ministry of Environment and Parks (MOEP), Technical Report 28, 38 p.

Howes, D.E., and E. **Kenk**, 1988, Terrain classification system for British Columbia (rev'd ed). British Columbia Ministry of Environment (MOE), Manual 10, 90 p.

Ice, G. G., 1985, Catalog of landslide inventories for the Northwest. National Council of the Paper Industry for Air and Stream Improvement (NCASI), Technical Bulletin 456, 78 p plus appendices.

Johnson, A. C., 1990, The effects of landslide dam-break floods on the morphology of channels. [Unpubl master's thesis], College of Forest Resources, Univ. of Washington; TFW-SH17-91-001, 90 p.

Kenard, P., 1994. Road Assessment Procedure (RAP), consultant report to the Weyerhaeuser Company, Tacoma, WA.

Manson, C. J., 1984, Index to geologic and geophysical mapping of Washington, 1899-1983. Wash. Division of Geology & Earth Resources (WDGER), Information Circular 77, 56 p.

Manson, C. J., 1994, Preliminary bibliography and index of the geology and mineral resources of Washington, 1993. WDGER, Open File Report 94-15, 102 p.

Manson, C. J., 1995, Geologic and geophysical mapping of Washington, 1984-1994; and Theses on the geology of Washington 1986-1994; WDGER, Open File Report 95-2, 41 p.

Montgomery, D. R., and W. E. Dietrich, 1994, A physically-based model for the topographic control on shallow landsliding: Water Resources Research, v. 30.4, pp. 1153-1171.

Pentec Environmental, Inc., 1991, Methods for testing effectiveness of Washington forest practices rules and regulations with regard to sediment production and transport to streams: report submitted to Wash. Dept. of Natural Resources, TFW-WQ8-91-008, 100 p.

Pierson, T. C., and J. E. **Costa**, 1987, A rheologic classification of subaerial sediment-water flows: in Costa, J. E., Wieczorek, G. F., eds., Debris flows/ avalanches - process, recognition, and mitigation: Geol. Society of America, Reviews in Engineering Geology, v.7, pp. 1-12.

Rib, H. T., and **Ta Liang**, 1978, Chapter 3, Recognition and identification; in R. L. Schuster and R. J. Krizek, editors, Landslides: analysis and control. National Academy of Sciences, Transportation Research Board Special Report 176, pp. 34-80.

Shaw, S. C., and D. **Johnson**, 1995, Slope morphology model derived from digital elevation (DEM) data: Wash. Dept. of Natural Resources - Forest Practices Division OFR 94-1.

Sidle, R. C., A. J. **Pearce**, and C. L. **O'Loughlin**, 1985, Hillslope stability and landuse. American Geophysical Union, Water Resources Monograph 11, 140 p.

Swanson, F.J., and R. J. **Janda**, T. **Dunne**, D. N. **Swanston**, 1982, Sediment budgets and routing in forested drainage basins: USDA Forest Service General Technical Report PNW-141, 165 p.

U.S Geological Survey, 1992. Washington Index to topographic and other map coverage [catalogue]. U.S.G.S national Mapping Program, 48 p.

Varnes, D. J., 1984, Landslide hazard zonation: a review of principles and practice. UNESCO Natural Hazards series n. 3, 63 p.

Wieczorek, G. F., 1984, Preparing a detailed landslide-inventory map for hazard evaluation and reduction. Assoc. of Engineering Geologists Bulletin, V. XXI.3., pp. 337-342.

Wu, T. H., C. J. **Merry**, M. **Abdel-Latif**, C. P. **Benasly**, 1993, Landslide hazard mapping - 1. Estimating piezometric levels: report submitted to Wash. Dept. of Natural Resources, TFW-SH15-93-001, and 100 p.

Citations for this reanalysis document

Dragovich, J.D.; **Brunengo**, M. J.; **Gerstel**, W. J., 1993, Landslide inventory and analysis of the Tilton Creek-Mineral River area, Lewis County, Washington; Part 1-Terrain and geologic factors: Washington Geology, v. 21, no. 3, p. 9-18.

Landslide Hazard Zonation Project Protocol, Version 2.1. 2006. Prepared by the Upslope Processes Science Advisory Group (UPSAG), a subcommittee of the Cooperative Monitoring, Evaluation, and Research (CMER) committee.

Forms and worksheets to be distributed by DNR