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TIMBER-FISH-WILDLIFE PROJECT

PROTOTYPE WATERSHED ANALYSIS

-REVIEW DRAFT-

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PROTOTYPE WATERSHED ANALYSIS

By

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and Washington Department of Natural Resources
Forest Regulation and Assistance
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DISCLAIMER

Summary

"Watershed Analysis" is a procedure of data collection, analysis and decision making for assessing the environmental effects of forest management on fish habitat and other public resources in Washington state. It is being developed by the state's Timber-Fish-Wildlife Program (TFW) for use on non-federal forestlands. This report is a prototype of the proposed watershed analysis.

Watershed analysis is envisioned by TFW to consist of two levels. This report covers a Level 1 watershed analysis which is designed to be conducted over a period of approximately 5 days by a four-person team with some expertise in the areas of geomorphology, hydrology, forestry, and fisheries.

The prototype is based on scientific theories and technologies for the analysis of cumulative watershed effects in managed forests. The procedure for conducting a watershed analysis develops maps and data bases relevant to the dominant watershed processes, including sediment production, water runoff, river-channel dynamics, and the interaction of riparian forests with stream channels. This data is integrated with information on the distribution and condition of fish habitats in order to evaluate how watershed processes and forest management combine to influence existing habitat conditions, and to predict the future conditions of habitat under a variety of management scenarios. These evaluations can be used to guide forest management in watersheds, including developing management prescriptions for mitigating existing or future problems. Watershed analysis recognizes the geographic variability of physical processes and rates across the state, and employs methodologies that can account for this spatial variability.

A Level 2 watershed analysis, which is not included in this report, should be designed to verify a Level 1 analysis, determine more accurately the relationship between forestry

activities and habitat, and to develop site specific information from which to make management prescriptions for the mitigation of existing or potential impacts, or for enhancement projects.

The proposed watershed analysis recognizes that scientific results must be integrated into a management-based decision making framework to be a workable tool for the participants of TFW. Imperfect scientific theories and technologies, measurement errors, and spatial and temporal variability combine to reduce the accuracy and therefore the effectiveness of an assessment of cumulative effects in watershed analysis. A decision making framework that accounts for these uncertainties through the application of decision rules is presented as part of the watershed analysis. The methods employed by a Level 1 watershed analysis are designed to be efficient and reproducible. Furthermore, watershed analysis can adopt new technologies and information as these become available in the future.

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Chapter 1 - Introduction

Background

In recent years, the cumulative effects of forest practices on aquatic and terrestrial forest resources has been the subject of heated and growing debate. The Washington State Forest Practices Board (FPB) commissioned a study in 1982 which generally described the types and causes of cumulative effects (Geppert, 1984). More recently, the FPB adopted a time schedule for developing and adopting regulations governing the management of cumulative effects on state and private forest lands. Concurrently, the Washington Department of Natural Resource (WDNR) and cooperators in the Timber/Fish/Wildlife (TFW) process have discussed technical methods for assessing the potential for cumulative effects.

In August, 1991, the FPB re-adopted emergency rules (WAC 222-16-040) governing cumulative effects and required the WDNR to develop a prototype cumulative effects analysis method by January 1, 1992. This method has been developed with the participation of TFW's Cooperative Monitoring Evaluation and Research Committee (CMER). The method will be further refined between January 1 and March 1, 1992. According to the current schedule, an operational methodology will be presented to the FPB on March 1 and undergo a public review prior to implementation. Corresponding regulatory changes designed to implement the watershed analysis are to be identified by the FPB by March 15, 1992.

As currently envisioned by TFW, watershed analysis for cumulative effects on aquatic habitat consists of two distinct but complementary levels of analysis. It is envisioned that Level 1 analysis can be accomplished in about one week using existing sources of information and expertise, and that the more detailed Level 2 will require a greater commitment of time and expertise. The management utility of the two levels of analysis, and the quality of information which will result from each, must be clearly identified and discussed if the methods developed are to acquire broad acceptance in forest management.

This document describes the prototype Level 1 Watershed Analysis developed by the Pacific Watershed Institute for the Northwest Indian Fisheries Commission and the Washington Forest Protection Association.

Purpose of the Analysis

The analysis is designed to interpret how forest management activities influence certain major watershed processes and affect the condition of fish habitat and other non-timber resources. In this analysis, watershed processes are grouped as follows:

(1) Sediment-producing processes, which includes landsliding and surface erosion. These are sometimes referred to as "hillslope processes" in the document;

(2) Runoff generation, also referred to as a hillslope process;

(3) "Riparian function", or the connections between riparian forests and stream channels. Also referred to as a hillslope process;

(4) River-channel-forming processes, or the way in which sediment, water and wood interact to define channel morphology. This is sometimes referred to in the document as "channel response";

(5) Fish habitat condition as determined by the interactions of hillslope processes and the observed preferences of fish.

One way of describing the flow of sediment, water and wood through the watershed and their final influence on fish habitat to the resources of interest is the concept of a "pathway."

"Risk" is used in this document to refer to an actual or potential impact from forest management to fish habitat or other public resource. "Hazard" is used to refer to any management-caused change or potential change to sediment production, runoff generation, and riparian function.

In order to be an effective management tool, watershed analysis must also be practical. State agencies, tribes, industry, and public interest groups have all stressed the need for a cumulative effects management system which can be implemented immediately, does not require inordinate commitments of time and human resources, and yet is technically supportable. The proposed method has been designed to meet these criteria.

The TFW cooperators and the State Forest Practices Board plan to identify resource "thresholds," or certain resource conditions that trigger a defined management response. Watershed analysis can generate information to managers and regulators which can be used to develop a threshold based regulatory system containing hillslope and channel (fish habitat) components. Thresholds are not included in this prototype method.

Goals

Based on directives from TFW, Level 1 analysis has been designed to be within the capabilities of TFW personnel possessing education and professional experience in geology, geomorphology, forest hydrology, forestry, and fisheries biology. The analysis could be completed in approximately one week by a four-person team. Level 2 analysis is intended to be a more detailed method and could require an additional one to two weeks in the same watershed.

The goals of Level 1 analysis are to:

1) Identify major physical processes operating in the basin (examples are landsliding or rain-on-snow generated runoff);

2) Attempt to establish a relationship between hillslope processes and forest management in the basin;

3) Assess present habitat conditions and sensitivity;

4) Produce maps indicating landslide erosion, surface erosion, areas of rain-on-snow potential, riparian forests, and fish habitat for establishing hazard and risk assessments.

Level 1 watershed analysis has been designed to be accomplished primarily by remote means, because of time limitations. It relies heavily on aerial photographs, precipitation data and topographic, geologic and habitat maps. A limited amount of additional information will be collected in the field as necessary. The analysis can be changed as new information and methods become available.

Data forms will provide accountability on all scientific evaluations and should allow replication of results. In a number of cases it will not be possible to make unambiguous evaluations or determinations regarding risk at Level 1, both because of the constraints of time and the expertise expected by practitioners at Level 1. In these cases, Level 2 analysis may be required. Level 2 analysis could also be used for verification of Level 1 interpretations, to confirm association with specific contributing practices, and to define appropriate management prescriptions where this is beyond the scope of Level 1.

Level 2 analysis is intended to:

1) Collect more detailed information on processes identified in Level 1 (e.g., specific trigger sites of road-related landslides, and the role of road construction methods in destabilizing the sites) in order to recommend site-specific management prescriptions;

2) Measure process rates for problem watersheds to identify the magnitude of problems;

3) Apply more time-consuming, theoretical or field-based models for analyzing processes if needed.

Approach

One objective of watershed analysis is to apply accepted scientific methods to interpret the influence of forest management activities on physical and biological watershed processes and their interaction with public resources (Figure 1.1). A second objective is to link this analysis with a management decision-making framework (Figure 1.2). These two components will be discussed in order below, beginning with the scientific basis.

Scientific Basis.

Sediment Budgets

The concept of the "sediment budget" is one of the foundations of modern forest geomorphology, and is integral to watershed analysis. Defined generally, a sediment budget is a statement about the erosion, transport and storage of sediment in a watershed.

A sediment budget includes the identification of sediment sources and the processes that erode them. An accounting of different sediment sources and erosion processes may be either qualitative or quantitative; depending on how much information is available or necessary.

Analysis of sediment sources and erosion processes can be extended back in time by analyzing archival materials, such as aerial photographs. The study of erosion can include information on the natural factors that influence the location and rate of erosion, as well as the effects of land management on erosion processes. Because information can be gathered on the factors that influence erosion, a sediment budget can also be a predictive tool. In summary, a sediment budget is a flexible tool for developing the needed level of detail on the historic, present, or future effects of land management and natural factors on the locations, rates, and grain size distribution of erosion.

Level 1 Analysis is intended to give a general assessment of erosional and channel conditions in a watershed within a short time frame. Thus, the sediment budgeting is mostly qualitative, and because of time constraints, relies heavily on remotely-sensed information.

CONCEPTUAL FRAMEWORK FOR PROCESS EVALUATION

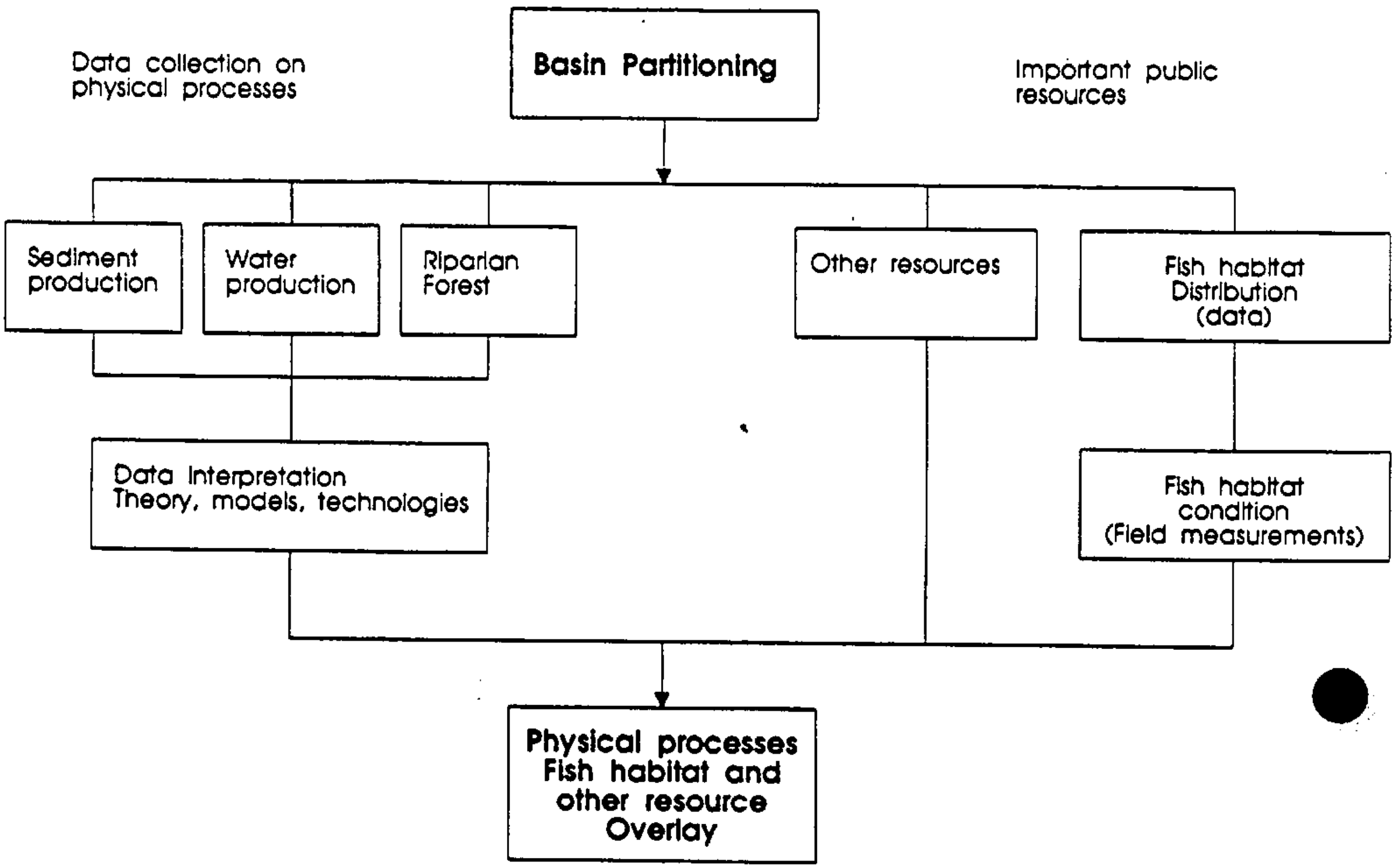
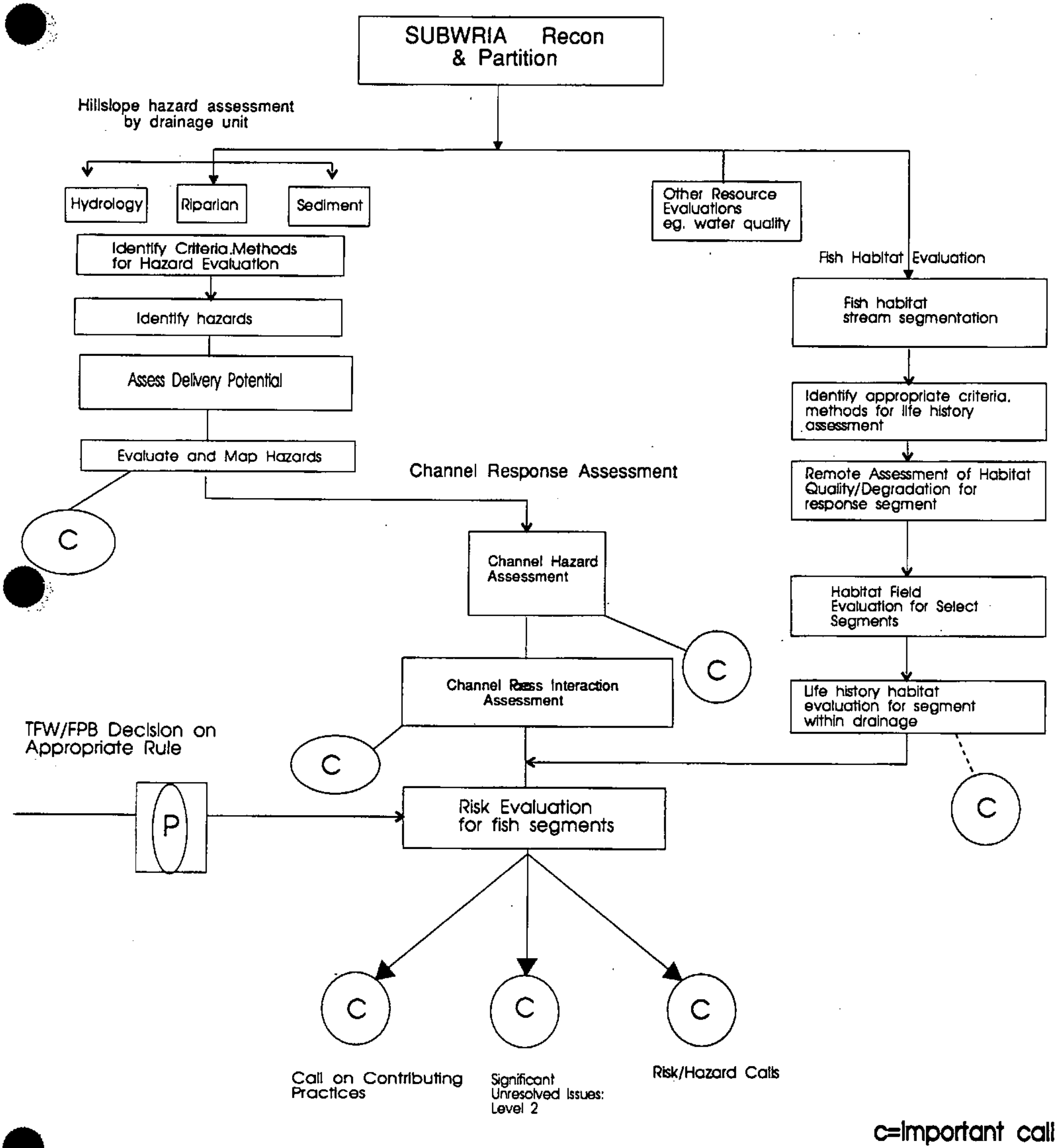


Fig. 1.1

Figure 1.2

Watershed Analysis Risk Assessment Procedure
Level 1



Level 2 Analysis, by contrast, is intended to give more detailed, site specific information. Sediment budgeting for Level 2 Analysis is more quantitative, and makes more use of information gathered in on-the-ground or in-channel investigations.

Hydrology

The principle of water balance is the basis for the analysis of hydrology. The hydrologic cycle as it pertains to forested mountain drainage basins is based on theories, models and technologies that describe the many pathways of water in all its phases through an ecosystem.

The pathways and properties of water, snow and water vapor movement important to watershed analysis includes precipitation intensity and duration, rain-on-snow augmentation of runoff, evapotranspiration by vegetation, surface and subsurface flow and water storage in soils.

Each of these components are understood quantitatively, some at a small scale, others at larger spatial scales. The interaction of these processes, however, at the scale of entire watersheds is more difficult to predict or model because of the inherent spatial and temporal variability.

Riparian function

The assessment of riparian vegetation in a Level 1 watershed analysis is based on the scientific understanding of the role of riparian vegetation in providing large woody debris (LWD), and shade to aquatic ecosystems. The methods in watershed analysis apply solely to the role of vegetation in and adjacent to streams. Other riparian functions, such as enhancing bank stability and providing nutrient and food input to streams, are not included in the prototype analysis.

Numerous studies have demonstrated the importance of large woody debris as a structural element in streams and as a source of shading and nutrient input to streams (for a synthesis see (Bisson, et al., 1987). LWD creates habitat features such as pools and riffles and provides instream cover and low velocity refugia. In general, as riparian forests are impoverished of vegetation, including large trees, and volumes of large woody debris in small streams are lowered, fish habitat quality and quantity is reduced.

The role of riparian vegetation depends on vegetation species and size. Quantitative indicators of riparian vegetation as they relate to the functioning of stream channels and fish habitat quality are generally not available for use in a Level 1 watershed analysis, so a more qualitative approach toward predicting recruitment potential for large organic debris is used.

Channel Response

Stream channels are formed by wood, water, and sediment and are continually modified as these inputs change through time. The science of fluvial geomorphology describes this interplay between supply of materials to channels and channel form. The sediment budget approach is an integral part of the study of fluvial geomorphology because it accounts for the delivery of eroded sediment to channels, and the transport and storage of sediment in the channel.

The effects of changing the timing, amounts, or sizes of inputs to channels can interact in complex ways. While it may not always be possible to quantify separately the role of individual, interacting causes, it is possible to describe qualitatively the effects of each.

The ability to assess and predict channel response to changes in the supply of wood, water, and sediment is important to a cumulative effects analysis because it allows fish biologists to make connections between habitat and watershed conditions.

Fish habitat

The fisheries resource component of Level I watershed analysis is based on the assumption that fish production from freshwater systems is directly related to the type, amount, and quality of physical habitat available for use. Numerous studies have documented this relationship (Bjornn and Reiser, 1991). An overview of models which predict standing crop of stream fish as related to physical habitat variables is provided by Fausch, et al. (1988). The relationship between physical habitat and fish production is the basis for the Habitat Evaluation Procedure (HEP) (U.S. Fish and Wildlife Service,1983). HEP is designed to relate physical changes in stream morphology to changes in the suitability of for fish. Level 1 analysis uses HEP and the understanding of physical watershed processes to make an assessment of past, present, and future conditions of fisheries habitat within a watershed.

Level 1 analysis uses habitat features, and associated suitability curves, which are as consistent as possible with features identified by TFW . The habitat features selected are thought to be the most strongly correlated with habitat productivity. Features for which this relationship is less clearly understood or are too difficult or time consuming to measure within a Level I analysis have been omitted.

Considerations in Defining Scale of Analysis.

TFW has indicated that the scale at which watershed analysis should be completed depends on the ability to detect and measure impacts and sensitivities. PWI proposes an approach that requires data collection for areas smaller than a sub-WRIA. A "WRIA" is a Water Resource Inventory Area as defined by the state Department of Ecology. The state has formally been divided and mapped into WRIA and "sub-WRIA" areas. The sub-WRIA can be partitioned into similar drainage units for extrapolating results and determinations within the same sub-WRIA.

Partitioning of each subWRIA is based upon an examination of 1:40,000-60,000 aerial photographs. It will include a cursory definition of significant geomorphic and landscape features and result in segregation of areas, each of which possesses roughly equivalent potential for cumulative effects. This can be accomplished, for example, by looking for land management features: e.g., forest age and species homogeneity, road density or pending Forest Practice Applications; and physical hillslope indicators: eg., density of landslides or debris flows.

Different watershed processes require different spatial scales of analysis. For example, riparian vegetation can be mapped for a sub-WRIA size area at a scale of 1:12,000 to 1:40,000 aerial photography. Mapping of sediment sources and channel widening should be done at the scale of approximately 2 - 20 square miles. The time, effort and cost for conducting watershed analyses depends on the size of the watershed. Because it will be possible to make extrapolations between places in a watershed or to different watersheds, the time and effort to conduct a watershed analysis is not linearly proportional to area. A 20-square-mile watershed will not take ten times the amount of effort as a 2 square mile watershed.

Risk Assessment Applied to the Forest Landscape

The second component of watershed analysis is to integrate watershed science into a management framework. This topic is treated in greater detail in the Chapter 2. The integration of science and policy shown schematically in Figure 1.2 indicates how watershed analysis can be used to define risks to public resources. These impacts are caused by potential or actual hillslope hazards such as shallow-rapid landslides or loss of riparian woody debris recruitment.

Pathways-Based Risk Assessment.

TFW has called for a "pathway-based" approach to the evaluation of risk. The proposed watershed analysis reflects this concept, identifying the processes by which beneficial uses may be affected by changes in the supply and timing of wood, water and sediment delivery to a channel. The analysis evaluates resource conditions and the hillslope processes that might affect them, which could be called a "bottom up approach", and simultaneously identifies changes or potential changes in amount and timing of sediment, water and wood and how this affects resources, or "top down approach." These matters are discussed in more detail in Chapter 2.

Structure of the report

Chapter 2 discusses a possible framework for making management decisions based on the results of watershed analysis. The next three chapters (3, 4 and 5) outline the watershed analysis methods for analyzing the sediment, hydrologic and riparian processes. Chapter 6 presents a method for detecting channel change from changes in sediment supply and changes in flood hydrology. Chapter 7 discusses fish habitat evaluation. Chapter 8 identifies other public resources at risk. Chapter 9 presents methods for integrating information on hillslope and channel processes with habitat assessments. Chapter 10 provides a worked example of the method. Figure 1.3 summarizes the structure of watershed analysis, and the role of the different chapters.

Components of Prototype Analysis

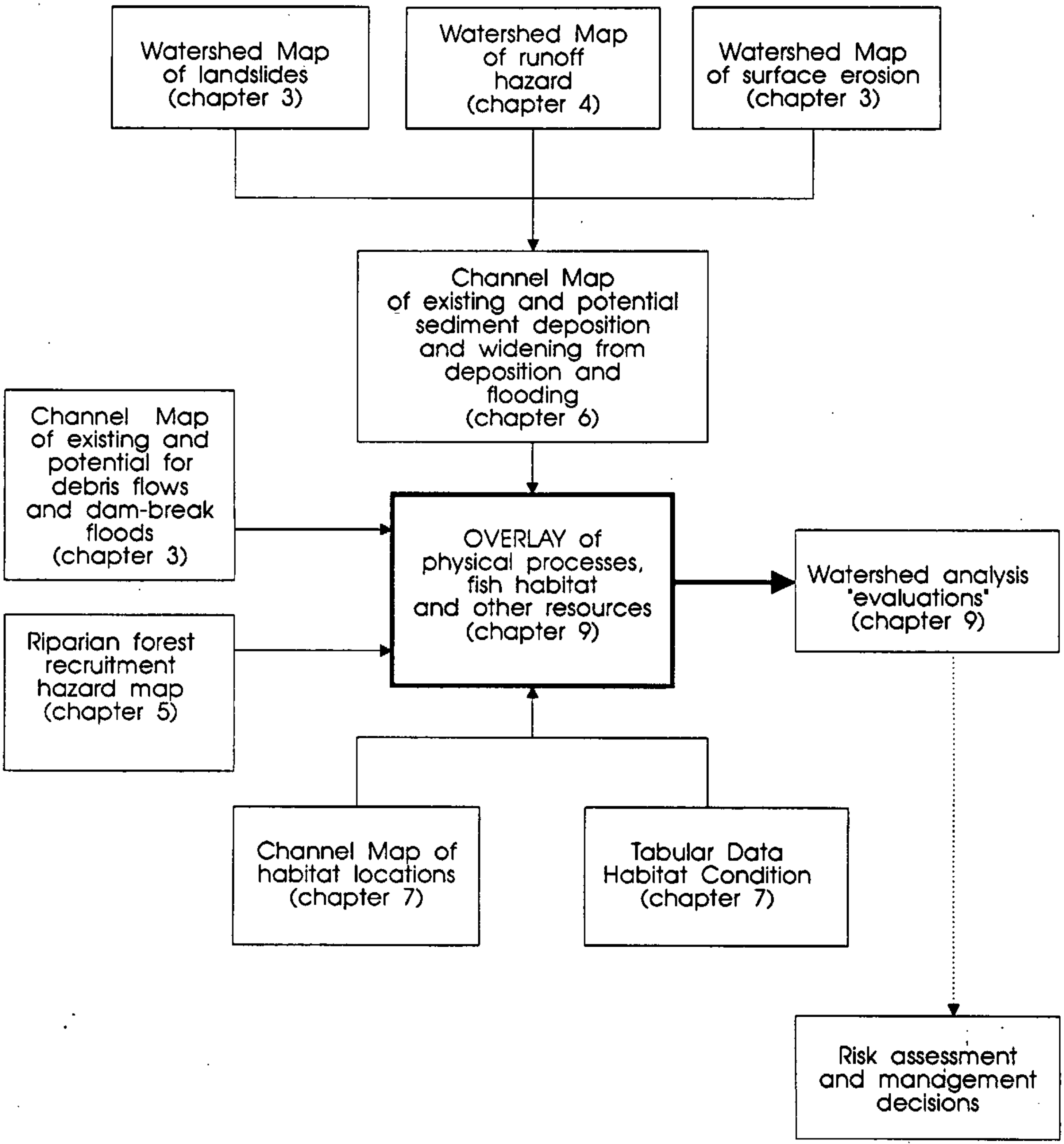


Fig 1.3

Chapter 2--Framework For Management Decisions

Introduction

To be useful, watershed analysis must be sensitive and responsive to watershed process complexities, but also to management needs and constraints. These needs and constraints require that the analysis method be:

1) Efficient;

2) Accountable;

3) Replicable;

4) Explicit in the definition of uncertainty

5) Permit the evaluation of risk to beneficial resources;

6) Adaptable and able to incorporate new information and methods as they become available.

A listing of how the method meets these objectives is provided in Figure 2.1.

Efficiency.

Practicality and efficiency considerations are reflected by the separate Level 1 and Level 2 assessment components. Having these two components should make it possible to rapidly define selected risks through a Level 1 analysis that relies on remote analysis and limited fieldwork. Level 2, which will require more time and manpower, can use the information gained during Level 1 analysis to focus and limit the scope of study. Partitioning, as described in the previous chapter, enhances the method's efficiency by reducing the area within a sub-WRIA which must be analyzed in detail.

Repeatability and Accountability.

Fig. 2.1

OBJECTIVES AND FEATURES OF THE METHOD

Objective	*Addressed by the method*	*Notes*
EFFICIENCY	•Level 1 & Level 2 Analysis •Hierarchical treatment of scale through watershed partitioning	☞ Level 1: approximately 1 week; Level 2: 2-4 wks. ☞ Initial partitioning and recon. of subWRIA at 1:40,000
ACCOUNTABILITY	•Identifies critical questions, determinations in analysis •Clear definition of methods to be used in assessing hazards, habitat conditions, response.	☞ Otherwise known as "calls" ☞ Methods include HEP,DNR runoff model,erosion mapping
REPEATABILITY	•Provides system for recording evaluations •Identifies criteria by which decisions are made.	☞ Includes resources and hazard maps as well as reporting forms. ☞ Selectively provides decision trees.
ABILITY TO CONNECT PHYSICAL PROCESSES TO RESOURCE EFFECTS.	•Identifies important indicators of active processes. •Identifies ways in which channels and habitat respond to hillslope processes and practices. •Provides a systematic way to determine principal agents of change.	☞Provides hillslope, channel and habitat indicators. ☞ Makes concrete the concept of pathways showing effects on flows of wood, water, and sediment. ☞ Addresses deliverability explicitly or implicitly.
TREATMENT OF UNCERTAINTY	•Defines key assumptions •Grounds proposed method and interpretive criteria on established scientific procedures. •Minimizes error by including both field and office components. •Identifies Level 2 methods for answering ambiguities and sharpening resolution. •Calls for use of decision rules that explicitly identify assumptions used in calls on risk/ sensitivity.	☞ Field component generally 2-3 days. ☞ See Figure 1-3
ALLOWANCE FOR REVISIONS	•Modular design allows for revisions in hazard evaluation without overall method revisions. •By identifying key assumptions & functions, allows for recalibration.	☞ Can be linked to a monitoring program.

Repeatability in watershed analysis refers to the ability of multiple users to obtain approximately the same results when applying the same analysis independently. Accountability is the need for the method to clearly define the basis for all important determinations. Repeatability and accountability in the proposed method are provided for by the specification of science-based methods for assessing processes, and through explicit treatment of uncertainty. The successful implementation of watershed analysis will be largely determined both by the technical strengths and weaknesses of the method, and reasonable application by managers.

The methods will only be replicable if users are required to possess a high level of education and training. In general, Level 1 methods require users to have college level education in the fields of geomorphology/geology, forest hydrology, vegetation ecology, forestry and fishery biology. In many cases supplemental training will be required.

Quality assurance, which may be viewed as an aspect of accountability, will be afforded through use of Level 2 analysis when significant ambiguities are present at Level 1.

As indicated in Figure 1.2, the method provides that all major determinations, interpretations and evaluations are based upon explicit criteria. This ensures that important inferences can be checked independently and that procedures can be replicated. An accounting trail will be left for major decisions or determinations, also referred to as "calls" in this document that includes maps and score sheets, with the score sheets identifying specific criteria and methods that have been applied in reaching conclusions.

Figure 1.2 also illustrates various calls, *analytical* and *prescriptive*, that will be made at both Level 1 and Level 2. *Analytical calls may be defined to include any important conclusions or inferences about hazard or risk based upon gathered data, models, or indicators. Prescriptive calls may be defined as recommendations or conclusions about management practices that might mitigate or prevent an existing or future hazard or risk.* In some cases a prescription might include a specific assessment or study.

Analytical calls may include:

1. Hazard Inferences. A call that a hazard exists or that its likelihood is high, medium, or low is the expected output from the assessment of individual processes (Figure 1.2). For each assessment, that likelihood will take into account the likelihood of initiation, for example of rapid shallow landslides or debris flows under the environmental and man-induced conditions present, and the likelihood that water, wood, or sediment will arrive in the channel or be "delivered" to a sensitive location.

2. Appropriate Methods, for example development of landslide hazard maps.

3. "Risk Calls," in other words, inferences linking hazards to fish habitat or water quality effects, taking into account:

   a) Plausibility or power of predictions made about the flows of wood water and sediment from hillslopes to channels;

   b) Plausibility or power of alternate explanations;

   c) Predefined confidence requirements, or "decision rules." Decision rules are no more than guidelines for making decisions under uncertainty. Uncertainty is discussed later in this chapter.

4. Cumulative Effects Calls. These calls are made on the same criteria as under Section 3, but take into account more than one aspect of the flow of water, sediment, and wood to a stream reach or situations where the same processes are active in two different areas, but affect the same stream segment. In most cases, such calls are difficult to make at Level 1. Examples are:

   a) Increased flood flows resulting from the alteration of runoff generation by forestry activities, which increases the probability of flooding, scour, and bank erosion, the latter posing a sedimentation hazard to spawning and rearing areas.

b) Loss of wood in the adjacent riparian areas plus the loss of channel wood from a recent debris flow combine to reduce channel complexity and pool frequency.

c) Surface erosion and debris flows from several basins overtax the transport capacity of a third basin resulting in filling of pools and intrusion of fine sediments in riffle gravels.

5. Contributing Practices. Calls on contributing practices will require logical connection between the management actions in question and the ways in which the practice can affect the flows of water, wood, or sediment to stream reaches in question in such a manner that significant effects can be deduced or inferred. Most of these calls will be made at Level 2. For example, to define precisely the role of forest practices in triggering landslides, landslide rates and triggering mechanisms would need to be determined, which would exceed the time and expertise assumed for Level 1 analysis.

Prescriptive calls can be made regarding:

1. Options. Various management options could be considered to alter the flows of organic debris, water and sediment to the potentially affected stream reach. These options may include BMP's, mitigation measures, or moratoria on certain activities.

2. More study. Level 2 Analysis is indicated to better determine a cause and effect relationship.

Treatment of Uncertainty.

All cause and effect linkages between geomorphic, runoff, or riparian processes and habitat are subject to error. Errors are compounded when analyzing several interactive processes, especially when assumptions regarding relationships may be untested. Error has the following components:

1. Basic measurement error--imprecision in basic data (eg. for such environmental factors as slope, gradient, soils, etc.) which are the drivers of various processes.

2 Method/model error--most predictive models or methods are only reliable within certain bounds. For example, a map of the number of landslides per year is reliable only for the conditions that pertained during the historical photo record that was used to make the map.

3. Aggregation error--associated with combining two process outputs together to estimate a combined result. An example is adding sediment contributions from various sources to determine the combined sediment load that is delivered to a particular channel segment.

Training and use of science-based-methods can help minimize error. Use of Level 2 for confirmation and verification also reduces the potential for incorrect readings of hazard, habitat sensitivity and overall risk.

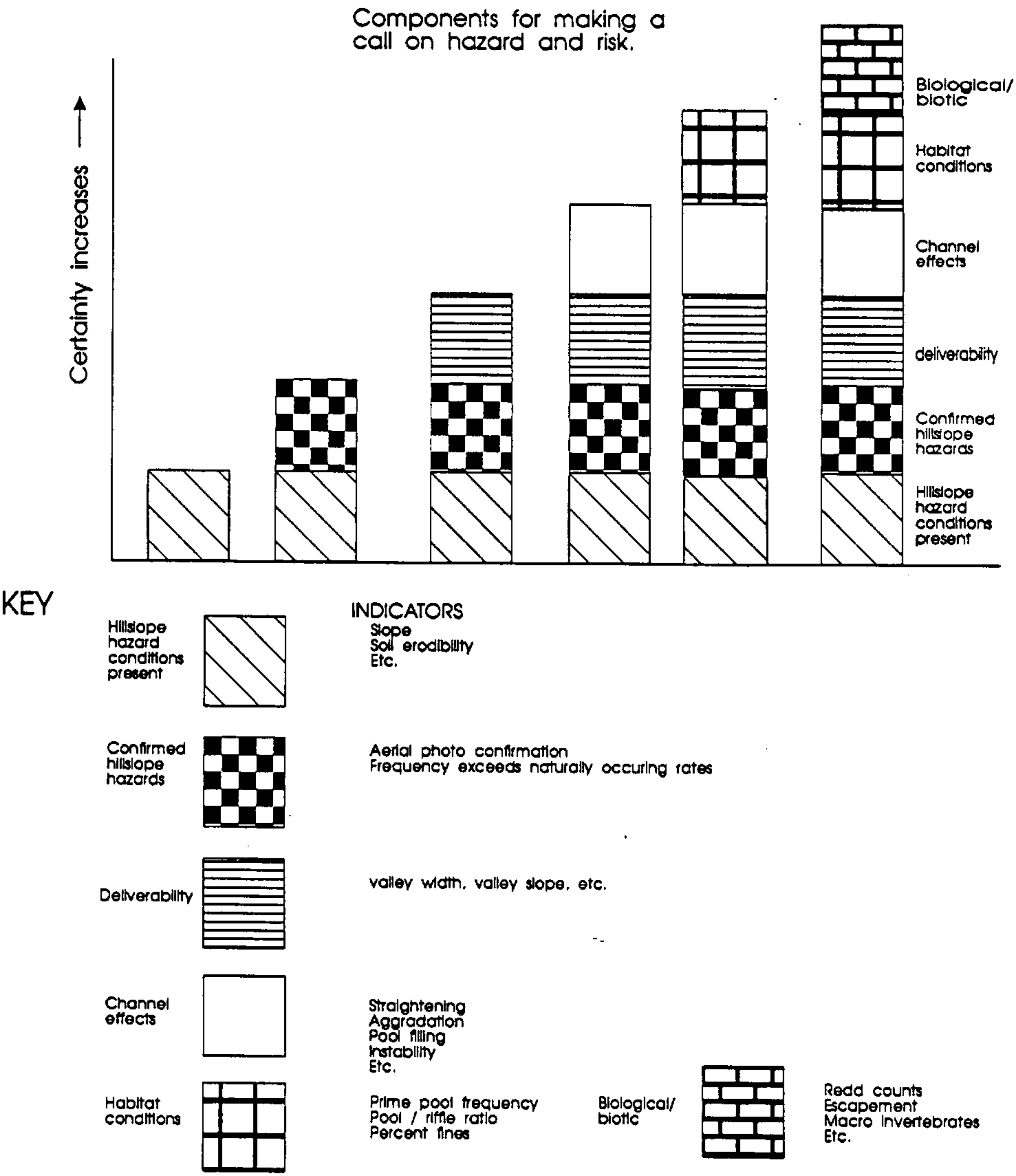
To a degree, potential error will be associated with all calls, which suggests the need for clear guidelines on levels of certainty that are required to make important judgments.

Because most of the calls described above are subject to significant error, predefining a required confidence level (eg. high likelihood, lower likelihood) may have an important effect on either circumscribing or expanding what can be said about a particular cause and effect linkage. For example, a cause and effect linkage between some habitat degradation and some hillslope process might be easier to conclude if the standard for arriving at such a conclusion is only "greater than a 50-50 likelihood". At a much higher confidencel level it would ordinarily be more difficult to arrive at the same conclusion.

How Decision Rules Might Be Applied To Watershed Analysis.

Figure 2.2 illustrates how hazard indicators, channel response indicators and habitat condition indicators combine to build the basis for a call on habitat sensitivity to a hillslope

Figure 2.2


Components for making a call on hazard and risk.
Certainty increases
Biological/ biotic
Habitat conditions
Channel effects
deliverability
Confirmed hillslope hazards
Hillslope hazard conditions present
KEY
INDICATORS
Hillslope hazard conditions present
Slope
Soil erodibility
Etc.
Confirmed hillslope hazards
Aerial photo confirmation
Frequency exceeds naturally occuring rates
Deliverability
valley width, valley slope, etc.
Channel effects
Straightening
Aggradation
Pool filling
Instability
Etc.
Habitat conditions
Prime pool frequency
Pool / riffle ratio
Percent fines
Biological/ biotic
Redd counts
Escapement
Macro invertebrates
Etc.

process. Certainty increases as the number of positive confirming signals are registered. In cases where the channel and habitat signals are especially strong, it is probably unnecessary to go to Level 2 analysis to confirm cause-effect linkages, or contributing practices. In other cases, however, the signals will be mixed. It is for these situations that assumptions need to be made regarding interpretation that directly confront potential error. There are two types of potential error:

1) Potential error 1--the risk of erroneously accepting the hypotheses of a cause-effect linkage, in other words, when the hypothesized linkage is spurious.

2) Potential error 2--error of rejecting the connection between hazard and habitat because of weak or inconsistent signals, when in actuality a real risk is present.

One or the other of the two types of potential error is always unavoidable: accepting one hypothesis necessitates accepting potential error. With this in mind we have identified the need for guidelines to determine which type of error should be weighed more heavily. Inherently this is a policy rather than technical decision. It basically involves deciding on whom should be placed the burden of proof in situations where the science cannot perish uncertainty. For this purpose, at least three alternative competing decision rules can be posited:

1. Rule 1--A certainty rule requiring that where a high certainty of risk cannot be demonstrated, level 2 analysis will be performed to demonstrate a greater certainty. This might be tantamount to requiring *preponderance of proof.*

2. Rule 2--A conservation rule dictating that because potential consequences are significant, when a cause-effect linkage can be demonstrated with better than a 50--50 likelihood, a risk call will be made at Level 1. The key driving factor here is *likelihood.* The likelihood standard might be applied where the

consequences or conditional probability of adverse impact is especially serious. An example might be a scour event resulting from a dam break flood.

3. Rule 3--A maximum protection rule where degraded resource conditions should not be subject to any increased risk.

Possible reasons to apply Decision Rule 1:

1. The consequences for a resource are relatively incremental.

2. There is good reason to believe that Level 2 analysis can considerably clarify the cause-effect linkage.

3. The presumed effect of taking action based on a lower confidence standard will be to permanently sanction a non-consensus action.

4. Lack of confidence in ability of monitoring system to validate and confirm Level 1 calls.

Possible reasons for applying Decision Rule 2

1.Consequences of a potential event are catastrophic for a resource.

2.Consequences of a potential event are not easily reversible.

3.The cost of mitigating or correcting for the impact if it does occur are especially high.

4.The resource is valuable and unique.

5.Lack of confidence in ability to condition potentially harmful activities .

6.Likelihood of time lag in impact to resource or time lag before the relevant indicators would be evident.

Possible reasons for applying Decision Rule 3

1.Existing degraded resource condition indicates that any further impact to a resource will result in a permanent loss of that resource.

Evaluation of Risk to Beneficial Resources

As indicated in Figure 1.2, the method provides for overall risk evaluation in drainage units through a modular approach that includes assessment of hazards, channel and fish habitat. This approach is premised on the fact that no systematic, comprehensive and rigorous method is currently available that integrates all the considerations that go into a determination of resource risk. The best feasible alternative is an approach that aggregates the assessment of hazards and their indicators through what is essentially an overlay process. Maps and data are assembled that define the delivery of hazard to a segment of interest having discrete sensitivities to impact based upon the habitat evaluation. Given assumed certainty requirements, inferences can then be made regarding risk.

The Hillslope Hazard Assessment.

When certain watershed processes can catastrophically or chronically affect fish habitat, they can be considered hazards. Hazards may include landslides, earthflows, and removal of trees that heighten rain-on-snow effects. The output of various hillslope hazard assessments is a qualitative rating of "high," "medium," or "low" for each important hillslope process. These are essentially judgment ratings based on data that is collected and compiled on maps. Interpretation of hazard is based upon determination that a process is active in a watershed, which in turn is based on models, methods, and scientific literature. Hazard evaluation also makes use of extrapolation. After the active process in an individual sub-basin have been evaluated, the linkage of natural and management induced physical factors and process can be extended to other sub-basins in which the key physical conditions remain the same. Guidelines for extrapolating across sub-basins are given in individual process chapters.

Because hillslope-based geomorphic, hydrologic and vegetative processes do not always deliver material to channels at a rate to be destructive to stream-based organisms, it is necessary to clearly define the conditions under which delivery occurs. Proximity (eg. distance) as well as various terrain features (eg. slope steepness) may enter into the determination of deliverability. In all cases, stream delivery is internalized in the individual hazard evaluations (eg. shallow-rapid landslides, surface erosion, riparian vegetation).

The Beneficial Use Assessment.

Risk assessment implies delivery of hazard to a resource of interest or beneficial use that is sensitive to impact. The method establishes this through a life-history based habitat assessment using both remote and field observation.

Risk: Delivery of Hazards to Habitat

Provided that wood, water or debris are delivered from a landslide, or some other process to a stream, the question remains as to what degree and in what way risk is actually heightened. Individual stream segments, as described in Chapter 7, will each have variable sensitivities to inputs depending upon fish habitat characteristics, which in turn will be related to such hydrological characteristics as gradient. In addition, sensitivity will be significantly related to magnitude and timing of inputs (eg. catastrophic inputs associated with dam-break floods). The method provides for confirmation of actual or delivered risk through overlay mapping of channel hazard areas and habitat types, and for qualitative consideration of various temporal and spatial interactions. Mapping criteria are explicitly defined under hazard, channel and habitat evaluations.

Adaptability in Method Design.

TFW has expressed interest in a method that will allow ease of revision. We have accomodated this through a modular approach for evaluating hazards, condition and sensitivity of beneficial uses, and risk. It should therefore be possible to make revisions in individual modules without revising the overall method.

Chapter 3 - Sediment Production by Mass Wasting and Surface Erosion

Introduction

The goal of this chapter is to identify the relative importance and locations of sediment-producing processes in a watershed, as well as the factors that influence those processes. Three generalized sediment sources are considered: shallow-rapid landsliding, deep-seated landslides (together called "mass wasting"), and surface erosion by water.

The variation in relative importance of these three sediment sources from managed Pacific Northwest watersheds as indicated by sediment budget studies reflect the variation in geology and land use, but some generalizations can be made. In the absence of glaciers or recently active volcanoes, landsliding is generally the dominant source of sediment. For example, mass wasting accounted for 80 to 89 per cent of sediment in the Queen Charlotte Islands (Roberts and Church, 1986), 60 per cent in the Olympic Mountains (Reid et al., 1981), 81 per cent in the Oregon Coast Range (Swanson et al., 1982), 95 per cent in the northern Cascades of Washington (Eide, 1990). An exception to this generalization is a sediment budget study of granitic terrain in the Idaho Batholith, where mass wasting accounted for 19 to 23 per cent of sediment production, and surface erosion dominated (Megahan, 1982; Megahan et al., 1986). It is possible that this result applies to granitic terrains elsewhere, as in north central Washington, as well as to granular soils in other rock types, but this is not yet known.

Surface erosion, while generally less important than mass wasting in total amount of sediment produced in most geologic terrains, is nonetheless an important source of fine sediment in managed watersheds. For example, in the sediment budget from the western

Olympics, while mass wasting accounted for 60 per cent and road surface erosion another 20 per cent of total sediment production, the two sources were equally important in producing sediment less than 2 mm in size (Reid, et al., 1981).

The methods for identifying the incidence, and location, of sediment production from mass wasting and surface erosion are presented below.

Mass Wasting

This section treats three distinct phenomena: shallow-rapid landslides, debris flows, and dam-break floods.

Shallow-rapid Landslides

Introduction

Shallow-rapid landslides deposit sediment in streams and damage roads. They also trigger episodic events such as debris flows and dam-break floods, which can devastate stream channels. Level I watershed analysis is geared toward identifying these processes and the physical and land use conditions under which they occur.

Shallow-rapid landslides commonly occur where soil overlays a more cohesive material (for example, bedrock or compacted glacial sediments). Soil thickness is typically small compared to slope length or the length of the landslide. Debris in the slide moves quickly downslope and often breaks apart to form a debris flow (see definitions below). Shallow-rapid landslides are also known as landslides, debris avalanches, or planar failures.

Shallow-rapid landslides typically occur on steep slopes and in convergent bedrock topography where subsurface drainage is concentrated (Sidle, 1985). Shallow-rapid landslides occur under natural forests and in clearcuts and adjacent to logging roads.

Susceptibility of an area to shallow-rapid failures is affected by steepness of slope, saturation of soil and root strength. Forest management activities affect rates of shallow-rapid landslides by altering these conditions.

Although the majority of shallow-rapid landslides occur under the conditions described above, it is impossible to predict precisely which locations in an unstable area will fail. Only a small portion (typically a few per cent) of the landscape actually fails following timber harvest (NCASI, 1985).

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

A ***debris flow*** is a highly mobile slurry of soil, rock, vegetation and water that can travel kilometers from its point of initiation, usually in steep (>5 degrees), confined mountain channels. Debris flows form when landslide material liquefies concurrently with or immediately after the initial failure. Debris flows contain 70-80% solids. As the debris flow moves through first- and second-order channels (Type 4 and 5 waters), the volume of material may be increased by 1000% or more over initial failure , enabling debris flows to become more destructive the further they travel. Debris flows are also known as debris torrents, sluice outs, and mud flows.

Debris flows are confined to steep, colluvium-filled first and second order streams; they can, however, deposit in streams of any order, typically at tributary junctions (Benda, 1988).

Debris flows occur in response to large storms and fires, and to land management activities, such as logging roads and clearcuts. Debris flows occur in both natural and managed landscapes, but because they are triggered by shallow-rapid landslides and landslide occurrence is increased by land management, debris flow incidence is increased by land management. Debris flows deposit large volumes of unsorted sediment and organic debris in lower-gradient reaches of alluvial channels or on alluvial-debris fans. Hence, debris flows can provide sediments locally at the site of deposition and downstream, increase fine sediments in spawning gravels, and cause secondary erosion of valley walls. Debris flows may damage structures and fish habitat at considerable distances from their points of initiation, and are considered one of the most damaging forms of erosion in mountainous regions (Eisbacher and Clague, 1984).

Landslides and debris flows that are deposited in narrow valley floors often create temporary dams that quickly impound water, creating small lakes. Rapid failure of these dams can lead to an extreme flood. These events are referred to as ***landslide dam-break floods***. These extreme floods can be one to two orders of magnitude greater in peak discharge than normal runoff floods, and have been observed in valleys of third through sixth order in the Washington Cascades (Benda and Zhang, 1989; Benda, Zhang, and Dunne, research in progress, University of Washington). Such floods have caused extensive downstream erosion and sedimentation along entire stream-order segments throughout the mountainous regions of the state. Dam-break floods may also be triggered by the buildup and failure of logging slash in steep, Type 4 and 5 waters in managed forests. A recent inventory of dam-break floods, however, showed that a majority of events were related to debris flow dams (Coho and Burges, 1991). Because dam-break floods result from the failure of dams formed by landslides and debris flows, they can occur at an accelerated rate in managed forests (Coho and Burges, 1991) .

These floods, freighted with large amounts of large and small organic debris, are capable of destroying entire riparian zones and of causing major valley-wall erosion. Subsequent erosion of the devegetated floodplains and valley floors by streamflow can lead to accelerated erosion for many years following the event. Both landslide dam-break floods and debris flows have and referred to as debris torrents in northwestern North America.

Methods Summary: Table 3.1

Questions

1) Are shallow-rapid landslides evident?

2) If so, with what landform and management-related characteristics are they associated?

Table 3.1. Components of landslide analysis.

	SHALLOW-RAPID	DEBRIS FLOWS/ DAM-BREAK FLOODS	DEEP-SEATED
DATA ACQUISITION	1) occurrence of landslides 2) slope, slope form, slope position, geology, soils, elevation 3) land use association	1) occurrences of debris flows or dam-break floods 2) geomorphic aspect, slope, width of valley, drainage area, geology	1) occurrences of deep-seated failures 2) slope, geomorphology, geology, vegetation, land use
SELECTION OF CRITERIA OR MODELS FOR DATA ANALYSIS	1) studies of root strength 2) infinite slope model 3) extrapolation	1) theoretical model of debris flow 2) emperical models of debris flows 3) ongoing studies of dam-break floods	1) theoretical and empirical models of process, effects of land use
INTERPRETA-TION AIDS AND QUALITATIVE DESCRIPTION	1) representation of high, moderate and low landslide densities 2) which landslides enter streams	1) high sensitivity of channels to debris flows	1) association with land use 2) high, medium, and low for slump map units based on failure density

3) Do landslides deposit sediment in stream channels?

4) If so, have they triggered debris flows or dam-break floods (when the two processes are indistinguishable, they will be termed debris torrents in this report)?

Assumptions of the method

1) Land use history from a series of aerial photographs is available for watersheds.

2) Most landslides, debris flows and dam-break floods (debris torrents) can be identified on aerial photographs.

3) Areas prone to these processes can be mapped based on physical characteristics obtainable from aerial photographs, topographic maps, and geologic and soil maps.

4) Extrapolation from one sub-basin to another with similar characteristics is feasible based on remotely-obtained information.

Assessment Procedure

Landslide hazards will be evaluated using a landslide map constructed for the basin of interest. This office-based mapping approach takes advantage of Washington's long history of land management and aerial photography to create a map based on local environmental processes. The map will show where landslides have occurred in both natural and managed areas, will note with which geomorphic characteristics they are associated, and highlight areas in the watershed with similar physical characteristics.

The first task in the analysis is to create a record of landslide occurrence and associated conditions for each watershed. The mapping process explicitly sorts for the important physical characteristics (e.g., slope, slope form, and rock type) governing slope failures in the watershed of interest. After identifying the most critical characteristics associated with landslides, other areas in the basin with similar characteristics can be flagged as potential hazard areas. As earth scientists work through Level 1 analyses, they will build up a library of characteristics associated with landslides in each region. Therefore, landslide hazard analyses should take decreasing effort and amount of time as watershed analyses are completed around the state.

The methodological framework for detecting shallow landslides (and debris flows and dam-break floods) and associating them with geomorphic indicators and land use for developing a landslide map is shown in a flowchart in Figure 3.1. The flowchart is a general road map of the major steps needed to construct a landslide map, assign relative hazard ratings, and extrapolate information from one portion of a watershed to another (or from one watershed to an adjacent one).

The procedure is as follows:

1. Identify, and Map Landslides

Shallow landslides can be identified on sequential aerial photographs by detecting the landslide which appears as a small, light colored linear feature oriented downslope. The linear feature may extend some distance down channel. If the travel distance in a channel is more than approximately 100 m, then the landslide has become either a debris flow or dam-break flood; this feature is mapped separately later.

Shallow landslides should not be confused with low-order streams, avalanche chutes or talus slopes. Landslide should be mapped onto a 7.5 minute, 1:24,000 USGS topographic map. Enlarging the area under study may make mapping easier.

2. Associate Geomorphic and Land use Indicators with landslides

Several geomorphic characteristics of hillslopes should be inventoried at each landslide scar. These may include slope gradient, slope form (i.e. convergent vs divergent). and slope position (high, moderate and low). Other factors include soil type, stability ratings from previous slope stability reports for the area, lithology, geologic structure and elevation; this list is not meant to be exhaustive and others can be used depending on the experience and expertise of the user(s). Sediment entry to streams should also be noted. Also note land use associated with each landslide scar on the landslide map: types of land use may include

Shallow Landslides Assessment

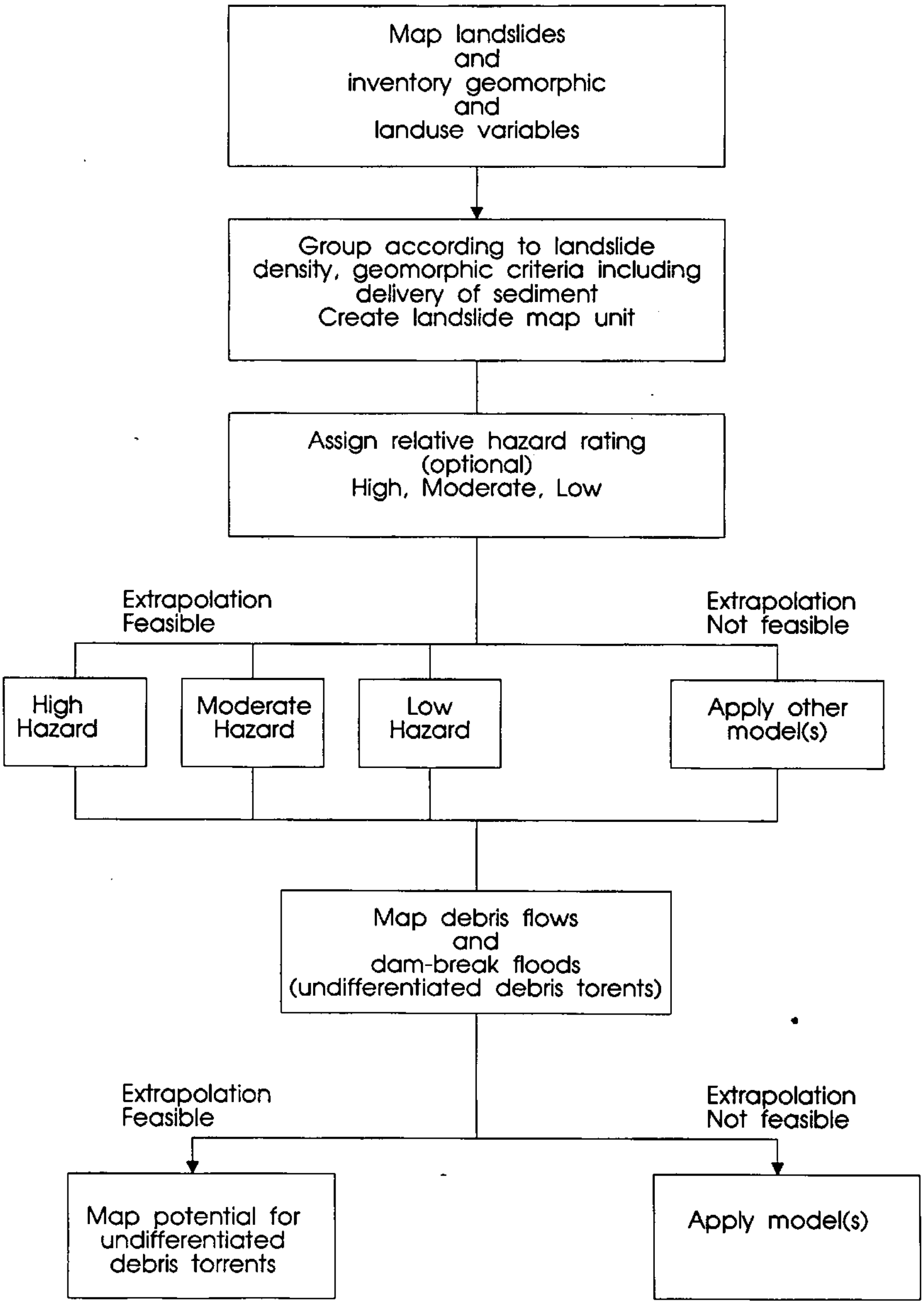


FIG 3.1

clearcut, partial cut, logging roads, road-stream crossings, and landings. Mature forest (no land use) should also be noted. The date of the aerial photo on which the landslide first appeared should be noted

Inspect the landslide base map, noting the associated geomorphic and land use variables for each landslide. Visually cluster relative densities of landslides into discrete areas with similar gradients, slope forms, slope position and sediment entry into streams. For example, the erosion unit containing the highest density of landslides may include gradients ranging from 32 - 42 degrees, numerous convergent slope forms, landslides in the mid and upper slope positions, and landslides reaching the channel. If, for example, several landslides are located immediately adjacent to the stream channel in an inner gorge, the inner gorge may be a different landslide map unit.

The accuracy of the landslide map unit increases with the area mapped, see PENTEC (1991) for a discussion of the sample size area necessary for calculating landslide rates.

3. Assign Relative Qualitative Hazard Indicators

The assignment of qualitative hazard ratings to landslide map units is a way to present the data in a form useful for land managers. The different landslide map units can be assigned a hazard rating, such as high, moderate and low (Figure 3.1). In most cases, one to three erosion categories for shallow landslides will be identified for the basin. A high hazard with respect to shallow landslides may mean qualitatively that the mapped erosion category is based on numerous landslides (e.g., more than a few per square mile), and that they enter stream channels. A moderate erosion hazard may mean that only a few landslides are contained in the mapped unit. A low rating means essentially no landslides, and that they do not enter stream channels.

The relative ratings should be specific to the individual watershed. For example, five landslides per square mile may be associated with a high hazard rating in southwest Washington, while twenty landslides per square mile is associated with a high hazard in the North Cascades. The ratings address the most likely sources of sedimentation in the watersheds: some watersheds may not contain a high rating while others may not contain a low hazard rating.

4. Extrapolating Map Units to Other Areas

Under certain circumstances, landslide map units and hazard ratings can be extrapolated to other nearby areas. Hillslope gradient is probably the only geomorphic indicator that can be obtained with certainty in areas with forest canopy. Other important indicators, such as convergent topography and inner gorges that control the slope position of landslides, may or may not be detectable from aerial photographs in forested areas. Because of these considerations, extrapolation of landslide map units requires that certain landform characteristics occur in both the original map unit and in the unmapped area. These landform characteristics should include some or all of the following: lithology and structure, geomorphology and Quaternary sediments, vegetational zones, and elevation. The more of these characteristics that do not vary between the mapped area and the area to be extrapolated, the more confidence one can have.

Therefore, prior to extrapolating landslide map units, geologic, vegetation, and topographic maps should be consulted. Some geological expertise may be required in addition to local knowledge of the general area. If large variations exist between the landslide map unit and the area to be extrapolated to, such as changing lithology or geologic structure, then extrapolation should be done with caution if at all. When landslide map units cannot be created or extrapolated then use of empirical or theoretical slope stability models may be necessary (e.g., the methods of Burroughs, 1984, or Hammond et al., 1988) in a Level 2 analysis.

5. Map Debris Flows and Dam-Break Floods

Debris flows and dam-break floods are collectively referred to in this analysis as debris torrents. If possible, they should be differentiated on the landslide map, and the channel and valley floor characteristics associated with the mapped occurrences should be noted. These associations can be used to delineate other channels with a potential for these events. Differentiating among these catastrophic stream processes can be based on the valley floor slope and width in some cases (Benda and Cundy, 1990; Coho and Burges, 1991) . In general, debris flows occur in steep, first- and second-order channels, compared to dam-break floods which can occur in much lower gradient channels of 3rd- through 5th-order. Dam-break floods can, however, occur within the same channels as debris flows. Hence, dam-break floods can be confused with debris flows, but the opposite is less likely. Where these processes cannot be differentiated, they are mapped as debris torrents.

Stream orders, channel or valley-floor slope, and valley floor width should be noted for each feature on the map. Knowledge of these physical attributes is important for extrapolating to other areas that have not had a history of land use, that do not have aerial photograph coverage or areas which have had land use but where debris flows have not occurred.

Where debris flows and dam-break floods can not be extrapolated, then a debris flow model can be used to predict potential initiation sites (on hillslopes) and deposition sites in channels (Benda and Cundy, 1990). A model for predicting dam-break flood initiation and travel distance is presently not available, but one is in development by Carolyn Coho and Steve Burges (Department of Civil Engineering, University of Washington). In the interim, the report by Coho and Burges, (1991) can be used as a guide.

Delivery of Sediment to Streams

Sediment from shallow-rapid landslides have the potential to enter streams because they are highly mobile and occur on very steep slopes. Sediment from landslides, however, can be intercepted by terraces, floodplains and footslopes and not enter channels. The ability of landslides to enter streams is noted during the construction of the landslide map, and landslide map units should account for the delivery of sediment to channels.

Debris flows and dam-break floods are channel processes, hence sediment delivery to streams that they flow through is integral in their definition. Debris flows and dam-break

Debris flows and dam-break floods are channel processes, hence sediment delivery to streams that they flow through is integral in their definition. Debris flows and dam-break floods also deposit in larger-order streams, typically at tributary junctions. This aspect of debris flow and dam-break flood movement needs to be considered during the development of landslide maps or application of models.

Deep Seated Landslides: Rotational, Translational, and Flow Failures

Introduction

Deep-seated landslides include rotational, translational, and flow failures. In the Pacific Northwest, one or all of these failure modes can be part of landslides referred to as slumps and earthflows.

For the purpose of watershed analysis it is important to distinguish persistent, usually large failures that typically predate land use. Such large, persistent failures are usually associated with specific geologic structures, such as faults and certain rock types, and therefore it is difficult to extrapolate a map unit containing these features. Smaller, sporadic deep-seated failures, on the other hand, may not pre-date land use, are generally associated broadly with a lithologic soil unit rather than a specific geologic structure (for example, a fault). Extrapolating a landslide map unit containing the smaller sporadic deep-seated landslides is feasible.

Deep-seated mass failures typically occur in fine-textured soils and weathered rock. In contrast to shallow-rapid failures, which commonly occur on very steep slopes, deep-seated failures can occur on slopes as gentle as 4 -20 degrees, Figure 3.2 (Sidle, 1985). In Washington, they occur in altered metamorphic sedimentary and volcaniclastic rocks and glacial sediments of both the western Cascades, Olympics, and coastal range and the drier eastern Cascades (Swanston, 1981; Fiksdal and Brunengo, 1980).

Deep-seated failures usually are associated with buildup of pore pressure and failure activity tends to be more intense as groundwater supply increases. Studies in the Pacific

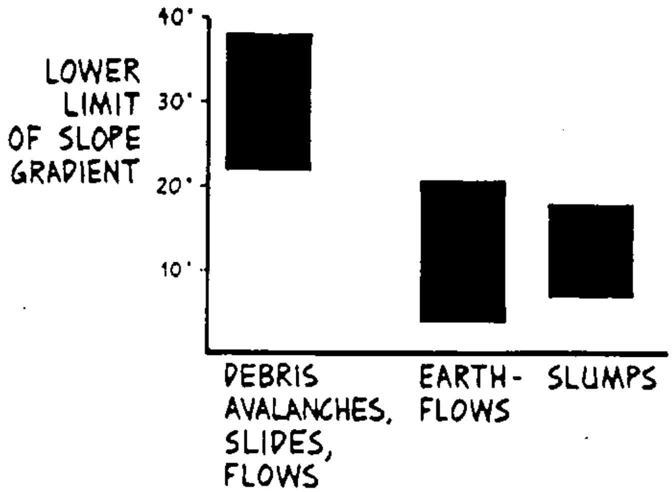


Figure 3.2. Lower limit of slope gradient, generally measured in a representative portion of the scouring zone, for various soil mass movements (adapted from Sidle, 1985)

by the seasonal buildup of groundwater at the base of the failure, although a single large storm may trigger the failure. (Iverson and Major, 1986; Swanston et al., 1988). Earthflow movement thus can accelerate as the wet season progresses.

Because of deep failure planes, tree cutting and accompanying root-strength loss is less important to triggering failures than subsurface hydrology and the residual shear strength of geologic materials. Because the failure normally takes place at least several meters below the ground surface, the loss of anchoring by tree roots is probably less important, although lateral roots may play a role in reinforcing across planes of weakness such as headwalls and tension cracks surrounding earthflows and slumps (Swanston and Swanson, 1976).

Tree cutting can affect the behavior of deep-seated landslides by reducing evapotranspirative water loss, and thus increasing pore water pressures at the failure zone. This increase may cause seasonal acceleration of the downslope movement of deep-seated failures (Swanston, 1981). Several field studies have demonstrated that when trees are cut, slumps and slump-earthflows can be reactivated or accelerated (Swanston et al., 1988; Swanston, 1981; Ziemer, 1984; Benda et al., 1988). In the one study where data are available for a sufficiently long period, movement on an active earthflow was accelerated by tree cutting but returned to the pre-harvest rate within three years (Swanston et al., 1988). Another study in the Cascades of Washington revealed good correlation between harvest in the groundwater recharge area of a large slump and accelerated failure activity (Benda et al., 1988).

The important issue for watershed analysis is whether land use causes or accelerates failure, and whether sediment from the slides enters into watercourses.

Methods Summary Table

Questions

1) Are there deep-seated landslides in the watershed of interest?

2) If so, are they active or dormant?

3) Do they deliver sediment to stream channels?

4) Are they related to land use activities?

Assumptions of the method

1) Land use history from a time series of aerial photographs is available for the watershed.

2) Most earthflows and existing slumps can be identified from aerial photographs.

3) Areas prone to these processes can be mapped based on physical characteristics obtainable from aerial photographs, topographic maps and geological and soil maps.

4) Extrapolation of hazard level from one sub-basin to another is feasible for smaller sporadic deep-seated landslides based on the physical characteristics listed above.

Assessment Methods Summary

The procedure for developing a landslide map for deep-seated landslides is shown in Figure 3.3. The flowchart presents the major steps necessary for analyzing deep-seated failures in a watershed analysis.

1. Identify and Map Active and Dormant Deep-Seated Failures

Use a time series of aerial photographs and topographic maps. Map failures onto the landslide map . The map can be the same one used for shallow landslides, or another map for deep-seated landslides can be created Sometimes, deep-seated and shallow landslides will overlap in some terrains, such as glacial outwash and lacustrine terraces (Heller, 1981).

Persistent deep-seated landslides. Persistent deep-seated landslides contain any or all of the principal failure types of rotational, translational or flow and usually predate land use. These landslides include the earthflow type that typically extend to valley floors, and large historical rotational slumps in glacial terraces.

Deep-seated Landslide Assessment

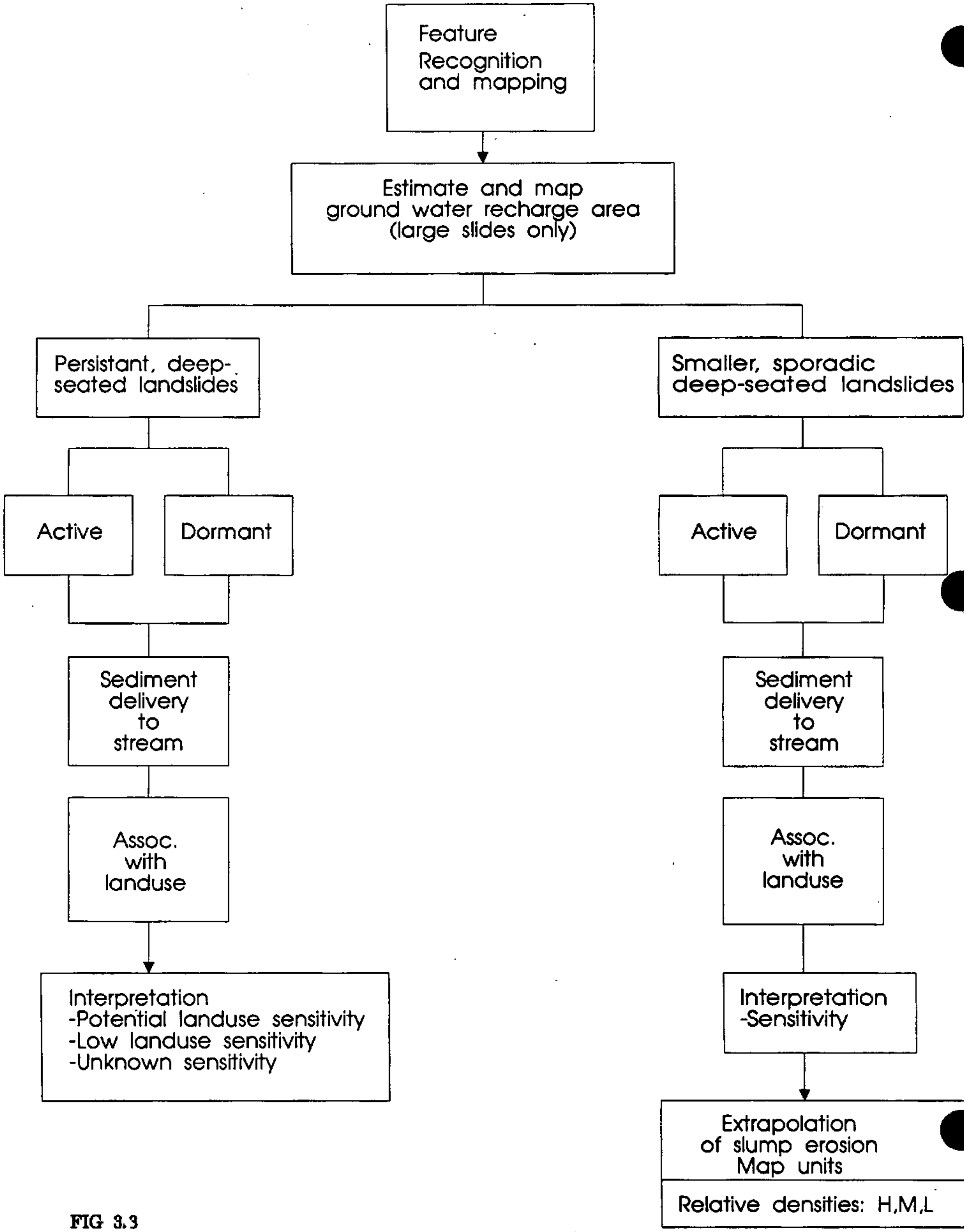


FIG 3.3

If the deep-seated landslide is active, then raw soil exposed along head scarps and toes may be exposed and visible from aerial photographs. If an earthflow is dormant, then detection may be based on topography, such as arcuate ridges representing old headscarps, sag ponds, and changing vegetation patterns (e.g. anomalous deciduous stands among a coniferous forest).

Map persistent deep-seated failures as individual features on the landslide map, delineating boundaries using the topographic and vegetative criteria mentioned above. Note direction of movement with an arrow. Usually this is directly downslope (see Fiksdal and Brunengo, 1981). For earthflows, the contributing groundwater recharge area should also be delineated. Do this from aerial photographs assuming that the groundwater table in the vicinity of the slide is approximated by the topography.

Because of their smaller size and because they are relatively short-lived features, **sporadic smaller deep-seated landslides** are sometimes more difficult to detect from aerial photographs than earthflows. Arcuate headscarps, chaotic soil surfaces, and deranged drainage patterns are indicators of slump movement. Vegetation on slumps may be either deciduous or conifer. Dormant slumps may never become active again, and new slumps may appear with no prior surface evidence of instability, other than the general character of the surrounding terrain: landscapes which have slumps have usually been formed to some degree by slump-block erosion.

Smaller, sporadic deep-seated failures are treated similarly to shallow landslides: count them by viewing a time sequence of aerial photographs; then group relative densities of failures into individual landslide map units based on associated geomorphic characteristics, such as rock or soil type, landforms (e.g. fluvial or glacial terraces), elevation, vegetation, slope position and slope gradient.

Each large deep-seated failure is assigned an activity level based on the procedure proposed by Wieczorek (1984). A deep-seated landslide which is "active" is one which appears to have moved during the time of the aerial photograph coverage (generally not more than 50 years). A dormant feature is one that has not been active within the aerial photographic record.

The ability of an earthflow or slump to deliver sediment directly to stream channels is determined for each feature or set of features on aerial photographs based on the proximity of the slide to active stream channels.

2. Land Use Activities should be spatially and temporally associated with persistent deep-seated landslides, and geomorphic characteristics and land use activities should be associated with smaller, sporadic deep-seated landslides

Information about terrain features such as rock type, landform (e.g., glacial terrace), soil type, slope position, slope gradient and vegetation should be noted. Group densities of smaller, sporadic deep-seated failures according to these features. The landslide map unit may also contain information on whether sediment is entering the stream channel.

To associate landslide movement with forestry activities, examine their occurrence with respect to the timing and location of roads and timber harvest. Sequential aerial photographs should indicate whether roads or harvest units existed on deep-seated landslides prior to their activation.

Because forestry activities affect the hydrology of deep-seated mass movements for at least 30 years because of reduced infiltration and rain-on-snow effects (Harr, et al., 1989), clearcuts less than 30 years old should be considered a possible trigger for deep-seated failures. Roads within the aerial photo record in spatial association with deep-seated failures should be considered as a possible trigger for that failure. Because deep-seated failures can occur naturally or increase their movement rate because of variation in climate (e.g., an exceptionally wet year) , a Level 2 analysis which considers climate may be required.

3. Assign Qualitative Hazard Ratings.

Relative hazard ratings can be assigned based on intensity of activity. This is similar to the technique used for establishing shallow-rapid landslide hazards. Hazard ratings can also be based on relative densities of smaller sporadic landslides, and whether sediment directly enters stream channels.

4. Extrapolate Mapped Slump Units to Other Areas

Mapped large, persistent landslides cannot be extrapolated to unmapped watersheds. Map units containing smaller, sporadic deep landslides, however, can be extrapolated similarly to shallow landslides. Once a map unit has been developed, it can be extrapolated to other nearby sub-watersheds if geology, geomorphology, soils, elevation, vegetation etc. do not change significantly. Because smaller sporadic failures are typically found in landscapes that have had activity for some time, landform features such as blocky ground, small arcuate scarps along the perimeter of fluvial or glacial terraces, and deranged drainage patterns can also be used for extrapolating landslide units.

Delivery of sediment to streams

If a deep-seated failure moves into a stream it can contribute a source of sediment with deleterious effects on habitat, depending on the failure location, volume of material, grain size of sediment and intensity of activity.

Large deep-seated failures, such as Earthflows, usually extend into the valley floor. Hence, failures and erosion in earthflows are typically most intense near streams and along valley bottoms, and therefore earthflows are effective at delivering sediment to streams. Because smaller, sporadic deep-seated landslides may not travel far after failure, sediment from them may not directly enter streams. Foot slopes, terraces, and floodplains may intercept sediment originating from slumps.

Whether sediment from deep-seated failures is actively delivering sediment to streams or has the potential to do so is considered directly in the assessment procedure described above.

Surface Erosion

Introduction

It is important in a watershed analysis to account for the magnitudes and locations of fine sediment eroded from hillslopes, because fine sediment can damage aquatic habitat and cause downstream water-quality problems. By locating and approximating the magnitude of management-related surface erosion, it is possible to plan remedies for existing problems, and to avoid future problems.

Water runoff and soil erosion occur when the intensity of precipitation exceeds the soil's capacity to absorb water. Runoff that is not channeled is called sheetwash. Channeled runoff carves erosional features called rills or, when large, gullies. The effectiveness of sheetwash erosion is increased by the erosive impact of raindrops. In loose, granular materials, rainsplash impact can effectively erode soil even in the absence of runoff.

In the forests of Washington state, erosion by water occurs mostly on soils that have had the vegetative duff layer disturbed or removed, either by natural or human causes. In addition, human activities that remove vegetation also compact the soil, reducing the soil's capacity to absorb water and increasing runoff and erosion. The major categories of soil disturbance related to forest management can be categorized as: roads; landslide scars; and logging, including skid trails and slash burning.

Roads.

Erosion of road margins is generally most rapid in the first year or two after construction, with stabilization taking place for physical reasons rather than due to revegetation (for example, see Megahan and Kidd, 1972; Megahan, 1974, 1978; Fredriksen, 1970; Reid, 1981). However, road cutslopes can provide a long-term source of sediment (Eide, 1990; Megahan et al., 1983), especially in response to the continual undercutting of the slopes by road maintenance (Megahan et al., 1983). In the situations where fill slopes and cut banks stabilize soon after construction, in the absence of road-related drainage problems, road margins account for a small amount of road-related sediment during the lifespan of a road (for example, see Reid et al. 1981). However, if runoff generated or diverted by roads is focused onto road fill, rilling and gullying can be a severe and chronic problem (for example, Burroughs and King, 1989; Hagans and Weaver, 1987).

In the absence of gullying induced by drainage problems, the road surface itself is the largest contributor of sediment from roads in use (for example, see Reid et al., 1981; Bilby et al., 1985, 1989). The intensity of road use is the most important influence on erosion rate (Reid, 1981; Bilby et al., 1989). In one study, heavily-used roads produced 1000 times more sediment than abandoned roads, and 100 times more than lightly-used roads (Reid and Dunne, 1984).

A road's surface condition is also an important influence on erosion rate. Erosion is significantly less on thick gravel layers compared to unsurfaced or thinly-graveled roads (Bilby et al., 1985; Swift, 1984; Kochenderfer and Helvey, 1989). Additionally, the rock type of gravel surfacing material can strongly influence erosion (Bilby et al., 1989, Swift, 1984; Kochenderfer and Helvey, 1989), as can the frequency of road grading (Swift, 1984).

Landslide Scars

Erosion of bare soil exposed by landslides can amount to a significant proportion of a basin's sediment budget. Landslide-scar erosion represented 6 to 9 percent of all sediment production in studies from the Olympic Mountains (Reid et al. 1981) and the Queen Charlotte Islands of British Columbia (Roberts and Church, 1986).

Logging

The magnitude of soil disturbance by logging and yarding varies greatly with the method used (Anderson et al., 1976; Dyrness, 1965, 1967; Rice and Datzman, 1981), with site characteristics, and with operator performance (Rice and Datzman, 1981).

In general, erosion from slash burning is limited to areas where burning was especially hot (Anderson et al., 1976; Mersereau and Dyrness, 1972; Dyrness, 1973; Beschta, 1978). However, erosion problems can be more significant on granular soils, such as form on granite or volcanic tephra (Anderson et al., 1976).

Other Sources of Fine Sediment

Fine sediment is eroded by water in some geologic settings that discourage vegetative growth, and by glaciers, or as a result of past or present land uses other than forest management. Common sources include sediment in runoff from glaciers; unvegetated debris in recently deglaciated landscapes; unvegetated mine tailings, or soils disturbed by other industrial or agricultural uses. Many Cascade Range watersheds also include unvegetated volcanic deposits from volcanoes such as Mt. Rainier or Mt. St. Helens, or volcanic vents.

Sediment in glacial runoff is typically concentrated during the summer ice-melt season, and is often fine sand and finer. In many glaciated watersheds, large amounts of loose, unvegetated or poorly-vegetated sediments are found downslope of glaciers. These materials are often subject to periodic reworking by stream action, landsliding and debris flow, and are maintained in a fresh, easily-erodible condition. Sand and finer material is contributed to streams by runoff events during the snow-free season.

Mining debris or soils disturbed or devegetated by other industrial or agricultural uses unrelated to forest management are also subject to erosion by rainfall. Many of these sites are unlikely to be subject to periodic reworking, and thus may develop a stable surface armoring and erosional network, which act to limit erosion.

Questions

1) Is road surface erosion a problem in the basin, and if so, what is the relative magnitude of road surface erosion in various sub-basins?

2) Which of the following factors contributes to road erosion? Annual precipitation; maintenance of road beds; road use; road drainage.

3) What is the relative importance of erosion associated with logging activities in various sub-basins?

4) Which of the following factors contributes to erosion on logged areas? Annual precipitation; design or conduct of logging operation; soil erodibility; slope steepness.

5) What other sources of fine-sediment erosion exist within the basin?

Assumptions of the Method

1) Road- and logging-related erosion is estimated for present conditions only, not for historical conditions because of the time needed to map historical photos.

2) Road surface erosion can be estimated indirectly by mapping controlling factors that influence erosion rate.

3) Extrapolation from sub-basins to similar sub-basins is feasible.

Analysis

Road Erosion

The approach to assessing erosion from roads is two-fold: to inventory gullies induced by road-generated or road-diverted runoff, and to construct an index of road-surface erosion. Road sidecast and cutbank erosion is ignored except for gullying, because of the time needed to measure and observe evidence for chronic sheetwash, rill and rainsplash erosion. The role of road surfacing, rock type and grading frequency are ignored because there are inadequate field data to make general statements about these influences. Sediment eroded but redeposited on hillslopes is ignored. Refer to Figure 3.4 and Table 3.2.

Office Component

1) Obtain an estimate of annual precipitation for the basin, or, if the precipitation amount changes significantly with location in the basin, by sub-basin.

2) Obtain the most recent set of aerial photographs. Map the road network from the photos onto a topographic map. Measure the total road mileage in each sub-basin. If there are no roads or road mileage is less than some value which could be determined as a matter of policy, then the rest of the analysis for roads can be omitted.

Surface Erosion Assessment

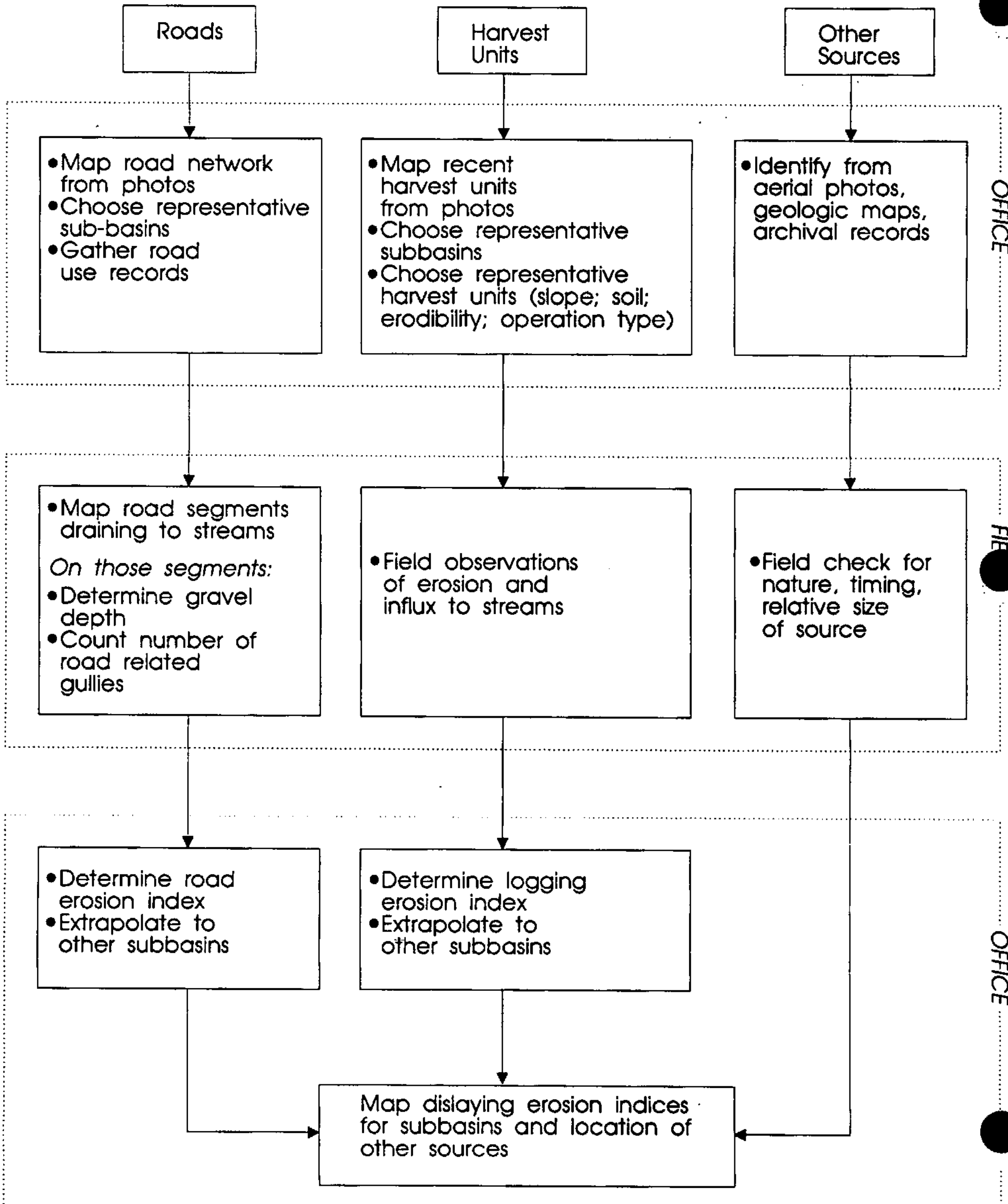


Fig 3.4

Table 3.2. Components of erosion analysis.

	ROADS	LOGGING
DATA ACQUISITION	-Road mileage (aerial photographs) -Road drainage (field) -Annual precipitation (records) -Road surface condition (field) -Road use intensity (records) -Number of gullies (field)	-Map logged areas (aerial photographs) -Field observations of erosion -slope, soil erodibility, and type of logging operation (records and topography map)
CRITERIA OR MODELS FOR DATA ANALYSIS OR PRESENTATION	-Index derived from field studies that relate road conditions to erosion	-Organize field observations according to site conditions
INTERPRETATION AIDS	-Ordinal-scale index of relative intensity and location of erosion -Hazard rating of high, medium, or low	-Ordinal-scale index of relative intensity and location of erosion -Hazard rating of high, medium, or low

3) From land manager information, for the most recent photo set, categorize road segments as "frequent use" or "low use or abandoned."

4) Choose representative sub-basins in which to make field measurements. The sub-basins should constitute a sampling of road densities (that is, road miles per sub-basin area), topography, geology, and road conditions that is representative of conditions in the watershed as a whole.

A sub-basin may be about 1-3 mi^2, but the optimum size should be determined from field testing of this method, where it will be possible to balance time constraints with the needed level of information.

Field Component

5) In each chosen sub-basin, map the road segments that drain directly to a stream channel (for example, see Bilby et al., 1989).

6) On the road segments that drain to a stream, assess the road surface condition. Assign the road to one of two categories:

i) Gravelled surface, gravel layer at least 3 inches thick;

ii) Gravelled surface, gravel layer less than 3 inches thick, or ungraveled, unpaved surface.

7) In the sub-basins, map significant gullies caused by road-generated or road-diverted runoff, and which contribute sediment to a stream.

Analysis

8) Add the total road mileage within the following categories:

i) High-use, gravel surface greater than 3 inches;

ii) High-use, gravel surface less than 3 inches, or no gravel;

iii) Low-use or abandoned, gravel surface greater than 3 inches;

iv) Low-use or abandoned, gravel surface less than 3 inches, or no gravel.

9) Multiply the total mileages as follows:

i) & iv)	x 1
ii)	x 4
iii)	x 0.1

Multiply each total by the annual rainfall in centimeters. Multiply this number by the number of hectares of road surface per road mile. The result is an index of the road surface erosion hazard for the sub-basin.

These numbers were derived from published field measurements, summarized for different use levels and surface types as annual erosion per unit road surface area per unit of rainfall (Reid, 1990; and Bilby, et al., 1989).

10) Total the number of road-related gullies from the field measurements.

<u>Harvest Units.</u>

The strategy for assessing logging-related erosion is to examine the field evidence for erosion on a sample of recently or concurrently logged areas. The field sample should be stratified by slope and published soil erodibility ratings. The effects of vegetative ground cover and soil disturbance by yarding are combined with slash burning because the activities and their effects are associated in time and space, and cannot be easily separated. Landslide-scar erosion is excluded from the analysis because of the time needed for field observation.

Office Component

1) Map logged units in order to identify the total ground surface area that is potentially susceptible to erosion.

2) Determine from published soils mapping the relative susceptibility of soils in the watershed to erosion. Soils have been mapped and erodibility rankings have been carried out by the state Department of Natural Resources and by private landowners.

3) From a map of units on which timber has been cut within the last year, a soils map, and a topographic or slope map, choose a sample of units that represent the range in soil

erodibility and slope steepness. Depending on basin size and on the intensity of logging, it may be necessary to limit the field assessment to a number of representative sub-basins.

Field Component

4) Visit the logged units, and make an assessment of erosion and sediment influx to streams. Make observations sufficient to put each unit into one of the following categories:

i) Few, discontinuous gullies; eroding, devegetated areas are small and do not contribute sediment to streams;

ii) Some gullies and bare areas are contributing sediment to streams, due to some damage to riparian soils and vegetation;

iii) Gullies and areas of devegetated mineral soil are extensive and contribute directly to streams because of extensive vegetative and soil damage within the riparian zone.

Analysis

5) For each sub-basin sampled, create an index of relative in-unit erosion by totalling the area in each of the above three categories. If there are any evident causal trends concerning the role of particular logging practices, soil erodibility, or slope steepness, summarize those trends in a narrative description for the watershed.

<u>Surface Erosion from Natural Sources and Other Land Uses.</u>

This portion focuses on identifying significant sources of fine sediment other than those identified above.

1) Identify from the aerial photographs whether the following are located in the drainage basin, and their approximate extent:

i) Active glaciers;

ii) Areas that have been deglaciated within the last decades or century and remain essentially unvegetated;

iii) Mining spoils piles or other unvegetated soils resulting from industrial land use.

iv) Unvegetated volcanic deposits from volcanoes;

v) Other significant fine sediment sources.

(2) If it is not possible to do so from the photographs alone, make a field visit to determine the intensity of and sediment production from these sources.

Hazard Decision

For representative sub-basins, the analysis produces an index of road surface erosion, a total number of road gullies, and an index of sediment potentially delivered to streams from logging unit erosion. These numbers or indices are intended to be determined for particular sub-basins and extrapolated to similar sub-basins and can be displayed on a map of sub-basins to show the spatial variation in index values, among sub-basins in a watershed.

The indices cannot be translated into hazard ratings such as "high," "medium," and "low" until the method proposed has been tested. Method testing is necessary to calibrate the indices with actual erosion rates. For roads, it may be possible to test by applying the proposed method to field measurements in the Washington field areas where extensive measurements have been made (e.g., Reid et al., 1981; Bilby et al., 1989). For logged sites, it will be necessary to field test the approach by making detailed field measurements of erosion rates on a number of sites that fall within the categories described in this method.

The analysis will also produce a narrative that will identify the key factors that are influencing erosion rates in a basin, such as, road surface maintenance for road surface erosion or soil erodibility for logging. The narrative should also indicate the location, nature of, and approximate intensity of natural or non-forestry land use erosion sources.

<u>Recommendations for Level 2 Analysis</u>

There is need for a method that will predict actual road surface erosion rates, taking into account all relevant variables. Such an effort is underway at the Forest Service Intermountain Research Station in Moscow, Idaho, and could be a potential method. Level 2 analysis should include an assessment of the relative importance, if not actual rates, of sources ignored in the Level 1 analysis: chronic sheetwash and rill erosion of road margins;

landslide scars. Road-related gullies and logging-related erosion should be quantified, when significant, as should non-forestry related sources.

A more sophisticated approach to routing sediment is also needed in a Level 2 approach. Whether sediment will be stored or transported in channels depends on stream order and stream structure (e.g., Bilby et al., 1989).

Determining the relative importance of landsliding and surface erosion

The methods discussed in this chapter produce indicators of the relative spatial importance of each sediment source. These sources are: shallow-rapid landslides; deep-seated earthflows and slumps; road-surface erosion; road-related gullies; and logging-unit erosion. No numerical cut-offs are given for assigning hazard ratings of "high", "medium" or "low" to map units on the landslide maps, because the ratings will be relative to particular regions. Similarly, the indices developed for erosion sources are not translated into hazard ratings, nor are they comparable to one another. The indices described for all of these processes, as far as they are developed in this chapter, have value only for expressing relative variation in process intensity with different locations across the landscape.

It is desirable to convert the indices to a common hazard rating that would allow the relative ranking of process intensity. In other words, a "high" ranking for surface erosion, for example, could then have some comparative value relative to a "low" ranking landsliding. Such a common ranking system could be developed in the next phase of testing and elaboration of this prototype method. To do this, it would be necessary to calibrate each of the indices to approximate magnitudes of sediment production from a combination of field testing and computation.

It should also be pointed out that the methods proposed in this chapter are based on a great number of simplifying assumptions which it was necessary to make in order to meet the requirements of simplicity and speed of use. In some cases these assumptions involve leaving out entire, and potentially important components of the sediment budget. In other cases the assumptions involve simplifying the range of variables that control processes to such an extent that the indices are no more than very crude indicators. Because of this great number of simplifying assumptions, it would be misleading and inappropriate to "push" these indices too far toward actual magnitudes. Level 2 analysis, as it is now envisioned, would be the appropriate setting for determining rates. The methods for determining rates in a Level 2 analysis require both more time and expertise.

Chapter 4 - Hydrology

Introduction

Runoff from Pacific Northwest forested hillsides to streams is comprised mostly of subsurface flow and, during storm events, some saturated overland flow. Aquatic ecosystems are influenced by the timing and magnitude of peak flows and low flows.

1. ***Water delivery to streams during storm events.*** Storm runoff is controlled by intensity and duration of precipitation, augmentation of runoff by snowmelt, amount of impervious areas, antecendent mosisture conditions, and water storage in a watershed Storm runoff to channels is delayed through interception or canopy storage, soil detention, and retention storage and storage in wetlands, lakes and reservoirs. The storage reserves link water movement from the hillside and valley soils to the channel and provide sustained flow during non-storm periods.

2. ***Peak Flows.*** Magnitude of peak flows will be influenced by drainage density, snow distribution and melt, storm intensity and duration, anticedent moisture conditions, and the amount of storage in the watershed-- soil, canopy, and waterbasins (eg lakes and wetlands). Peak runoff is attenuated through evaporation of snow from canopy, and storage of water.

Rain-on-snow. Rain-on-snow conditions occur during cloudy-weather periods when warm winds and rain produce rapid snowmelt (Coffin and Harr 1991). These events occur frequently along the western slopes of the Cascades, less frequently on the Olympic Penninsula, and even less frequently in mountaineous areas of central and eastern Washington. Rain-on-snow often occurs in the lower and middle elevations of the Cascades, but can occur wherever there is a snowpack that is subjected to maritime warm fronts. There are no discrete boundaries to the elevation range. Coffin and Harr (1991) suggest that the transient snow band in the Washington Cascades is approximately 1,000 - 3,000 feet or 300 - 900 meters. However, elevation boundaries will vary with latitude and geographic position for inland zones Actual snowmelt limits can even vary during a given storm due to depth of snow, wind conditions, temperature changes, and numerous other factors. For a thorough discussion of the energy processes involved with rain-on-snow; refer to Coffin and Harr, (1991) and Coffin (1991).

The storm flow produced from rain-on-snow events play an important role in runoff patterns and impacts on hillslopes and channels. The increased rates of water delivery to the soil can be translated rapidly to streamflow thereby altering the timing of peak flows in addition to increasing the magnitude of the peaks.

Non rain-on-snow floods. Although rain-on-snow floods do occur in central and eastern Washington, they are not as significant as they are in the Cascades and Olympic Mountains. Floods generated in zones not dominated by rain-on-snow can be influenced by timber management activities, especially activities which compact soils. Compaction of soil has been found to alter peak flows for small to intermediate sized floods (Harr et al. 1979). The intermediate-sized floods, in particular, are important because they dominate the formation and maintenance of channels. Thus these peak flows can play an important role in maintaining or altering the aquatic habitat in the channel.

3. ***Low flows.*** Two low flow periods exist in Washington: 1) in all areas, low flows occur from July - October; and, 2) in the snow-dominated zone, low flows also occur from time of freezing to snowmelt. Approximately 75 - 85% of annual precipitation in most of the region occurs between October 1 and March 31. Very little rain falls in July and August. Consequently flows are low from August - October with the exception of basins dominated by glacial melt waters. Contribution to low flows in summer include groundwater flow, fog drip, outflow from lakes and reservoirs, and glacial/snow melt. Groundwater contributions is

influenced by the size of the groundwater reservoir and seeps from bedrock fractures. Drainage density will also affect low flow, with higher densities capturing more subsurface flow.

Management Influences.

The components of the water balance most often affected by forestry activities can be grouped into three categories (Chamberlin et al 1991): 1) snow accumulation and melt rates; 2) evapotranspiration; and, 3) soil structure. Total water yield can be increased by the reduction of interception, transpiration, and compaction of soil especially in regards to storm flows and low flows. Timber harvesting practices can influence interception of snow, melt rates, and wind-dependent transfer of latent and sensible heat. Clearcutting can increase melt rate by increasing the rate at which energy becomes available to the snowpack. It also eliminates the canopy storage capacity of the forest therefore altering the distribution of snowpack and providing additional snow for melt. Clearcut areas are also more susceptible to wind and its influence on snow melt (Chamberlin et al. 1991, Berris and Harr 1987).

Although there is contradictory evidence on the amount of additional water output generated by timber harvesting practices, especially in terms of rain-on-snow events (refer to Coffin and Harr 1991), most studies show an increase in water levels following harvest. Much of this is due to loss of evapotranspiration which causes increases soil moisture. As saturation increases the potential for overland flow increases.

Harvesting of trees can create an increase in water yield during the summer low flow period due to decrease in transpiration. However, this yield may be short-lived(5-10 years) because of rapid regrowth of vegetation (Harr and Krygier 1972; Harr et al. 1979). Harr (1983) found that summer flows may decrease below prelogging levels due to the growth of phreatophytes such as willows, cottonwoods, alders and other water-tolerant species adjacent to channels. Heavy water use by the phreatophytes can continue for decades, thus low flow recovery may be slow. These findings, although contradictory to other studies, may have important ramifications in the drier portions of Washington.

Cutting of tall mature trees within the fog drip zone may have significant influence on water yield during low flow periods. Fog drip can be an important contributor to the water budget during the droughty season along the western half of Washington. The amount of water contributed depends not only on the availability of windblown fog but also on the profile and canopy density of trees exposed to fog. Tall trees with dense canopies experience greater fog drip. Harr (1982) found that fog drip contributed 88.2 cm to the water budget in Oregon. Twenty-five percent of the water reaching the soil beneath of ridge-top conifer forest about 4 km inland from the Oregon coast was found to be from fog drip (Isaac 1946). Areas of fog drip can be roughly identified by coincidence with certain vegetation types (Harr 1982). For example, along the coast, the sitka spruce zone closely follows the fog zone. In the western Cascades, Pacific silver fir is an indicator of the fog zone.

Hydrology--Watershed Analysis Methodology

The purpose of the Level 1 hydrologic watershed analysis is to estimate potential increase or decrease in flow, and change in timing of runoff, due to existing or proposed management activities. The analysis addresses three aspects of hydrology: 1) peak flows due to rain-on-snow; 2) peak flows due to compaction; and, 3) low flows.

The methodology requires the uses of 7.5-minute topographic maps, streamflow data when available, and hydrograph simulation methods when stream gage data is not available. Additional information that may be needed includes percent of watershed area in vegetation age categories of 0-18 years, 18-40 years, 40-60 years, percent of area to be harvested, percent of watershed area compacted (e.g. roads, landings, yarding areas), and additional watershed area projected to be in compacted areas. Other information, particularly for a level 2 analysis, may include drainage density (channel length/basin area), basal area/ft^2, and snow depth and distribution. The methodology idnetifies which is necessary on a step by step basis depending on the particular application and/or conditions that may occur in the watershed being analyzed. Each step in the methodology follows the format of a) question, b) discussion c) method.

Assumptions.

1. Hydrologic runoff models can be used to estimate changes in storm flow conditions due to management activities.

2. Meteorological records in the vicinity of the basin can be used in the analysis if records are not available for the basin of interest.

3. Drainage density and pattern are indicators of similarity between basins.

4. Hydrologic data or simulated storm hydrographs can be extrapolated from one basin to a similar one by the use of runoff coefficients.

6. Precipitation records can be used to simulate hydrographs.

7. Compacted areas have lower infiltration rates than forest floors, thus they can increase peak flows.

Steps in the Methodology.

The following methods are proposed for determining imcreased peak flows for basins of fourth order or smaller. The issue of whether rain-on-snow floods affect larger channels has not been resolved. A flowchart illustrating the methodology is shown in Figure 4.1.

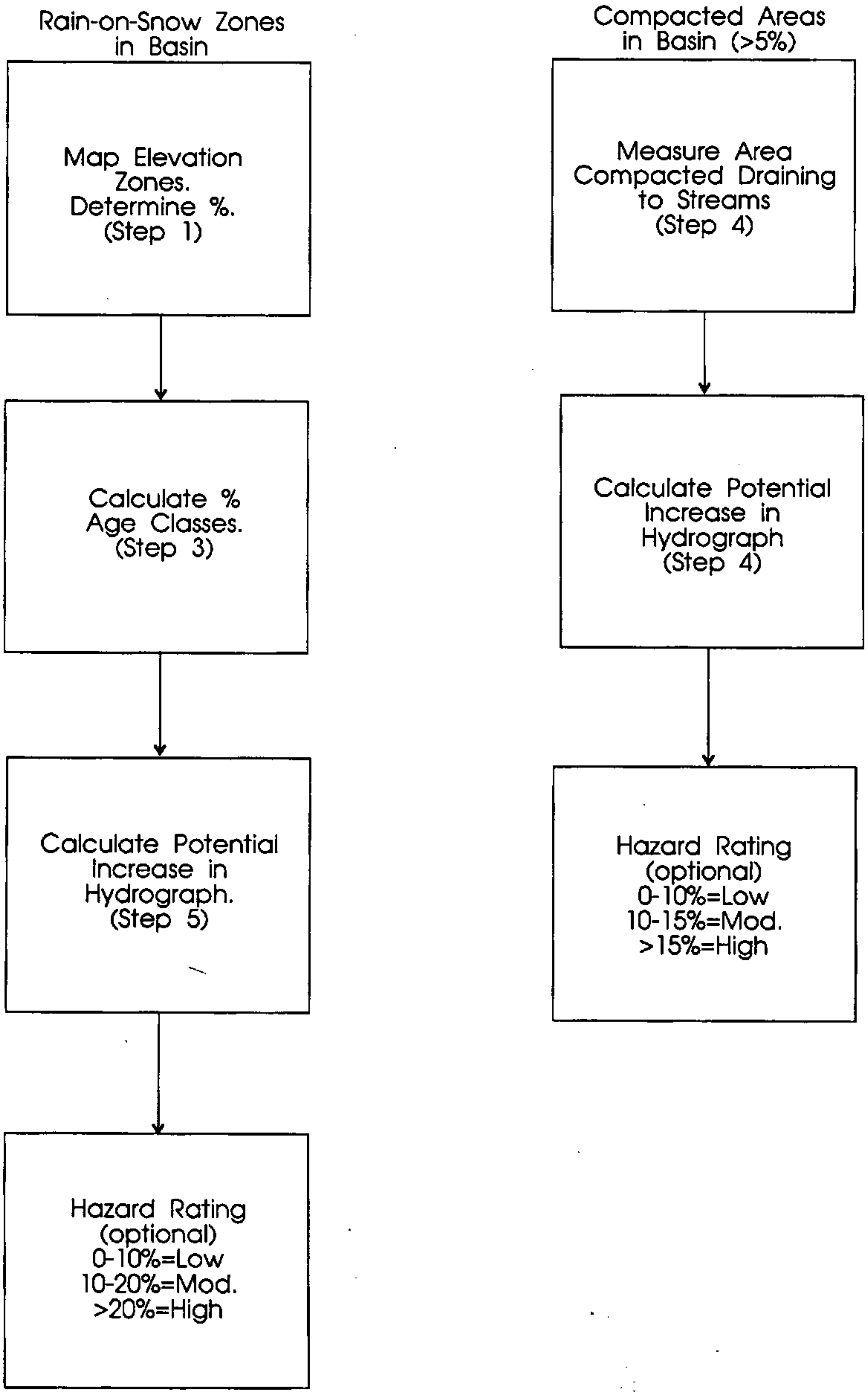
Step 1. a) Question: What elevational zone(s) are in the basin and what percentage of the basin is contained within each zone?

b) Discussion: Elevation is the primary attribute for determining potential for rain-on-snow events for Level 1 analysis. Other factors such as topographic alignment, wind direction, aspect, fetch are also important. However, analysis of these parameters are more appropriate for Level 2. There are five precipitation zones : 1) lowland, 2) rain-dominated, 3) rain-on-snow, 4) snow-dominated, and 5) highland (Figure 4. 2, adapted from Brunengo, 1991). Rain-on-snow events occur most frequently in precipitation zone 3, also called the transient snow zone. The transient snow zone occurs at intermediate elevations of the Cascades and lower elevations of the valley floors. This zone as defined by Coffin and Harr (1991) extends from 1,000 - 3,000 feet in Washington, although the upper and lower boundaries vary somewhat with latitude. The Washington DNR (Hulsey, 1991) has proposed the rain-on-snow zone boundaries to be from 1600 - 4000 feet for the interim rain-on-snow rules (WAC 22-16-046 (7)). One the windward side of the Olympic Mountains, the rain-on-snow zone extends from 1,400 to 4,000 feet (Harr, 1982). Considering the range in elevational definitions, this method considers that the the rain-on-snow zone extends from 1,000 - 4,000 feet.

The other elevation zones extend as follows: 1) Zone 1 : sea level to approximately 700 feet, 2) Zone 2: approximately 700 - 1000 feet (1400 feet on the Olympic Peninsula), 3) Zone 4: approximately 4,000 - 5,000 feet, and 4) Zone 5: >5,000 feet. Refer to Figure 4.2).

The elevation zones refers to the potential or magnitude of rain-on-snow events occurring within them. High potential rain-on-snow zone is Zone 3; moderate potential rain-

Figure 4.1
Flowchart of Peak Flow Analysis



Precipitation Zones

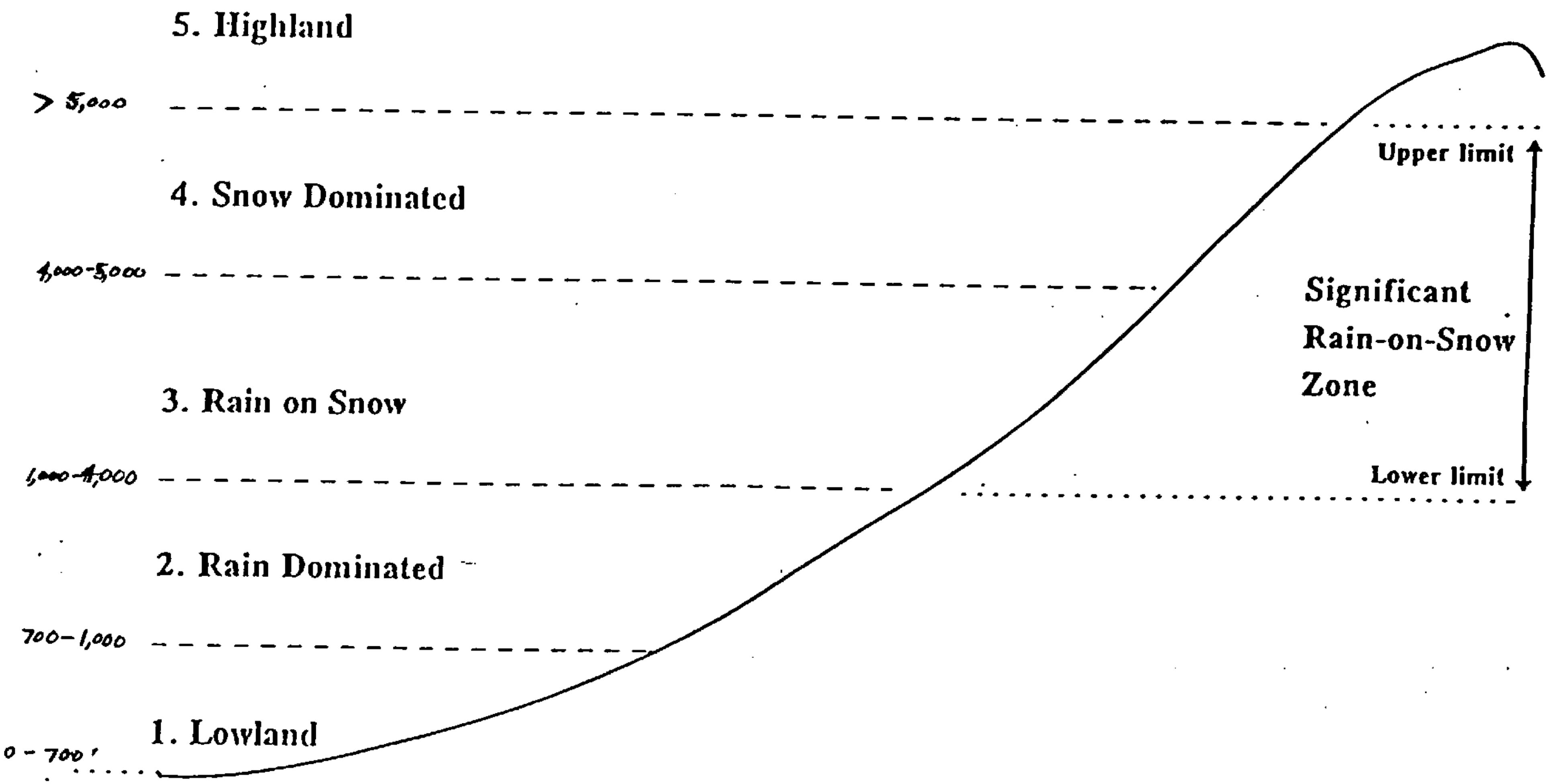


Figure 4.2
Elevation Zones, Step 2 (from Hulsey, 1991)

on-snow zone includes Zones 2 and 4; and, low potential rain-on-snow zone includes Zones 1 and 5.

c) Method:

1. Map the three potential rain-on-snow zones: 1) rain-on-snow, 2) rain-dominated and snow-dominated , and 3) the lowland and the highland from 1:24,000 maps or from DNR GIS maps (corrected for elevation change) where available. (Refer to example in Chapter 10).

2. Determine the proportion of watershed in diffferent elevation zones.Step 2. a) Questions: What is the hydrology and precipitation for the watershed?

b) Discussion: These data are necessary to simulate runoff, and develop hydrological scenarios for management activities. Where hydrologic records are available, hydrograph analyses such as separation of stormflow and baseflow, development of recurrence intervals and flow duration curves can be done. Such information can be used to determine the existing hydrologic conditions of a watershed and to assess potential increases, decreases, or desychronization of flows based on management scenarios.

When hydrologic data is not available, hydrographs need to be simulated by the models. Recommendations for simulating hydrographs are briefly discussed later under methods.

c) Methods:

1) Obtain available hydrologic and precipitation records for flows or storms of interest in the watershed or from a similar nearby catchments.

We recommend developing hydrographs and recurrence interval curves for five of the maximum storms for rain-on-snow dominated floods, and five small to intermediate floods for non rain-on-snow floods.

Potential Sources of data: Hydrodata and Climate data CDROM Package; USGS Water Supply Data for Washington, USGS offices usually have published recurrence intervals for gage sites; USGS Water Basin Characteristics (WATSTORE).

2) In some instances the gage data may be influenced by previous management activities. If this is a serious concern, a double-mass analysis can be conducted to determine the period of record that is not influenced. Numerous hydrology or water resources planning textbooks describe the method, for example Linsley et al. (1982), and Dunne and Leopold (1978). Should a trend related to previous management activities be evident for most of the period of record, then the hydrographs can be adjusted accordingly from the equations in Steps 4 and 5.

3) Simulate hydrographs where hydrologic records are not available. Methods proposed are:

a. When precipitation records are available within proximity to the watershed, then a rainfall-runoff model can be used, such as the API method developed by Fedora (1987) to simulate storm hydrographs. The method is briefly described in Attachment 1. Use the API method, or similar rainfall-runoff model of your choice, to generate hydrographs for the top five storms and five small-to-intermediate storms in the most recent 15-year period of record.

b. If precipitation records are not available then use:

1) DNR method. This method estimates a hypothetical 10 year, 24 hour storm. Hydrographs for rain only and rain and snow melt can to be estimated (Figure 4.3). A description of the method will be produced in DNR's screening process. Extending the method to incorporate other storms such as the 2 year 24 hour, the 20 year 24 hour, would increase its applicability. The method only determines water available for runoff. A means for routing it to the stream from the hillslope should be incorporated into the model.

2) Two methods developed by the USGS: 1) Magnitude and Frequency of Floods in Washington (USGS 1974) and 2)Evaluation and Design of a Streamflow-Data Network in Washington (USGS 1978) contain regression equations for calculating flood flows and mean annual flow. Recurrence intervals can be developed from this data. The equations concerning this method are contained in Attachment 1.

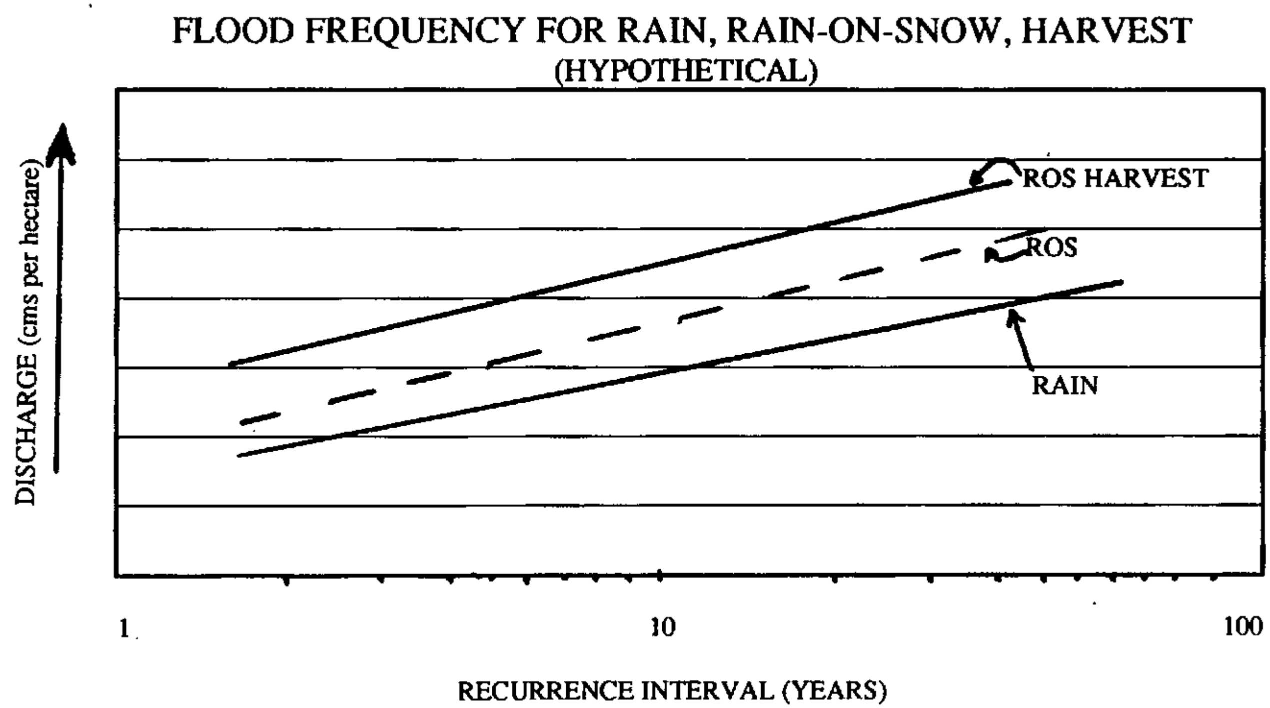


Figure 4.3
Frequency Analysis for Change in Peak Flows

3) Develop runoff coefficients from adjacent and similar gaged watersheds (similar drainage density, pattern, climate) for flows of interest (includes low flow) for extrapolation (Refer to item c below).

4) On the Olympic Peninsula, the flow analysis developed by J. Orsborne (1991) for the TFW Ambient Monitoring Committee can be used to develop discharge values for certain cases.

c) Under certain conditions, hydrologic and meteorological data and hydrologic simulations can be extrapolated to other basins. The criteria that should be met are: 1) similar geology and geomorphology, 2) similar drainage pattern and drainage density; and, 3) similar climate and storm patterns.

Where precipitation data are also available then this data can be used in conjunction with flow data to form rainfall-runoff relationships. This provides the simplest method of predicting the volume of storm runoff. the storm runoff coefficients (i.e. volume/unit time/unit area) for flows of interest and rainfall runoff relationships can be used to extrapolate flows upstream of gages and to similar basins of interest. Rainfall-runoff relation graphs for peak flows and their coinciding storms, rain-on-snow period rainfall-runoff relation graphs

Step 3. a) Question: What is the distribution of vegetation ages in each zone?

b) Discussion: Age of vegetation can be used as a surrogate for runoff potential , also known as hydrologic maturity. The age classes can be used to determine runoff depending on the proposed management scenario (amount and timing of runoff). Recent plot studies in the Cascades of Washington have shown that outflow increases in clearcut plots (25 -174%) and in plantation plots (-19 - 96%) when compared to outflow from mature forests (Coffin 1991). Stream hydrographs of some of the storm events from this study have been developed and are included in Attachment 1. A physically based routing model has not yet been used to simulate rain-on-snow augumented runoff. Equations for estimating amount of additional runoff vs age can be determined from the rain-on-snow analysis of Coffin and

Harr (1991) The age class categories are: 0 - 18 years, 18-40 years, 40 - 60 years, >60 years. Information on age class should be available from the land managers.

c) Methods:

1) Determine the percent basin area in different vegetation age classes (0 - 18 years, 18 - 40 years, 40- 60 years, and > 60 years).

2) Equations for estimating amount of additional runoff vs age are:

0-18 years : $Y_{pred} = 15.72 + 1.13X$ (=input in mm/24 hr) SE of Y = 18.49, $r^2 = 0.95$; SE of Coefficient = 0.05; Y_{pred} =Outflow (mm/24hr); To convert to outflow to m3/sec/ha multiply : (Ypred)(.0028)

18-40 years: $Y_{pred} = 12.37 + .91 X$ SE of Y = 16.91; SE of Coef. = 0.05; $r^2 = 0.91$

40-60 years: Outflow coefficient = 12 mm/24 hours

> 60 years: assume recovery is complete and hydrologically mature.

Step 4. a) Questions: What is the percent of watershed area compacted (area in roads, landings)? What percent of compacted area is directly connected to channels (all water types)?

b) Discussion: Harvesting activities such as yarding, burning, road building, and falling can affect water yield for small to intermediate sized floods (Chamberlin et al. 1991). When soil is disturbed through compaction, infiltration rates may suffer drastic reductions increasing potential for overland runoff which will decrease time of travel to the channel and increase peak flows. Harr et al. (1979) found that the percent of compacted soils on a watershed appears to be a good indicator of increased size of peakflows. Important factors include proximity of compacted areas (roads, landings) to channels, interception of subsurface water by road cuts and ditches, soil type, and topography.

The relationship developed by Harr et al. (1975) is proposed as an index for determining potential increase in peak flows due to compaction. The regression equation developed by Harr(1975) needs to be tested to be more representative of areas in Washington.

Methods:

1) Determine proportion of compacted area draining to channels.

2) Determine:

a. Compacted area draining to channels: $Y_{pred.} = 0.85\ (X^{1.54})$, where X is percent area, where $Y_{pred.}$ is percent increase in size of peak flow runoff per hectare (Harr et al. 1975).

b. Compacted area not draining to channels: $Y_{pred.} = 0.20\ (X^{1.54})$.

4) Sum 3)a. and 3)b. to obtain percent increase over peak flow per hectare.

5) Determine peak flow per hectare for storms of interest defined in Step 2. and divide by the number calculated in item 4) to obtain numerical runoff volume per hectare for calculating routing flows in Step 5.

Step 5. a) Question: What are the potential changes in flow due to management activities?

b) Discussion: This step deals with the development of management scenarios, estimating potential increase or decrease in channel flow, and routing of flow to reaches of stream designated as fish zones as per method described in Chapter 7. The hydrographs developed in Step 2. are considered to be the baseline data. Management scenarios should be expressed in hectares proposed to be cut and additional proportion of compacted area to be added. The basin can be divided into subbasins if more convenient for calculations.

c) Methods:

1) Develop scenarios for additional water input based on hectares of basin to be cut. Add additional input to hydrographs simulated for the proportion of basin in moderate to high potential rain-on-snow, where (Runoff coefficient for 0 -18 year age class)(hectares to be cut)= additional peak discharge

2) Equation for determining potential input to peak flows for simulated hydrographs: (Runoff coefficient for 0 - 18 year age class)(hectares to be cut) = additional peak discharge

3) The method for determining potential increase to peak flows from compaction is the same as for rain-on-snow except use the estimated values from Step 4.

4) If the basin is divided into subbasins to develop management scenarios, then route new discharge downstream to the beginning of a designated fish zone and to the mouth of the basin.

Step 6. a) Question: Are there water supply reservoirs within, or downstream of the watershed and is there a potential for water supply conflict during the low flow period?

b) Discussion: Timing of snowmelt runoff may be crucial for replenishment of water-supply reservoirs and augmentation of downstream low flows for instream uses and water appropriations. Harvesting can desynchronize the timing of snowmelt runoff and impact water supply. Changes in timing should be estimated to evaluate potential hazard and investigate operating schedules for reservoirs.

c)Method: The WRENSS model (USFS 1980), (For contacts refer to Attachment 1), can simulate potential change in timing of water yield from snowmelt in snow-dominated regions. For additional information refer to Toews and Gluns (1986).

Step 7. a) Question: Is the watershed in a summer fog zone?

b) Discussion: This question relates only to low flow. If the watershed is in a summer fog zone, potential decreases in low flow are a possibility. This is a potential hazard that should be considered.

Assigning hazards.

The following qualitative ratings can be used to estimate potential hazards in a watershed for increases in peak flows due to rain-on-snow events or compaction, or a change in water supply timing or decrease in low flows.

1) Rain-on-Snow

	AGE CLASS OF TREES		
Elevation Zone	Young 0 - 18 years	Plantation 18-40 years	Mature > 40 years
ROS	high	high	moderate
2, 4	high	moderate	low
1, 5	moderate	low	low

	PERCENT OF BASIN CUT		
Elevation Zone	< 20 %	20 - 40 %	> 40 %
ROS	moderate	high	high
2,4	low	moderate	high
1,5	low	low	moderate

2) Compaction

PERCENT OF WATERSHED COMPACTED		
< 5 %	5 - 10 %	> 10 %
low	moderate	high

3) Low flow

Location/ Source	Fog Zone	Ground water source	Appropria-tions

Coastal	moderate	low	moderate
Ridgetop	high	moderate	high
Other	N/A	low	moderate
Reservoir	N/A	moderate	high

Chapter 5 - Riparian Function

Introduction

Riparian forests interact with and modify stream channels and habitat in the following ways:

1. Recruitment of woody debris to channel. Woody debris may be either fine (litter) or large woody debris (LWD). LWD is known to be an important agent in providing habitat morphological diversity in the form of pools and riffles, and instream cover. Habitat use by species which remain in freshwater for an extended rearing stage, such as coho salmon, has been shown to be strongly influenced by the presence of instream LWD (Bisson et. al., 1987).

2. Bank Stability. Root systems of riparian forests have been shown to significantly increase stream bank stability and significantly influence channel morphology. This is particularly true of small streams bordered by large trees or dense herbaceous vegetation. In large streams and rivers, the role of root binding of stream banks is diminished although it may still be significant (Gregory and Gurnell, 1988).

3. Shading/temperature. Riparian vegetation can provide significant shading to stream channels. Shading reduces the input of solar radiation into the stream. Solar radiation is the primary source of input of heat to a stream (excluding geothermal sources if present). Thus riparian vegetation can strongly moderate stream temperatures, reducing temperatures during summer low flow periods. The influence of riparian shading in general is greatest in smaller streams and declines as stream width increases.

4. Nutrient and food supply. Litter (plant material) from riparian forests provides a significant source of nutrients to stream systems (Murphy and Meehan,1991).

These nutrients are consumed by a number of invertebrate species which in turn are a source of food for vertebrates such as fish and birds.

Level 1 watershed analysis emphasizes the physical influence of riparian forests on stream habitat and the role of riparian vegetation for providing shade. The influence of large woody debris on stream form and process and the role of riparian shading in regulating stream temperatures are well understood. These aspects of riparian function are easily measurable and can be rapidly characterized over broad areas. The importance of riparian vegetation on stream bank stability is also fairly well established, but we have not found an existing method for characterizing this process at the watershed level. The inputs of nutrients and food organisms are also generally understood, but the magnitude of these processes and the resulting effects on fish production are difficult to determine at a level of effort suited to a Level 1 analysis

Woody Debris Inputs to Channel

Introduction

The quantity of LWD within a channel is determined by the rate of recruitment of wood to the channel and the loss of wood from the channel.

Recruitment

The recruitment of LWD to a stream channel depends on the availability of suitable wood within the riparian zone which can be delivered to the channel, and the actual delivery of wood to the channel (Vansickle and Gregory, 1990). Availability of wood can also be thought of as riparian recruitment potential. Riparian recruitment potential is influenced by:

1. Age of riparian stand;
2. Species composition of riparian stand;
3. Disturbance type (fire, wind, channel movement, forest management).

The actual delivery of wood to a stream segment can come from either or both of two sources, the adjacent riparian zone and upstream channel segments. Downstream transport of wood can be the result of normal instream flows and catastrophic flows such as debris torrents. Recruitment from the adjacent riparian zone will be strongly influenced by:

1. Proximity of a tree to the stream channel;
2. Bank slope;
3. Disturbance type;
4. Tree fall.

Vansickle and Gregory (1990) concluded that the lack of field studies regarding tree fall limit our ability to accurately predict the probability of a tree falling during any given time period, and therefore limit our ability to model or predict recruitment rates to stream channels. Although general recruitment rates of course woody debris have been measured (Harmon et. al., 1986), the wide variation in measured values restricts the advisability of generalizing rates of recruitment for use in watershed analysis.

Loss from channel

Loss of wood from the channel can be caused by decomposition or by downstream transport by normal or catastrophic stream flows. Decomposition rates are thought to vary by species and wood size, however rates for LWD which is partially or fully submerged have not been well documented. Estimates of LWD age indicate that western red cedar and Douglas fir may persist for over one hundred years (Harmon et al., 1986). Anderson et al. (1978) show that alder LWD decomposed much faster than conifer species. Total amount of LWD within stream channels begins to decline soon after timber harvest within adjacent riparian areas (Bryant, 1985).

Bilby and Ward (1989) have shown a strong relationship between stream width and the length, diameter, and volume of LWD found within the channel. This is apparently due to stream transport capacity and is analogous to sediment transport capacity.

Grette (1985) measured LWD loss from small streams on the Olympic Peninsula. He found that losses averaged 0.5 pieces of LWD\100 m\year, or 1%/year. Recruitment of

LWD from second growth riparian stands (<62 yrs) was less than channel losses, resulting in lower LWD levels in all second growth streams studied. Significant inputs of alder LWD were not measured until 40 years after logging. Recruitment of conifer LWD was very low for a period of 62 years after logging.

Major losses of LWD from stream channels by catastrophic processes such as debris torrents can also occur. Debris torrents are natural occurrences in steep forest streams of Washington. Natural rates for debris torrents have been estimated at 0.0005 - 0.0008/ sq. km for two forested areas in the Oregon Cascade range. Rates calculated for clear cut areas was 0.036 -0.044/sq. km and 0.340 - 0.667 for roaded areas . Removal of LWD from the stream channel is essentially total for streams with gradient in excess of 7 -8° (Swanston, 1991).

Debris torrents can be a major source of LWD within channels below 7-8°. Wood and sediment transported by a torrent is deposited in the channel and along the channel margins. Below the deposition zone however, short term (3-5 yrs) increases in fine sediment can significantly degrade existing habitat conditions (Swanston, 1991).

Approach

Level 1 watershed analysis for riparian LWD recruitment is based on the importance of riparian recruitment potential in determining LWD abundance in stream channels. While actual recruitment rates will vary from site to site, existing research and data are not available to support the calculation or estimation of actual LWD recruitment rates to a particular stream channel segment within a Level 1 analysis . We recommend that the use of the Vansickle and Gregory (1990) recruitment model be tested for use in Level 2 analysis.

Evaluation

The purpose of the LWD assessment is to characterize the potential for riparian zones throughout a watershed to recruited LWD to adjacent stream channels.

The initial watershed examination involves determination of the following:

1. Partitioning of riparian vegetation age class distributions within the basin based on broad patterns of vegetation age classes such as young (0-40 yrs), mature (40-80 yrs), and old (80+yrs).

In watershed partitioning, a determination is made as to whether there are broad areas within the sub-WRIA which have relatively homogenous riparian stand conditions and can be analyzed quickly as a unit. An example is a sub-WRIA which is approximately 80 sq. miles, the upper one-half which is young plantation with no riparian leave trees. The lower one-half of this sub-WRIA is young second growth which was also harvested without riparian leave trees. The upper watershed can be analyzed quickly using high altitude photography, the lower one-half contains young riparian stands which need further analysis as to species composition.

2. Identification of vegetation composition of riparian stands within the basin as either deciduous, coniferous, or mixed.

Assumptions

For the purposes of the Level 1 analysis of LWD recruitment, we have made the following assumptions:

1. Riparian trees must be within 100 feet of the stream channel in order to have the potential to recruited to the stream.

2. All channel types have equal recruitment rates. Bank slope, confinement, alluvial and non-alluvial channels are all treated equally.

3. Habitats and stream channels in excess of 20 meters are not as sensitive to inputs of LWD and are adequately addressed by existing riparian leave regulations.

4. Recruitment potential increases with stand age, and therefore average tree size. Stand age must be in excess of 50 years in order to ensure long term supply of LWD (Andrus et al., 1988; Grette, 1985).

5. Mixed stands (coniferous and deciduous) are of higher recruitment value than coniferous stands, which are of higher value than deciduous stands.

Office Assessment

The purpose of the office assessment is to map riparian stands within the watershed based on their recruitment potential.

The following steps are involved in Level 1 analysis:

1. Examine 1:40,000 or similar high altitude aerial photographs. Partition basin if appropriate into large areas of homogenous riparian condition.

2. Map stream size for all streams within sub-WRIA;

   If channel is >20 m wide - stop. (See assumption #3)

   If channel is < 20 m wide - proceed to step 3.

3. Map riparian right and left bank vegetation types and age classes using 1:40,000 or greater aerial photographs (1:12,000 preferred).

Vegetation types	-coniferous (>80 % of stand is conifer)
	-Deciduous (>80% of stand is deciduous)
	-Mixed (all other cases)
Vegetation age (yrs)	-young (0-40)
	-Mature (40-80 decid., 40-120 conif., 40-80 mixed)
	-Old (80 + decid. and mixed, 120+ conif.)

4. Determine Hazard for each segment based on Table 5-1 and map hazard classes.

Field Assessment

The purpose of the field assessment is to determine if the riparian stand maps produced in the office assessment are generally accurate.

The field evaluation steps are:

Table 5.1

Stream Reach Hazard Rating
(from Riparian LWD analysis)

	Young (0-40yrs)	**Mature (40-80)**	**Old (80+)**
Deciduous	High	High	Medium
Coniferous	High	Medium	Low
Mixed	High	Medium	Low

1. Select representative riparian stands for field verification.

2. Walking survey of representative stream reaches. Reaches should be selected to represent the range of riparian age classes and stand composition types identified from aerial photos. Categorize right and left bank stands within 100 feet of the channel by their age class and stand composition. For Level 1 analysis, a visual estimation is suggested

3. Correct office assessment maps if necessary.

Hazard Decision

The hazard rating for each stream segment is based on Table 5.1.

Treatment of Delivery

Delivery of wood to the channel is assumed to come from the adjacent riparian zone. Downstream transport is not considered although it may easily be included in Level 1 analysis by identifying debris torrent deposition zones. Downstream transport of wood through normal flow events indicates unstable wood size. Transport by normal flows is not considered within Level 1 analysis.

Delivery is assumed if the riparian zone has the appropriate vegetation. No models are used for Level 1 analysis. The VanSickle and Gregory (1990) method proposed for use in Level 2 contains probabilistic models.

Suggested Level 2 Analysis

Level 2 analysis should include a Level 1 analysis with the following additions:

1. Increase field effort to include quantification of age and species present, proximity to stream, bank slope, stand density, tree height.

2. Application of Van Sickle and Gregory (1990) riparian recruitment model to representative stream reaches to predict potential inputs of LWD.

3. It was suggested during initial review of this method by TFW cooperators that a riparian forest "desired condition" statement be included in this document. While we have not provided such a statement, we believe that elements of a desired condition are suggested

by the literature and are also inherent in the prototype method. These elements are managing for long term and continuous recruitment potential through mixed age stands along all stream reaches, managing for mixed species stands, and recognizing the positive influence of some canopy opening along streams. We recommend that a more comprehensive desired future condition statement be developed by TFW. This statement would provide a guide by which Level 1 an Level 2 results could be interpreted.

Riparian Shading and Stream Temperature

Introduction

Riparian forests strongly influence stream temperatures by providing shade. TFW has developed and tested a reach based temperature model for predicting the potential for high summer water temperatures (TFW, 1991). The proposed Level 1 analysis incorporates general principles of the TFW model to identify broad areas of potential temperature problems.

Because stream temperature problems are only verifiable during summer, this issue does not completely lend itself to a Level 1 analysis. Maximum water temperature is also controlled and limited to maximum air temperature. Field verification therefore requires either deployment of recording thermographs or visiting high hazard sites during extreme weather conditions. Due to these factors, Level 1 analysis will have limited ability to produce high certainty of resource risk.

A working version of Level 1 analysis is being developed by Cascade Environmental Services. The method described below outlines the proposed Level 1 approach which is under development.

Evaluation

The assessment of stream temperature hazard for Level 1 involves the following questions:

1. Which streams within a basin are of a size which is vulnerable to high stream temperatures?

2. Which streams within the watershed are within the elevation range known to be susceptible to high stream temperatures?

3. For sensitive streams, what level of shading is provided by the riparian forest?

Assumptions

The following assumptions are made within Level 1 analysis:

1. Vegetative density does not influence stream temperature. Density is assumed to be adequate if tree height is sufficient to provided shade.

2. Adequate tree height is provided by trees with height equal to or greater than 0.85 X channel width (Kent Doughty, personal communication). This is equivalent to an angle to tree tops from vertical of 30 degrees.

3. Topographic shading is not a critical factor.

4. Stream temperature problems are generally limited to 2nd and 3rd order streams (Kent Doughty, personal communication).

If any of these assumptions can be shown to be not valid for a particular stream (conclusions based on assumptions contrary to field evidence), a Level 2 analysis should be performed.

Assessment

The office component of the stream temperature hazard consists of the following steps:

1. Map the upper elevation boundaries of temperature hazard area as 3600'. There is no lower boundary.

2. Map second and third order channels within the hazard zone.

3. For 2nd and 3rd order streams within the hazard zone, measure channel width and riparian canopy height from most recent aerial photographs.

The field component of the temperature assessment consists of the following steps:

1. Select stream reaches representative of sensitive streams within the hazard zone.

2. Field survey tree height at regular intervals along stream reach. Suggested interval is 100m.

3. Correct maps produced in office analysis based on field survey.

Hazard Evaluation

A hazard rating system should be developed by TFW when the design of the final Level 1 temperature analysis is complete.

Delivery

Delivery of temperature to downstream reaches is limited by air temperature and tributary size. The TFW temperature study concluded that a reach by reach assessment of temperature was better able to predict stream temperatures than a watershed level assessment which includes routing of temperature. Therefore delivery to downstream reaches is not proposed for Level 1 analysis.

Level 2 Recommendations

Level 2 should emphasize more accurate assessment of the hazard to a sensitive stream reach by applying the TFW stream temperature method.

Channel Stability

The influences of riparian vegetation on channel stability are not analyzed by the prototype Level 1 analysis. No existing methods which link vegetation type or density to channel stability were identified during prototype development.

Nutrient Supply

The role of riparian vegetation on nutrient supply is not included in the prototype watershed analysis. No methods were identified for analyzing the changes in nutrient supply caused by forest management, or the resulting impacts to fish or habitat, during prototype development.

Chapter 6 - Channel Response to Sedimentation and Flooding

Introduction

River channels in mountain drainage basins are dynamic, formed and continuously modified by the supply to them of water, sediment, and wood which are influenced by forest management practices.

For purposes of this Level 1 of watershed analysis, forest-management effects on channel sedimentation and flooding are grouped as follows:

1) Destabilization of channel margins by logging equipment or livestock grazing, and by removal of in-channel wood and riparian trees, either by riparian logging or some other practice, such as historic splash-damming;

2) Channel sedimentation by debris flow and dam-break floods; e.g., changing the amount, sizes and timing of sediment flux;

3) Bed and bank erosion, changes to particle size of sediment load, and changes to channel bed morphology resulting from change in the size and frequency of floods. The method focuses on rain-on-snow flow increases that can be used to infer increased bed and bank erosion.

The categories of impact listed above are discussed sequentially below.

Channel Destabilization by Bed and Bank Damage.

The practice of felling, yarding and skidding near and in streams can destabilize channels by mechanically destabilizing the river bank and bed. This sort of damage now occurs less commonly than it did historically, but the consequences can be long-lasting.

Stream-bank erosion can result in channel widening and an increase in sediment supply. In three of four basins studied in British Columbia by Roberts and Church (1986), bank erosion contributed from more than 50 to as much as 85 percent of total sediment production in the basin, and streams widened by 50 to 190 percent over the course of about a decade.

Grazing by livestock can mechanically destabilize banks (see Platts, 1991 for discussion). Riparian logging can also destabilize banks because tree roots are an important constituent of bank strength, and that strength is lost when roots of dead trees decay.

Logging of stream-bank trees can also have a destabilizing effect on channels because large trees that fall into channels, especially narrow, higher-gradient channels, are an important element of stream channel morphology (see chapter on riparian function). Trees that fall into the channel can become incorporated into the channel and trap sediment, creating a step-pool structure, which is important to fish habitat (see chapter on habitat).

Removal of organic debris from channels can cause the bed to erode (degrade); the release of previously-trapped sediments can cause deposition downstream.

Many streams in Washington state were subject earlier this century to log drives that were damaging to the stream morphology (Sedell and Luchessa, 1981). The release of water and logs from "splash dams" produced a flood torrent heavily-freighted with woody debris. The effects of such an event have not been well documented, but probably had the effect of removing much in-channel and riparian wood, and destabilizing channel beds and banks. The effects in some channels are still apparent.

Debris Flows and Dam-Break Floods.

Debris flows and dam-break floods are discussed in the shallow-rapid landslide analysis in Chapter 3. Debris flows are extremely erosive and incorporate sediment, water and vegetative debris in steep first- and second-order channels. This material is deposited by debris flows further downstream in lower-gradient channels of third- and higher order, often at tributary junctions or on alluvial fans. Scoured channel beds and valley walls in steep, low-order channels may be a source of coarse and fine sediment years following the event (see discussion below on changes in sediment influx).

Debris flows contribute large amounts of unsorted, coarse sediment, including fines, that can accelerate sediment transport downstream of the deposits. Accelerated sediment supply can cause channel aggradation by coarse sediment, increased channel instability, and decreased water quality. Debris flows, in certain circumstances, can have localized beneficial effects on habitat (Everest and Meehan, 1981). Because debris flows naturally occur, some ecological processes in mountain stream channels may depend on them (Swanson et al., 1987).

Valley walls and floors scoured by dam-break floods contribute to erosion and accelerated sediment supply as normal runoff floods erode these areas following the event (Johnson, 1991). Dam-break floods also incorporate organic debris from within channels and carry it long distances and deposit in clumps discontinuously along the valley floor, often away from the channel.

Channels impacted by dam-break floods usually exhibit increased braiding (decreased stability), higher water temperatures because of decreased shading, accelerated sediment transport because of loss of stabilizing floodplain and valley wall vegetation, loss of in channel organic debris, and aggradation downstream of the event because of increased sediment supply. As a result the channel becomes dominated by riffles, loses pools, loses cover and complexity and is less suitable for fish.

Changes in Water and Sediment Supply

The effects of management-induced changes to the supply of sediment and water to streams depends on the nature of the sediment or water source. For purposes of organizing this summary, three cases are considered:

1) Increased supply of sand and silt, referred to in this document as fine sediment;

2) Increased supply of mixed grain sizes of sediment; and

3) Increased peak flows.

Fine Sediment Supply

An increased supply of fine sediment often results from erosion of logging road , the surface erosion of logging- or road- related landslide scars, or in some situations, surface erosion of harvest units (see Chapter 3). Fine sediments can fill pools, and can also intrude into bed gravels; both of these effects are of consequence to habitat (see Chapter 7).

Increased fine sediment supply can also increase turbidity. This can be important to habitat, and also for downstream uses of waters, such as for industrial or domestic supply.

Mixed Sediment Grain Size Supply

Unlike surface erosion which produces fine sediment only, landslides and debris flow contribute to streams the mix of sediment sizes that comprise the soil and colluvial mantle, which often includes sizes from clay to boulder.

After a landslide or debris flow deposits in a channel, the stream erodes the deposit. The fate of the eroded sediments is different for different grain sizes. Boulders in the mixed-grain size deposits from landslides or debris flows are generally immobile, and can persist for decades to centuries in channels, where they are important structural elements (Benda, 1990).

The sand, gravel and cobble-size fractions are mobilized from landslide and debris flow deposits within a time scale of years to decades (Perkins, 1989; Benda, 1990). The downstream transport of this sand-through-cobble portion of mixed-grain-size sediment is intermittent, and is characterized by migrating gravel sheets and intermittent deposition in bars and aggraded channel beds. Increased bar deposition tends to deflect streamflow into banks, causing the banks to erode, which causes the channel to widen (for example, Madej, 1981). The degree of channel widening is controlled by the volume of sediment entry into streams.

Deposition can also cause significant build up of the bed (aggradation), which can bury spawning habitat. Aggradation can also cause streamflow to become subsurface flow during low flows, where previously it did not.

Finally, coarse sediment aggradation can fill pools, and "smooth out" the longitudinal, pool-and-riffle profile of a stream.

Mixed-grain-size sediment supply also have the same consequences as listed for fine sediment, including the downstream transport of clay- and silt-sized particles, which can cause problems for water supply.

Increased Flood Peaks

Increased flood peaks can result from tree harvest and road building, as described in Chapter 4 (Hydrology). Increased flood peaks often combine with increased landsliding and erosion in managed drainage basins, and so the effects to channels are typically interconnected with the effects of increased sediment supply.

In the case where there is increased flood peaks but no increased sediment load, increased flood peaks can cause a coarsening or armoring of the channel bed, and in some situations, scour or degradation. Bank erosion can also occur, but its occurrence as a result of forest management-caused hydrologic changes is not well documented. Several field studies have suggested that channel-bank erosion that accompanies forest management is more related to increased coarse sediment supply than hydrologic effects (Sullivan et al., 1987; Beschta, 1984; Lyons and Beschta, 1983).

Questions

1) What stream segments are susceptible to the effects of increased sediment influx?

2) What channel segments are susceptible to increased flood peaks?

Assumptions

1)Stream reaches that show evidence of widening or increased braiding on sequential aerial photographs are at greater risk to future sedimentation.

2) Channel gradient as mapped from topographic maps is a useful surrogate for sediment transporting ability and can be used to predict zones of declining transport ability

and sediment deposition. Sediment deposition, in turn, is used as an indicator of potential channel impacts.

3) The effects on channel widening of increased peak flows and increased influx of sediment are inseparable using remotely-sensed information alone.

4) Increased hillslope runoff generation is inferred by mapping factors that have been shown by field research and theory to cause increased runoff. The likelihood that increased hillslope runoff will translate into measurable increased channel flood flows is assumed to be greater in small drainage basins.

Analysis

1) Construct a sedimentation and flood hazard map. Sedimentation and flooding are considered together because their effects cannot be differentiated based on the remotely-sensed methods being proposed. Begin by mapping stream reaches which appear on sequential aerial photographs to have widened or to have undergone a noticeable trend toward braiding over time. This is taken as an indicator of increased sediment transport, although it may also indicate the effects of flooding (Grant, 1988).

Figure 6.1 shows an example of a stream reach where channel widening is apparent from aerial photographs. Figure 6.2 shows how this reach corresponds with a zone of declining channel gradient on the topographic map.

Where there is no width change noticeable on aerial photos, identify stream reaches that are most susceptible to the effects of increased sediment transport and flooding by mapping zones of declining stream gradient. To do this, plot stream gradient, as measured on a topographic map, as a function of distance along the stream.

It is desirable to be able to predict the exact mobility and deposition of sediments along the stream by a remote method, or a method that involves a small amount of field work. Bradley and Whiting (1991) proposed the use of a fundamental idea in sediment transport theory known as the Shield's diagram for classifying Type 4 and 5 streams in the

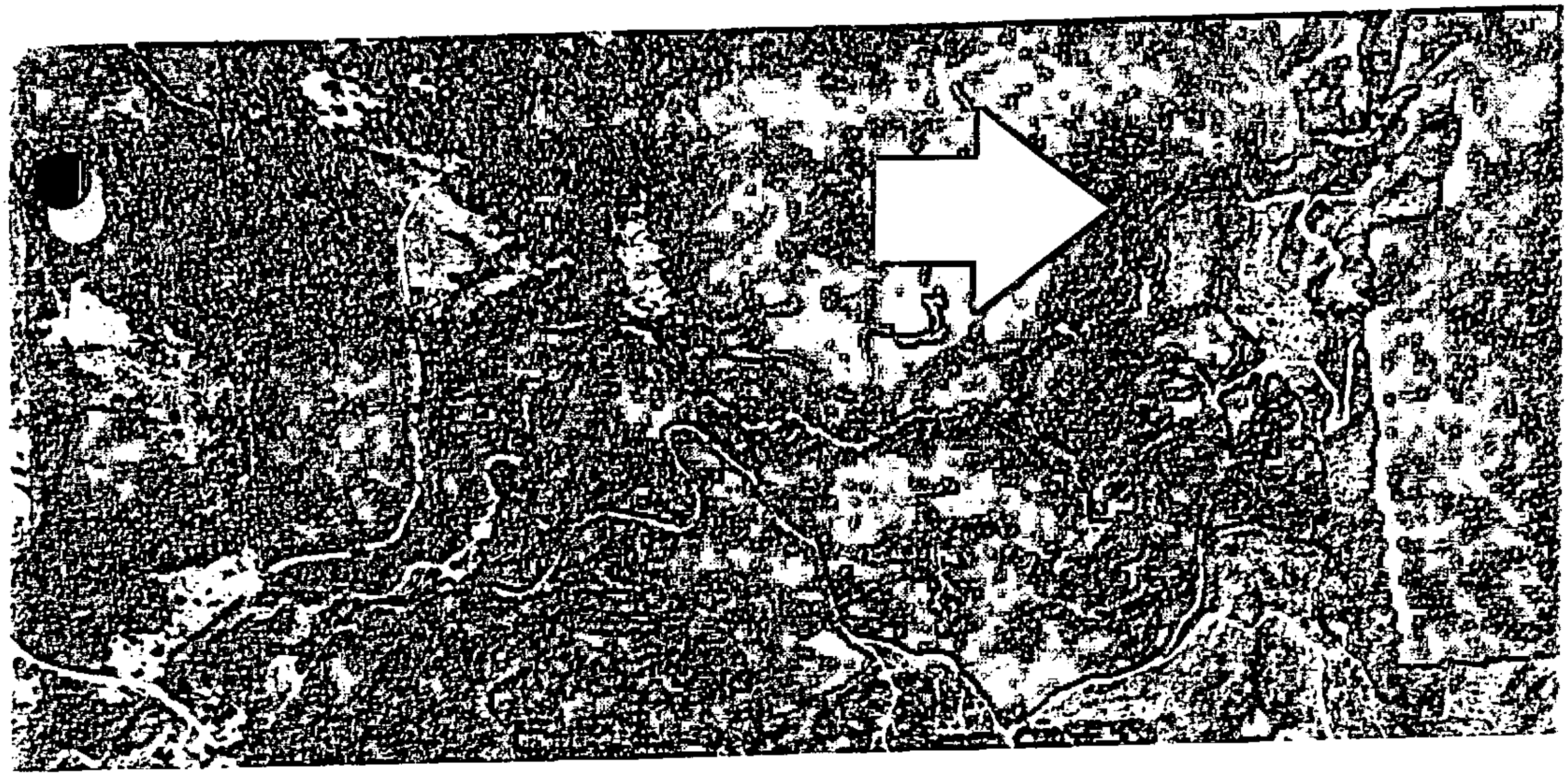
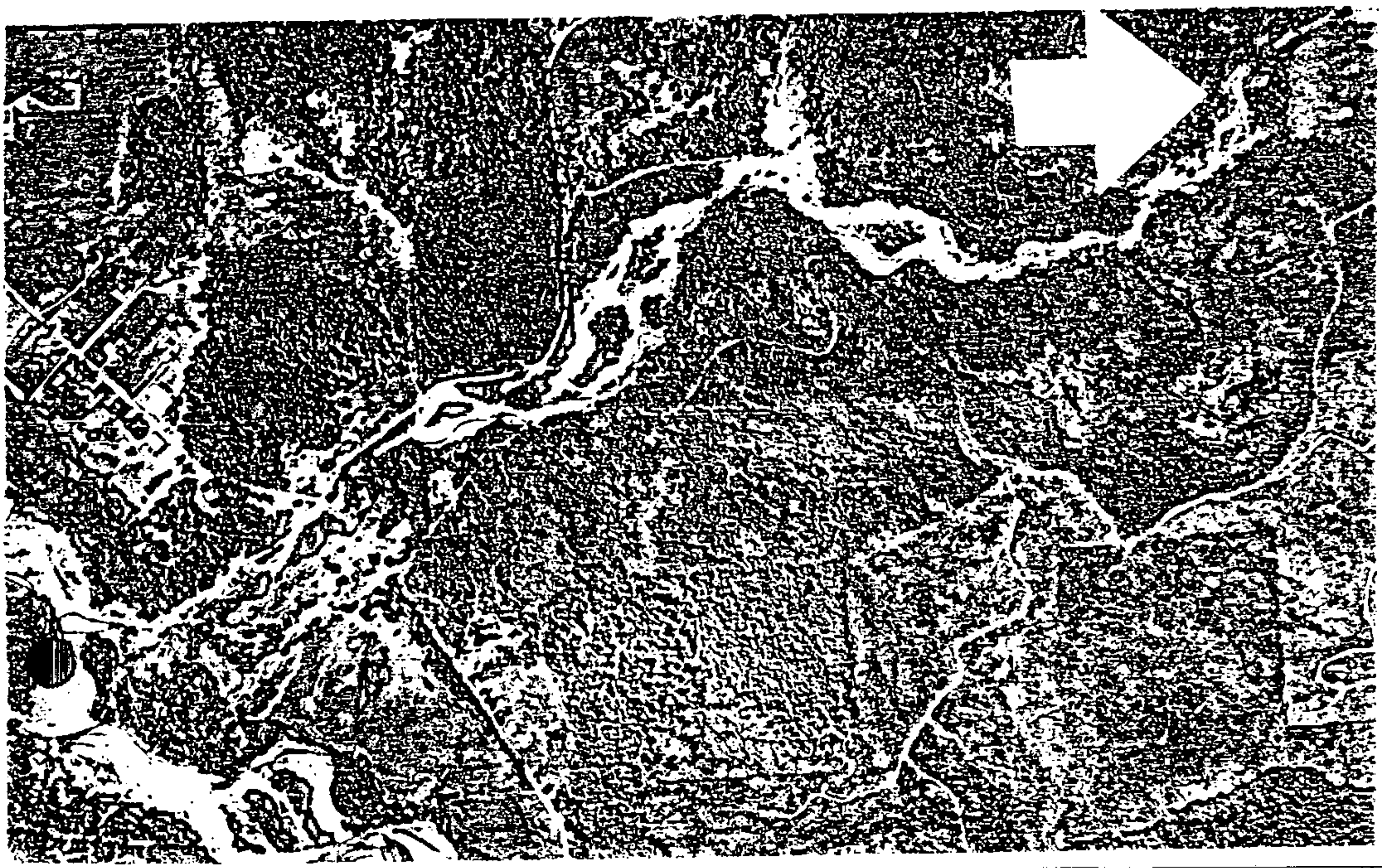


Figure 6.1 Upper: 1983 aerial photograph of Canyon Lake Creek, a tributary to the Middle Fork Nooksack River. Lower: 1987 aerial photograph of same location. The channel has widened downstream of arrow due to sediment deposition and flooding during the winter of 1984-85. The reach that shows evidence of deposition and widening corresponds ot zone of declining gradient downstream of steep canyon reach (see topographic map, Figure 6.2)



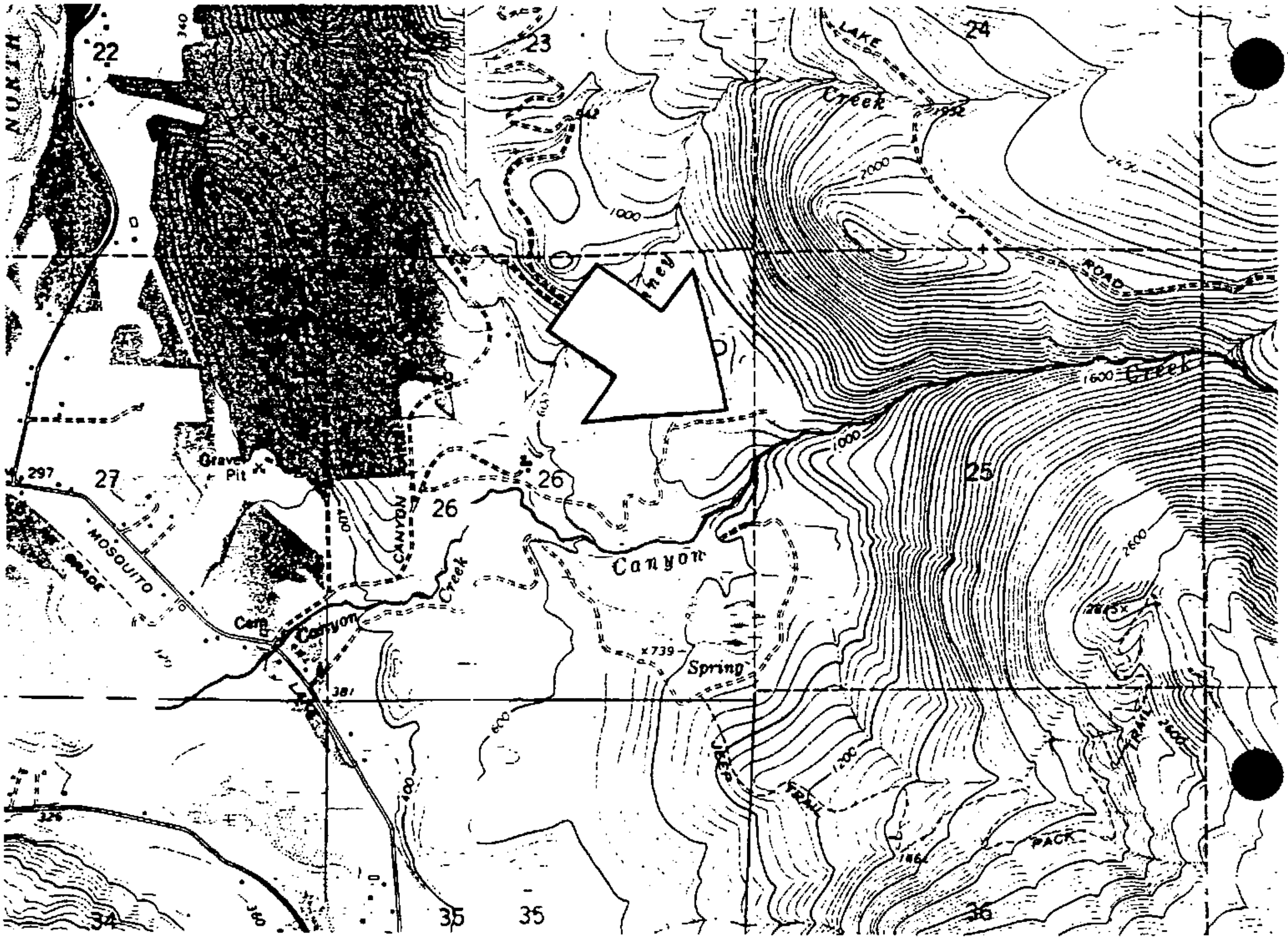


Figure 6.2. USGS 7.5 minute topographic map of lower Canyon Lake Creek. Arrow corresponds to the upper end of the declining stream gradient reach.

Pacific Northwest. While sound and well-suited for watershed analysis, the approach needs further development, as has been proposed by the University of Washington's Department of Geological Sciences Watershed Geomorphology Project funded by TFW.

In the interim, the suggested approach is to identify stream zones of declining channel gradient as a way of identifying reaches that are particularly sensitive to sediment deposition, and as a way of prioritizing the field examination for channel impacts detailed in the chapter on habitat.

Hazard Decision

The result of the analysis will be a map showing channel reaches that exhibit evidence of historic widening or increase in braiding, as mapped from sequential aerial photographs, as well as zones of declining channel gradient, which have been determined from a topographic map.

Chapter 7 - Habitat

Introduction

Watershed analysis assesses the influences of hillslope processes on fish habitat. Habitat quality is largely determined by the delivery of water, wood and sediment to a stream segment. In order to assess the risk to habitat quality and fisheries by watershed processes, we must identify stream morphological features which form habitat and which can be directly or indirectly altered by these processes. These habitat features should ideally have a direct relationship to fish use or stream carrying capacity.

In order to assess the suitability of a stream segment as fish habitat, it is necessary to identify specifically which channel features are important to critical life stages of species present. The Cumulative Effects Taskforce of the TFW CMER Committee has identified six potential critical habitat features for coho salmon (See Table 7.1). It is the intent of the Taskforce to identify threshold levels for these six parameters, however, at the present time, these levels have not been identified.

In lieu of finalized TFW parameters, we propose using habitat suitability indices (HSI) developed by the U.S. Fish and Wildlife Service (USFWS, 1983-86). Habitat suitability criteria have been developed for chinook, coho, pink, and chum salmon as well as rainbow and cutthroat trout. HSI for each species are shown in Tables 7.2 - 7.7. These suitability ratings will be used for field assessment of habitat condition during the Level 1 analysis. Parameters listed as proposed for use are those parameters which have been shown to strongly influence the use or production of fish and/or for which it is presently possible to relate to forest management induced channel responses. HSI can not be used to predict the actual production from a stream, however they are designed to be used as indicators of the carrying capacity of a stream (USFWS, 1982).

Table 7.1

TFW/CMER Draft Resource Threshold Parameters

SPECIES	HABITAT PARAMETER
Coho	Large Organic Debris
	Spawning gravel Quality
	Spawning gravel stability
	Primary pool frequency
	Cobble embeddedness
	Temperature

Table 7.2

Chinook Salmon Habitat Requirements
(USFWS, 1986)

Life History Stage	**Habitat Parameter**	**Proposed for Use**
Adult	Average max or min pH	no
	Max temp	no
	Min D.O.	no
	% pools	**yes**
	Pool class	**yes**
Embryo	Min D.O.	no
	Max or min temp	no
	Avg gravel size	**yes**
	Avg water velocity	no
	% fines	**yes**
	Avg base flow	no
	Avg peak flow	no
Juvenile	Avg max or min pH	no
	Max temp	no
	Min D.O.	no
	% pools	**yes**
	Pool class	**yes**
	Avg base flow	no
	Avg peak flow	no
	Substrate class	**yes**
	% riffle fines	**yes**
	Nitrate-nitrogen	no
	% cover	**yes**
	Substrate cover	**yes**
	Average velocity	no

Table 7.3
Pink Salmon Habitat Requirements
(USFWS, 1985)

Life History Stage	Habitat Parameter	Proposed for Use
Adult	Annual max-min pH	no
	Avg max-min temp	no
Embryo	**Avg substrate size**	**yes**
	% fines	**yes**
	Avg water velocity	no
	Min dissolved oxygen	no
	Avg max-min temp	no
	Max salinity	no
	Avg base flow	no
	Peak flow	no
Fry	Max temp	no

Table 7.4
Chum Salmon Habitat Requirements
(USFWS, 1985)

Life History Stage	**Habitat Feature**	**Proposed for Use**
Upstream migration	Temperature	no
	Dissolved oxygen	no
Spawning, embryo, alevin	Temperature	no
	Dissolved oxygen	no
	Substrate composition	**yes**
	Discharge pattern	no
	Salinity	no
Rearing, downstream migration	Temperature	no
	Dissolved oxygen	no

Table 7.5
Coho Salmon Habitat Requirements
(USFWS, 1983)

Life History Stage	Habitat Feature	Proposed for Use
Adult	Temp during migration	no
	D.O. during migration	no
Spawning, embryo, alevin	Temperature	no
	D.O.	no
	Substrate composition	yes
Parr	Temp. during rearing	no
	D.O.	no
	% canopy	yes
	Veg comp of riparian zone	yes
	% pools (food)	yes
	Substrate composition	yes
	%pool s (cover)	yes
	% cover	yes
	Proportion of pools	yes
Smolt	**Winter cover**	yes
	Temp during smoltification	no
	D.O. during migration	no

Table 7.6
Rainbow Trout and Steelhead Habitat Requirements

Life History Stage	Habitat Feature	Proposed for Use
Adult	Avg. thalweg depth	no
	% instream cover	yes
	% pools	yes
	Pool class	yes
Juvenile	**% instream cover**	yes
	% pools	yes
	Pool class	yes
Fry	**% substrate class**	yes
	% pools	yes
	% riffle fines	yes
Embryo	Avg. max. temp.	no
	Avg. Min. D.O.	no
	Avg. water velocity	no
	Avg. gravel size in spawning areas	no
	% riffle fines	yes
Other	Max. temp.	no
	Avg. min. D.O.	no
	pH	no
	Avg. base flow	no
	Predominant substrate	yes
	% streamside vegetation (V11)	yes
	% riffle fines	yes
	% streamside vegetation (V12)	yes
	% midday shade	no
	% Avg. daily flow	no

Table 7.7
Cutthroat Trout Habitat Requirements

Life History Stage	Habitat Feature	Proposed for Use
Adult	**Avg. thalweg depth**	yes
	% adult cover	yes
	% pools	yes
	Pool class	yes
Juvenile	**% Juvenile cover**	yes
	% pools	yes
	Pool class	yes
Fry	% substrate class	no
	% pools	no
	% riffle fines	no
Embryo	Avg. max. temp.	no
	Avg. min. D.O.	no
	Water velocity	no
	Avg. gravel size	no
	% fines	no
Other	Max. temp.	no
	Avg. min D.O.	no
	pH	no
	Base flow	no
	Dominant substrate	no
	% vegetation (V11)	no
	% vegetation (V12)	no
	% riffle fines	no

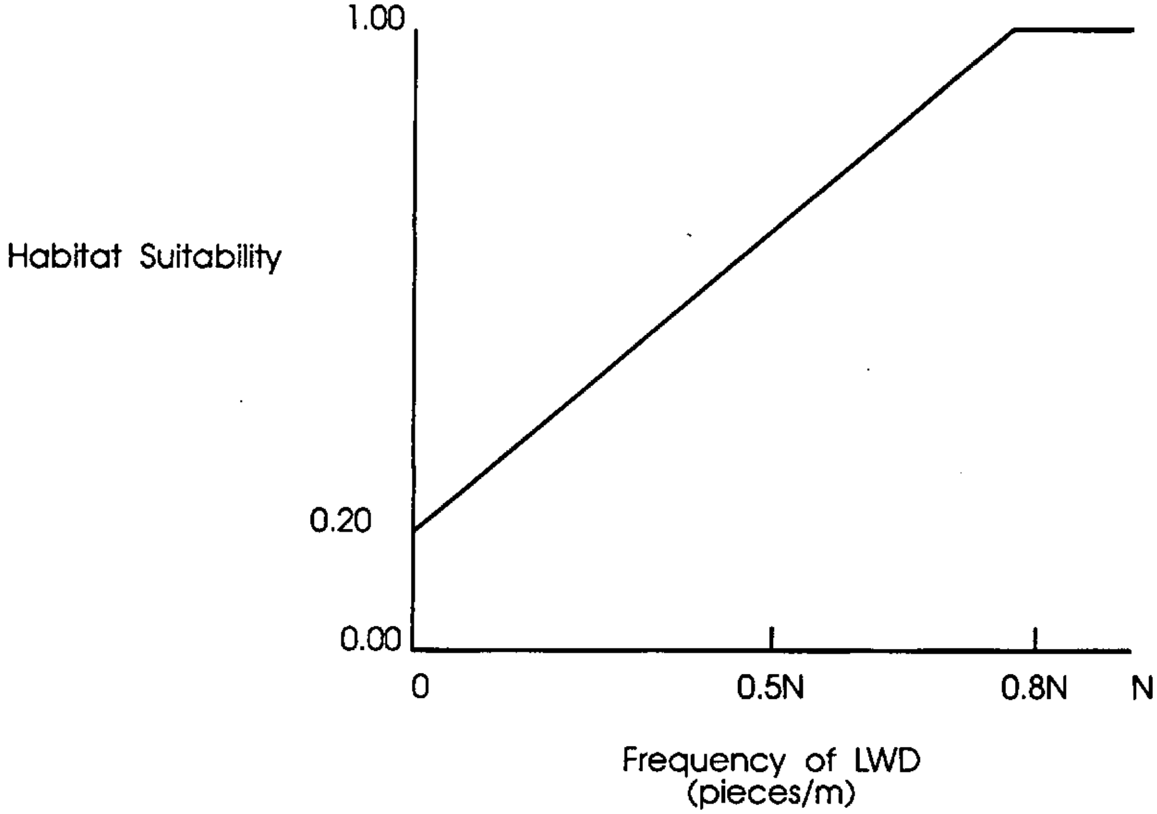
Habitat Suitability Indices (HSI) are developed based on research which has shown a relationship between a habitat parameters and fish production. Actual production in a stream will be influenced by biotic and abiotic factors such as food supply, disease, predation, water quality, escapement, and competition. Bjornn and Reiser (1991) provide and excellent overview of the observed relationships between fish use, or production, and habitat features. HSI are analogous to forest productivity site classes used in forestry. Although two sites may have the same potential productivity class, actual production will depend on stocking rates, competition from other species, insect or disease problems, etc. HSI represent a way of generalizing documented habitat/fish suitability relationships for use in impact analysis.

In addition to the USFWS criteria, we propose including LWD in the analysis of coho rearing suitability. LWD has been shown to play an important role in providing diverse pool/riffle conditions and instream cover. While each of these features is covered by a USFWS habitat suitability criteria, LWD lends itself to easy field measurement and interpretation in relation to riparian recruitment potential. In order to be consistent with the other parameters, LWD levels have been characterized in the form of a suitability index curve. The proposed HSI for LWD is shown in Figure 7.1. This figure is based on an observed relationship between LWD and coho production, and on the relationship between LWD and pool formation. The value N on the HSI graph is the level of wood expected for a given channel width. N is calculated using the relationship developed by Bilby and Ward (1989).

Salmonids can be stratified as spawning limited species and rearing limited species. Spawning limited species are those which spawn in freshwater and spend limited time in freshwater rearing habitats. These species are pink, chum, and chinook salmon. Rearing limited species are those which spend extended periods, ranging from one to several years, in freshwater habitats; or spend their entire life cycle in freshwater. These species are coho salmon, steelhead, rainbow, and cutthroat trout.

Figure 7.1

Proposed LWD HSI



logN= -1.12(log channel width) + 0.46

(Bilby and Ward, 1989)

In general, the spawning limited species utilize larger order streams (4+) for spawning activities. Rearing limited species are dominant in lower order channels (~1-3) which have suitable access and low gradient (<3-5%), or in higher gradient streams which have sufficient pool area to support resident fish.

It is also proposed for Level 1 analysis that watershed habitats be identified as to dominant species use. By identifying dominant species use, analysis can be simplified to a degree which makes it possible to consider salmonid habitat within the constraints of a Level 1 analysis. In many or most cases, identification of a dominant species will accurately reflect actual use and will provide adequate protection for other species. This assumption is based on the overlapping habitat requirements for most salmonid species. In cases where local or historic knowledge of a stream indicate that identification of a dominant species is not appropriate, a Level 2 multispecies analysis will probably be necessary.

Evaluation

The evaluation of the Habitat Response component of the prototype watershed analysis consists of:

1. Identifying fisheries species, and their habitats, which are present in a watershed;
2. Identifying the locations of these habitats within a watershed;
3. Documenting the existing conditions of these habitats as measured by the presence of morphological features which have been shown to correlate to the utilization of these habitats by salmonids.

Assumptions

Level 1 analysis makes the following assumptions:

1. Impacts to habitat represents impacts to the carrying capacity of a stream.

2. Habitats can be categorize into spawning, rearing, or other (such as transportation or holding waters which are not thought to be as sensitive to forest management related channel changes).

3. Fish species can be categorized into spawning or rearing limited species.

4. HSI can be used to make a general assessment of habitat quality.

Assessment

Level 1 habitat assessment is divided into office analysis and field analysis. Office analysis is intended to identify watershed habitat types, access to habitat, identify habitats at risk by hillslope and channel processes, and identify other relevant limiting factors.

Office analysis involve four steps:

1. Map (using 7.5' USGS topographic maps) stream reaches accessible to anadromous fish. This map may be based on the WDF Stream Catalog, or other information and local knowledge.

2. Map stream reaches by habitat "type" based on dominant species use. Relevant supporting data includes WDF stream catalog; WDF, WDW, and tribal spawning ground and habitat surveys; and other local knowledge. Habitat types are:

Rearing	coho
	steelhead
	resident trout
Spawning	chinook
	chum
	pink
Mixed Use	(go to Level 2 analysis)

Transportation or other non-sensitive uses (Level 2)

It is recommended that coho HSI be used in low gradient mixed use streams or where specific delineations between coho and steelhead habitats cannot be made due to the lack of field level channel gradient measurements. Coho utilize lower gradient habitats than steelhead and are thus more susceptible to most channel processes. Coho HSI will also provide some steelhead habitat.

3. Select "representative stream reaches" for field visits. Representative areas should typify the dominant hillslope and channel processes which are active in the watershed as identified in the hillslope and channel portions of the Level 1 analysis. If representative reaches can not be identified due to diverse processes and habitat sensitivities, a Level 2 analysis may be necessary.

Field analysis is intended to provide data regarding the current condition of the habitat, provide information regarding the sensitivity of the habitat, and determine if natural or non-forest management related channel constraints exist at a particular location.

Field analysis consists of three steps:

1. Field survey of representative stream reaches. Survey will measure USFWS habitat features appropriate for the habitat type. LWD counts will also be made for channels less than twenty meters in average width.

Specific Level 1 stream survey techniques have not yet been developed, however the emphasis of such methods should be the rapid characterization of stream reaches.

We recommend a "walking" survey which quantifies habitat characteristics such as pool/riffle ratios based on linear measurements taken with a hip chain or other similar device. Detailed measurements such as width and depth should not be taken within a Level 1 analysis. Techniques which may be used are included in the Technical Appendix.

2. Field measurements compared to USFWS suitability criteria for existing habitat suitability. For USFWS habitat suitability criteria, see Attachment 2.

3. Stream reaches are rated for each of the appropriate suitability criteria. This is done by finding the measured habitat parameter value on the X axis of the appropriate suitability curve and then reading the corresponding Y value for suitability.

4. Suitability values are recorded for each reach surveyed on Form F1.

5. LWD suitability is calculated by estimating average channel width and determining the expected level of woody debris based on the relationship developed by Bilby and Ward (1989). The proposed HSI curve is shown in Figure 7.1.

Hazard Assessment

Risk to fisheries resources is determined in the interpretation and integration component of Level 1 analysis (Chapter 9). Resource value criteria which might be used to determine the value of fisheries resources is considered a policy level determination and is not included in the prototype Level 1 method.

Suggestions received for value determination include:

1. Natural production system
2. Catch and release areas
3. Major production area/minor production area
4. Threatened and Endangered
5. Unique habitats
6. Angler use levels
7. Hatchery present
8. Degraded habitat
9. Good habitat

Delivery

Impacts to fisheries habitat resources from active hillslope processes are assessed in the interpretation and integration component of Level 1 analysis.

Level 2 Recommendations

Level 2 analysis should emphasize:

1. Improved habitat survey methods. Include subsurface sampling for fine sediment and more quantitative measurement of morphological features, perhaps using modified Ambient Monitoring survey method.

2. Additional habitat parameters identified by TFW as critical to life history stages.

3. Multi-species or multi-use assessment for areas which cannot be identified by primary use.

4. Verification of fish access.

5. Collection of Level 1 survey data in as many streams within sub-WRIA as possible.

Chapter 8 - Beneficial Resources at Risk

Introduction

Hillslope hazards which can have catastrophic effects on stream channels can also have effects on other non fisheries resources such as roads, bridges, homes, and human life. Hillslope processes of particular concern are debris flows and dam break floods triggered by shallow rapid landslides, and flooding caused by rain-on-snow and decreased interception of rainfall (see hydrology section for more detail).

The Level 1 evaluation of risk to non-fisheries resources involves identifying resources at risk and determining locations where hillslope hazards have the potential to cause harm. Beneficial resources include hatcheries, public water supplies, roads, bridges, homes, commercial development, and agricultural facilities.

Evaluation

The evaluation of beneficial resources at risk involves the determination of the following:

1. Location of beneficial resources. These resources are identified from existing data sources, local knowledge, and aerial photographs.

Assumptions

NA

Assessment

The Level 1 method consists of the following step:

1. Map existing beneficial resources based on aerial photos, public and tribal records, and local knowledge. Map entire sub-WRIA. on 7.5 minute USGS quad.

Hazard Evaluation

No criteria are proposed to rank resources by value. Final risk call is made in the interpretation and integration step of Level 1 analysis.

Delivery

NA. Delivery of hillslope hazard to beneficial resource is assessed in the interpretation and integration step of Level 1 analysis.

Level 2 Recommendations

Emphasis on Level 1 should be placed on providing as complete a resource map as possible. Risk determinations to these resources will be improved under Level 2 analysis by improving hillslope hazard assessments.

Chapter 9 - Integration of Watershed Processes

Introduction

The physical and biological data bases developed in the preceding chapters can be integrated to evaluate the relationships between hillslope-based geomorphic, hydrologic and vegetative processes, and habitat conditions in streams. Watershed analysis attempts to determine the probable causes of existing habitat conditions, and the probable condition of future habitat conditions given various identified geomorphic, hydrologic and vegetative processes in watersheds.

First, the data bases acquired from analyses of sediment production, hydrology, and riparian vegetation are overlaid with data on habitat distribution and condition. This is used to define probable causes of existing habitat condition. Second, this information is used to predict the future habitat response to various processes in a watershed.

Overlaying Physical and Biological Data Bases

The following data bases from the watershed analysis are required for the evaluation of existing habitat conditions:

1) Map of documented debris flows and dam-break floods; and reaches susceptible to these events in the future;

2) Map of existing channel widening from sediment deposition or flooding, and zones susceptible to widening and deposition;

4) Map of riparian recruitment hazards;

5) Landslide map;

6) Map of sub-watersheds showing surface erosion indices;

7) Increase in peak flows;

8) Map of habitat locations; and

9) Tables of habitat condition.

The channel sensitivity indicators contained in 1 - 4 are overlaid with 8 (habitat distribution) to identify where fish habitat overlaps with channels that are either potentially sensitive to certain watershed processes or which have had processes occur that can negatively affect habitat. The landslide, and surface erosion maps, and results from peak flow runoff analyses are used along with the sedimentation map to predict likelihood of sedimentation and flooding effects. The overlay and integration of all the physical and biological data are shown in Figure 9.1.

For streams which have been surveyed for existing large woody debris (LWD), it is possible to combine this information with the riparian hazard rating developed in Chapter 7. This results in a ranking of overall risk of inadequate amounts of channel LWD which considers both existing LWD levels and the potential for riparian recruitment. The recommended final rating criteria are shown in Table 9.1.

While the channel sedimentation map will predict likely locations of impact, the hillslope-process maps can be used to estimate likelihood of occurrence. For example, a very high surface erosion index in several adjacent sub-basins--a high "hazard"--would indicate a high likelihood that fine sediment is depositing in the low-gradient reaches identified in the channel map--a high "risk." This approach corresponds to the "top-down" approach to assessment described in Chapter 2. These predictions can be made prior to the field assessment, and used to focus field efforts.

The "bottom up" approach of Chapter 2 takes place in a field evaluation of river geomorphologic features. Determining the cause of a channel morphological feature important to fish habitat, as summarized in the habitat condition table, depends on accurate interpretation of channel geomorphology and flood hydrology. Therefore, a field assessment of channel morphology should be conducted by the project geomorphologist. The geomorphologist may make observations or measurements to assess the cause(s) of a channel morphologic condition relevant to fish habitat. These observations or measurements should take into account the fluvial geomorphic indicators of hillslope-based geomorphic,

Integration Of Watershed Processes

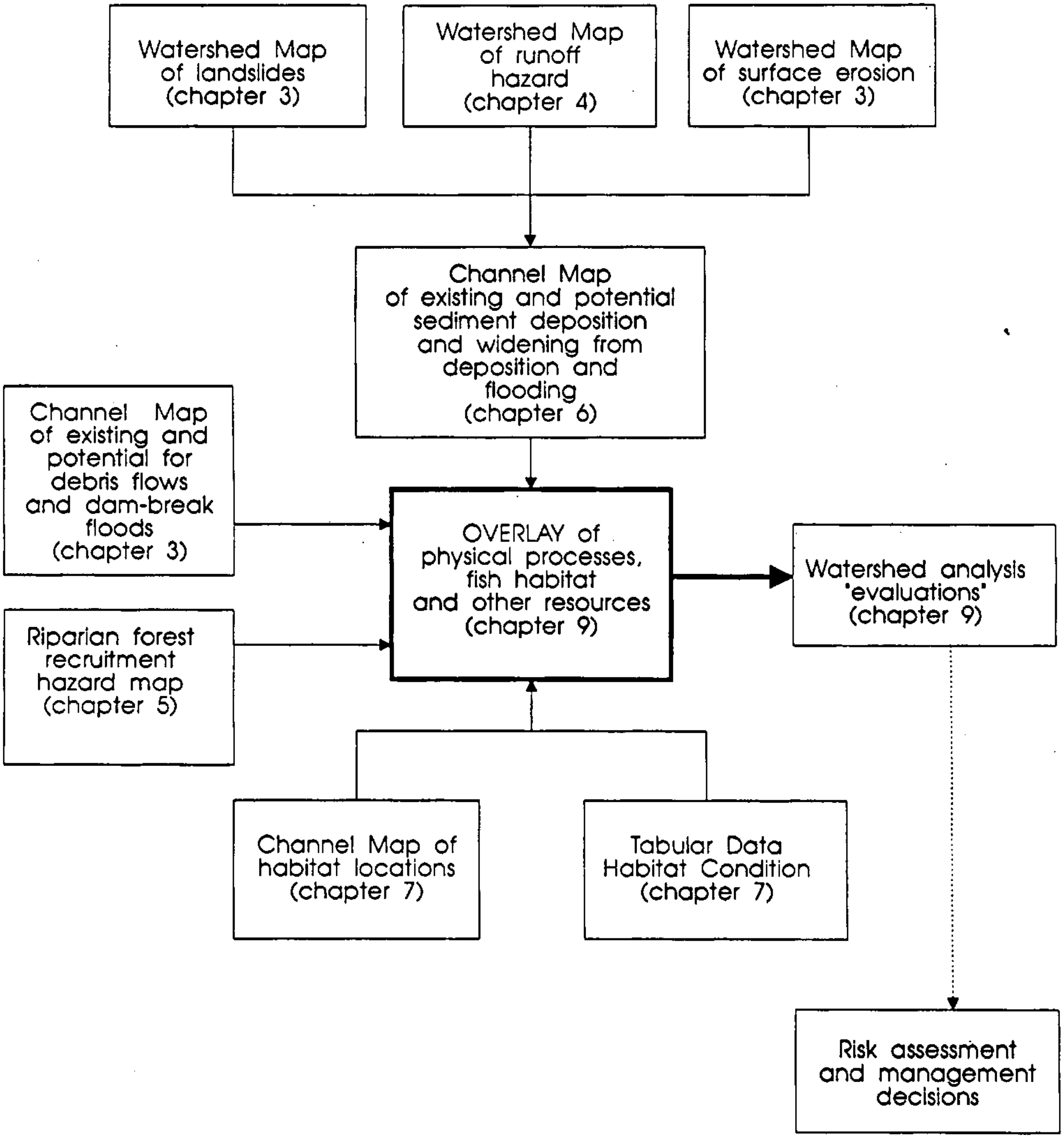


Figure 9.1

Table 9.1.

Riparian LWD Recruitment Risk

Final Call

Field data)> (Riparian hazard rating)	**Low Existing Wood**[1]	**Adequate Existing Wood**
High	High	High
Medium	High	Medium
Low	Low	Low

A final call is made on a reach by reach basis as to the risk to habitat based on the potential of the riparian zone to deliver wood to the channel and the channels existing wood levels.

1 Low wood is defined by the USFWS coho rearing suitability curve relating suitability to percent of total area consisting of quiet backwaters and deep (>45cm) pools with dense cover of roots, logs, debris jams, flooded brush, or deeply undercut banks. Substitute TFW AMSC wood related pools. Low equals < 30% of area in pools. Adequate equals > 30%.

If Bilby and Ward (1989) based HSI criteria is used, low wood is suggested to be defined as less than 80% of the expected abundance (N).

hydrologic and vegetative processes. The fluvial geomorphic indicators of hillslope processes are shown grouped by changes in channel morphology relevant to fish habitat in Table 9.2. The table can be used as a guide to relate channel conditions to hillslope-based processes, involving sediment, hydrology and vegetation. In general, the more of the indicators listed in Table 9.2 which are observed in channels, the higher the confidence with which cause and effect relationships can be made.

Because several different hillslope-based processes can cause a similar condition to exist in channels, it will often be difficult to isolate the cause of a channel condition when several processes are active. To help in isolating the possible cause(s) of a channel condition, it is necessary to consider the effectiveness of individual processes. Table 9.3 lists several series of processes ranked by their relative effectiveness at causing changes to specific channel-based attributes of fish habitats. By considering the relative contributions of each process, it may be feasible to isolate the cause of an existing degraded habitat condition. Table 9.3 can also be used as a mental check list to use when studying the maps of watershed processes.

The outcome from this analysis is a series of evaluations that link existing condition of habitat to watershed processes. For example:

HABITAT CONDITION	PROBABLE CAUSE
Loss of pools	Debris torrent
Instability	Numerous landslides Debris torrent Floods
Fine sediment in gravels	Landslides Road surface erosion

Table 9.2. Watershed processes, channel response , fluvial geomorphology, and vegetative indicators.

HILLSLOPE BASED GEOMORPHIC, VEGETATIVE, AND HYDROLOGIC PROCESS	CHANGING CONDITION	CHANNEL RESPONSE	CHANNEL-BASED GEOMORPHIC AND VEGETATIVE INDICATORS
#1 Landslide/Debris-flows	Accelerated sediment supply (mixed grain size)	Decreased channel stability	-Existence of non-vegetated erodable banks -Numerous abandoned channels -Braided channel pattern -Large, unvegetated mid-channel bars
#2 Landslide/Debris-flows	Accelerated sediment supply (mixed grain size)	Filling of pools; Low pool/riffle ratio	same as above, and in addition: -lack of pools where expected such as outside of meanders, below or against obstructions (LOD and boulders)
#3 Landslide/Debris-flows	Accelerated sediment supply (mixed grain size)	Coarsening or fining of substrate	Same as #1 and 2 above, and in addition, particles are angular
#4 Stream cleanout/Splash damming	Loss of LOD	Loss of pools and loss of cover	Riparian old growth stumps, lack of LOD in streams
#5 Harvest riparian zone	Loss of LOD	Loss of pools and loss of cover (delayed)	Riparian zone harvested
#6 Harvest riparian zone	Increased sunlight	Increase in water temperature	Lethal temperature recorded in summer
#7 Rain-on-snow flooding	Channel bank erosion	Decreased channel stability	Fresh, raw bank erosion, many roots of trees and stumps are exposed

Table 9.2., continued

HILLSLOPE BASED GEOMORPHIC, VEGETATIVE, AND HYDROLOGIC PROCESS	CHANGING CONDITION	CHANNEL RESPONSE	CHANNEL-BASED GEOMORPHIC AND VEGETATIVE INDICATORS
#8 Dam-break floods	Loss of LOD	Loss of pools - increase in riffles	Geologic and rheologic evidence for a dam-break flood: -particles may be more rounded than #3 -channel LOD incorporated by flood and deposited in clumps on the sides of channels and valleys -large woody debris piles at the terminus of the flood -batter-marks in trees far above normal flood height
#9 Dam-break floods	Increase in sediment supply (mixed grain size)	Loss of pools/pools filled	Geomorphic and rheologic evidence for floods: -Lack of pools where you would expect to find them
#10 Road and surface erosion	Increase in fine sediment	Increased fines in substrate and in suspended load	Elevated fines in substrate and in pools - no other source of fine sediments

Table 9.3. Varying effectiveness of watershed processes on habitat conditions

	LOSS OF POOLS/COVER	COARSENING OF SUBSTRATE	INCREASE IN FINE SEDIMENT IN SUBSTRATE
Most effective	-Dam-break floods	-Debris flows	-Road erosion
	-Loss of riparian zone(delayed)	-Landslides	-Other surface erosion
	-Debris flows	-Dam-break floods	-Debris flows
	-Landslides	-Numerous gullies	-Dam-break floods
effective		-Flooding	

	DECREASED CHANNEL STABILITY	INCREASED WATER TEMPERATURE	LOSS OF LARGE ORGANIC DEBRIS
Most effective	-Dam-break floods	-Loss of riparian trees	-Dam-break floods
	-Debris flows	-Dam-break floods	-Stream clearcut
	-Landslides	-Debris flows	-Loss of riparian trees (delayed)
	-Flooding	-Landslides	
	-Stream cleanout		
effective	-Loss of riparian zone (delayed)		

Two physical processes, such as dam-break floods and overbank flooding, can interact. For example, in situation 2 above, flooding by itself may not have a major effect on bed and vegetated bank stability. However, following a dam-break flood which destroys ripariàn vegetation and exposes previously vegetated floodplains to erosion, flooding can be much more effective at eroding channel beds and banks, thereby destabilizing fish habitat. This interaction between processes is an important aspect of cumulative watershed effects but unfortunately most of these interactions are not well enough understood to allow their quantification. Many of these interactions, though, are qualitatively explained by existing geomorphic and fisheries science theory.

The interactive effects of two processes on a single channel response are listed in Table 9.4. This table can be used to evaluate in qualitative terms whether the existence of two processes is strengthening, weakening or having no effect on a given channel/habitat response. For example, landslide or debris flow-accelerated sediment supply can fill downstream pools. This effect will be strengthened by a dam-break flood because it will remove the woody debris which helps form pools. The occurrence of a dam-break flood by removing woody debris that helps form pools will actually strengthen the pool filling effectiveness of accelerated sediment supply from landslides or debris flows (Row 1, Table 9.4). By using table 9.4, one can establish the combinations of processes which are causing (or will potentially cause) the largest habitat problems, or slow habitat recovery. Return to Chapter 10 for an example of watershed analysis.

The timing and persistence of effects on fish habitats varies with the hydrologic, geomorphic, and vegetative watershed processes. Some processes have immediate result, such a dam-break floods, while other processes, such as loss of riparian forests, will have a delayed response. In addition, the effects of watershed processes will have various levels of persistence. Table 9.5 lists the variation in the timing and persistence of effects on channel and fish habitats by various watershed processes.

Table 9.4. Interactions between two watershed processes on a single habitat condition.

PROCESS/ INITIAL CHANNEL RESPONSE (from table 8-1)	ADDITIONAL PROCESS: STRENGTHENING, WEAKENING , OR HAVING NO EFFECT ON INITIAL RESPONSE					
	Landslide-Debris flow accelerated supply	Stream cleaning	Harvest of riparian zone	Rain-on-snow flooding	Dam-break floods	Surface erosion
#1 Landslide-debris flow/ decreased channel stability		strengthen	delayed strengthen	strengthen	strengthen	no effect
#2 Landslide-debris flow/ filling of pools		strengthen	delayed strengthen	no effect	strengthen	possible strengthen-depends on grain size
#3 Landslide-debris flow/fining or coarsening of substrate		no effect	no effect	depends on sediment - water balance	strengthen or weaken - depends on grain size	no effect
#4 Stream clean/(loss of pools and cover)	strengthen		delayed strengthen	no effect	strengthen; weaken if adds LWD	no effect
#5 Harvest riparian zone/loss of pools and cover	strengthen	strengthen		no effect	strengthen; weaken if adds LWD	possible strengthen - depends on grain size
#6 Harvest riparian zone/ increase stream temperature	strengthen	no effect		no effect	no effect	no effect

T[illegible].4., continued.

PROCESS/ INITIAL CHANNEL RESPONSE (from table 8-1)	ADDITIONAL PROCESS: STRENGTHENING, WEAKENING, OR HAVING NO EFFECT ON INITIAL RESPONSE					
	Landslide-Debris flow accerated supply	Stream cleaning	Harvest of riparian zone	Rain-on-snow flooding	Dam-break floods	Road and surface erosion
#7 Rain-on-snow flooding/ decreased channel stability	strengthen	strengthen	delayed strengthen		strengthen; weaken if adds LWD	no effect
#8 Dam-break floods (loss of LOD)/loss of pools and cover	strengthen for accelerated sediment supply; weaken for accelerated LWD supply	strengthen	delayed strengthen	no effect		possibly strengthen
#9 Dam-break floods (by accerated sediment supply)/loss of pools and cover	strengthen	strengthen	delayed strengthen	weaken if sediment transport increases		possibly strengthen
#10 Dam-break floods (by accelerated sediment supply/ decreased channel stability	strengthen	strengthen	delayed strengthen	strengthen		no effect
#11 Road and surface erosion/ increase fines in substrate	strengthen	no effect	no effect	strengthen if banks are composed of fine sediment; weaken if banks are composed of coarse sediment	no effect	

Table 9.5
Timing and Persistence of Effects

HILLSLOPE BASED GEOMORPHIC, VEGETATIVE, AND HYDROLOGIC PROCESS	CHANGING CONDITION	EFFECTS IMMEDIATE OR DELAYED?	PERSISTENCE OF EFFECTS
#1-#3. Landslide/Debris-flows	Accelerated sediment supply (mixed grain size)	Effects are immediate at site(s) of transport and deposition. May continue for years to decades downstream of deposit(s)	Initial delivery of large volume of sediment is short term (hrs.-days). Continued delivery of coarse and fine sediment may persist for several years, particularly below deposition zone.
#4 Stream cleanout/Splash damming	Loss of LOD	Immediate	LOD deficit will remain until new wood enters stream from riparian forest. Persistance will thus depend on riparian recruitment potential. (10's - 100's years)
#5 Harvest riparian zone	Loss of LOD	Delayed	Loss of LOD will usually be gradual through process of decomposition. LOD deficit will remain until new wood enters stream from riparian forest. Recruitment potential of riparian forest may be minimal for 80-200+ years after harvest.
#6 Harvest riparian zone	Increased sunlight	Immediate	Will persist until riparian forest is sufficiently tall to provide shade. Height dependent on stream width.
#7 Rain-on-snow flooding	Channel bank and bed erosion (decreased channel stability)	Immediate	May persist until basin vegetation returns to "hydrologically mature" state (up to 40 years)
#8 Dam-break floods	Loss of LOD	Immediate	LOD deficit will remain until new wood enters stream from riparian forest. Persistence will thus depend on riparian recruitment potential

Table 9.5
(continued)

HILLSLOPE BASED GEOMORPHIC, VEGETATIVE, AND HYDROLOGIC PROCESS	CHANGING CONDITION	EFFECTS IMMEDIATE OR DELAYED?	PERSISTENCE OF EFFECTS
#9 Dam-break floods	Increase in sediment supply (mixed grain size)	Immediate and Delayed	Transport of large volumes of sediment is immediate (first year although in some cases it may persist for years). Continued delivery of fine sediments may persist for several years, particularly below deposition zone of coarse materials
#10 Road and surface erosion	Increase in fine sediment	Continuous	Persists until road is no longer in use and road surface is revegetated.

From a fisheries perspective, geomorphic, hydrologic and vegetative watershed processes can be related directly to fish habitat. Table 9.6 lists the potential effects on fish habitat from various watershed processes.

The proposed watershed analysis is conducted at a basin size of 2 - 20 mi^2, and hence assessment of cumulative effects in larger areas is not accounted for in the analysis. Spacing and timing of impacts is important when considering aspects of ecosystems such as refugia, recovery of impacts and diversity of habitats and species. Therefore, it is recommended that individual watershed analyses be considered together within the context of entire sub-WRIA's to address spatial and temporal aspects of forestry-induced impacts in watersheds.

Predicting the Future Condition of Habitat

The map overlays, habitat location data, and information on the effect of watershed processes on habitats gained from other watershed analyses can be used to predict the future condition of habitat.

Three categories of future effects need to be considered in assessing future conditions. They include:

1) Delayed deterministic. These are ongoing processes of degradation or healing which have been activated but which have not yet been fully realized in the channel (e.g. loss of wood from a stream channel with inadequate recruitment);

2) Delayed stochastic. These are processes for which there is an element of probability associated with future occurrence (e.g. basin has been recently harvested, no mass wasting or floods yet); and

3) Impacts from future management activities.

Each of these processes requires a different approach for assessment.

<u>Ongoing Processes</u>

Table 9.6
Potential effects on fish habitat from watershed processes.

HILLSLOPE BASED GEOMORPHIC, VEGETATIVE, AND HYDROLOGIC PROCESS	POTENTIAL EFFECTS ON FISH HABITAT
#1 Landslide/Debris-flows	Filling of pools, scouring of spawning and food production riffles, loss of LWD from channel, opening of riparian canopy.
#2 Landslide/Debris flows	Downstream increases in fine sediment in spawning and food production riffles resulting in decreased spawning success and food production.
#3 Landslide Debris flows	Increase of LWD at deposition site. Possible source of gravels in sediment starved systems.
#4 Stream cleanout/Splash damming	Removal of instream cover, decrease in pool/riffle ratios, bank and bed destabilization.
#5 Harvest riparian zone	Decrease in recruitment of LWD to channel resulting in loss of instream cover, decrease in pool/riffle ratios, bank and bed destabilization. Possible increase in small woody debris which may provided nutrients to stream but may also destabilize stream.
#7 Rain-on-snow flooding	Scour of spawning and food production riffles, coarsening of substrate, decreased channel stability, increased hillslope and bank erosion.
#8 Dam-break floods	Loss of LWD in channel resulting in decrease of instream cover, decrease in pool/riffle ratios, scouring of spawning and food production riffles.
#9 Dam-break floods	Filling of pools resulting in decrease in pool/riffle ratios, increase in fines in spawning and food production riffles resulting in decreased spawning success and lower food production.
#10 Road and surface erosion	Increase fines in spawning and food production riffles resulting in decreased spawning success and lower food production

Ongoing hillslope and channel processes can be identified and a determination made of whether the impacts from those processes on channel morphologic features are still increasing or decreasing. If the impacts on the channel are largely over, such as after a debris flow, channel and habitat can be characterized as beginning recovery (Figure 9.2). Channels which will continue to see increasing impacts from past activities can be characterized as declining (Figure 9.2). Examples of this are the continued loss of LWD from a stream through decomposition and lack of recruitment from the riparian zone from past harvest activities. This is an example of a delayed deterministic impact. The examples in the figures indicate recovery and decline as vectors from the existing habitat condition. The exact angle of the vector represents the rate at which recovery or decline is likely to occur. This rate is not calculated at Level 1 but the assessment of future impacts requires that an educated estimate of the direction of the vector be identified based on Level 1 analysis. Tables 9.1 through 9.5 can be used as an aid in making this estimation.

Future potential impacts

Assessment of potential future impacts to habitat requires extrapolation to similar areas within the watershed or watershed partition. Extrapolation has been discussed previously in the hillslope and channel sections of this report. During Level 1 analysis, field data from streams within the basin representing extremes in conditions are collected. In order to predict likely impacts to a stream from future management activities (Stream B, Figure 9.3), a stream or number of streams with similar watershed hazard conditions (Stream A, Figure 9.3) can be used as a guide from which extrapolations may be made. If Stream A has a lower measured habitat suitability, and this lowered suitability has been linked to management activities, this lower suitability can be used as a guide to the expected impacts of planned management activities to Stream B. If Stream A is of higher suitability than Stream B , and this higher suitability is associated with management, then the condition of Stream A can be used to estimate an expected upper suitability value or potential for Stream

Figure 9.2

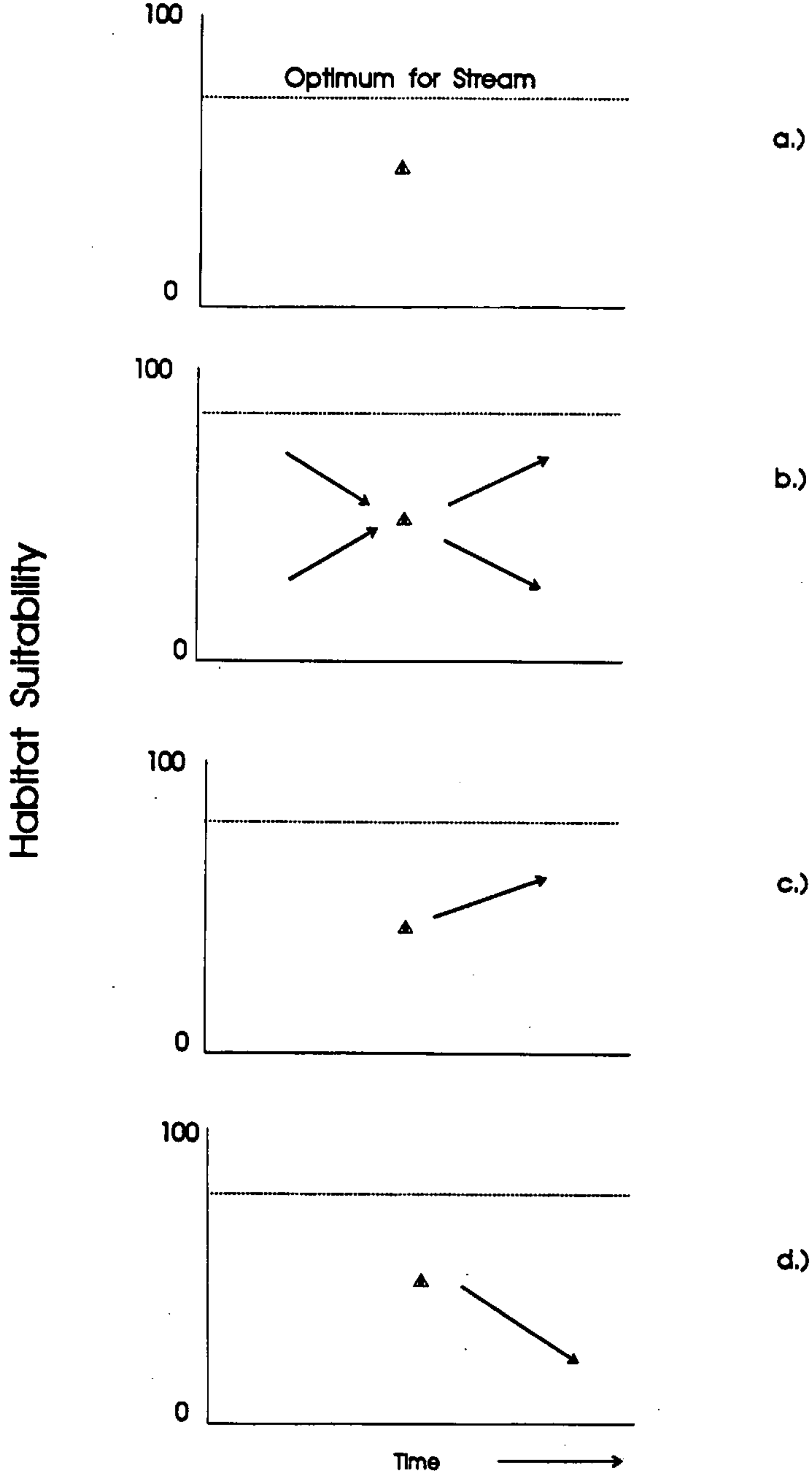
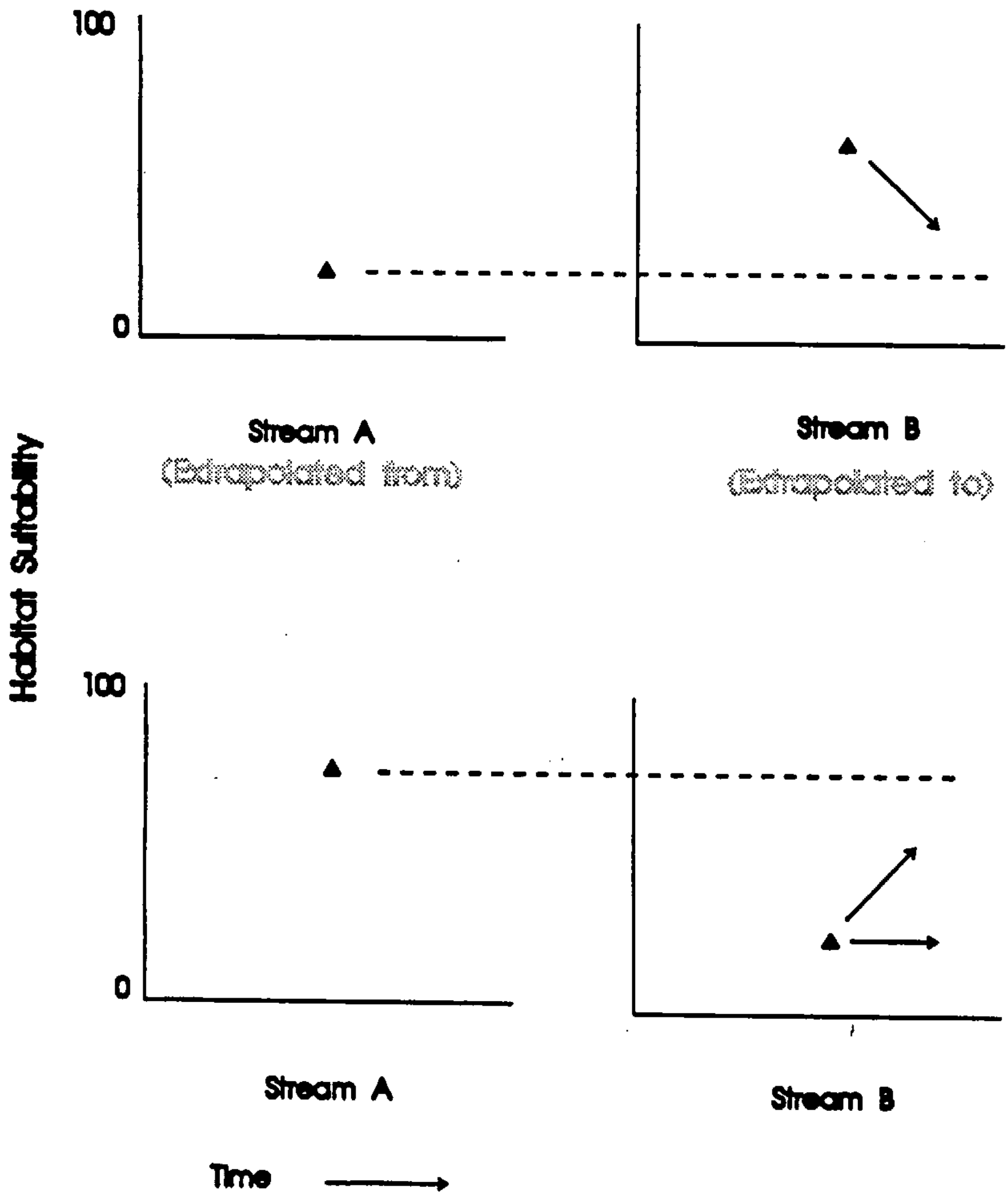

Habitat Suitability
100
Optimum for Stream
0
a.)
100
0
b.)
100
0
c.)
100
0
d.)
Time

Figure 9.3


Habitat Suitability
100
0
Stream A
(Extrapolated from)
Stream B
(Extrapolated to)
100
0
Stream A
Stream B
Time

B. If the higher suitability in Stream A is not attributable to management, then the assumption is made that there is no impact on habitat from the management activity and the future condition of Stream B will depend on natural channel processes.

Ideally, in order to use Stream A as an indicator of change, we would have a time series of habitat suitability data which could be used to determine the magnitude and rate of change which was associated with management. Since most streams have not been surveyed even once, this is not feasible at this time and research from the region must be used to estimate the rate of habitat recovery or decline associated with hillslope processes. We believe that establishing a monitoring program associated with Level 1 and II analyses is essential if within-watershed extrapolation is deemed superior to regional extrapolation from research.

By considering the process/resource overlay described above, and by referring to Tables 9.1 through 9.5, estimations of future habitat conditions can be made. Accuracy and therefore confidence in the predictions will depend on which geomorphic, hydrologic and vegetative processes are being considered, and how the data bases were created (e.g. past occurrences in the same stream, extrapolation or models, Chapters 2 - 5). Predictions will also be much easier for watersheds where a single hillslope process dominates the stream channel, such as where debris torrents are common. The channel response to debris torrents is quite well understood and varies little from stream to stream. Estimations of likely future condition will be more difficult watersheds where many processes are interacting. In these cases, a Level 2 analysis may be required.

Estimates of likely past, present and future habitat conditions are made using Form F2. Existing habitat suitability, as measured by survey or estimated by extrapolation, are entered on the left hand side of the form. Using the information gathered during Level 1 analysis regarding the active and possible hillslope and channel processes in the basin, and information from Table 9.1 through 9.5, estimates of likely past and future habitat conditions are made. The emphasis on this exercise should be the careful examination of the information collected and the construction of a logical scenario of past and future habitat conditions based on this information. The hillslope processes active or likely in the basin and the rationale used to estimate past and future condition are documented in the right hand portion of Form F2. An example of this process is included in the worked example (Chapter 10).

We recommend that HSI values be analyzed individually. Although the HEP procedure combines a number of HSI values into one index of suitability, we believe that this results in a loss of information and adds a level of subjectivity to the analysis that is not necessary. Subjectivity is introduced by the necessity to put weighting factors on each HSI variable when combining them to create the overall index. This creates additional uncertainty regarding the meaning of the HSI relationships.

Evaluation of the overall health and sensitivity of the stream should include an examination of the number of HSI parameters which indicate either high or low suitability, and the examination of the magnitude of deviations from high habitat value. As discussed in Chapter 2, if many HSI parameters indicate low habitat quality, and a causal link can be made to hillslope processes, then a relatively high level of certainty regarding causality can be made (Stream 1 in worked example, Chapter 10). If HSI indicators are mixed, and strong hillslope hazards cannot be identified in the basin or the partition, then less certainty is possible.

Further work in interpreting HSI values is recommended for future enhancements of the prototype.

Decision Making

As discussed in Chapter 2, in order to be useful, the technical data collected during Level 1 analysis must be analyzed and applied to a decision making process. Management decisions will be influenced by the level of certainty obtained regarding the analysis of hillslope hazards, channel response, and habitat response. As depicted in Figure 2.2, levels of certainty will vary with each analysis. The management decision may also be strongly influenced by the sensitivity and value of the resource at risk. Although this is necessarily a policy decision, three example decision rules which specify three different certainty requirements based on resource sensitivity and value are described in Chapter 2. Whether or not these decision rules, or alternatives, are made explicit through the regulatory process, or remain unstated as is currently the case, value judgements and decisions will be made.

Watershed analysis will sometimes result in very clear understanding of hillslope, channel, and habitat interactions between forest management and channel habitat. In this case, high certainty will be attained. In some cases however, a poor understanding will be the result. In these cases, a determination must be made of the need for certainty in light of the resource at risk. It is recommended that a thorough discussion of the need for decision rules be conducted within the regulatory process.

Evaluating the causes of damage to other resources

Potential loss of life and damage to public and private resources, such as homes, state highways, bridges and logging roads can be assessed similarly to fish habitats as described above. Hillslope hazard and channel response maps should be overlaid on the map depicting locations of these resources.

Chapter 10 Worked Example

In order to illustrate the prototype method, it has been applied to several sub-basins of the South Fork Hoh River basin. The Hoh sub-basins were identified for analysis during the partitioning step of the watershed analysis because of the large number of debris torrents evident on small-scale aerial photos and similarity of landforms. This worked example includes mass wasting, rain-on-snow hazard, riparian function, and fish habitat. Surface erosion is not included because it was not possible to undertake the needed field work.

Shallow-Rapid Landslides and Debris Torrents

A landslide map was constructed using the methodology presented in Chapter 3 for the two sub-basins using one set of aerial photos from 1990. Shallow rapid landslides were mapped in sub-basin 1 (or stream 1) from aerial photographs (Figure 10.1) and drawn onto a topographic map (Figure 10.2). Landform and land use data for each landslide, determined from the photos, is shown in Table 10.1. Using Figures 10.1 and Table 10.1, two areas were delineated in the sub-basin as having different landslide densities. The two map units are explained in Table 10.2 and are shown in Figure 10.2.

There is one debris torrent evident on the 1990 photos in sub-basin 1 (stream 1). It is not possible to differentiate between debris flows or dam-break floods using aerial photographs alone, so the channel was mapped as a "debris torrent" (Figure 10.2).

To illustrate the extrapolation of photo-mapped information to an adjoining basin that has not been photo-mapped, the map units developed for sub-basin 1 are extrapolated to sub-basin 2, as shown in Figure 10.2. As noted in Chapter 3, in order to extrapolate map units from one sub-basin to another, there can be no major changes in landform, lithology, geologic structure, vegetation, and elevation between the two sub-basins. The debris torrent

Figure 10.1. 1:12,000 1990 aerial photograph of the Hoh basin .

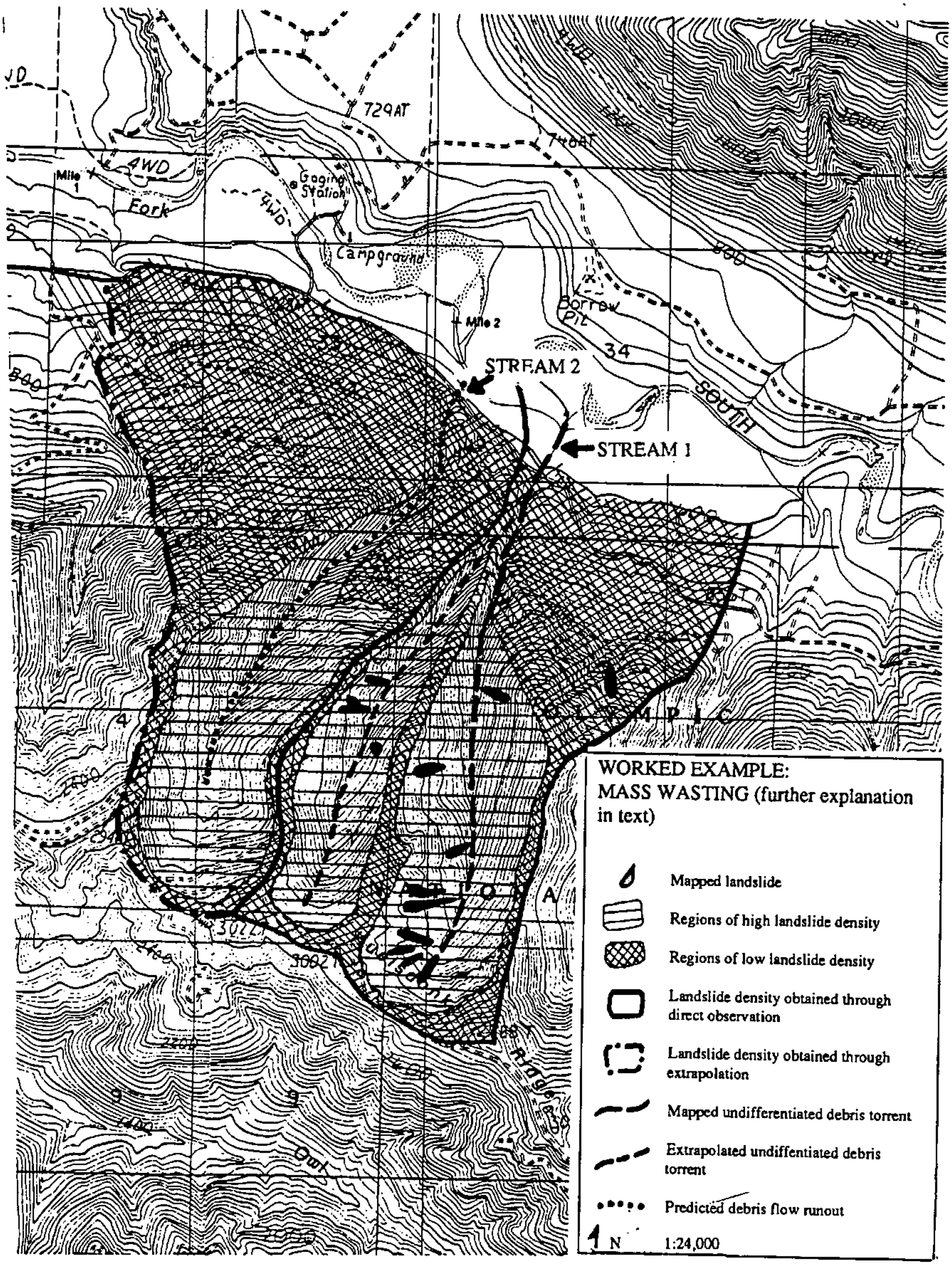


Figure 10.2. Landslide map of the Hoh basin.

Table 10.1. Data sheet for analysis of shallow landslides for the Hoh basin.

LANDSLIDE NUMBER	SLOPE GRADIENT (degrees)	SLOPE FORM	SLOPE POSITION	SEDIMENT TO STREAM	LAND USE
1	39	convergent	up	yes	CC
2	39	convergent	up	yes	RD
3	39	convergent	up	yes	RD
4	39	convergent	up	yes	RD
5	38	convergent	up	yes	CC
6	38	unknown	up	yes	CC
7	40	planar	up	yes	CC
8	40	unknown	low	yes	CC
9	37	planar	up	no	CC
10	39	planar	mid	yes	CC
11	36	planar	mid	no	CC
12	37	planar	up	yes	CC
13	35	planar	mid	yes	CC
14	25	convergent	mid	no	CC

DEBRIS TORRENT DATA

INITIATION	GRADIENT: 16 degrees	STREAM ORDER: 1	DRAINAGE AREA: 0.3 sq. mi.
DEPOSITION	GRADIENT: 5 degrees	STREAM ORDER: 2	DRAINAGE AREA: 2.3 sq. mi.

Table 10.2. Landslide map units for the Hoh basins.

<u>LANDSLIDE MAP UNIT NUMBER ONE (HIGH HAZARD)</u> - Landslide density: 8 per sq. mi. - Gradient range: greater than 35 degrees - Hillslope form: convergent topography, frequency 1 bedrock hollow per 135 meters -Sediment to stream: 11/13 = 85% of landslides - Triggered debris torrent(s) - Land use: clearcuts (10/13), roads (3/13) - Hazard rating: high
<u>LANDSLIDE MAP UNIT NUMBER TWO (LOW HAZARD)</u> - Landslide density: less than 1 per sq. mi. - Gradient range: 20 to 35 degrees - Hillslope form: mostly planar - Sediment to streams: none directly - No torrents triggered - Land use: clearcuts (3/3) - Hazard rating: low

map unit from stream 1 is also extrapolated to stream 2. This landslide and debris torrent map will be overlaid with respect to fish habitat later in this example.

Surface Erosion

Assessing surface erosion (Chapter 3) requires field work, which it was not possible to undertake during the writing of this report, and so the surface erosion analysis was omitted from this example.

Rain-on-Snow

Elevation zones for rain-on-snow hazard were mapped based on Step 1 in Chapter 4. The lower boundaries of the rain-on-snow zone is 1,400 feet on the westward side of the Olympic Peninsula. A transition zone is added to designate the area from 1,000 to 1,400 feet. The rain-on-snow zones are mapped for the Hoh sub-basins in Figure 10.3. This mapping leads to analysis of peak flows as described in Chapter 4, but was not carried out for this example.

Flood and Sedimentation Map

Because of the dominating effect of debris torrents in the sub-basins, flood and sedimentation hazards (Chapter 6) were not mapped.

Riparian Hazard

The hazard rating for riparian forest stands in the two sub-basins is shown in Figure 10.4. Forest age and stand structure within 100 feet of the stream channels was determined using 1:12,000, 1990 aerial photographs. Hazard ratings were developed using the information in Chapter 7.

Figure 10.4 shows that large areas of riparian forest are in the high hazard category. These stands were harvested recently, but prior to the enactment of riparian leave

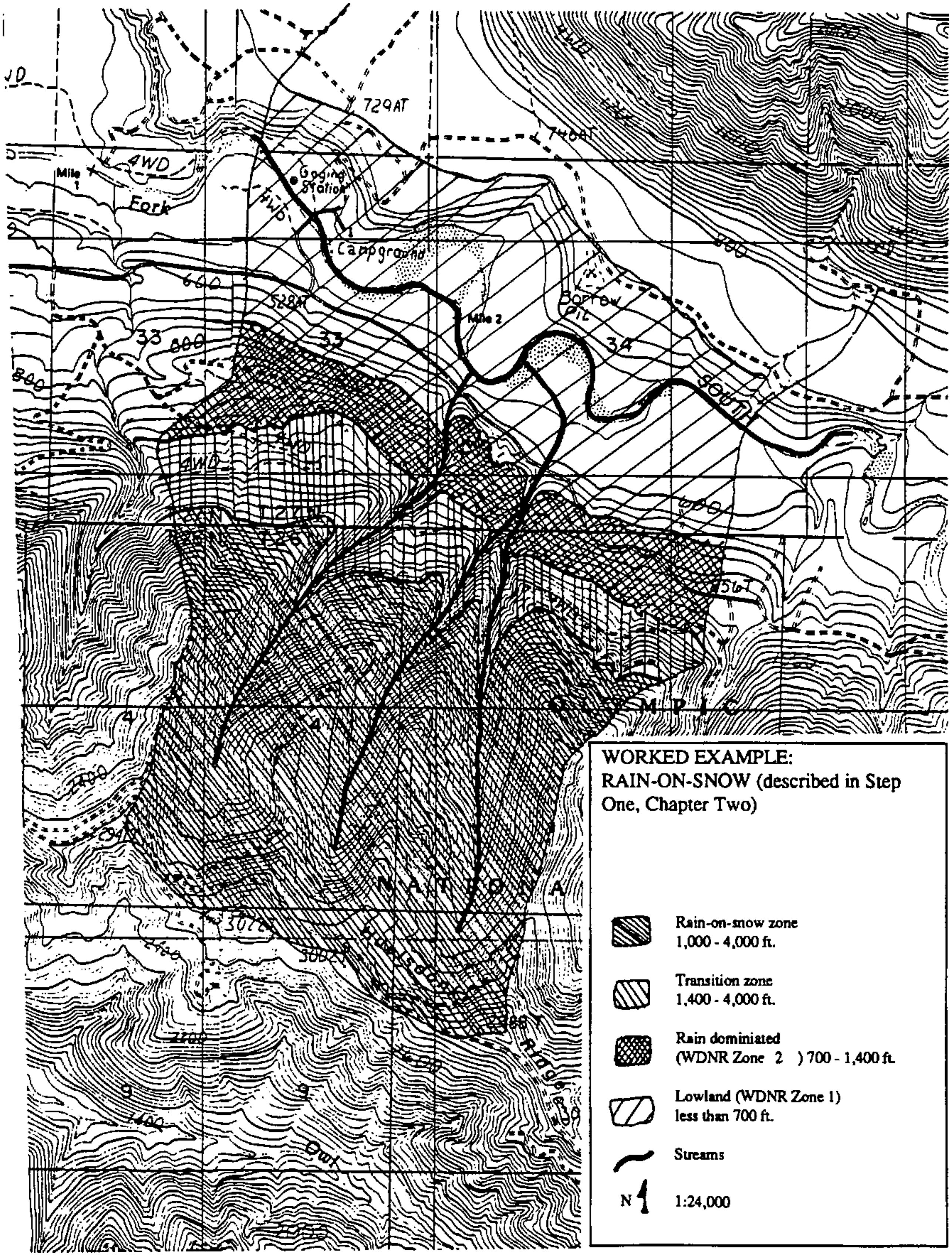


Figure 10.3. Rain-on-snow zone for the Hoh basin.

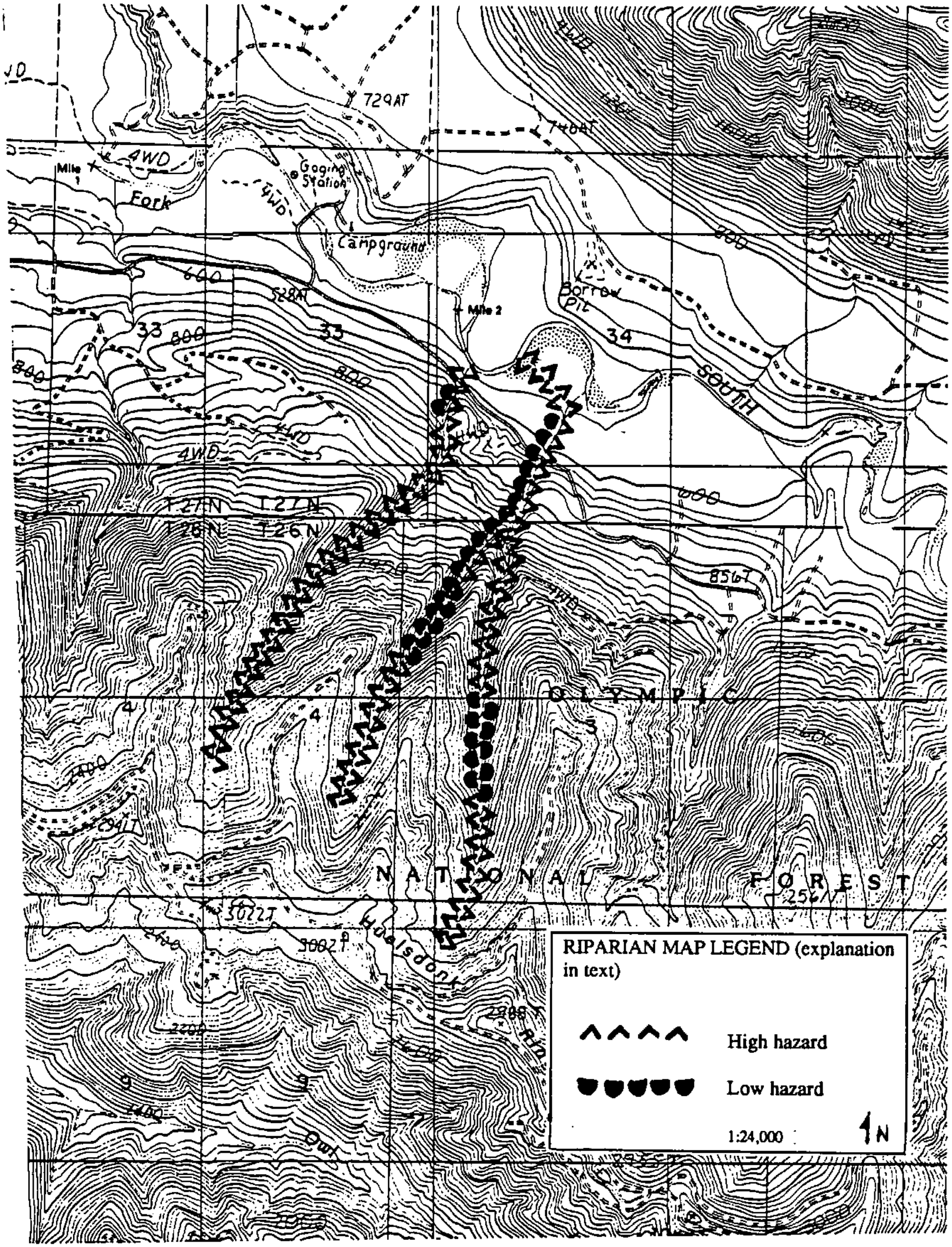


Figure 10.4. Riparian hazard map.

requirements or in an area not currently protected. Several areas are mapped as having a low recruitment hazard. These areas are currently forested in old growth stands. No moderate hazard ratings were assigned.

Fish Habitat

The location of anadromous fish habitat, and habitat use by different species, was determined for the two South Fork Hoh sub-basins using the Washington Department of Fisheries Stream Catalog (Figure 10.5).

Two habitat types were identified. The mainstem Hoh River has been categorized as "transportation" waters. No HSI (habitat suitability index) criteria are applied to this category. Low gradient tributaries to the Hoh have been designated as coho salmon habitat. Other stream types have no known fish use and have not been classified.

The completed fish suitability forms for Stream 1 (Forms F1 and F2), are shown in Figures 10.6 and 10.7. Figure 10.6 applies to river mile 0.0 to 0.2 below the debris torrent zone, and Figure 10.7 applies to the reach between miles 0.2 and 0.5, which was impacted by the debris torrent.

Overlaying Data Bases: Integration of Watershed Processes

In the prototype level 1 watershed analysis proposed in this document, the individual component maps are overlaid or considered together to develop evaluations on the causes for existing habitat condition(s). This includes for this worked example, Figures 10.2, 10.3, 10.4, 10.5, and Forms F1 and F2 (Figures 10.6 and 10.7). Tables 9-2 through 9-5 were used to establish the cause(s) of existing habitat conditions.

The future conditions of habitat in Stream 1 are estimated based on the evaluation that debris torrents are a likely occurrence in the future because of the recent clearcuts in the basin. This prediction of future habitat conditions is displayed for both reaches in Form F2 (Figures 10.8 and 10.9).

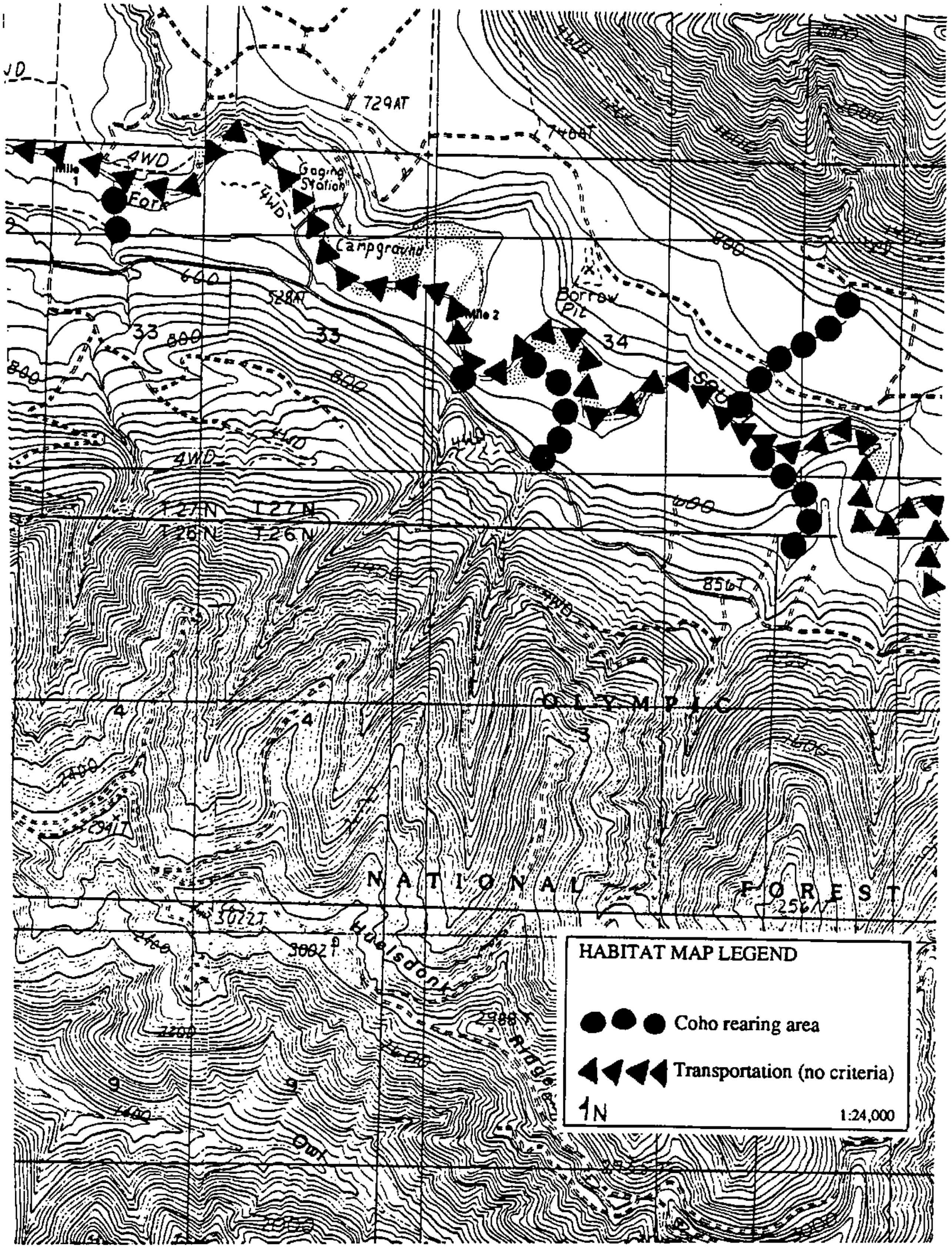


Figure 10.5. Fish habitat distribution map.

Table 10.3. Habitat evaluation for the Hoh basin.

HABITAT CONDITION	PROBABLE CAUSE(S)
Loss of LOD	Debris torrent: removal of LOD
Loss of pools/filling of pools	1) Debris torrent: removal of LOD 2) Landslides: accelerated sediment supply 3) Loss of riparian zone (delayed)
Loss of cover	1) Debris torrent: removal of LOD 2) Riparian forest removal
Channel instability	1) Landslides: accelerated sediment supply 2) Debris torrent: removal of LOD
High fines	1) Landslides 2) Logging roads

INTERACTIVE EFFECTS

HABITAT CONDITION	PROCESSES	STRENGTHEN/WEAKEN
Decreased stability	Landslide/harvest riparian zone	Delayed strengthen
Loss of pools	Debris torrent/harvest riparian zone	Delayed strengthen
Decreased stability	Debris torrent/rain-on-snow	Strengthen

FORM F1

COHO SALMON HABITAT TYPE

1/2

2005 Soleduck - Hoh
WRIA \ SUBWRIA

12/13/91
DATE

Unnamed Example 1
STREAM

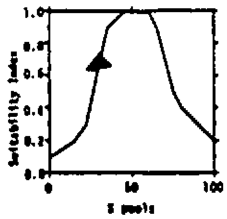
D. Base
SURVEYOR

0 TO 0.2
R.M. R.M.

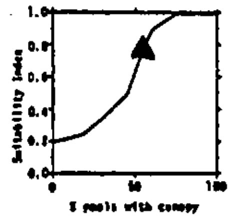
F3
SEGMENT TYPE

HSI	SUITABILITY SCALE

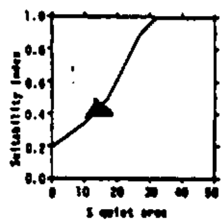
V[illegible] Percent pools during summer low flow period.



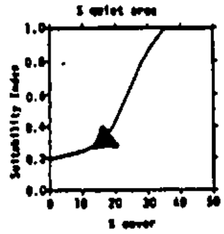
V[illegible] Proportion of pools during summer low flow period that are 10 to 80 m² or 50 to 250 m² in size and have sufficient riparian canopy to provide shade.



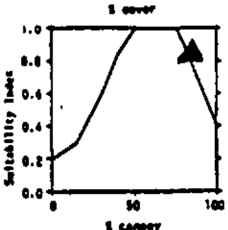
V[illegible] Percent of total area consisting of quiet backwaters and deep (≥ 45 cm) pools with dense cover of roots, logs, debris jams, flooded brush, or deeply-undercut banks during winter.



V[illegible] Percent instream and bank cover present during summer low flow period.

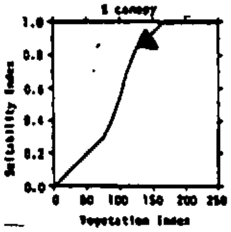


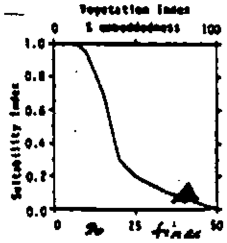
V[illegible] Percent vegetative canopy over rearing stream.



V[illegible] Vegetation index of riparian zone during summer.

Vegetation Index = 2 (% canopy cover of deciduous trees and shrubs) + (% canopy cover of grasses and forbs) + (% canopy cover of conifers). For measurement techniques, see Terrell et al. (1982), p. A.19 and A.37.





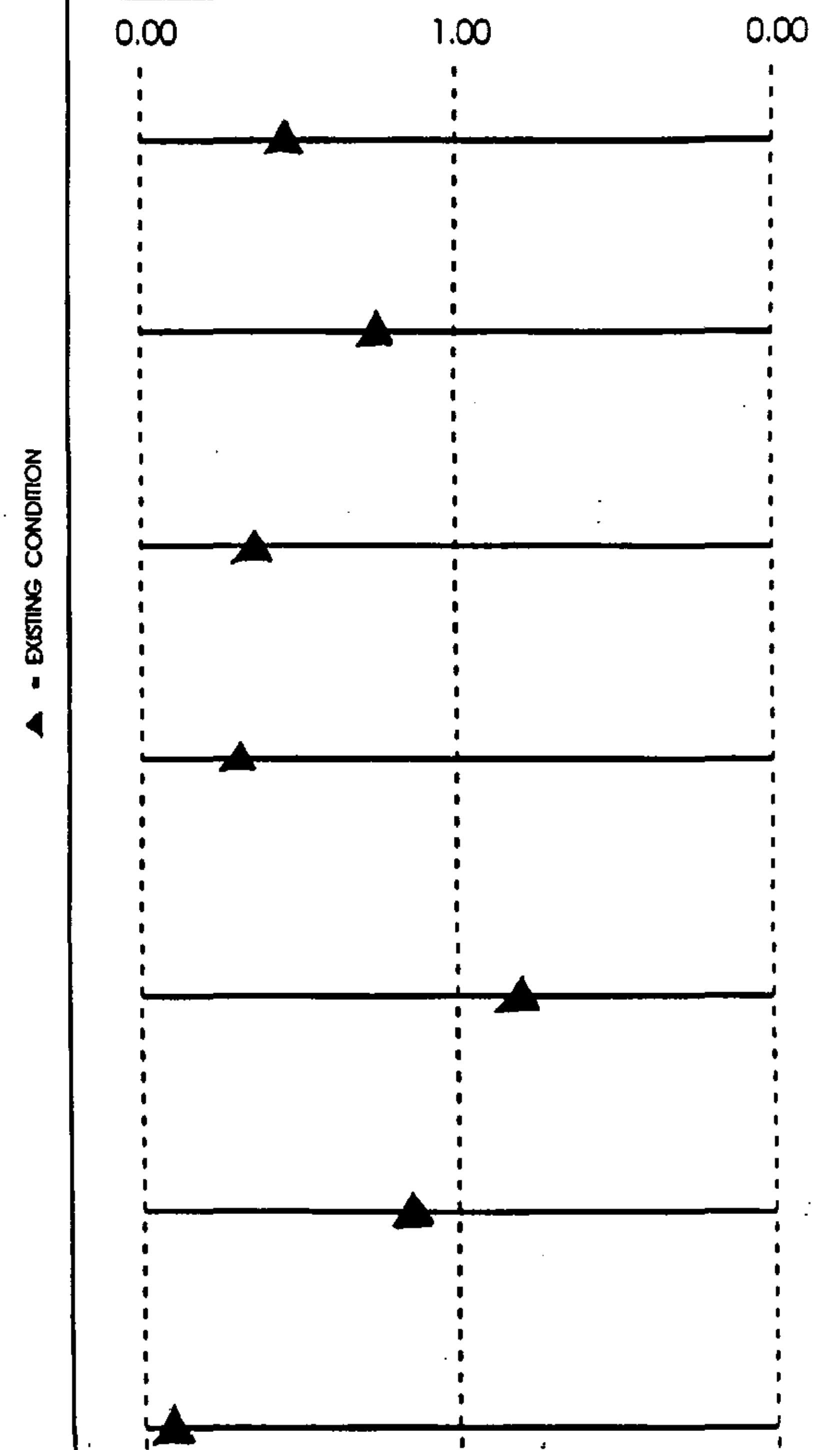


Figure 10.6. Coho salmon habitat suitability form (F1) for stream 1 in the Hoh basin.

FORM F1
COHO SALMON HABITAT TYPE

2005 Soleduck - Hoh
WRIA \ SUBWRIA

12/13/91
DATE

Unnamed Example 1
STREAM

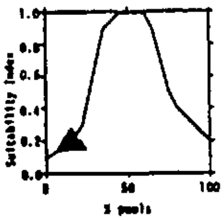
D. Base
SURVEYOR

0.2 TO 0.5
R.M. R.M.

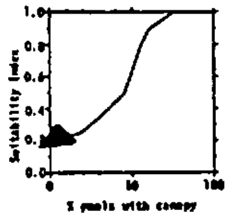
F3
SEGMENT TYPE

HSI	SUITABILITY SCALE

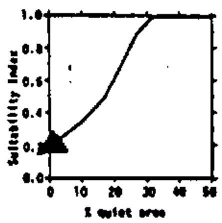
V[illegible] Percent pools during summer low flow period.



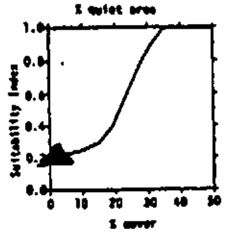
V[illegible] Proportion of pools during summer low flow period that are 10 to 80 m² or 50 to 250 m² in size and have sufficient riparian canopy to provide shade.



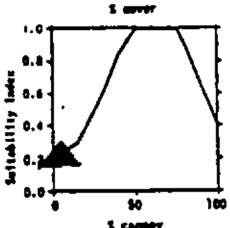
V[illegible] Percent of total area consisting of quiet backwaters and deep (≥ 45 cm) pools with dense cover of roots, logs, debris jams, flooded brush, or deeply-undercut banks during winter.



V[illegible] Percent instream and bank cover present during summer low flow period.

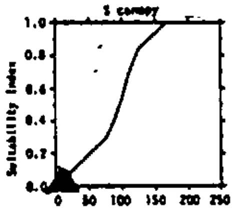


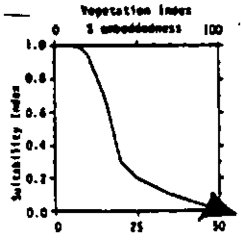
V[illegible] Percent vegetative canopy over rearing stream.



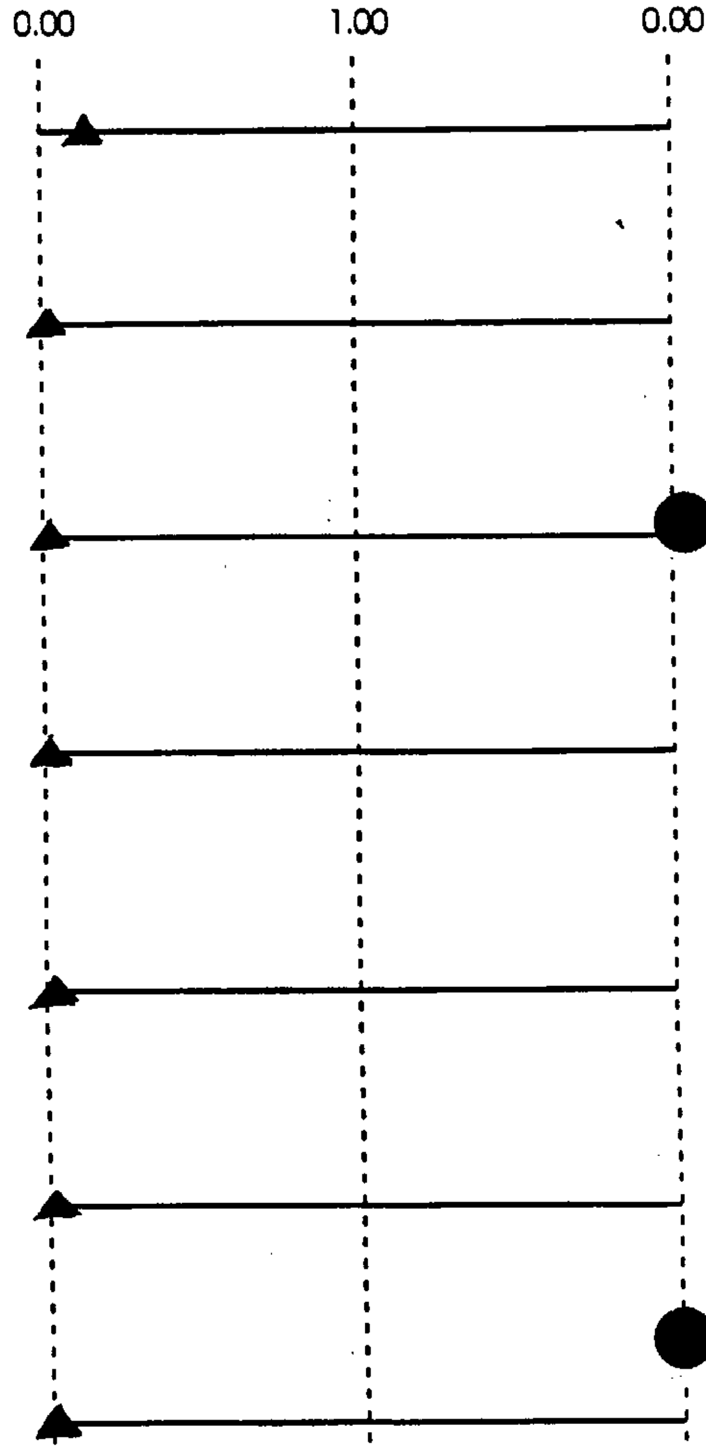
V[illegible] Vegetation index of riparian zone during summer.

Vegetation Index = 2 (% canopy cover of deciduous trees and shrubs) + (% canopy cover of grasses and forbs) + (% canopy cover of conifers). For measurement techniques, see Terrell et al. (1982), p. A.19 and A.27.





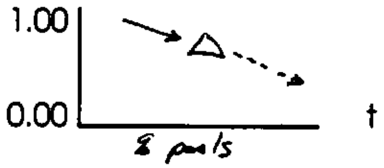
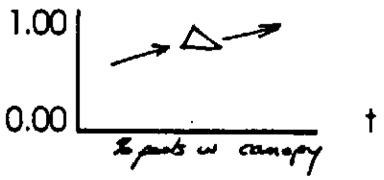
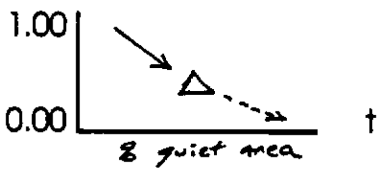
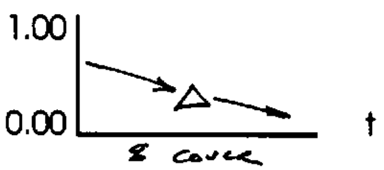
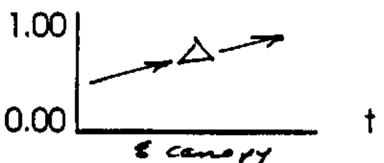
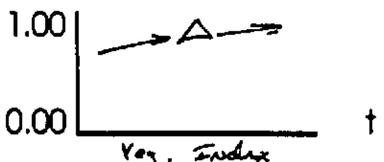
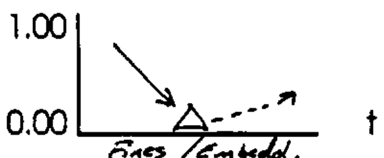
Δ = EXISTING CONDITION



FORM F2
PAST, PRESENT, AND LIKELY FUTURE HABITAT CONDITIONS

2005 Soleduck - Hoh	12/13/91
WRIA	DATE
Stream 1	D. Base
STREAM	SURVEYOR
0.0 TO 0.2	Coho
R.M. R.M.	HABITAT TYPE

SUITABILITY (SPECIFIY FEATURE)

Past, Present, Potentential Future HSI	Likely Cause and Rationale
	-Decline from historic probable ~~[illegible]~~ - lack of LWD in channel. Cleanout possible - Future decline likely due to lack of recruitement potential in riparian forest.
	- Increase from recent past likely - 2nd growth maturing riparian forest. - Future increase likely - maturing 2nd growth riparian zone.
	- Decline from past condition likely - low LWD - Future decline probable due to young 2nd growth riparian.
	- General decrease likely due to low LWD & low recruitment potential.
	- General increasing trend due to maturing 2nd growth riparian forest
	- Same as above
	- Decline from historic probable due to fines leaching from upstream debris torrent deposition zone - Decrease in fines in future probable due to flushing from system.

△ = EXISTING CONDITION

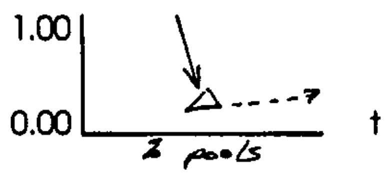
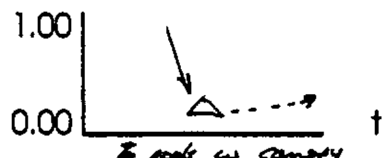
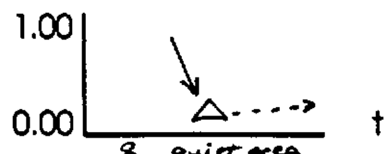
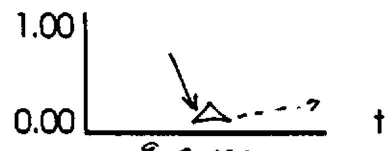
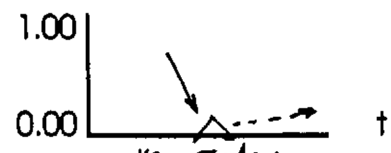
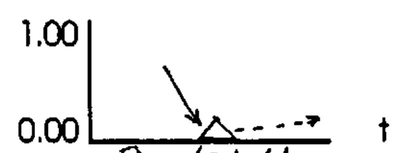
Figure 10.8. Changing habitat conditions for stream 1.

FORM F2

PAST, PRESENT, AND LIKELY FUTURE HABITAT CONDITIONS

2005 Soleduck-Hoh	12/13/91
WRIA	DATE
Stream 1	D. Base
STREAM	SURVEYOR
0.2 TO 0.5	Coho
R.M. R.M.	HABITAT TYPE

SUITABILITY (SPECIFIY FEATURE)

Past, Present, Potenfential Future HSI	Likely Cause and Rationale
 % pools	- Recent severe decline due to debris torrent. - Slow formation of pools (bedform) - low recruitment of LWD
 % pools w canopy	- Recent complete loss of canopy due to debris torrent and clear cut logging - Slow regeneration of riparian veg.
 % quiet area	- Recent complete loss of wood due to debris torrent - Slow recovery. Low LWD recruitment potential from Riparian forest.
 % cover	" "
 % canopy	" "
 veg. index	" "
 Fines/embedd.	- Recent increase in fines & course sediment due to debris torrent - Slow flushing of fines in future probable after stabilization of erosion sources.

△ = EXISTING CONDITION

Figure 10.9. Changing habitat conditions for stream 1.

Because a debris torrent was identified from the aerial photos from the aerial photos in the two sub-basins (Figures 10.2 and 10.3), it is not necessary to use Tables 9.2 through 9.5 as a guide for field identification of the watershed process to determine the dominant influence on channel habitat. The tables can be used, however to indicate which conditions in the channel, such as sediment characteristics or woody debris, are likely to be changing as a result of the debris torrent, and how these characteristics are altering fish habitats. Evaluations on causes of existing habitat conditions can be made using Tables 9.2 - 9.5. These evaluations for the Hoh example are shown in Table 10.3.

One objective of watershed analysis is to predict the habitat response to debris torrents. Stream 2 in the example has been mapped as a debris torrent prone channel, although a debris torrent was not evident on the 1990 photos used in the analysis.

Predicting habitat response to processes which have yet to occur in a watershed is based on extrapolation of habitat conditions from one stream to another, similar to the way in which landslide map units are extrapolated between sub-basins. When this is done, it is feasible to anticipate that channel 2 will respond to a debris torrent in a way similar to channel 1. Form F1 (Figure 10.10) shows the present habitat condition impacted by recent debris torrents. Form F2 (Figure 10.11) indicates the likely future habitat conditions in the event of a debris torrent occurring within stream 2 basin. This is a scenario labeled "H" in the habitat trajectories (Figure 10.11). Scenario "A" is the evolving habitat conditions without debris torrents.

Risk Assessment and Decision Making

The example illustrates a watershed analysis which shows a high certainty of hillslope hazard and risk to fish habitat. The partitioning process indicates that there are broad areas of relatively homogeneous geologic, topographic, and climatic, and management conditions. Other basins within the partition can be expected with high certainty to respond the same as Stream 1 in our worked example.

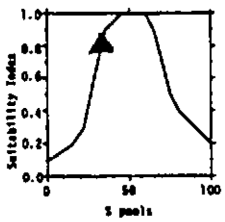
FIGURE 10.20

FORM F1
COHO SALMON HABITAT TYPE

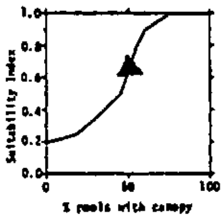
2005 Soleduck-Hoh	12/13/91
WRIA \ SUBWRIA	DATE
Stream 2	C. Steel
STREAM	SURVEYOR
0.0 TO 0.15	F3
R.M. R.M.	SEGMENT TYPE

HSI	SUITABILITY SCALE

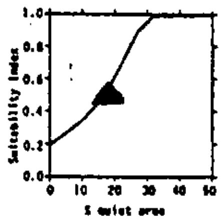
V_{10} Percent pools during summer low flow period.



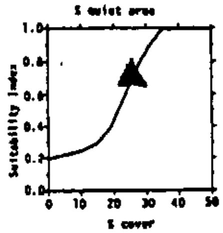
V_{11} Proportion of pools during summer low flow period that are 10 to 80 m² or 50 to 250 m² in size and have sufficient riparian canopy to provide shade.



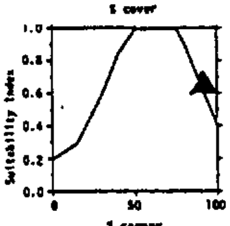
V_{14} Percent of total area consisting of quiet backwaters and deep (≥ 45 cm) pools with dense cover of roots, logs, debris jams, flooded brush, or deeply-undercut banks during winter.



V_{15} Percent instream and bank cover present during summer low flow period.

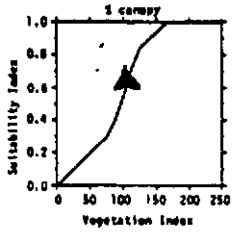


V_4 Percent vegetative canopy over rearing stream.



V_5 Vegetation index of riparian zone during summer.

Vegetation Index = 2 (% canopy cover of deciduous trees and shrubs) + (% canopy cover of grasses and forbs) + (% canopy cover of conifers). For measurement techniques, see Terrell et al. (1982), p. A.33 and A.37.

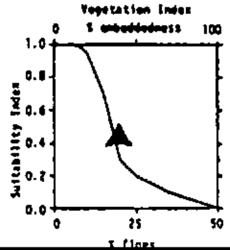


V_6 Substrate composition in riffle/run areas.

A. Percent of gravel (10 to 40 mm) and rubble (61 to 250 mm) present.
B. Percent fines (< 6 mm) or percent embeddedness of substrate.

$SI = \frac{A + B}{2}$, where B = % fines

or % embeddedness, whichever is



Δ = EXISTING CONDITION

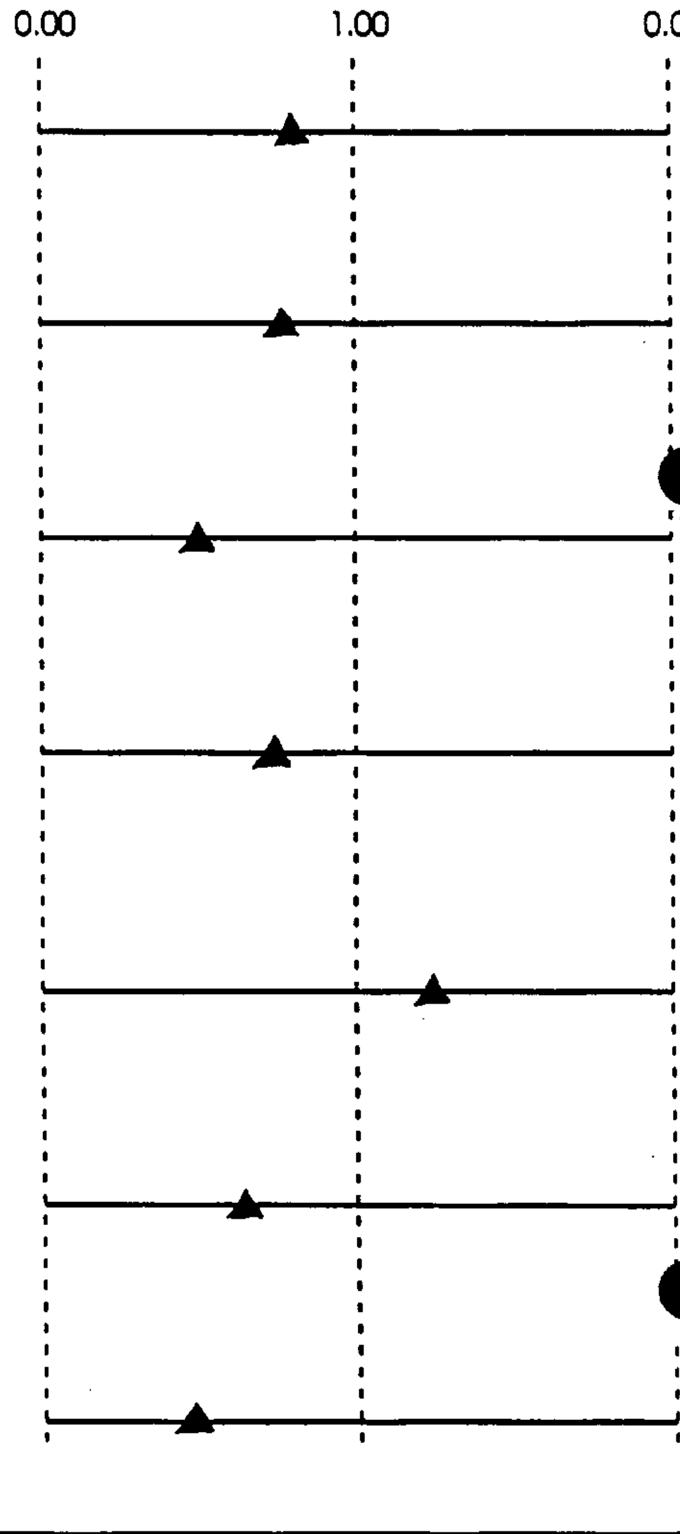
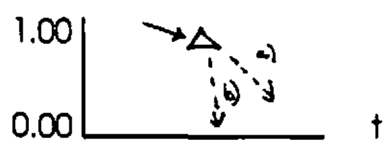
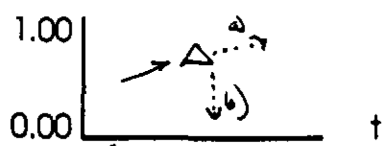
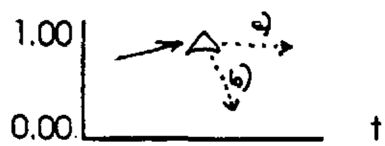
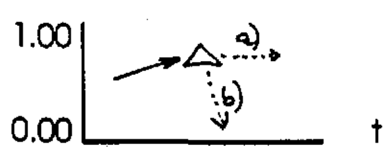
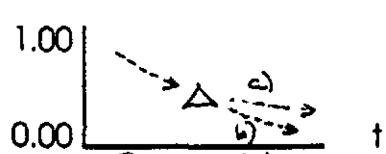


FIGURE 10.11

FORM F2
PAST, PRESENT, AND LIKELY FUTURE HABITAT CONDITIONS

WRIA: 2005 Soleduck-Hoh	DATE: 12/13/91
STREAM: Stream 2	SURVEYOR: C. Steel
R.M. 0.0 TO R.M. 0.15	HABITAT TYPE: Coho

Past, Present, Potentential Future HSI	Likely Cause and Rationale
 % pools	- Decline from historic probable - low count of lg. old wood. May have been cleaned - Future decline likely due to low recruitement potential of riparian forest - Also high likelihood of debris torrent.
 % pools w canopy	- Increase from recent historic likely - 2nd growth riparian vegetation. - Future increase likely if no debris torrent a) Future decline if debris torrent. b)
 % quiet area	- Decrease from historic evident due to low amounts of LWD. Stream clean out may have occured - Future decline likely due to low recruitment potential from riparian forest.
 % cover	- Recent historic increase due to regeneration of 2nd growth riparian forest - Future conditions likely stable unless subject to a debris torrent
 % canopy	- Same as previous
 veg. Index	- Historic loss of conifer or mixed forest due to harvest - Future conditions stable unless subject to a debris torrent
 % embeddedness	- Increased sedimentation & embeddedness due to recent harvest and erosion evident in photos - Future increase likely until erosion sources heal. High likelihood debris torrent will also cause increase sed. & embedd.

SUITABILITY (SPECIFIY FEATURE)

△ = EXISTING CONDITION

a) No future debris torrent
b) future debris torrent

In this case, the most lenient certainty criteria for our example decision rules (Decision Rule 1, Chapter 2) are met. Management decisions could be made, in light of the analysis, with the knowledge of high certainty.

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FORM F1

COHO SALMON HABITAT TYPE

2/2

2005 Soleduck - Hoh
WRIA \ SUBWRIA

12/13/91
DATE

Unnamed Example 1
STREAM

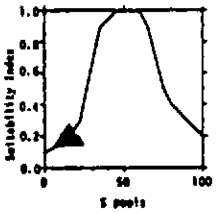
D. Base
SURVEYOR

0.2 TO 0.5
R.M. R.M.

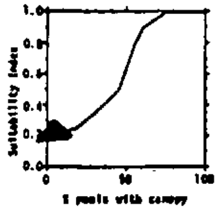
F3
SEGMENT TYPE

HSI	SUITABILITY SCALE

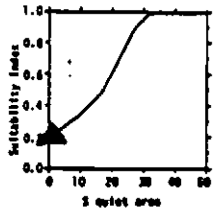
V_{10} Percent pools during summer low flow period.



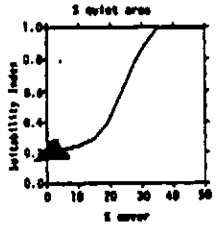
V_{11} Proportion of pools during summer low flow period that are 10 to 80 m² or 50 to 250 m² in size and have sufficient riparian canopy to provide shade.



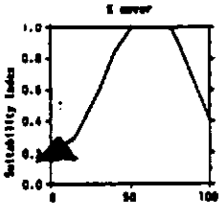
$V_{[illegible]}$ Percent of total area consisting of quiet backwaters and deep (≥ 45 cm) pools with dense cover of roots, logs, debris jams, flooded brush, or deeply-undercut banks during winter.



$V_{[illegible]}$ Percent instream and bank cover present during summer low flow period.

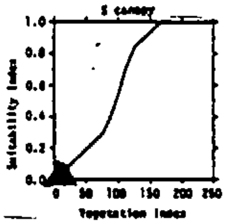


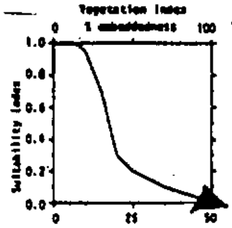
$V_{[illegible]}$ Percent vegetative canopy over rearing stream.



$V_{[illegible]}$ Vegetation index of riparian zone during summer.

Vegetation index = 2 (% canopy cover of deciduous trees and shrubs) + (% canopy cover of grasses and forbs) + (% canopy cover of conifers). For measurement techniques, see Terrell et al. (1982), p. A.19 and A.37.





Δ = EXISTING CONDITION

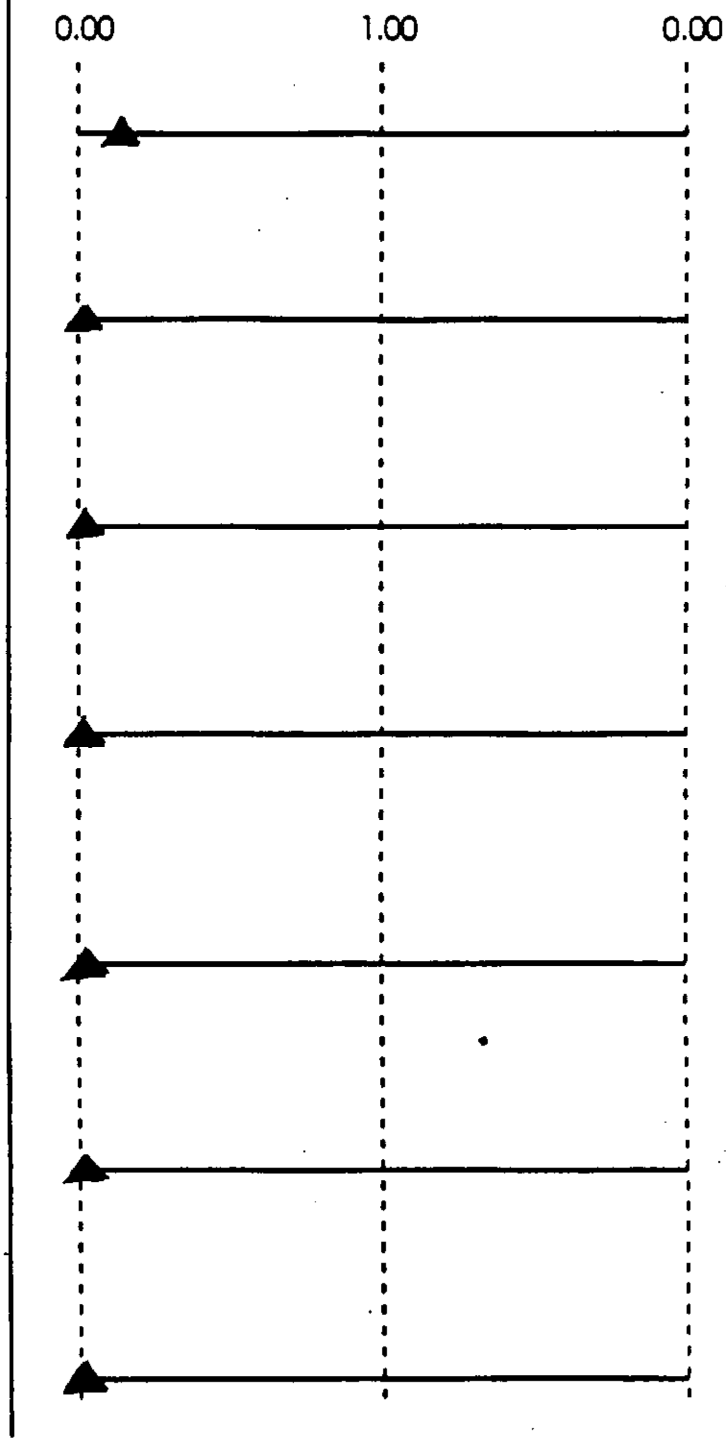


Figure 10.7. Coho salmon habitat suitability form for stream 1 in the Hoh basin.

FORM F1 1/2

COHO SALMON HABITAT TYPE

2005 Soleduck - Hoh	12/13/91
WRIA \ SUBWRIA	DATE
Unnamed Example 1	D. Base
STREAM	SURVEYOR
0 TO 0.2	F3
R.M. R.M.	SEGMENT TYPE

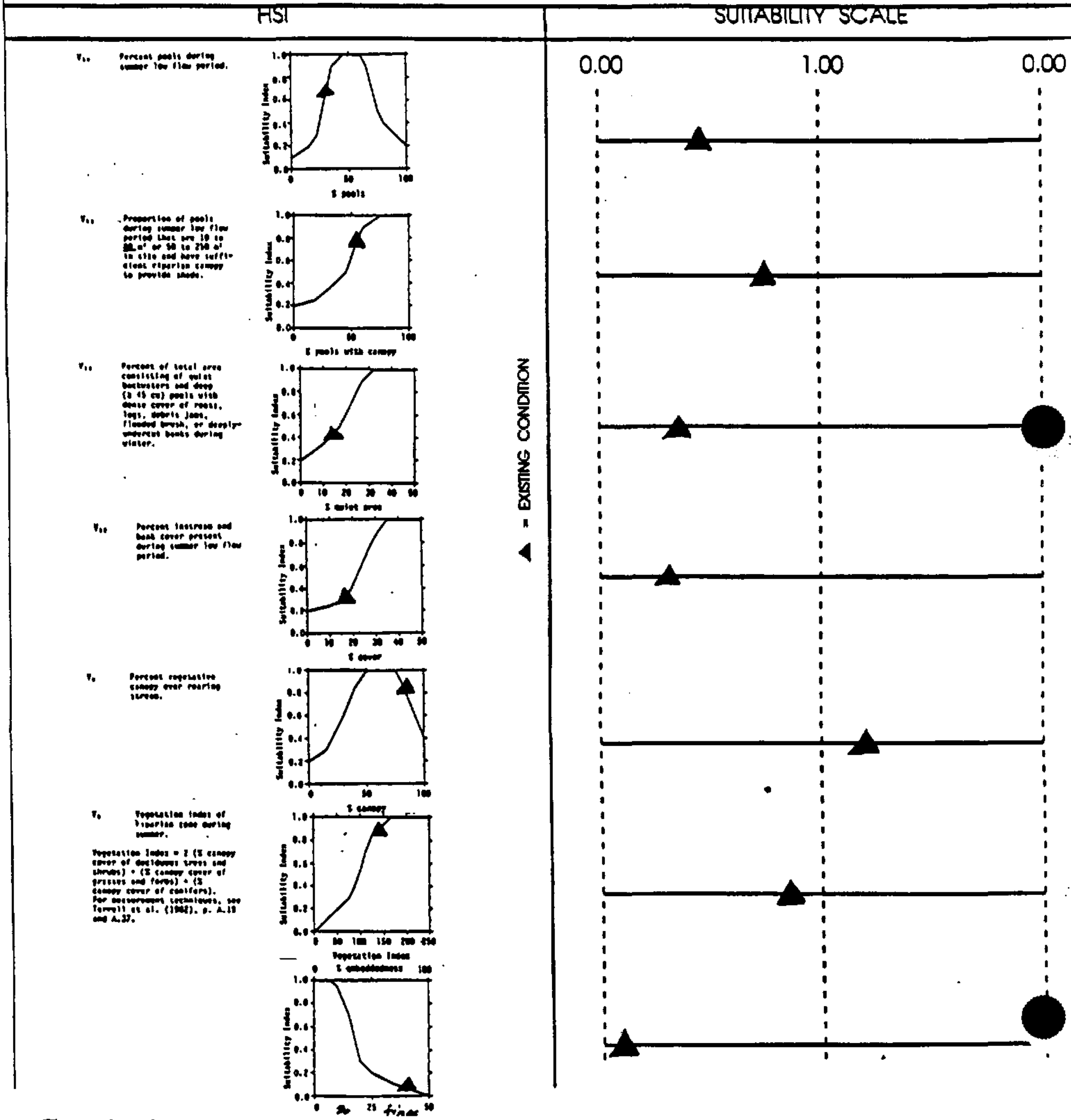


Figure 10.6. Coho salmon habitat suitability form (F1) for stream 1 in the Hoh basin.

Table 10.3. Habitat evaluation for the Hoh basin.

HABITAT CONDITION	PROBABLE CAUSE(S)
Loss of LOD	Debris torrent: removal of LOD
Loss of pools/filling of pools	1) Debris torrent: removal of LOD 2) Landslides: accelerated sediment supply 3) Loss of riparian zone (delayed)
Loss of cover	1) Debris torrent: removal of LOD 2) Riparian forest removal
Channel instability	1) Landslides: accelerated sediment supply 2) Debris torrent: removal of LOD
High fines	1) Landslides 2) Logging roads

INTERACTIVE EFFECTS

HABITAT CONDITION	PROCESSES	STRENGTHEN/WEAKEN
Decreased stability	Landslide/harvest riparian zone	Delayed strengthen
Loss of pools	Debris torrent/harvest riparian zone	Delayed strengthen
Decreased stability	Debris torrent/rain-on-snow	Strengthen

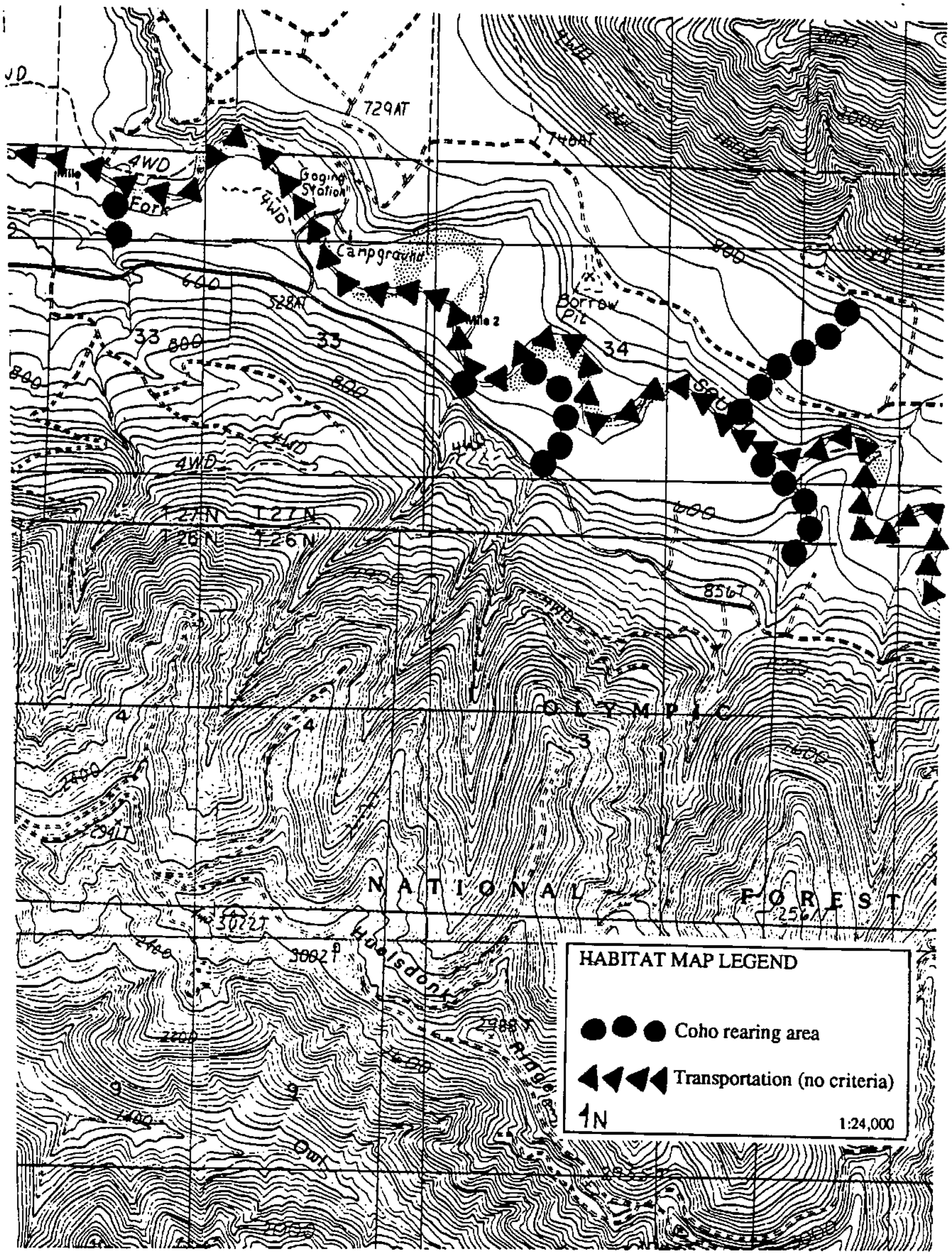


Figure 10.5. Fish habitat distribution map.

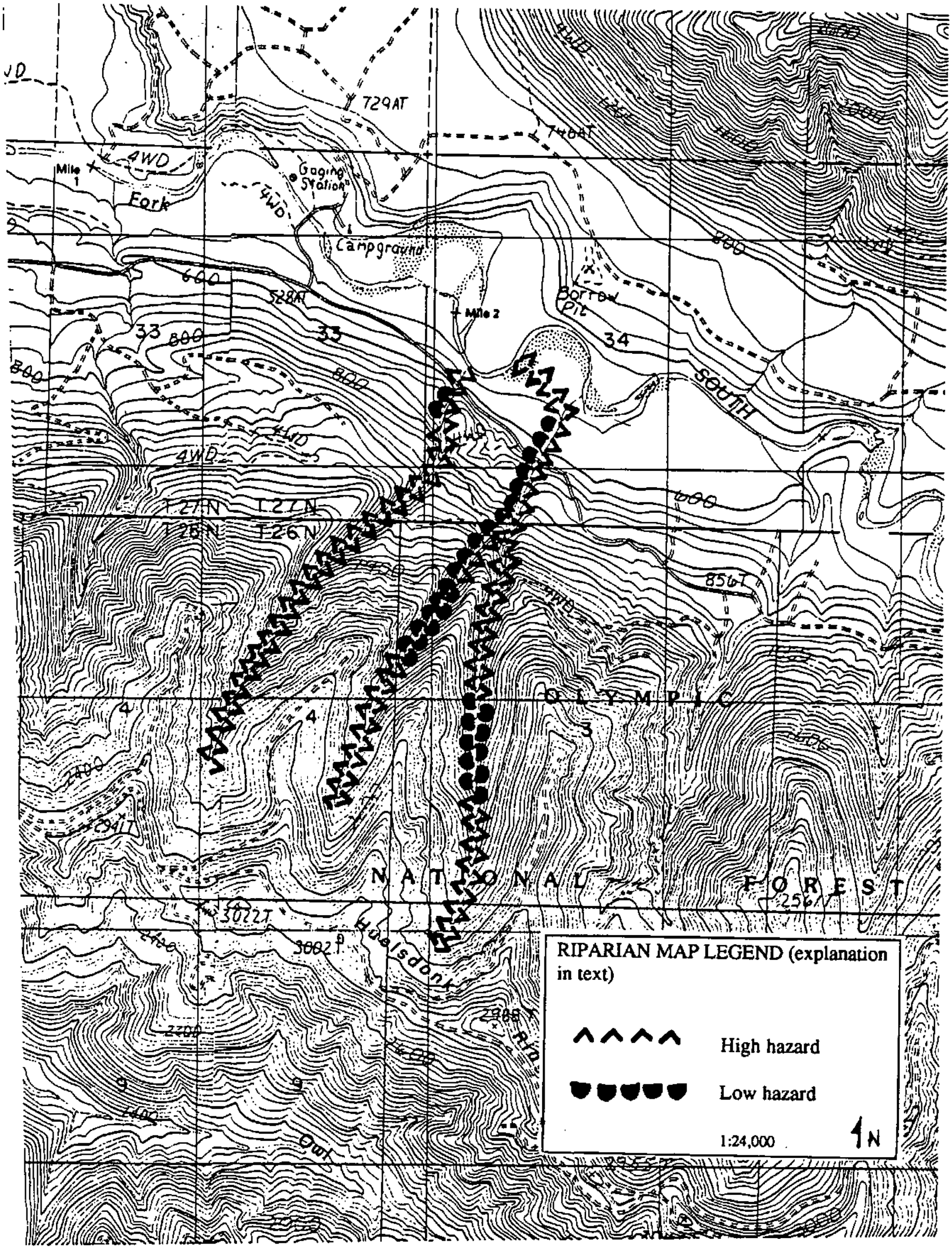


Figure 10.4. Riparian hazard map.

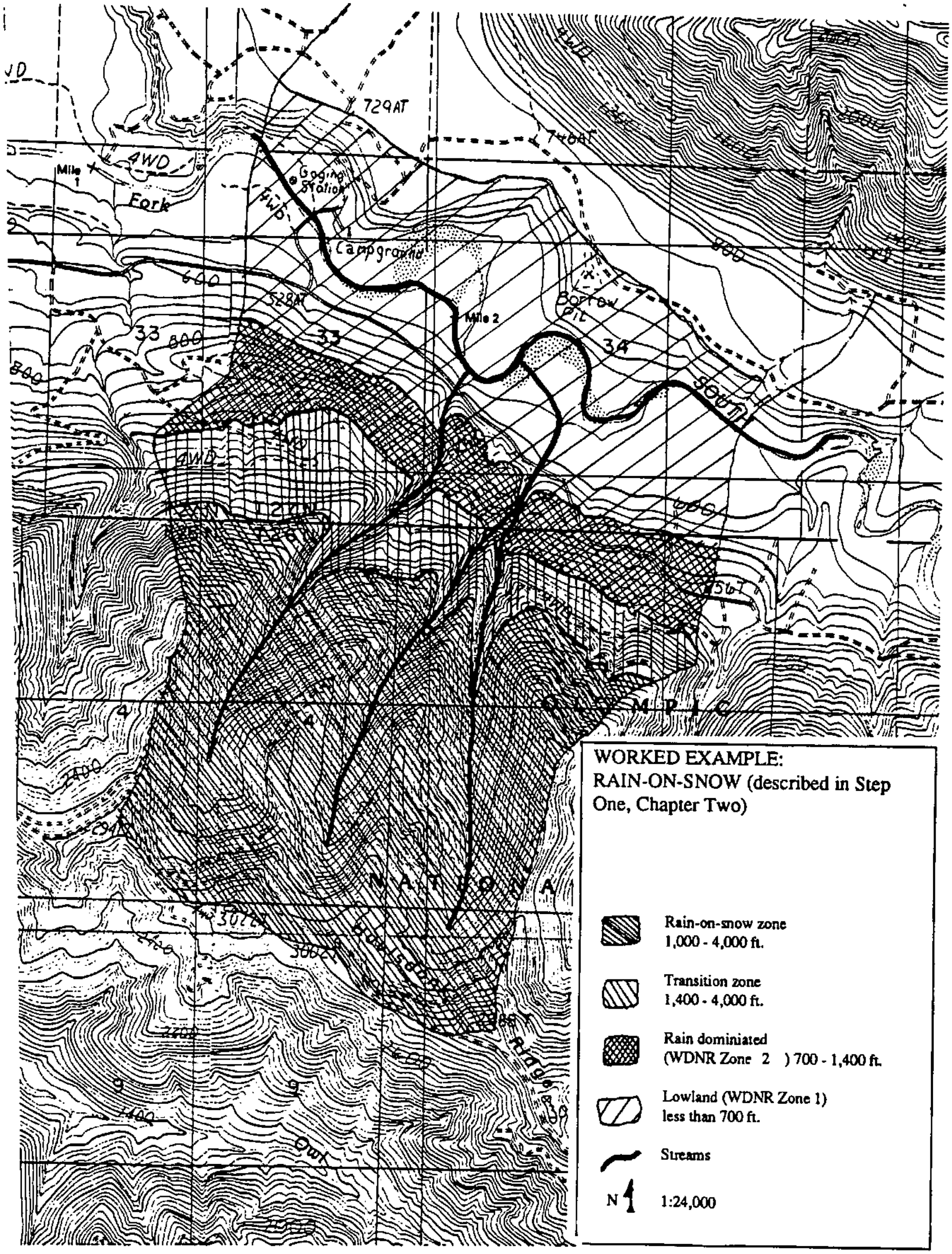


Figure 10.3. Rain-on-snow zone for the Hoh basin.

Table 10.2. Landslide map units for the Hoh basins.

LANDSLIDE MAP UNIT NUMBER ONE (HIGH HAZARD) - Landslide density: 8 per sq. mi. - Gradient range: greater than 35 degrees - Hillslope form: convergent topography, frequency 1 bedrock hollow per 135 meters -Sediment to stream: 11/13 = 85% of landslides - Triggered debris torrent(s) - Land use: clearcuts (10/13), roads (3/13) - Hazard rating: high
LANDSLIDE MAP UNIT NUMBER TWO (LOW HAZARD) - Landslide density: less than 1 per sq. mi. - Gradient range: 20 to 35 degrees - Hillslope form: mostly planar - Sediment to streams: none directly - No torrents triggered - Land use: clearcuts (3/3) - Hazard rating: low

Table 9.3. Varying effectiveness of watershed processes on habitat conditions

	LOSS OF POOLS/COVER	COARSENING OF SUBSTRATE	INCREASE IN FINE SEDIMENT IN SUBSTRATE
Most effective ↓ effective	-Dam-break floods -Loss of riparian zone(delayed) -Debris flows -Landslides	-Debris flows -Landslides -Dam-break floods -Numerous gullies -Flooding	-Road erosion -Other surface erosion -Debris flows -Dam-break floods

	DECREASED CHANNEL STABILITY	INCREASED WATER TEMPERATURE	LOSS OF LARGE ORGANIC DEBRIS
Most effective ↓ effective	-Dam-break floods -Debris flows -Landslides -Flooding -Stream cleanout -Loss of riparian zone (delayed)	-Loss of riparian trees -Dam-break floods -Debris flows -Landslides	-Dam-break floods -Stream clearcut -Loss of riparian trees (delayed)

Attachment 1

Hydrology

API MODEL. The API model developed by Fedora (1987) and reported by Fedora and Beschta (1989) is a simple rainfall-runoff model that is based on physical principals that drive antecedent moisture conditions. The model has been used in one watershed analysis conducted in Washington (Benda, per. comm.) and provides a alternative method for developing hydrographs for watersheds with no or partial streamflow gages. A computerized version of the API model can be obtained from the BLM (Fedora 1989).

The basis of the API model is development of an antecedent precipitation index from precipitation records to determine rainfall-runoff relationships. It is an event based storm hydrograph model that can be used where streamflow data is not available. The model was developed to provide a tool for developing storm hydrographs, and proposed to be coupled with a supply-bassed suspended sediment model (for example Vansickle and Beschta, 1983) and for recreating historic events for fisheries, stream morphology, and slope stability research. Precipitation events drive peak flow events. The antecedent moisture condition (dependent on soil and vegetation) can be characterized for a precipitation or runoff event. This relation can be used to synthesize hydrographs based on soil moisture conditions.

The API can be used to develop precipitation-runoff relations for storms events of interest. The API values are directly related to storm runoff and are developed from pre-storm baseflow. Fedora and Beschta (1989) recommend values to be calculated starting 72 hours before the beginning of a ruonoff event for Oregon streams. The API method will discussed under models. For detailed explanation of the model refer to Fedora (1987).

Two types of simulations that are applicable to runoff events in Washington that the model can address are:

1. Rain only: snowpack is assumed not present.

2. Rain-on-snow: for forested watershed, combined effects of rain and snowmelt. A snowpack is assumed to be present and snowmelt occurs when temperatures are greater than 32 ^{o} F. The USCOE (1956) snowmelt equations can be used to simulate snowmelt.

The model has been used to simulate rain-on-snow hydrographs for clearcuts, however, it may have limitations for this application (J. Fogg, BLM, Denver, Co., November 1991, per. communication).

2. USGS Equations

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

MAGNITUDE AND FREQUENCY OF FLOODS IN WASHINGTON

By J. E. Cummans, M. R. Collings, and E. G. Nassar

Open-File Report 74-336

Prepared in cooperation with the
State of Washington Department of Highways

Tacoma, Washington
1975

RESULTS

The regression relations selected as the most practical were as follows:

For western Washington:

$$Q_2 = a\,A^{0.86}\,P^{1.51}$$

$$Q_5 = a\,A^{0.86}\,P^{1.53}$$

$$Q_{10} = a\,A^{0.85}\,P^{1.54}$$

$$Q_{25} = a\,A^{0.85}\,P^{1.56}$$

$$Q_{50} = a\,A^{0.86}\,P^{1.58}$$

$$Q_{100} = a\,A^{0.86}\,P^{1.60}$$

For eastern Washington:

$$Q_5 = a\,A^{0.90}\,P^{1.35}\,F^{-0.21}$$

$$Q_{10} = a\,A^{0.88}\,P^{1.16}\,F^{-0.23}$$

$$Q_{25} = a\,A^{0.87}\,P^{1.03}\,F^{-0.25}$$

$$Q_{50} = a\,A^{0.86}\,P^{0.95}\,F^{-0.27}$$

$$Q_{100} = a\,A^{0.85}\,P^{0.89}\,F^{-0.29}$$

Q_T is the flood magnitude for recurrence interval T, in cubic feet per second. No equation was defined for Q_2 in eastern Washington because the value was zero at a number of sites;

A is drainage area size, in square miles;

P is mean annual precipitation, in inches;

F is forest cover, in percent of drainage area, and

a is a regression constant that varies for each region and equation.

The equations for each region are given in table 3. The first column indicates the recurrence interval (Q_T) for the Q_2, Q_5, Q_{10}, Q_{25}, Q_{50}, and Q_{100} floods. The other columns show the regression constant, the regression coefficients for each of the significant basin or climatic characteristics, and the percentage standard error of estimate.

... regression coefficients for equations, for regions shown on plate 3

Recurrence interval, T	Regression coefficient: Regression constant, a	Drainage area, A	Annual precipitation, P	Forest cover, F	Standard error of estimate (percent)
		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
		Region VI			
5	0.260	0.90	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
		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

3. Drainage Density and Pattern

Concepts/Indices

Drainage Density and Pattern. The drainage network of a watershed is largely determined by climate and surficial and bedrock geology. There is a close relationship between watershed or basin characteristics and stream characteristics (Orsborn 1991, Chamberlin et al 1991). Physical basin characteristics fall under the analysis of drainage network. There is a plethora of studies that attempt to mathematically relate streamflow and channel characteristics to measurable basin characteristics such as drainage density, channel length, channel slope, basin width, basin length, basin slope, etc. Unfortunately, most of these relational or regression equations apply only to the area they were determined for and can only be extrapolated to basins with similar geology, climate, and geomorphology.

Drainage density and pattern are indicators of runoff conditions, timing, and soil permeability depending on diferences of soil and underlying rocks (geology eg. fractures). Drainage density is important to hydrology because it is a factor that controls the conveyance and speed of runoff following a periods of precipitation. The higher the drainage density, the more efficient the capture of runoff for streamflow. Smaller moutain channels respond quickly to precipitation events exhibiting increasing streamflow and expanding channel network. As the network expands (varaible source area) drainage density increases and efficientcy for routing water increases (Swanston 1991). Following the succession of precipitation, streamflow peaks receed rapidly (Figure). Channel head locations may be controlled by landsliding on steeper slopes, and by seepage erosion and saturation overland flow on gentler slopes (Montgomery and Dietrich 1989). A relationship for basins in southwest Washington was found between drainage density, precipitation, and basin relief (Orsborn 1991, p. VII-23). He stated that it has been shown to be a reasonable index for soils, geology, groundwater and low flows. Harr (1987) reports that the highest drainage densities are found furing winter storm runoff in the Olympic Mountains and the lowest densities are found in the lowlands of southwestern Washington. Low drainage densities imply greater distance for subsurface water to travel to a channel.

Topographic maps and aerial photographs, can be used to indicate the probable paths of lateral flow to channels. Actual paths may be modified by subsurface relief that is not visible from maps or photos, for example buried hollows or channels. However, identification of probable flow paths can be used to determine potential drainage density for storm flow events. The identified drainage pattern and density can be used to evaluate basin runoff characterisitics (Table 1 and Figure 1). Drainage density as an descriptive index on Level I provides a means to identify similar watersheds for extrapolation of hydrologic information in that basins with similar drainage density pattern and climate will have similar hydrologic regimes.

Runoff coefficients. Runoff values vary greatly where adjoining drainage areas have different conditons of topography, precipitation, wind movement, infiltration, and vegetation. Runoff is specified as volume of flow per unit of depth per unit of area per unit of time (eg cm/ha/day or cms/km/year: a coefficent of annual streamflow produced per kilometer of area). Runoff relationships are useful for not only providing a simple means to route water from the hillslope to the channel, but also for determining similarity between basins. Runoff maps or numbers of the flow conditions of interest, make clearer the interrelationship between basins and allow grouping of like basins for extrapolation of gaged data to ungaged basins. For example, Orsborn (1991) found a wide range in the unit runoff for Olympic Penninsula rivers to be caused primarily by variations in precipitation, elevation, and geology.

4. Rain-on-Snow Hydrographs. The attached hydrographs were developed from outflow data from the rain-on-snow plots (Coffin 1991). The hydrographs were simulated by the SSARR Model.

5. WRENSS Model. Contacts for obtaining a copy of the Model diskette and instructions are: Glen McDonald, Department of Ecology, Olympia, WA.

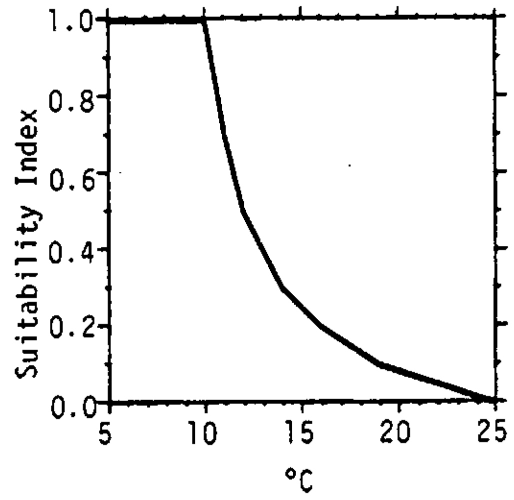
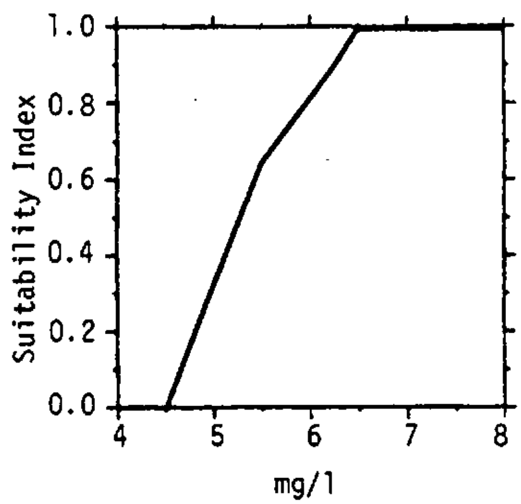
Attachment 2

Fish Suitability Indices and Habitat Forms

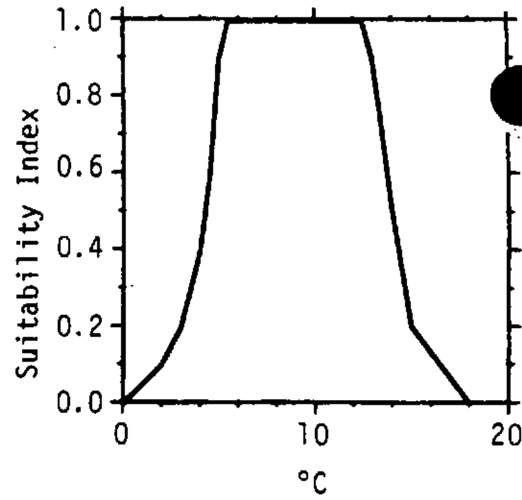
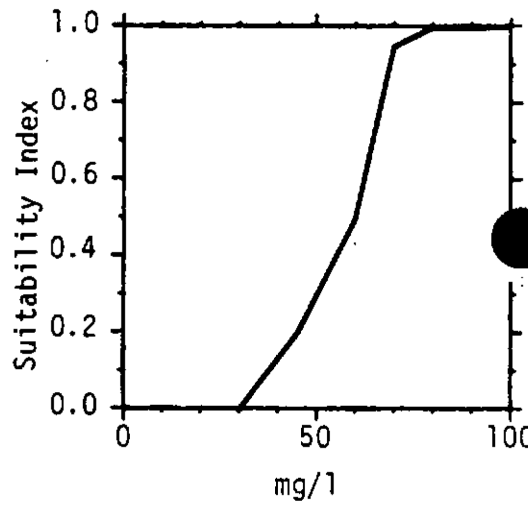
Coho Salmon

Suitability Index (SI) Graphs for Model Variables Coho

All variables pertain to riverine (R) habitat. Table 1 lists the information sources and assumptions used in constructing each SI graph.

Habitat	Variable		Suitability graph
R	V_1	Maximum temperature during upstream migration.	
R	V_2	Minimum dissolved oxygen concentration during upstream migration.	

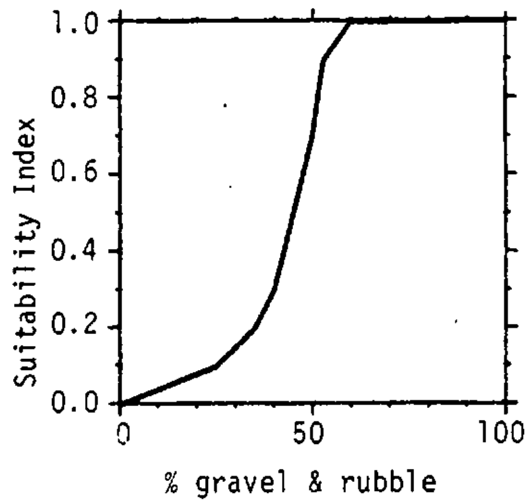
FWS/OBS-82/10.49

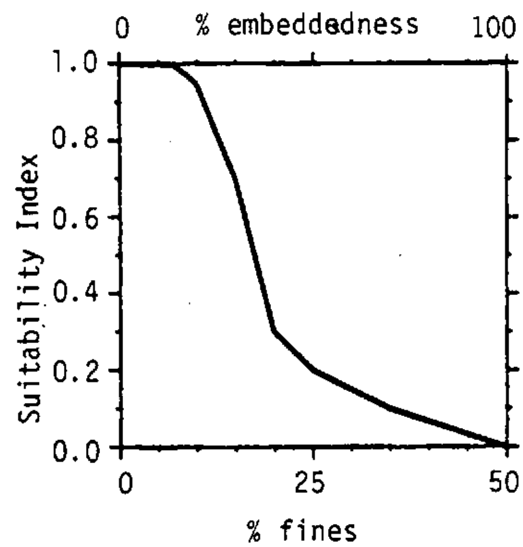
R	V_3	Maximum temperature from spawning to emergence of fry.	
R	V_4	Minimum dissolved oxygen concentration from spawning to emergence of fry.	

R V$_5$ Substrate composition in riffle/run areas.

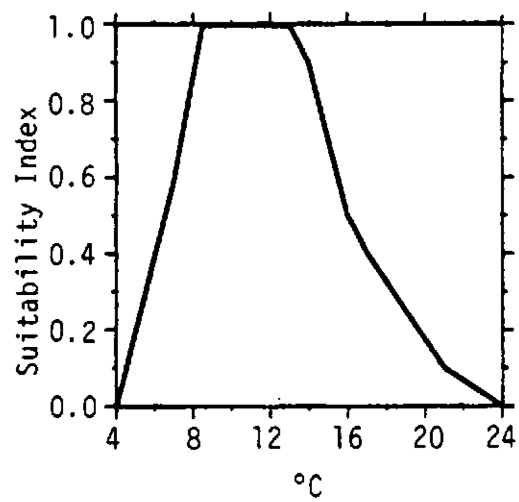
A. Percent of gravel (10 to 60 mm) and rubble (61 to 250 mm) present.
B. Percent fines (< 6 mm) or percent embeddedness of substrate.

$$SI = \frac{A + B}{2}$$, where B = % fines or % embeddedness, whichever is lower.

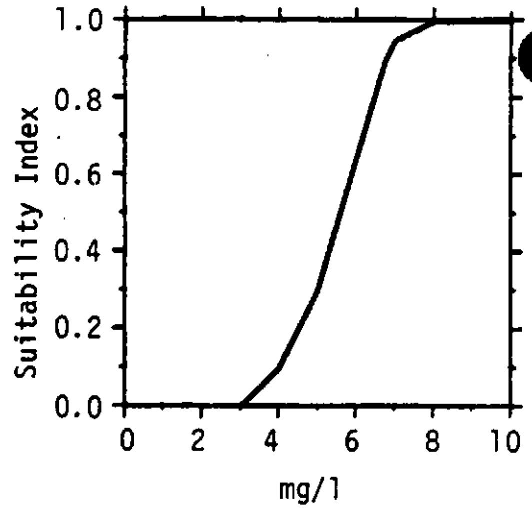




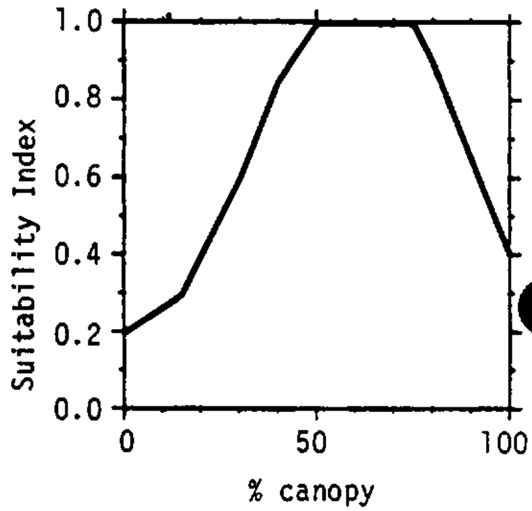
R V$_6$ Maximum temperature during rearing (parr).



R V_7 Minimum dissolved oxygen concentration during rearing (parr).

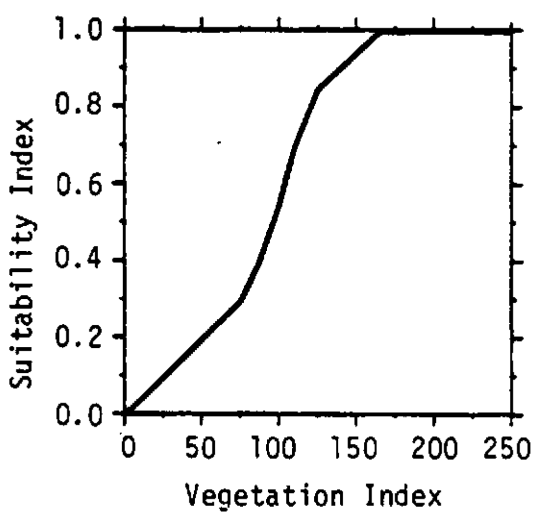


R V_8 Percent vegetative canopy over rearing stream.

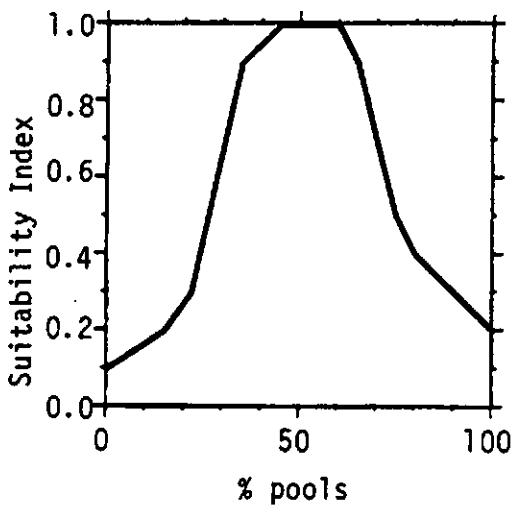


R V_9 Vegetation index of riparian zone during summer.

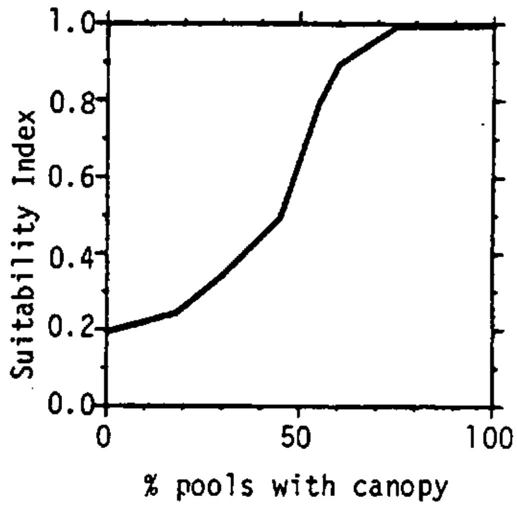
Vegetation Index = 2 (% canopy cover of deciduous trees and shrubs) + (% canopy cover of grasses and forbs) + (% canopy cover of conifers). For measurement techniques, see Terrell et al. (1982), p. A.19 and A.37.



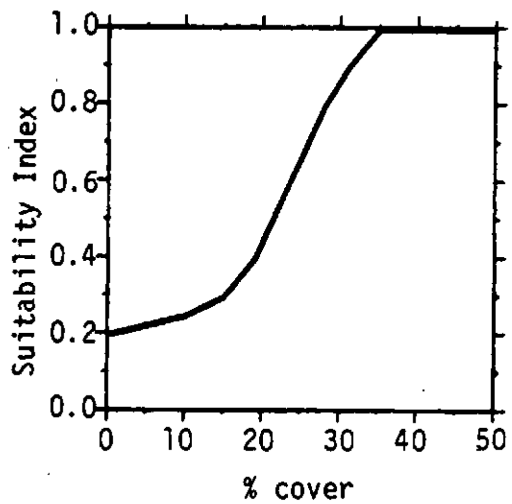
R V$_{10}$ Percent pools during summer low flow period.



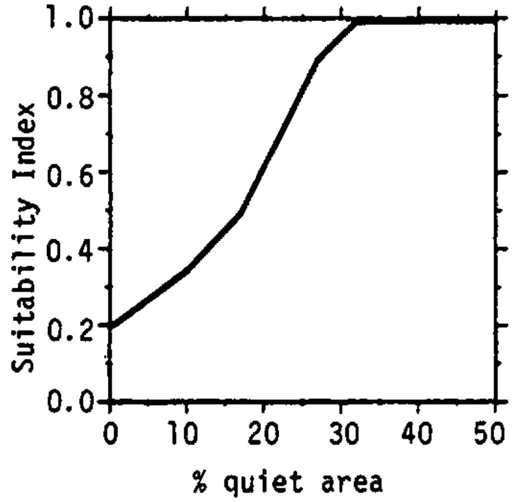
R V$_{11}$ Proportion of pools during summer low flow period that are 10 to 80 m^3 or 50 to 250 m^2 in size and have sufficient riparian canopy to provide shade.



R V$_{12}$ Percent instream and bank cover present during summer low flow period.

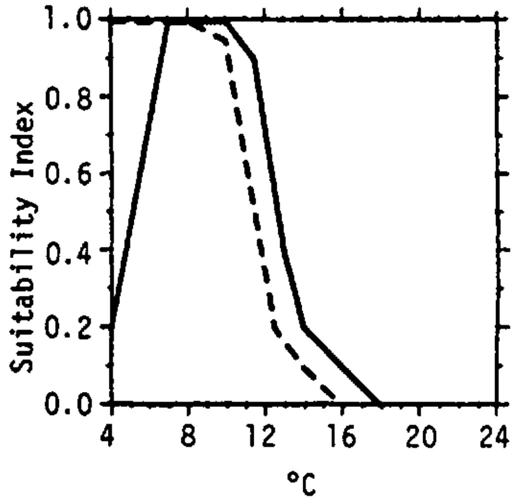


R V_{13} Percent of total area consisting of quiet backwaters and deep (≥ 45 cm) pools with dense cover of roots, logs, debris jams, flooded brush, or deeply-undercut banks during winter.



R V_{14} Maximum temperature during (A) winter (Nov.-March) in rearing streams and (B) spring-early summer (April-July) in streams where seaward migration of smolt occurs.

A. - - - -
B. ______



R V_{15} Minimum dissolved oxygen concentration during April-July in streams where seaward migration occurs.

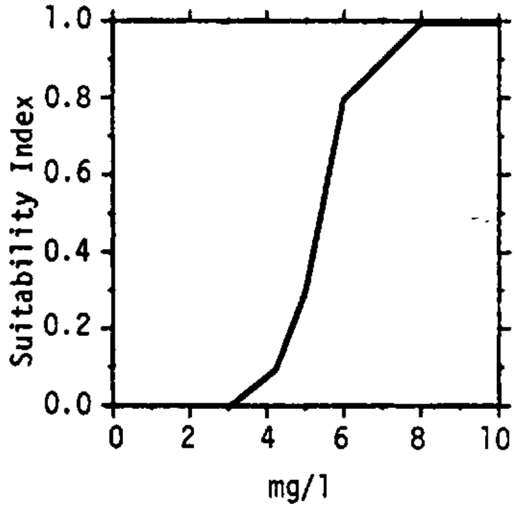


Table 1. Sources of information and assumptions used in construction of the suitability index graphs are listed below. "Excellent" habitat for coho salmon was assumed to correspond to an SI of 0.8 to 1.0, "good" habitat to an SI of 0.5 to 0.7, "fair" habitat to an SI of 0.2 to 0.4, and "poor" habitat to an SI of 0.0 to 0.1.

Variable	Assumptions and sources
V_1	Temperatures that are lethal or that correspond to high mortality rates in infected coho are poor (Bell 1973; Fryer and Pilcher 1974; Holt et al. 1975). Temperatures where mortality of infected coho is moderate or where activation of latent infections begins to increase are fair (Fryer and Pilcher 1974; Groberg et al. 1978). Temperatures that correspond to low disease mortality (Fryer and Pilcher 1974; Holt et al. 1975) and that are recommended for minimizing prespawning mortality are excellent (Wedemeyer pers. comm.).
V_2	D.O. levels that correspond to undiminished swimming ability (Davis et al. 1963) and that are recommended for successful upstream migration (Davis 1975) are excellent. Levels where swimming speed is greatly reduced (Davis et al. 1963) and avoidance is high (Whitmore et al. 1960) are poor.
V_3	Temperature ranges corresponding to those recommended as optimum for spawning and for incubation of embryos (Bell 1973) are excellent. Temperatures outside of this range are less suitable.
V_4	D.O. levels at or near the saturation level corresponded to the highest survival and emergence of fry and, therefore, are excellent. Levels that correspond to reduced emergence, delays in hatching or emergence, smaller size of fry, or increased incidences of developmental abnormalities (Alderice et al. 1958; Cobel 1961; Silver et al. 1963; Shumway et al. 1964; Mason 1976a) are fair. D.O. levels below 5 mg/l (Reiser and Bjornn 1979) or that approach lethal conditions (3 mg/l) (Coble 1961; Shumway et al. 1964; Davis 1975) are poor.

Table 1. (continued).

Variable	Assumptions and sources
V_5	(Embryo) Substrate composition that corresponds to high embryo survival and high emergence of fry is excellent. Compositions that contribute to reduced emergence (high percentage of fines, high embeddedness) are good-poor depending on the severity of the impact on survival and emergence (Koski 1966; Hall and Lantz 1969; Phillips et al. 1975; Cloern 1976; Platts et al. 1979; Reiser and Bjornn 1979).
	(Parr-Food) Gravel-rubble substrate composition corresponds to a high production of aquatic invertebrates (Giger 1973; Reiser and Bjornn 1979) and, therefore, is excellent in providing food for coho. Other substrates produce decreasing amounts of invertebrates in this order: rubble > bedrock > gravel > sand (Pennak and Van Gerpen 1947). It is assumed that the higher the percentage fines or percent embeddedness, the lower the production of aquatic invertebrates (Phillips 1971; Crouse et al. 1981).
V_6	Temperatures that correspond to high growth (9 to 13° C) (Stein et al. 1972) are excellent. Temperatures that correspond to reduced growth (Stein et al. 1972) are fair. Temperatures that are lethal or where growth of parr ceases are poor.
V_7	D.O. levels that correspond to the highest growth and food conversion rates (Herrmann et al. 1962; Brett and Blackburn 1981) are excellent. Levels that correspond to greatly reduced swimming speed (Dahlberg et al. 1968), avoidance behavior (Whitmore et al. 1960), and cessation of growth are poor.
V_8	It is assumed that 50 to 75% canopy enclosure is excellent. Other percentages are less suitable because cooler winter and warmer summer temperatures, associated with low canopy cover, result in decreased survival of embryos and fry (Chapman 1962; Hall and Lantz 1969; Stein et al. 1972). Lower biomass of coho corresponds to a high percent (> 90%) of canopy closure (Pearson et al. 1970; Chapman and Knudson 1980), so percentages ≥ 90% are fair.
V_9	Based on the work of Chapman (1966b), deciduous trees and shrubs are excellent as habitat for terrestrial insects and in providing high amounts of leaf litter used as food for aquatic invertebrates. Grasses/forbs and conifers are less suitable. The equation was formulated so that no riparian vegetation rates poor and so that ≥ 75% deciduous trees and shrubs rates excellent. It was based on the assumption that deciduous trees and shrubs provide twice the amount of terrestrial insects and leaf litter per unit area as do grasses/forbs and conifers.

Table 1. (continued)

Variable	Assumptions and sources
V_{10}	(Food-Cover) A pool to riffle ratio of 1:1 in streams is excellent in providing both food and cover for coho parr because: (1) food production is highest in riffles (Ruggles 1966; Waters 1969); (2) coho fry are most abundant in pools (Ruggles 1966; Lister and Genoe 1970; Mason 1976b); and (3) the highest number of coho fry remained in stream channels with a 1:1 ratio (Ruggles 1966). Higher or lower percentages of pools are less suitable because fewer coho fry remain in the stream channels (Ruggles 1966). This variable should be measured during summer low flow because this is the critical summer period for parr (Burns 1971).
V_{11}	The graph is based on studies on Oregon streams by Nickelson and colleagues where: (1) positive correlations were found between standing crop of age 0+ coho and pool volume (Nickelson and Reisenbichler 1977; Nickelson et al. 1979); and (2) coho fry biomass was highest in pools 10 to 80 m^3 or 50 to 250 m^2 in size (Nickelson pers. comm.). It is assumed that a positive relationship exists between proportion of pools 10 to 80 m^3 or 50 to 250 m^2 in size and habitat suitability (= carrying capacity) for coho fry. If such pools are absent from the reach, it is assumed that some other pool habitat would exist but would be poor, capable of supporting parr in relatively small numbers (therefore, SI = 0.2 at 0%).
V_{12}	Because there is a positive relationship between number of coho parr remaining in an area and amount of instream cover (Mason and Chapman 1965) and, because parr are most abundant near instream and bank cover (Ruggles 1966; Lister and Genoe 1970; Mason 1976b), it is assumed that habitat suitability is proportional to the amount of instream or bank cover present in a reach. Zero percent cover is assigned an SI of 0.2 because the stream may still be able to support coho parr, although at a greatly reduced level.
V_{13}	It is assumed that quiet backwaters and deep pools with dense cover are excellent winter habitat for coho parr because parr are most abundant in these areas during the winter (Hartman 1965; Bustard and Narver 1975a). Because several studies infer that the amount of suitable winter habitat may be a major factor limiting rearing capacity and smolt production (Chapman 1966a; Mason 1976b; Chapman and Knudsen 1980), it is assumed that habitat suitability is proportional to the amount of suitable winter habitat available. Zero percent winter cover has an SI rating of 0.2 because it is assumed that other potential sites can still support some overwintering parr. Thirty percent and above has an SI of 1.0, because it is assumed that optimum values of this variable are obtainable in conjunction with optimum riffle-pool ratios (V_{10}).

Table 1. (concluded).

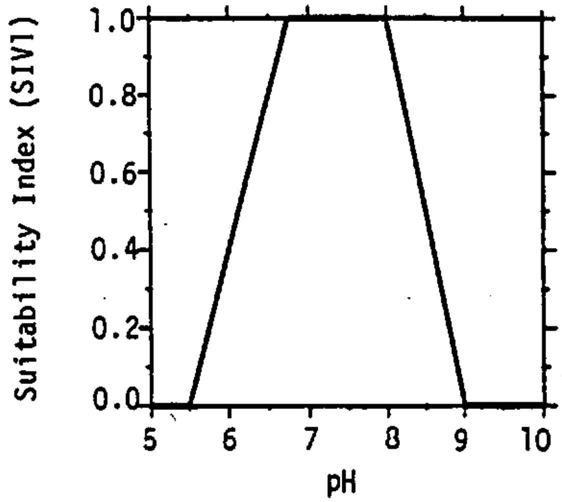
Variable	Assumptions and sources
V_{14}	Temperatures that correspond to a long and normal pattern of gill ATPase activity during smoltification (Zaugg and McLain 1976) are excellent, as are temperatures recommended for optimum smoltification and timing of seaward migration; i.e., $\leq$ 10° C during winter and $\leq$ 12° C during spring (Wedemeyer et al. 1980; Wedemeyer pers. comm.). It is assumed that the shorter the duration of gill ATPase activity, the less suitable the temperature. Also, temperatures > 12° C are considered fair-poor because the risk of infections from pathogens is assumed to be higher than at lower temperatures (Fryer and Pilcher 1974; Holt et al. 1975).
V_{15}	It is assumed that D.O. requirements for smolts are similar to those of parr, thus the same assumptions and sources used in developing the D.O. graph for parr (V_7) were used in constructing the SI graph for V_{15}.

Chinook Salmon

Chinook

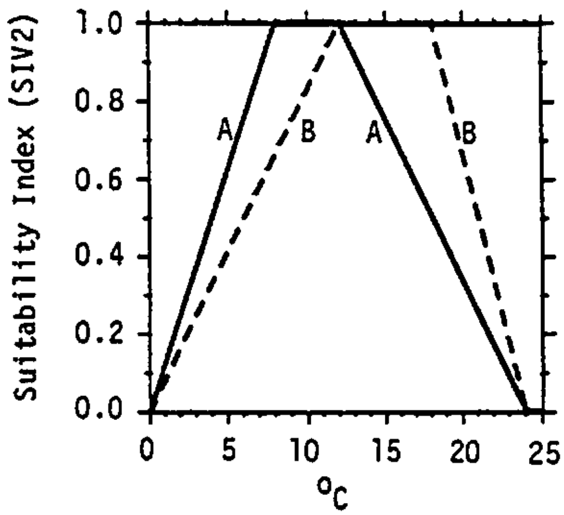
Variable | Suitability graphs

V_1 Annual maximal or minimal pH. Measure during the summer to fall season. Use the measurement with the lowest SI value.



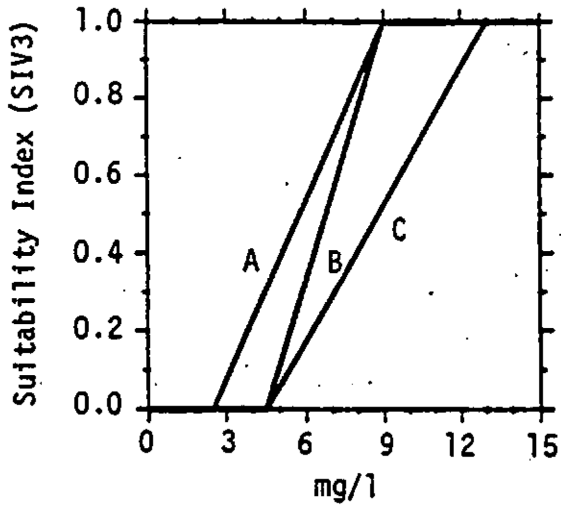
V_2 Maximum temperature during warmest periods when adults or juveniles are present. Measure at locations where problems may exist. Down-river, migration block areas and stream resident locations.

A = prespawning adults
B = juveniles



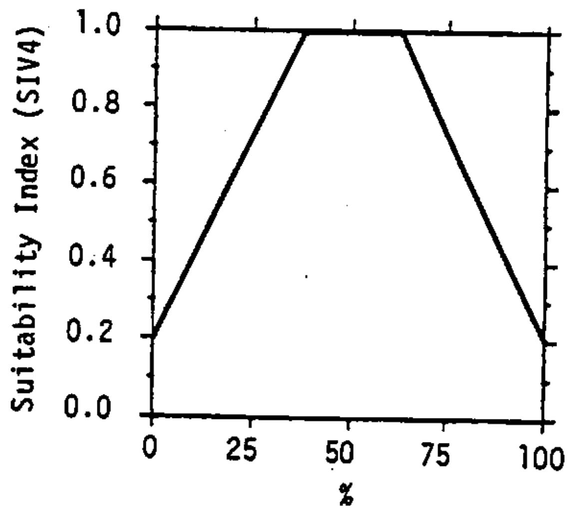
V_3 Minimum dissolved O_2 level during egg and preemergent yolk sac fry period, and during periods of occupation by adults and juveniles.

A. ≤5 °C
B. >5 - ≤10 °C
C. >10 °C



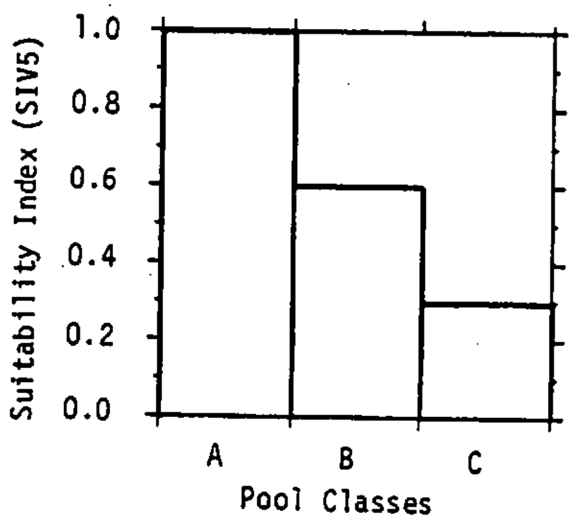
From

V_4 Percent pools during the late growing season low water period.



V_5 Pool class rating during the late growing season low flow period.

A. ≥30% of the habitat classified as pools is composed of 1st class pools.
B. ≥10% but <30% of the habitat classified as pools is composed of 1st class pools or ≥50% is 2nd class or better pools.
C. <10% of the habitat classified as pools is composed of 1st class pools and <50% is 2nd class pools.



First-class pool: Large and deep. Pool depth and area are sufficient to provide a low velocity resting area for several adult chinook. More than 30% of the pool bottom is obscure due to surface turbulence, turbidity, or the presence of structures such as logs, boulders, or overhanging objects. Or, the greatest pool depth is ≥1.5 m in streams ≤5 m wide or ≥2 m in streams >5 m wide.

Second-class pool: Moderate size and depth. Pool depth and area are sufficient to provide a low velocity resting area for a few adult chinook. From 5 to 30% of the bottom is obscured by surface turbulence, turbidity, or the presence of structures. Typical 2nd class pools are large eddies behind boulders and low velocity moderately deep areas beneath overhanging banks and vegetation.

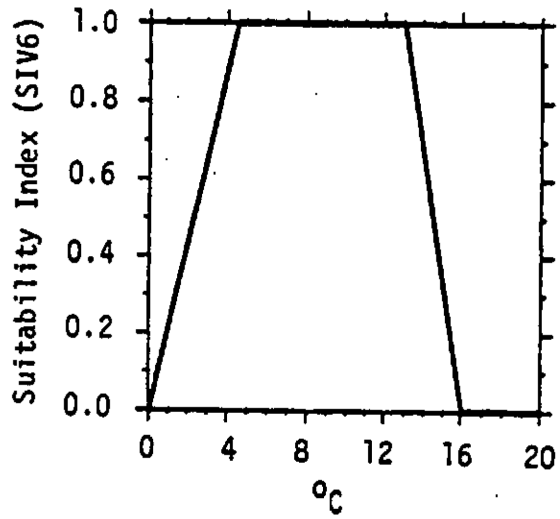
Third-class pool: Small in area, or shallow, or both. Pool depth and area are sufficient to provide a low velocity resting area for one to very few adult chinook. Cover, if present, is in the form of shade, surface turbulence, or very limited structure. Typical 3rd class pools are wide, shallow areas of streams or smaller eddies behind boulders. The entire bottom of the pool may be visible.

Variables

Suitability graphs

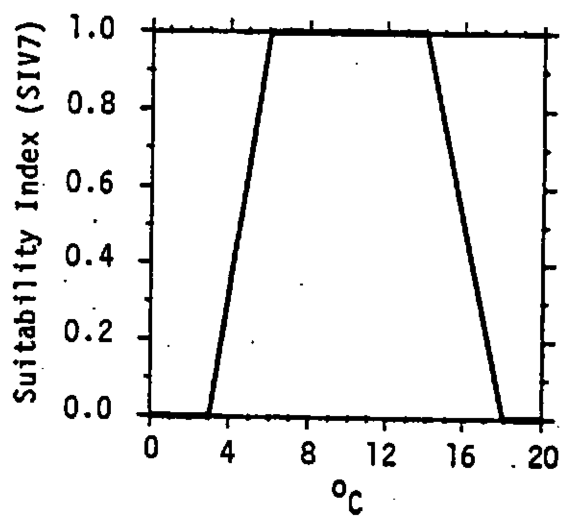
V_6 Maximum or minimum temperature at beginning and end of first month of spawning of late summer or fall spawning stocks. Use the temperature that yields the lowest SI.

Minimum temperature must remain ≥4.5 °C for ≥3.5 weeks after fertilization.



*V_7 Maximum or minimum temperature at beginning and end of embryo incubation period. Use the temperature that yields the lowest SI.

*Use for spring spawning stocks only.

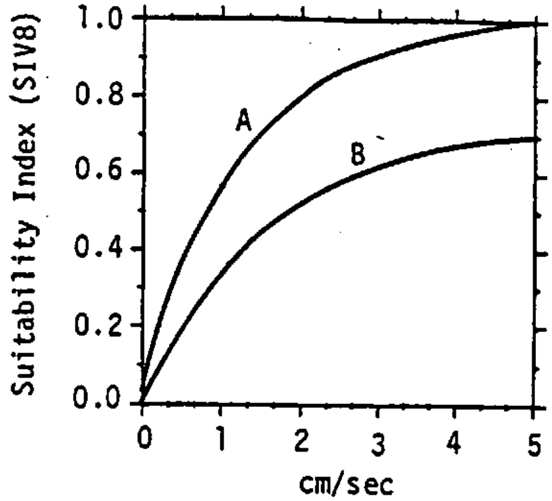


V_8

Percentage of spawning gravel in each of two classes: A. 2-10.6 cm B. 0.3-≤2, and ≥10.6-15 cm. Measure during or within 30 days after spawning.

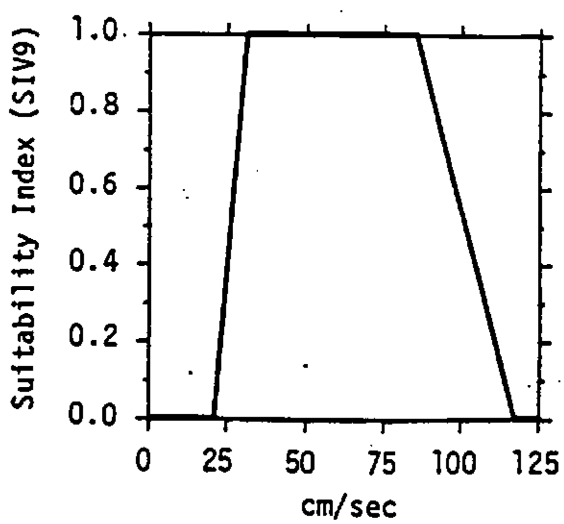
Record total area (m²) of gravel in each class. To derive an SI score, use the best substrate (class A) until the sample contains an area equal to 5% of the entire chinook habitat area sampled. If class B substrate must be included to obtain a 5% sample, derive an arithmetic mean SI score from the two individual SI scores obtained from the graph.

$$V_8SI = \frac{SIA + SIB}{2}$$



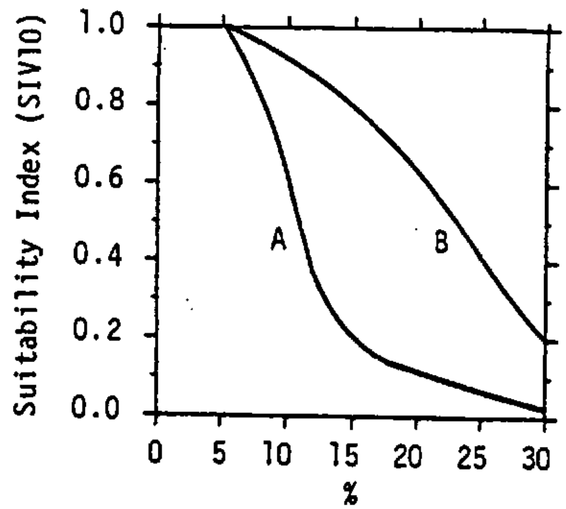
V_9

Average water column velocity (cm/s) over areas of spawning gravel used by chinook salmon during period of spawning and embryo development. Measure only at depths ≥20 cm and at same location as gravel (V_8).

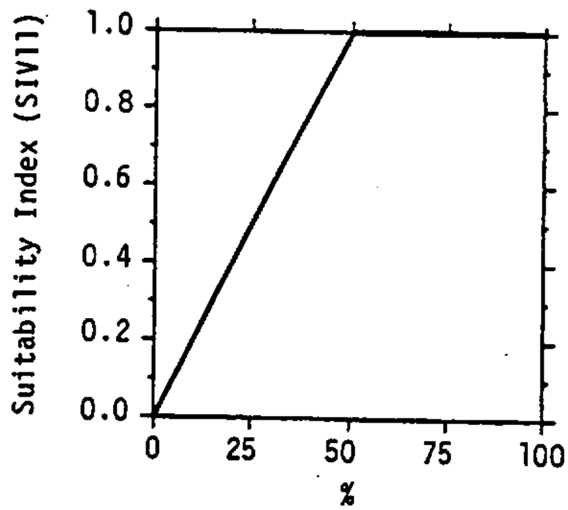


V_{10} Average percentage of fines in spawning gravel in major spawning areas. Measure within 30 days after spawning is over and at the same sites as V_9.

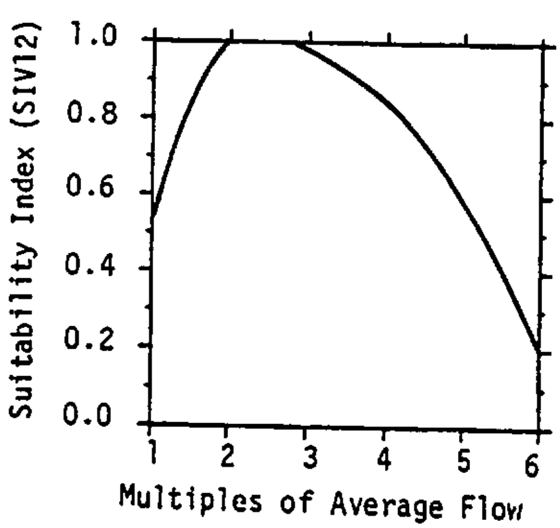
A. Fines ≤0.8 mm in size (silt).
B. Fines >0.8 to 30 mm in size (sand).



V_{11} Average annual base flow during the late summer to winter low-flow period as a percentage of the average annual daily flow. For embryo and preemergent fry use the average and low flows that occur during intergravel occupation period.

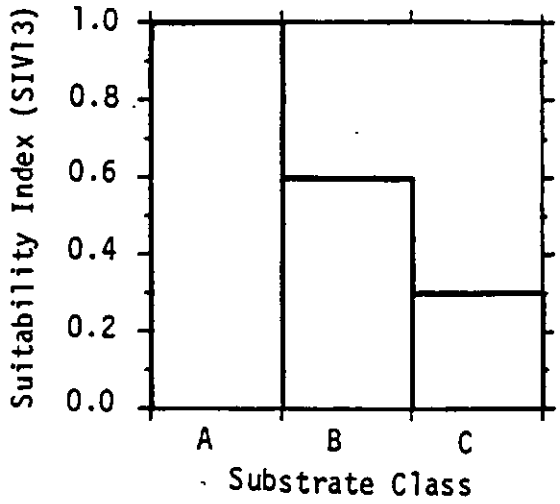


V_{12} Average annual peak flow as a multiple of the average annual daily flow. For embryo habitat suitability use the peak flow measurment that occurs from time of egg deposition until two weeks after fry emergence from the gravel.

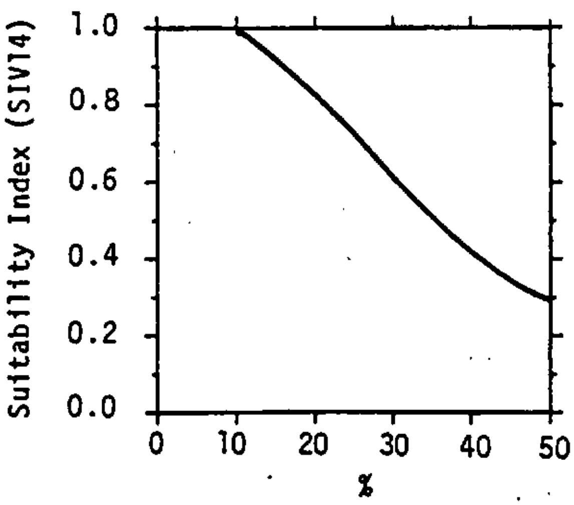


V_{13} Predominant (≥50%) substrate type in riffle-run areas for food production indicator. Measure in juvenile rearing and upstream areas.

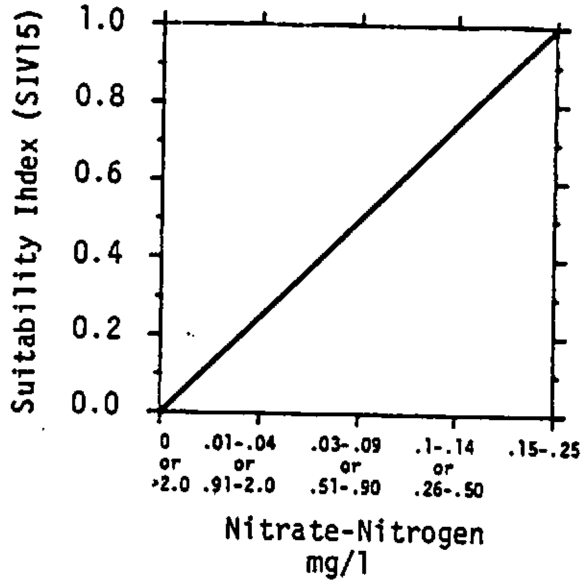
A. Rubble or small boulders (or aquatic vegetation in spring areas) dominate; limited amounts of gravel, large boulders, or slab rock may be present.
B. Rubble, gravel, and boulders occur in roughly equal amounts, or gravel or small boulders predominant. Fines, large boulders, or slab rock may be present in moderate quantities (≤25%).
C. Fines, slab rock, or large boulders predominate. Rubble or gravel are insignificant (≤25%).



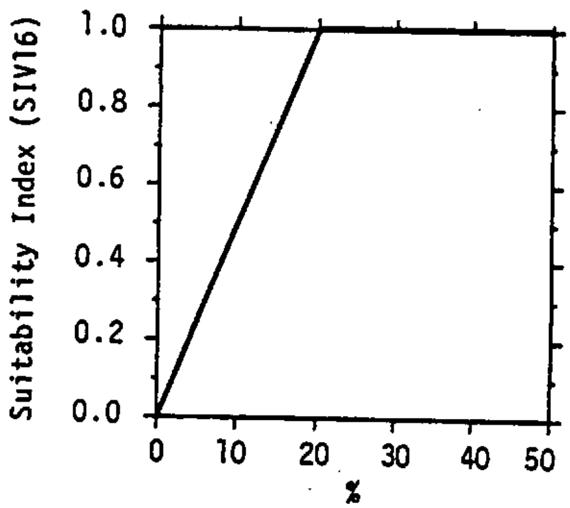
V_{14} Average percentage of fines (<3 mm) in riffle-run areas. Measure in juvenile rearing areas during average flow period.



V_{15} Levels of late summer nitrate-nitrogen (mg/l). Measure after spawner die off.



V_{16} Percentage of stream area providing escape cover. Measure during late summer-fall average to low flow period at depths ≥15 cm and with bottom velocities ≤40 cm/s.



*V_{17} Percentage of stream area with 10 to 40 cm average sized boulders. Measure at same time and areas as V_{16}.

*Use only for juveniles that overwinter in the freshwater.

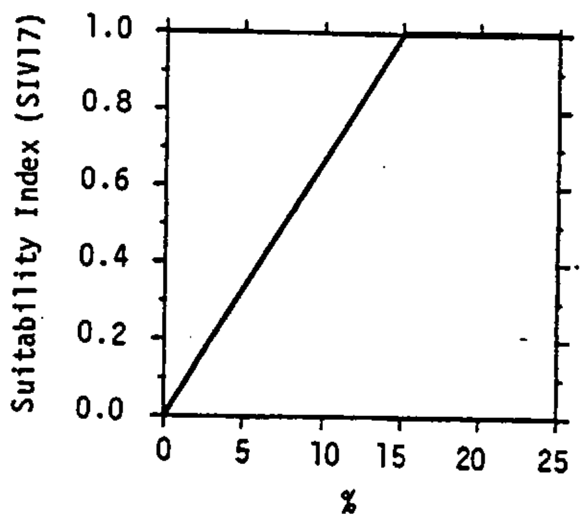


Table 1. Literature sources and assumptions for chinook salmon suitability index graphs.

Variable and source		Assumptions
V_1	Behnke and Zarn 1976	We assumed that an acceptable pH range and optimal values were similar to other sympatric salmonid species.
V_2	Mattson 1948 Burner 1951 Brett 1952 Black 1953 McAfee 1966 Bidgood and Berst 1969 Behnke 1986 (review comment)	Because chinook salmon are often sympatric with rainbow-steelhead trout, range from coastal areas to elevations of 1200+ m, and from California to Northern Alaska, we assumed they would have a fairly wide temperature tolerance range, similar to rainbow-steelhead, but with a lower maximum and optimal range. Northern and high elevation stocks may have a more restricted range.
V_3	Gangmark and Bakkala 1960 Eddy 1972 Davis 1975 Bustard 1983	Dissolved oxygen concentrations below minimum levels associated with temperature thresholds affect the development and survival of chinook salmon embryos and juveniles.
V_4	Needham 1940 Hartman 1965 Edmundson et al. 1968 Lister and Genoe 1970 Everest and Chapman 1972 Platts 1974	A pool to riffle ratio of about 1:1 (about 40%-60% pools) provides an optimal mix of prespawning adult holding area, juvenile cover and resting area, and stream food-producing habitat for chinook salmon.
V_5	Hartman 1965 Edmundson et al. 1968 Lister and Genoe 1970 Everest and Chapman 1972 Platts 1974	Pools differ in their ability to provide cover and adequate resting habitat. Pool classes utilized by prespawning adults, schools of juveniles, and as summer and winter cover by chinook salmon were considered essential.

Table 1. (Continued)

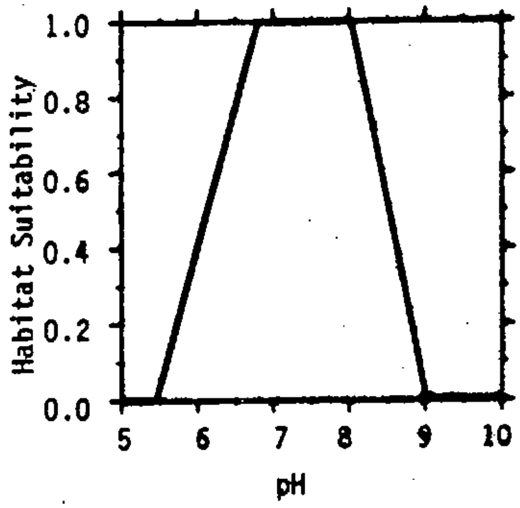
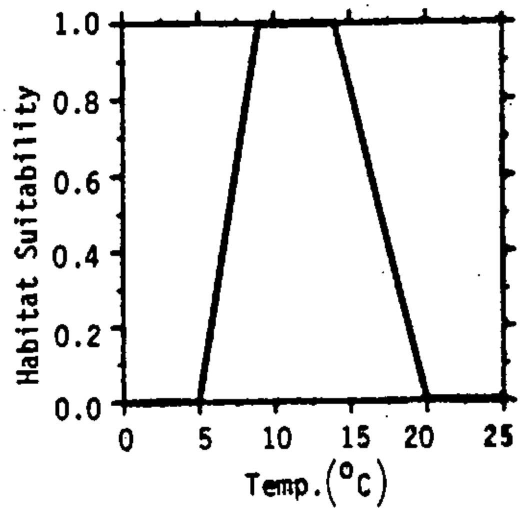
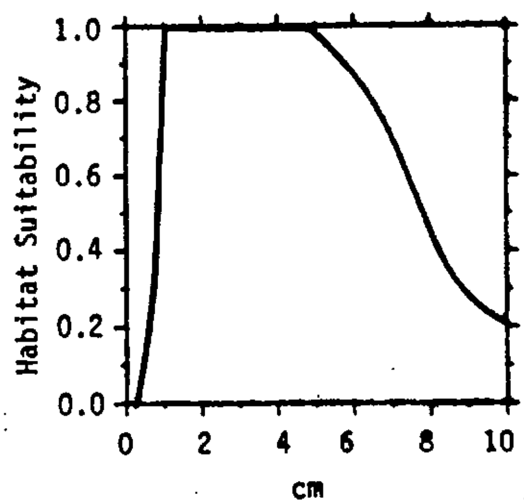
Variable	and source	Assumptions
V_6	Chambers 1956 Seymour 1956 Gangmark and Bakkala 1960 Eddy 1972 Brett et al. 1982 Behnke (correspondence)	Temperatures associated with high survival of spring spawning stocks were considered optimal. Those associated with poor survival were considered suboptimal.
V_7	Slater 1963	Temperatures during the first 3.5 weeks of embryo development associated with high embryo survival were assumed optimal. Temperatures associated with developmental abnormalities and poor survival were considered suboptimal.
V_8	Hobbs 1937 Burner 1951 Chambers 1956 Fulton 1968 McNeil 1968	Gravel size ranges selected for spawning by chinook salmon were used to set the size range. The optimal size range was those gravel sizes associated with the best permeability, survival of embryos, and emergence of yolk sac fry.
V_9	Andrew and Geen 1960 Smith 1973	Average water column velocities selected by spawning adult chinook salmon and associated with high survival of embryos were considered in selecting velocity ranges and optimal values.
V_{10}	Burner 1951 Cordone and Kelly 1961 McNeil and Ashell 1964 Koski 1966 McNeil 1968 Bjornn 1969 Phillips et al. 1975	The percentages of fines in spawning gravel areas associated with high embryo survival and emergence of yolk sac fry were considered optimal. Suitability decreased as the percent fines and embryo mortality increased.
V_{11}	Andrew and Geen 1960 Tennent 1976 Binns and Eiserman 1979 Wesche 1980 Nehring and Anderson 1982, 1983	Base flows as a percentage of the average annual daily flows that were associated with high embryo survival and high standing crops of juvenile salmonids were considered optimal.
V_{12}	Lister and Walker 1966 Nehring and Anderson 1982, 1983	Average annual peak flows as a multiple of the average annual daily flows that were associated with high embryo survival and high standing crops of salmonids were considered optimal.

Table 1. (Concluded)

Variable and source		Assumptions
V_{13}	Hynes 1970 Binns and Eiserman 1979	The predominant substrate type containing the greatest numbers and kinds of aquatic insects was considered optimal.
V_{14}	Cordone and Kelly 1961 Crouse et al. 1981	The percentage of fines in riffle-run areas associated with the highest standing crops of aquatic food organisms was considered optimal.
V_{15}	Binns and Eiserman 1979	Nitrate nitrogen levels in rivers that are associated with the highest standing crops of aquatic food organisms and fishes are considered optimal.
V_{16}	Hartman 1965 Everest 1969 Platts 1974	The percentage of instream and bank cover in juvenile rearing areas associated with the highest standing crops of juveniles are optimal.
V_{17}	Hartman 1965 Everest 1969 Chapman and Bjornn 1969 Everest and Chapman 1972	The size range of substrate selected most often by juvenile chinook as escape and winter cover was considered optimal. Percentages needed were estimated.

Pink Salmon

Pink Salmon

Variable		Suitability graphs
V_1	Annual maximal or minimal pH. Measure during summer to fall. Use the measurement with the lowest SI value.	
V_2	Maximal or minimal water temperature during the adult upstream migration and spawning period. Measure in downstream areas during stream entry and migration period, and on the spawning grounds during the spawning period. Use the measurement with the lowest SI score.	
V_3	Average size of substrate particles (cm). Measure in gravel bottom areas of stream used by spawning pink salmon during the spawning season and only where the water depth is ≥ 15 cm.	

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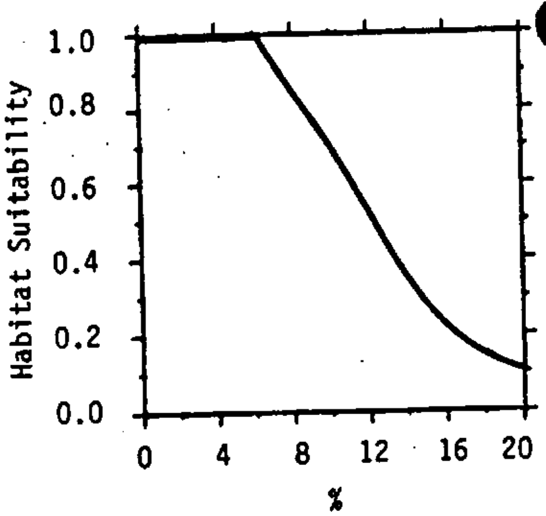
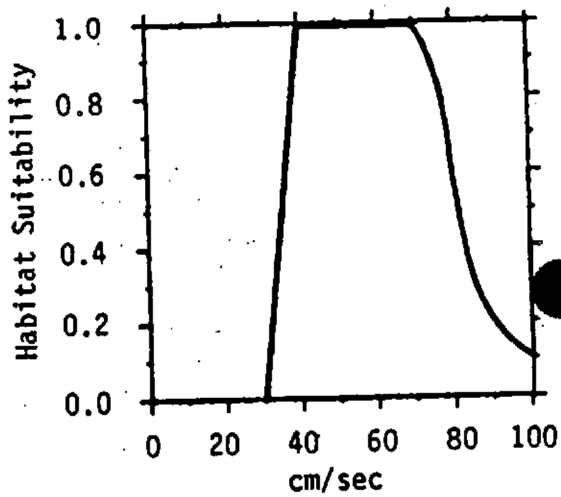
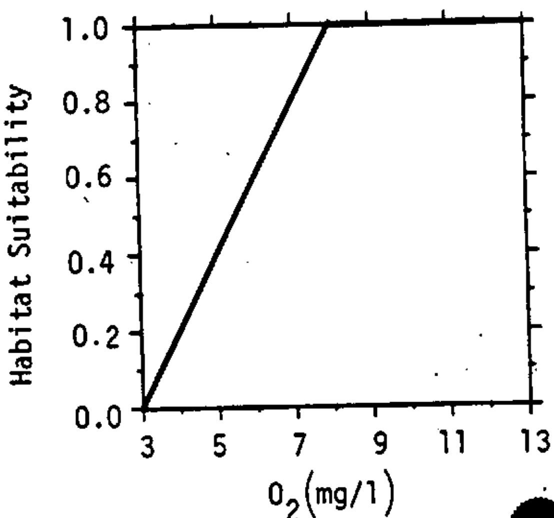
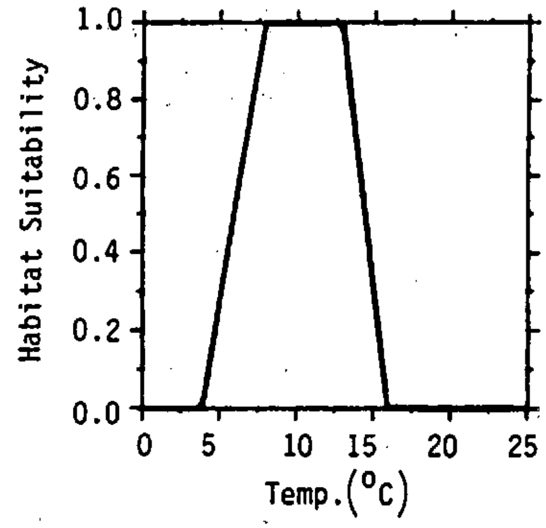
Variable		Suitability graphs
V_4	Percent fines (< 0.3 cm). Measure at the same time and sites as V_3.	
V_5	Average water column velocities for spawning and embryo incubation. Measure at the same time and sites as V_3.	
V_6	Minimal dissolved O_2 level during the egg incubation and preemergent yolk sac fry period. Measure at time of highest temperatures during the incubation period.	

Variable

Suitability graphs

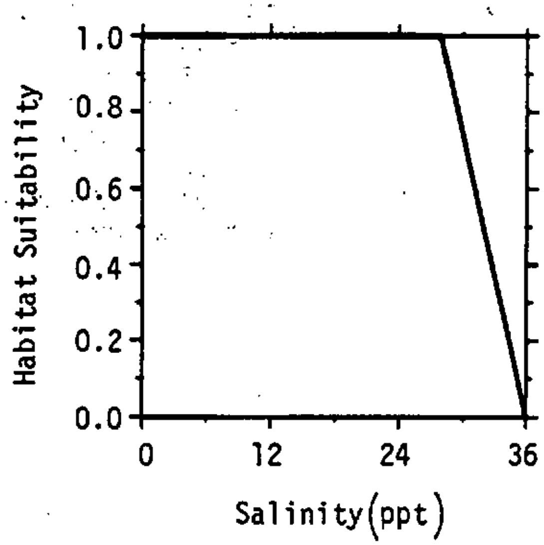
V_7

Maximal or minimal water temperatures during the early embryo development period. Measure on the spawning area within the first 10 days after spawning commences. Use the measurement with the lowest SI score.



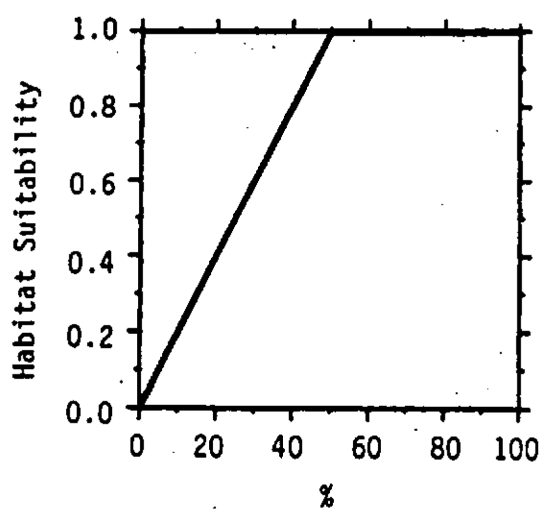
V_8

Maximal salinity during the early embryo development period. Measure intergravel at egg depth at or near the four hour tide exposure level.



V_9

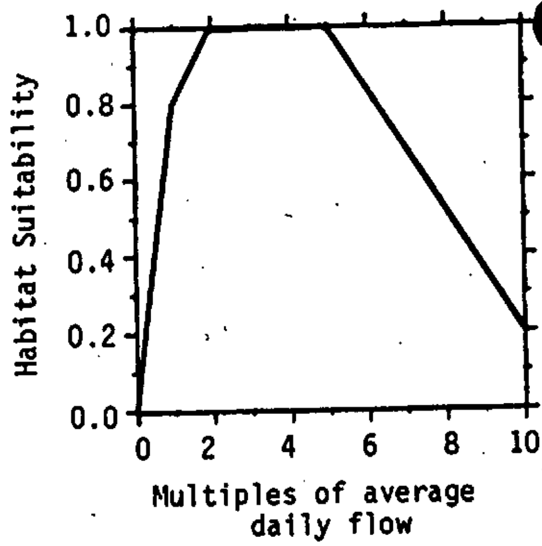
Average base flow during the embryo incubation period as a percentage of the average daily flow during spawning. Measure during peak spawning and at incubation low flow periods.



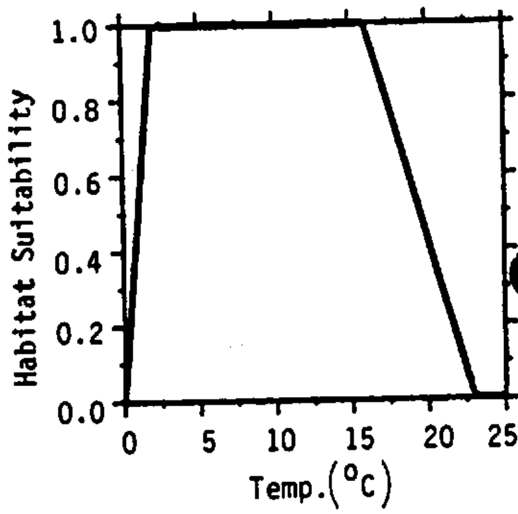
Variable

Suitability graphs

V_{10} Peak flow during incubation period as a multiple of the average base flow (as in V_9).



V_{11} Maximum temperature during the period of seaward migration. Measure in downstream areas in the post-peak migration period during the hottest period of the day; usually mid-afternoon.



The data sources and assumptions used to construct the pink salmon suitability graphs are summarized in Table 1.

Table 1. Specific habitat requirements, sources, and assumptions.

Variable and sources	Assumptions
V_1 Behnke and Zarn 1976 Ishida 1966	Ranges of pH selected by most trout and salmon were considered applicable to pink salmon, and the pH concentrations correlated with abundant pink salmon populations were considered to be the optimal range.
V_2 Divinin 1952; Kuznetsov 1928; Semko 1939	Water temperature extremes can prevent stream entry and spawning. Temperatures associated with normal stream entry and spawning were considered optimal.
V_3 Andrew and Geen 1960; Chambers 1956; Neave 1966; and Semko 1939.	The substrate sizes selected by adult spawners were considered to constitute the size range of gravel used. The gravel sizes correlated with high embryo survival and fry emergence was considered optimal.
V_4 McNeil and Ahnell 1964; Wickett 1962	The percent fines associated with the highest survival of embryos and emergent fry was considered optimal. Those associated with high mortality were considered suboptimal.
V_5 Andrew and Geen 1960; Divinin 1952; Ishida 1966.	Average water velocities most often selected by adults and those associated with high embryo survival were considered optimal.
V_6 Doudoroff and Shumway 1970; Ishida 1966; McNeil 1966; Nikolskii and Soin 1954.	Dissolved oxygen concentrations associated with normal development and high survival of embryos were considered optimal. Those associated with development abnormalities and high mortality of salmonid embryos were considered suboptimal.
V_7 Bailey and Evans 1971 Bell 1973; Divinin 1952; Petrenko 1964; Sheridan 1962; Semko 1939; McNeil 1968; Bailey 1985	Maximum and minimum temperatures associated with high embryo survival and normal time of fry emergence were considered optimal. Those associated with poor survival or time of emergence were suboptimal.
V_8 Bailey 1966; Hanovan and Skud 1954; Helle et al. 1964; Ishida 1966; McNeil and Bailey 1975	Maximum salinities of ≤ 4 hours exposure duration associated with high embryo survival and a low incidence of deformities were optimal. Higher salinities with greater exposure times were progressively further from optimum.

Table 1. (concluded)

Variable and sources	Assumptions
V_9 Andrew and Geen 1960; Binns and Eiserman 1979; Lister and Walker 1966; Sheridan and McNeil 1960; Tennant 1976; Wesche 1980.	Average base flows during embryo incubation as a percentage of average daily flows associated with high salmonid embryo survival were considered excellent; intermediate base flows were considered fair to good; and base flows of < 25% were considered poor.
V_{10} Andrew and Geen 1960; Lister and Walker 1966; Nehring and Anderson 1982, 1983; Sheridan and McNeil 1960, 1968	Embryo incubation season peak flows of two to five times greater than the average base flow were considered to be excellent, but increasingly higher flows were considered to be progressively worse.
V_{11} Brett 1952; Divinin 1952; Ishida 1967; Semko 1939.	The range of maximum temperatures were those over which seaward migrations had been observed with an upper tolerance level and an optimal range of preferred temperatures for pink salmon fry as reported by Brett.

Chum Salmon

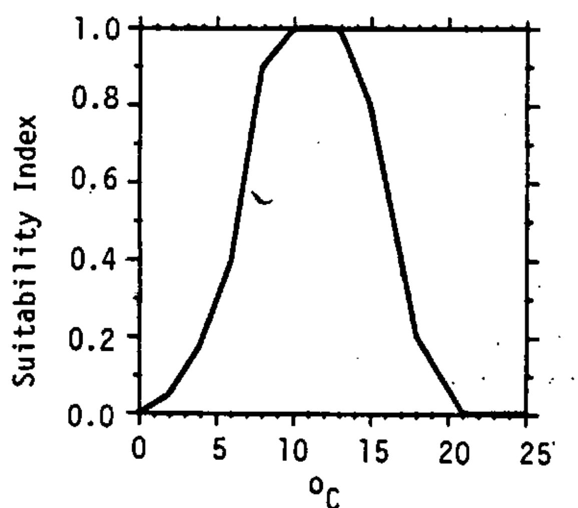
Chum Salmon

Cederholm and Koski 1977). V_7 was included because salinity affects embryo survival (Rockwell 1956; Kashiwagi and Sato 1969). Water depth and the presence or absence of upwelling ground water should also be considered as factors influencing spawning and incubation.

Rearing and downstream migration component. We included V_8 in this component because temperature affects the mortality of chum salmon fry (Brett 1952) and, in general, can alter the timing of seaward migration, smoltification, and the susceptibility of salmonid smolts to disease (Wedemeyer et al. 1980). The index V_9 was included because DO concentration could potentially affect downstream migration by decreasing swimming speed (Dahlberg et al. 1968), eliciting avoidance (Whitmore et al. 1960), or causing direct mortalities of smolts. Model users may also want to consider discharge pattern. Out-migration of chum fry in the Susitna River is correlated with discharge level (Roth et al. 1984). Fish appear to reach a point where they are physiologically ready to migrate downstream and then an increase in discharge provides the environmental cue to begin migrating. There may also be some physical flushing of fish as the heads of rearing sloughs are inundated by rising water. Food availability should also be considered.

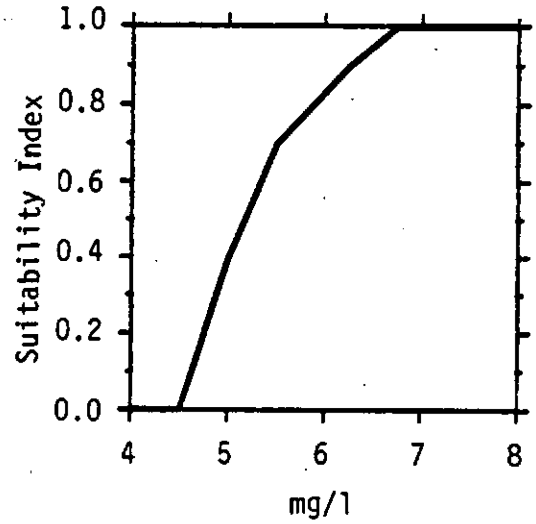
Suitability Index (SI) Graphs for Model Variables

Table 1 lists the sources of information and rationale used in constructing each SI graph. Graphs were constructed by converting available information on the habitat requirements of chum salmon into an index of suitability ranging from 0.0 (unsuitable) to 1.0 (optimum or most preferred level). These graphs should not be construed as graphical presentations of real data, but rather as hypothetical models of the relation between levels of a particular environmental variable and its corresponding suitability as habitat for chum salmon. All variables pertain to riverine (R) habitat.

Habitat	Variable		Suitability graphs
R	V_1	Maximum temperature during upstream migration.	

From:
Biological Report 82(10.108) USFWS

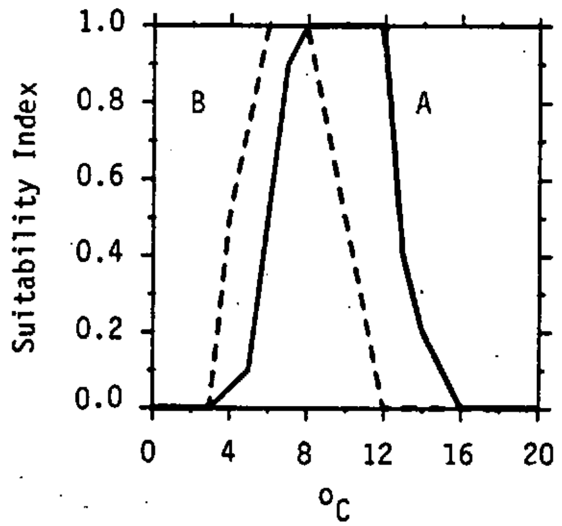
R V$_2$ Minimum dissolved oxygen (DO) concentration during upstream migration.



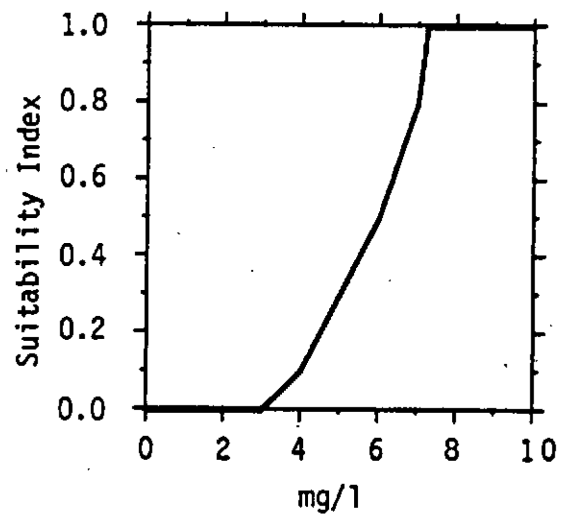
R V$_3$ Extreme intragravel temperatures from spawning to emergence of fry.

A. Maximum
B. Minimum

SI for V$_3$ = SI for A or B, whichever is lower

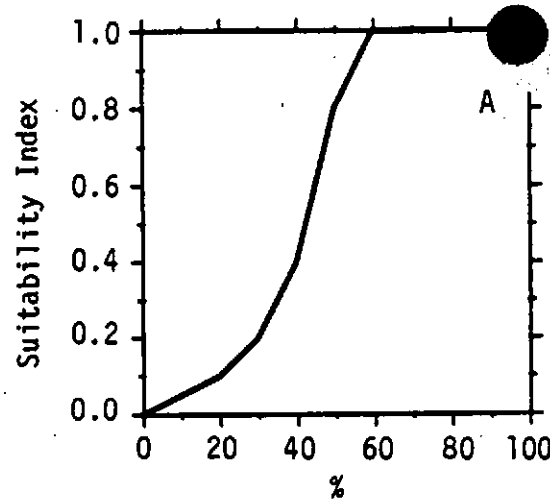


R V$_4$ Minimum DO concentration from spawning to emergence of fry.

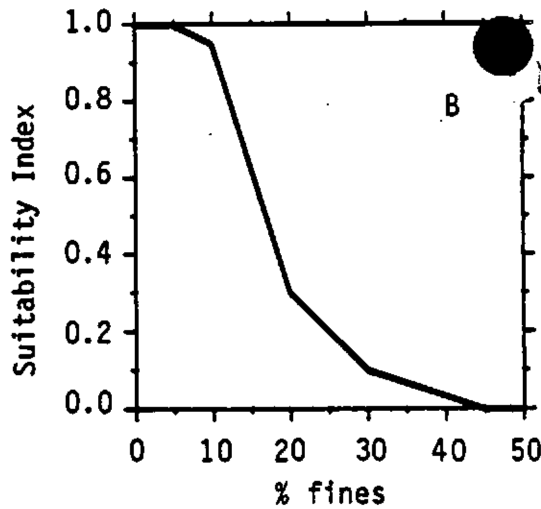


R V_s Substrate composition within riffle and run areas.

A. Percent of gravel substrate 10-100 mm in diameter.



B. Percent fines (< 6 mm) or $\frac{\text{(Percent embeddedness of substrate)}}{2}$



$$\text{SI for } V_s = \frac{\text{SI for A} + \text{SI for B}}{2}$$

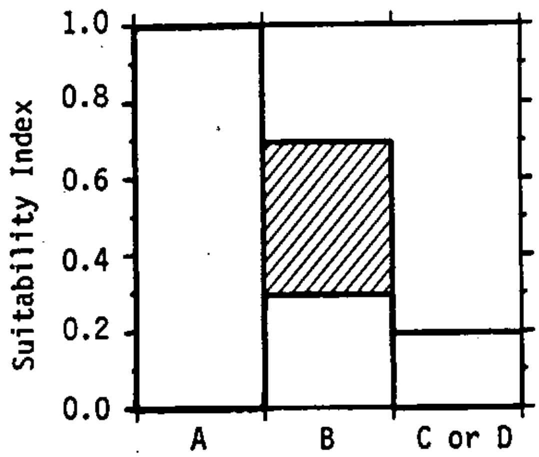
R $\quad$ V_6 $\quad$ Stream discharge pattern from egg deposition to downstream migration of fry.

A. Streamflow stable, < 100-fold difference between extreme average daily stream discharges; stream channel stable, with little shifting.

B. Moderate potential for flooding: 100 to 500-fold difference between extreme average daily stream discharges. (Hatch marks indicate suggested range of SI's for discharge range, 100-fold equals 0.7, 500-fold equals 0.3).

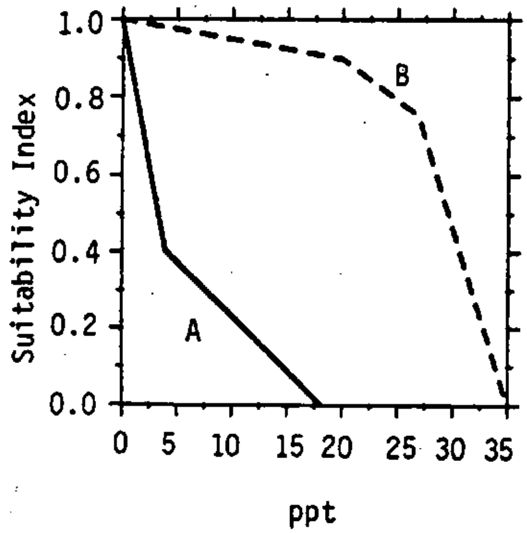
C. High potential for substrate scouring: > 500-fold difference between extreme average daily stream discharges during this period; stream channel easily altered during freshets; substrate unstable and easily displaced during freshets.

D. High potential for low winter flow or dewatering, resulting in exposure or freezing of redds.



R V$_7$ Mean intragravel salinity.

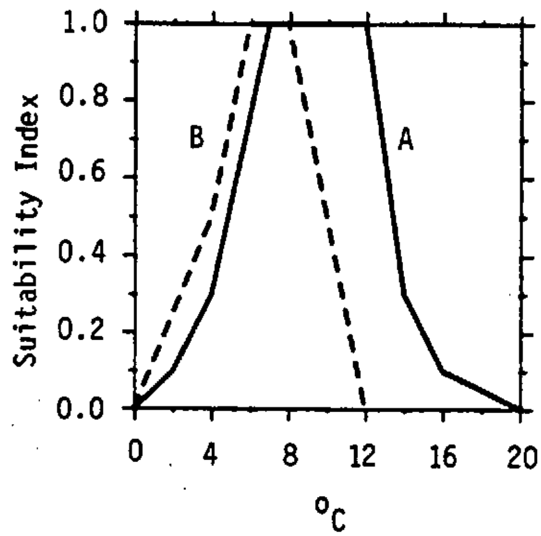
A. For eyed embryos.
B. For alevins.



R V$_8$ Temperature extremes during rearing and downstream migration of fry.

A. Maximum
B. Minimum

SI for V$_8$ = SI for A or B, whichever SI is lower.



R V$_9$ Minimum DO concentration during rearing and downstream migration of fry.

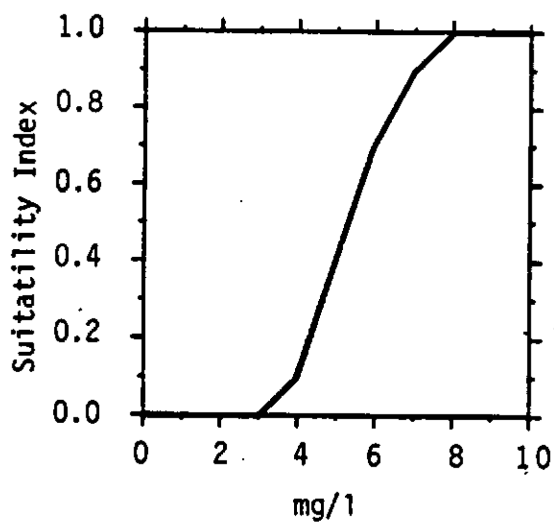


Table 1. Sources of information and rationale used in constructing suitability index graphs. Habitat for chum salmon is classified as "excellent" at 0.8 to 1.0, "good" at 0.5 to 0.7, "fair" at 0.2 to 0.4, and "poor" at 0.0 to 0.1.

Variable	Sources and rationale
V_1	Inasmuch as upstream migration of salmon is closely tied to the temperature regime characteristic of each spawning stream (Sheridan 1962), we assumed that any deviations from the normal seasonal temperature cycle during upstream migration would be suboptimum. Chum salmon migrate upstream primarily at 8 to 14° C (Hunter 1959; Sano 1966). However, temperatures of 8 to 12° C were considered excellent, because disease rates for anadromous salmonids increase markedly at temperatures above 12.7° C (Fryer and Pilcher 1974; Holt et al. 1975; Groberg et al. 1978). Temperatures ≥ 20° C were deemed poor because: (1) temperatures ≥ 25.5° C are lethal to anadromous salmonids (Bell 1973); (2) sublethal temperatures > 20° C are associated with high disease-induced mortality (Wedemeyer 1970); and (3) upstream migrations of Pacific salmon are delayed by temperatures > 20° C (Bell 1973). Temperatures of 15 to 20° C were deemed only fair because little upstream migration has been observed within this temperature range (see text).
V_2	Dissolved oxygen concentrations that enable undiminished swimming abilities (> 6.5 mg/l; Davis et al. 1963) and that are recommended for successful upstream migration of anadromous salmon (> 6.3 mg/l; Davis 1975) were considered excellent. We considered as poor the levels at which coho salmon swimming speed is greatly reduced (Davis et al. 1963) or avoidance is high (< 4.5 mg/l; Whitmore et al. 1960), or that are associated with high mortality of ripe pink salmon in southeast Alaska streams (≤ 4 mg/l; Edgington 1981 pers. comm. in Krueger 1981).
V_3	Unusually low or high temperatures result in emergence of salmonid fry at times inappropriate for their survival in the estuary (Sheridan 1962). Delayed chum salmon fry emergence due to reduced temperatures has been documented by Koski (1975) and Wangaard and Burger (1983). Temperatures of 7.2 to 12.8° C were considered excellent because they were related to high survival (Bailey and Evans 1971) and normal timing of emergence of pink salmon fry (Godin 1980). Temperatures that adversely affect survival and development of chum salmon eggs (< 4.4° C; Schroder 1973; Koski 1975; Raymond 1981; Wangaard and Burger 1983) or that inhibit chum salmon spawning (< 2.5° C; Schroder 1973) were considered poor, as were temperatures above the upper threshold for successful incubation of pink salmon embryos (≥ 15° C; Kwain 1982).

Table 1. (continued)

Variable		Sources and rationale
		McNeil and Bailey (1975) suggested that, like pink salmon embryos (Bailey and Evans 1971), chum salmon embryos tolerate temperatures near freezing, provided temperatures exceed 4.4° C for at least 30 days after fertilization.
V_4		Low DO levels increase mortality, decrease fitness, and alter timing of emergence of chum salmon embryos and fry (Wickett 1954, 1958; Alderdice et al. 1958; Koski 1975). Levels corresponding to high survival, unaltered timing of emergence, and highest fitness of chum salmon embryos and fry (> 6 mg/l; Alderdice et al. 1958; Lukina 1973; Koski 1975) were considered good to excellent. Concentrations corresponding to poor or no survival (< 3 mg/l; Wickett 1954; Mattson et al. 1964; Koski 1975), or delayed timing of emergence (< 3 mg/l; Alderdice et al. 1958; Koski 1975), were deemed poor.
V_5	A.	Hunter (1959) reported that chum salmon spawn in gravel 13 to 130 mm in diameter. Sano (1959) reported that chum salmon redds consisted of > 30% gravel (> 31 mm in diameter). Burner (1951) reported that chum salmon redds in tributaries of the Columbia River were composed of 81% gravel (< 152 mm). Dill and Northcote (1970) found survival of chum salmon eggs to be 100% in gravel 50 to 102 mm diameter but only 38% in gravel of 10 to 38 mm. On the basis of this information, we assumed that a substrate composition of ≥ 60% gravel 10 to 100 mm in diameter (and < 10% fines) is excellent.
	B.	Sedimentation during incubation is a major source of chum salmon egg mortality (Neave 1953; Wickett 1954; McNeil 1966; Rukhlov 1969; Scrivener and Brownlee 1982, in prep.). Koski (1975) observed an inverse relationship between percent fines (< 3.3 mm but > 0.1 mm) and percent survival to emergence of chum salmon. Higher percentages of fines led to premature emergence of fry, lower yolk conversion efficiency, smaller size at hatching, and slower growth. Thorsteinson (1965) reported that redds with > 13% fines (< 0.833 mm diameter) were poor producers of chum salmon fry because intragravel permeability was reduced. Scrivener and Brownlee (1982) found reduced chum egg-to-fry survival with increased sedimentation. Thus, levels of fines associated with high production and survival of chum eggs and fry (< 13%, Thorsteinson 1965; < 14%, Rukhlov 1969) and high survival and emergence of salmonid fry in general (< 10%, Hall and Lantz 1969; Phillips et al. 1975) were considered excellent. Levels of fines (> 15%) corresponding to lower survival and emergence of fry were considered fair to poor. We assumed that, if necessary, percent fines could be estimated by dividing the percent embeddedness by 2.

Table 1. (continued)

Variable	Sources and rationale
V_6	Survival of chum salmon embryos and alevins is high in more stable flow regimes (McNeil 1966, 1969), whereas it is poor in streams with shifting stream channels and extreme fluctuations in discharge that result in scouring of redds (Neave 1953; Wickett 1958; McNeil 1966, 1969). Poor survival of chum salmon eggs and alevins has also been observed during periods of low winter flows (Hunter 1959; McNeil 1966, 1969). On the basis of the findings of McNeil (1966, 1969), Cederholm and Koski (1977), and Lister and Walker (1966), we classified as excellent the streams with a low probability of redd scouring, i.e., those with stable flow regimes (< 100-fold difference between extreme average daily stream discharges) and stable stream channels. Considered poor were streams with a high probability of redd scouring (> 500-fold difference between extreme average daily stream discharges during winter) or redd freezing or desiccation, i.e., streams with unstable stream channels and streambeds and high potential for flooding, or high probability of very low flows during the incubation period. Streams with characteristics intermediate between these extremes were assumed to be good to fair.
V_7	Rockwell (1956) reported that survival of chum salmon embryos was highest in constant salinities < 6 ppt (corresponding to upper and middle reaches of the study area); mortality increased to 67% at 6.0 to 11.6 ppt, and 100% at > 12 ppt. Kashiwagi and Sato (1969) found that percent mortality of chum salmon eggs to hatching was 0 at ≤ 9 ppt, 25 at 18 ppt, 50 at 27 ppt, and 75 at 35 ppt. However, nearly all alevins hatched from eggs exposed to salinities > 9 ppt died within a few days. Helle (pers. comm.) found no survival of eggs deposited by chum and pink salmon in a saline (4 to 8 ppt) stream. On the basis of these somewhat conflicting results, we assumed < 4 ppt to be excellent, 4 to 9 ppt to be good to fair, and > 9 ppt to be poor. It should be noted that Hartman (pers. comm.) has observed that chum eggs can survive tidal inundation by water of up to 24 ppt salinity if there is periodic (daily) flushing of redds by freshwater. The laboratory observation by Rockwell (1956) that chum salmon eggs and alevins can survive in seawater up to 30 ppt for several days at low temperatures provides corroborating support for this suggestion. We therefore assumed that short term high salinities caused by tidal inundation would be a less appropriate measure of habitat suitability than some measure of average salinity conditions.

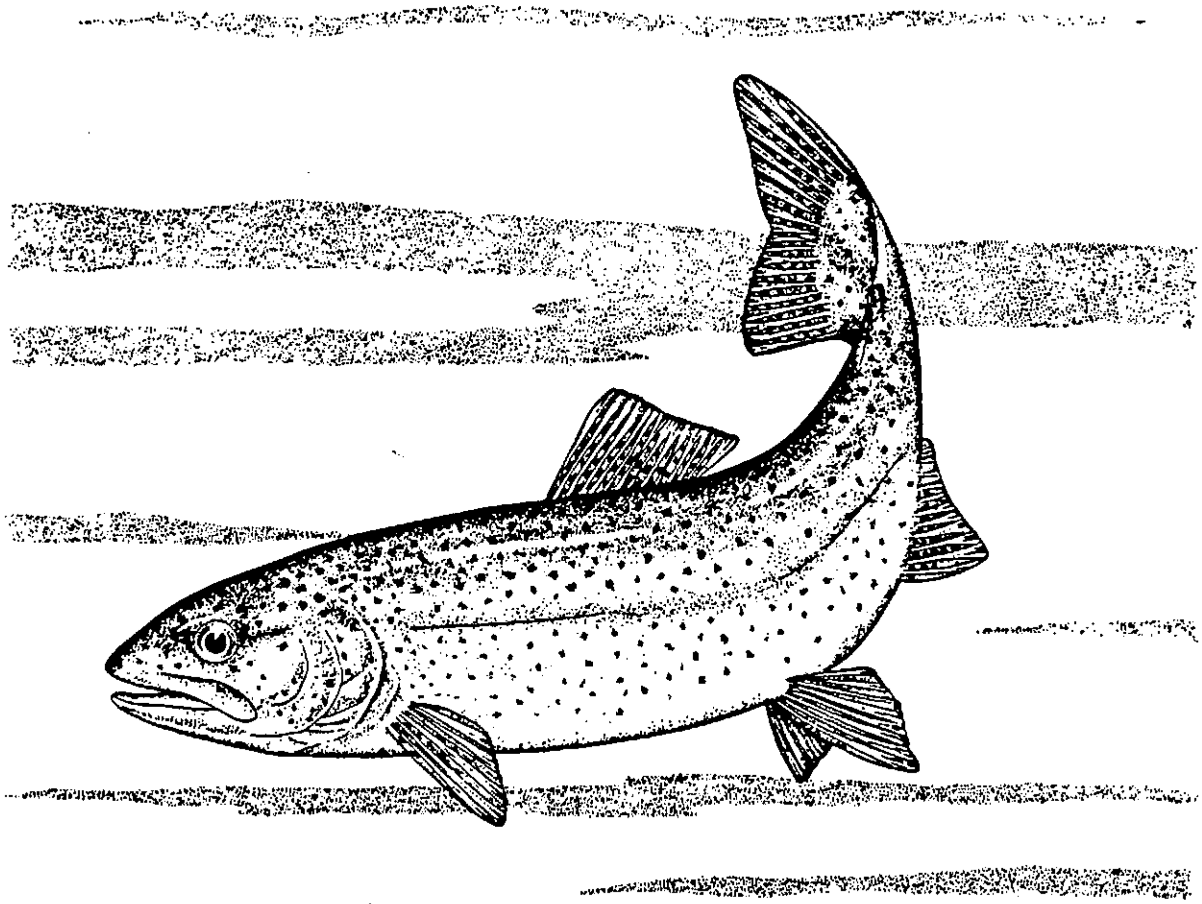
Table 1. (concluded)

Variable	Sources and rationale
V_8	To insure optimum conditions for smoltification, timing of seaward migration, and survival of chum salmon smolts, temperature should follow a natural seasonal cycle as closely as possible (Wedemeyer et al. 1980). Temperatures of 7 to 12° C were considered excellent because temperatures ≤ 12° C were recommended by Wedemeyer et al. (1980) for seaward migration of salmonid smolts to prevent altered timing of migration and smoltification, and because Bell (1973) listed 6.7 to 13.3° C as the temperature range suitable for downstream migration of chum salmon. Slightly warmer temperatures (about 8 to 13° C) would be optimum for growth (Brett 1952; Levanidov 1954; McNeil and Bailey 1975). Temperatures of 14 to 20° C were considered only fair because the risk of disease is probably higher (Fryer and Pilcher 1974; Holt et al. 1975). Temperatures > 20° C were considered poor because growth of the fry of chum salmon (Kepshire 1976) and other salmonids (Reiser and Bjornn 1979) ceases in this range and because mortality occurs at 23.8° C (Brett 1952).
V_9	We considered as excellent the DO levels corresponding to high feeding and growth rates in chum salmon fry (> 5 to 11 mg/l; Levanidov 1954) and the lack of impairment in swimming (> 5 mg/l; Dahlberg et al. 1968) and lack of avoidance (> 5 mg/l; Whitmore et al. 1960). Levels causing high avoidance and reduced swimming ability in salmonid fry in general, or mortality in chum salmon fry (1.5 mg/l; Levanidov 1954), were deemed poor.

Rainbow Trout

FWS/OBS-82/10.60
JANUARY 1984

HABITAT SUITABILITY INFORMATION: RAINBOW TROUT



Fish and Wildlife Service

U.S. Department of the Interior

FWS/OBS-82/10.60
January 1984

HABITAT SUITABILITY INFORMATION: RAINBOW TROUT

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Western Energy and Land Use Team
Division of Biological Services
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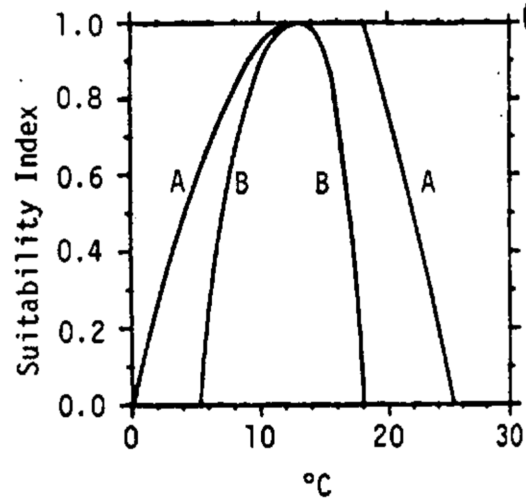
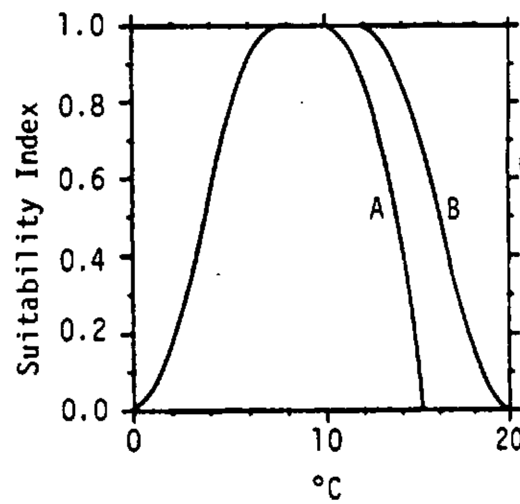
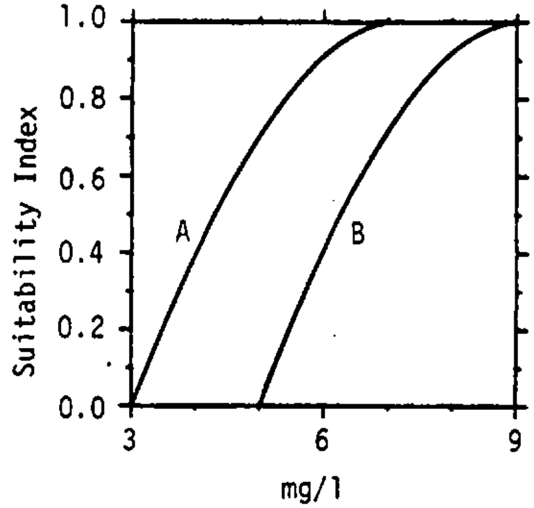
Habitat	Variable		Suitability Graph
R,L	V_1	Average maximum water temperature (°C) during the warmest period of the year (adult, juvenile, and fry), and during upstream migrations of adult steelhead. For lacustrine habitats, use the temperature strata nearest to optimal in dissolved oxygen zones > 3 mg/l. A = resident rainbow trout B = migrating adult steelhead	
R	V_2	Average maximum water temperature (°C) during embryo development (all rainbows) and during the March to June smoltification period (steelhead juveniles). A = steelhead smolts B = embryos	

R,L V_3

Average minimum dissolved oxygen (mg/l) during the late growing season low water period and during embryo development (adult, juvenile, fry, and embryo).

For lacustrine habitats, use the dissolved oxygen readings in temperature zones nearest to optimal where dissolved oxygen is > 3 mg/l.

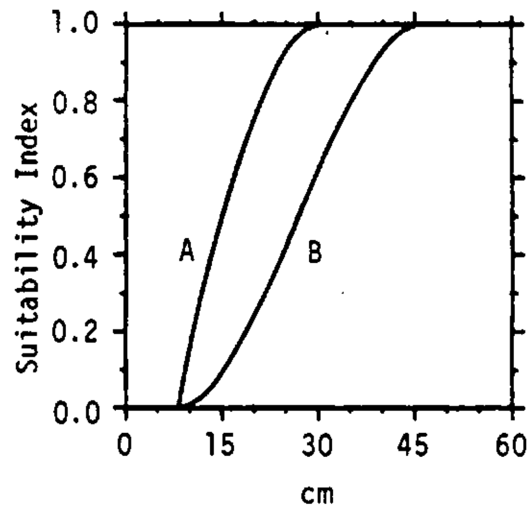
A = ≤ 15° C
B = > 15° C



R V_4

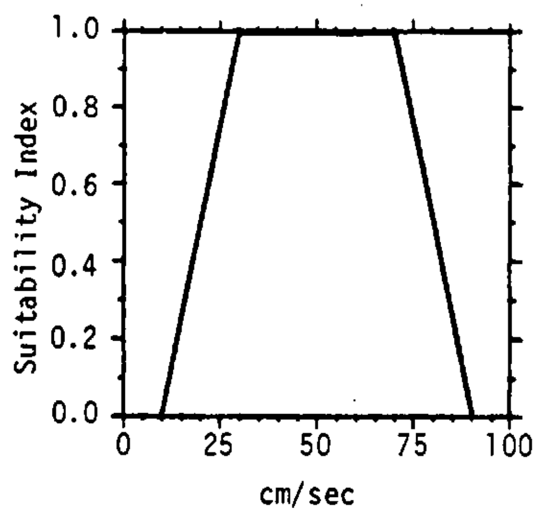
Average thalweg depth (cm) during the late growing season low water period (adult).

A = ≤ 5 m stream width
B = > 5 m stream width



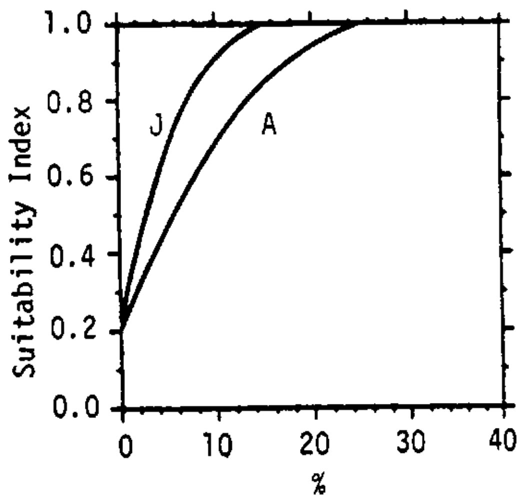
R V_5

Average velocity (cm/sec) over spawning areas during embryo development.



R V_6 Percent instream cover during the late growing season low water period at depths ≥ 15 cm and velocities < 15 cm/sec.

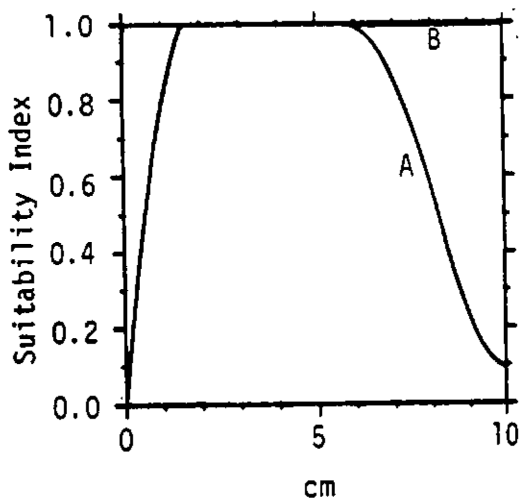
J = juveniles
A = adults



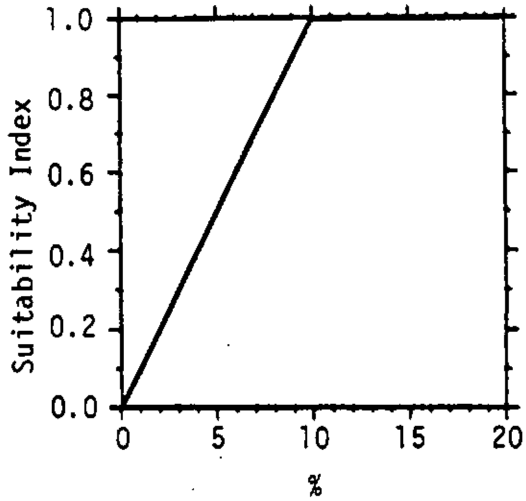
R V_7 Average size of substrate (cm) in spawning areas, preferably during the spawning period.

A = average size of spawner < 50 cm
B = average size of spawner ≥ 50 cm

To derive an average value for use with graph V_7, include areas containing the best spawning substrate sampled until all potential spawning sites are included or until the sample contains an area equal to 5% of the total rainbow habitat being evaluated.



R V_8 Percent substrate size class (10 to 40 cm) used for winter and escape cover by fry and small juveniles.

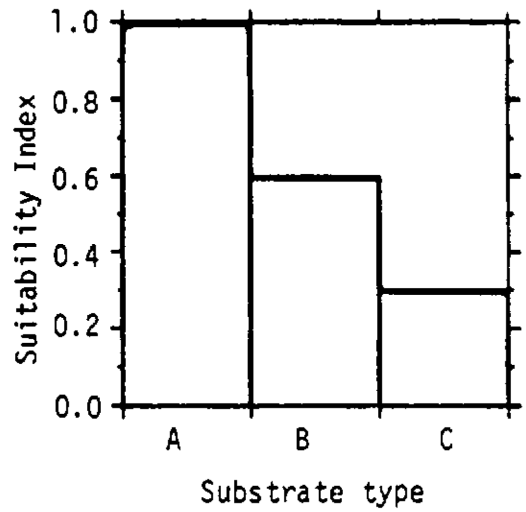


R V_9 Predominant (≥ 50%) substrate type in riffle-run areas for food production.

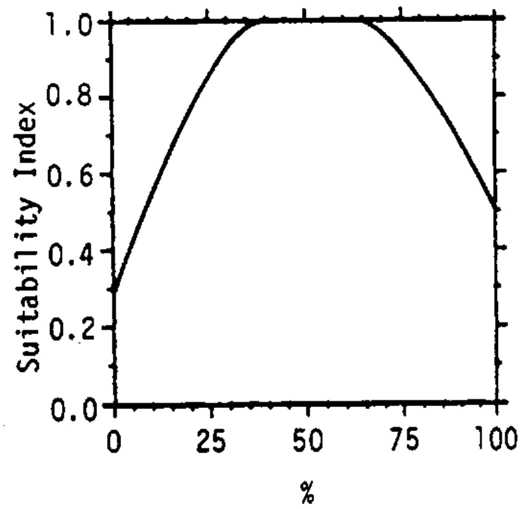
A) Rubble or small boulders (or aquatic vegetation in spring areas) predominant; limited amounts of gravel, large boulders, or bedrock.

B) Rubble, gravel, boulders, and fines occur in approximately equal amounts, or gravel is predominant. Aquatic vegetation may or may not be present.

C) Fines, bedrock, or large boulders are predominant. Rubble and gravel are insignificant (≤ 25%).

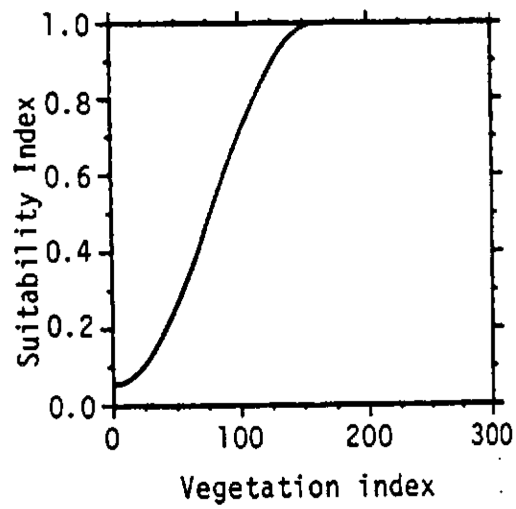


R V_{10} Percent pools during the late growing season low water period.

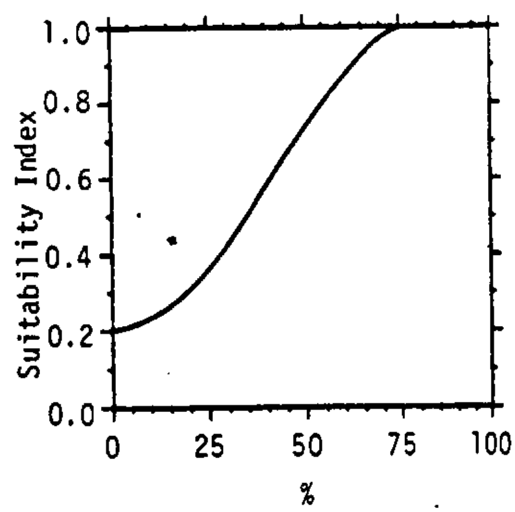


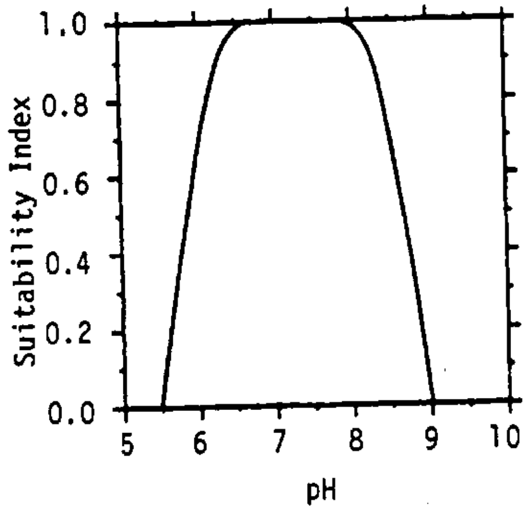
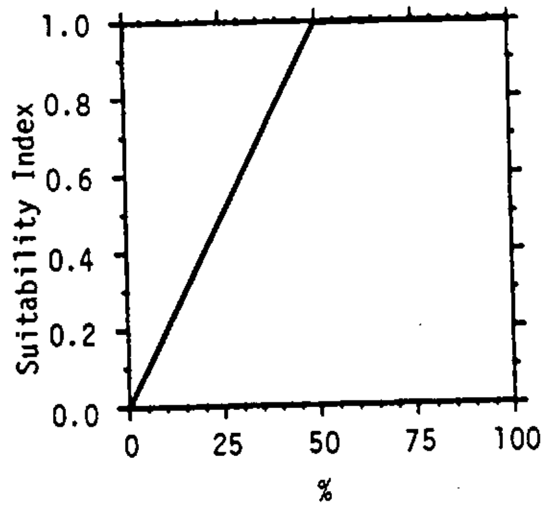
R V_{11} Average percent vegetational ground cover and canopy closure (trees, shrubs, and grasses-forbs) along the streambank during the summer for allochthonous input. Vegetation Index = 2(% shrubs) + 1.5(% grasses) + (% trees).

(For streams ≤ 50 m wide)



R V_{12} (Optional) Average percent rooted vegetation and stable rocky ground cover along stream bank.

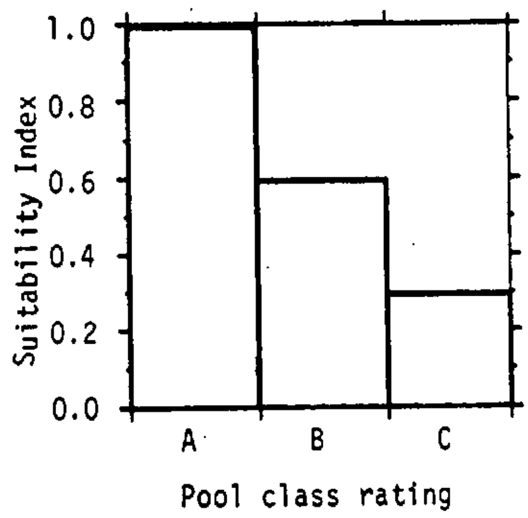


R,L	V_{13}	Annual maximal or minimal pH. Use the measurement with the lowest SI value. For lacustrine habitats, measure pH in the zone with the best combination of dissolved oxygen and temperature.	
R	V_{14}	Average annual base flow regime during the late summer or winter low flow period as a percentage of the average annual daily flow.	

R V_{15} Pool class rating during the late growing season low flow period. The rating is based on the % of the area that contains pools of the three classes described below:

A) ≥ 30% of the area is comprised of 1st-class pools.
B) ≥ 10% but < 30% of the area is 1st-class pools or ≥ 50% is 2nd-class pools.
C) < 10% of the area is 1st-class pools and < 50% is 2nd-class pools.

(See pool class descriptions below)



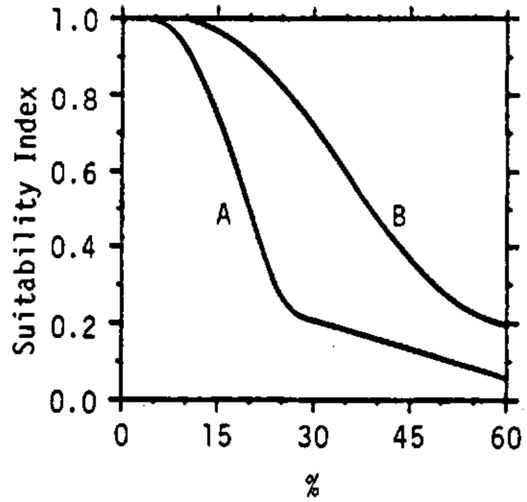
- First-class pool: Large and deep. Pool depth and size are sufficient to provide a low velocity resting area for several adult trout. More than 30% of the pool bottom is obscured due to depth, surface turbulence, or the presence of structures, such as logs, debris piles, boulders, or overhanging banks and vegetation. Or, the greatest pool depth is ≥ 1.5 m in streams ≤ 5 m wide or ≥ 2 m deep in streams > 5 m wide.

- Second-class pool: Moderate size and depth. Pool depth and size are sufficient to provide a low velocity resting area for a few adult trout. From 5 to 30% of the bottom is obscured due to surface turbulence, depth, or the presence of structures. Typical second-class pools are large eddies behind boulders and low velocity, moderately deep areas beneath overhanging banks and vegetation.

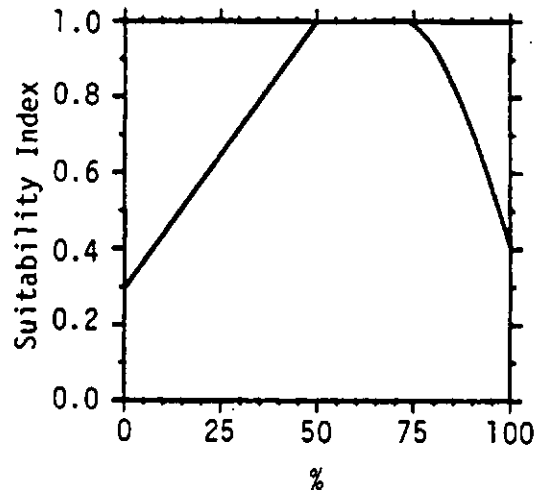
- Third-class pool: Small or shallow or both. Pool depth and size are sufficient to provide a low velocity resting area for one to a very few adult trout. Cover, if present, is in the form of shade, surface turbulence, or very limited structures. Typical third-class pools are wide, shallow pool areas of streams or small eddies behind boulders. The entire bottom area of the pool is visible.

R V_{16} Percent fines (< 3 mm) in riffle-run and spawning areas during average summer flows.

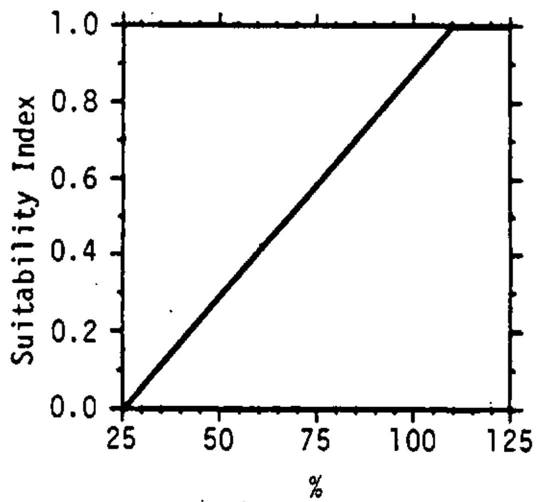
A = spawning
B = riffle-run



R V_{17} (Optional) Percent of stream area shaded between 1000 and 1400 hrs (for streams ≤ 50 m wide). Do not use for cold (< 18° C max. temp.), unproductive streams.



R V_{18} (Optional) Percent average daily flow during the season of upstream migration of adult steelhead.

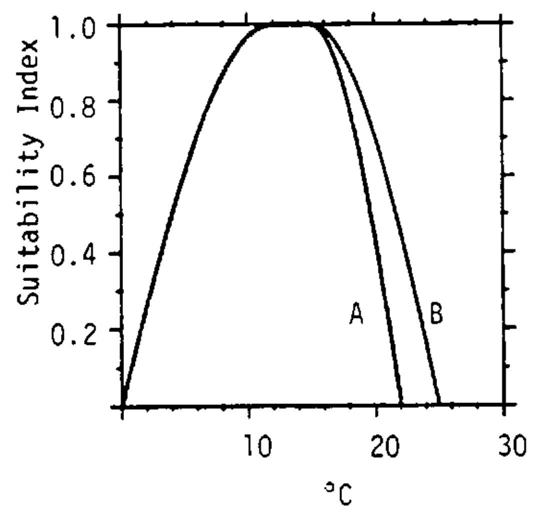
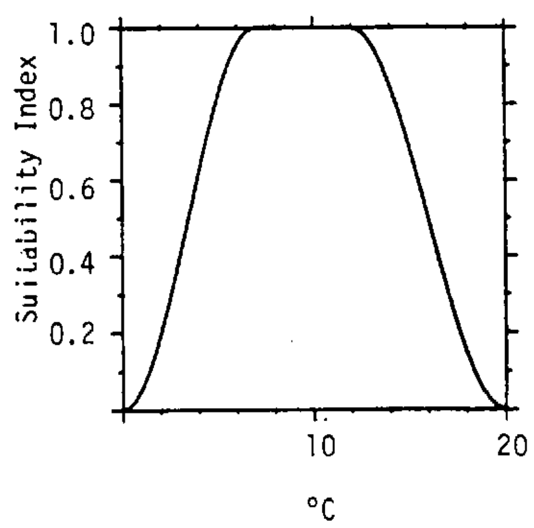


Cutthroat Trout

Cutthroat

levels of each variable presented. The graphs have been reviewed by biologists familiar with the ecology of the species, but obviously some degree of SI variability exists. The user is encouraged to vary the shape of the graphs when existing regional information indicates that the variable suitability relationship is different.

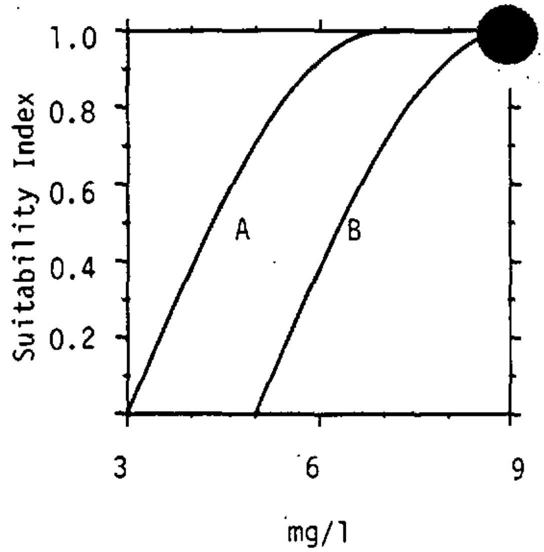
The habitat measurements and SI graph construction are based on the premise that it is the extreme, rather than the average, values of a variable that most often limit the carrying capacity of a habitat. Thus, measurement of extreme conditions, e.g., maximum temperatures and minimum dissolved oxygen levels, are often the data used with the graphs to derive the SI values for the model. The letters R and L in the habitat column identify variables used to evaluate riverine (R) or lacustrine (L) habitats.

Habitat	Variable		Suitability Graph
R,L	(V_1)	Average maximum water temperature (°C) during the warmest period of the year (adult, juvenile, and fry). For lacustrine habitats, use temperature strata nearest optimal in dissolved oxygen zones of > 3 mg/l. A = General B = Lahontan Basin	
R	(V_2)	Average maximum water temperature (°C) during embryo development.	

R,L (V_3) Average minimum dissolved oxygen (mg/l) during the late growing season low water period and during embryo development (adult, juvenile, fry, and embryo).

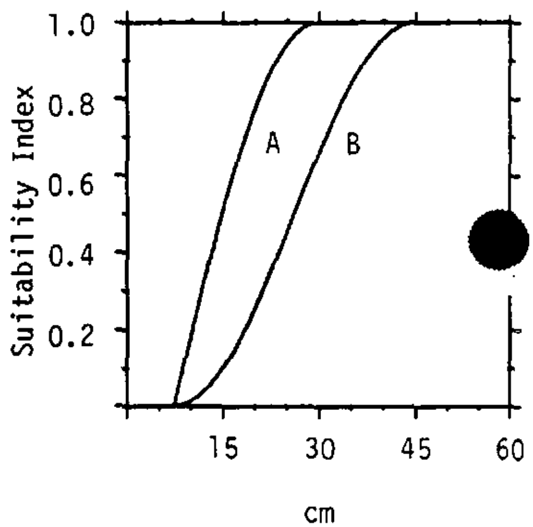
For lacustrine habitats, use the dissolved oxygen readings in temperature zones nearest to optimal where dissolved oxygen is > 3 mg/l.

A = ≤ 15° C
B = > 15° C

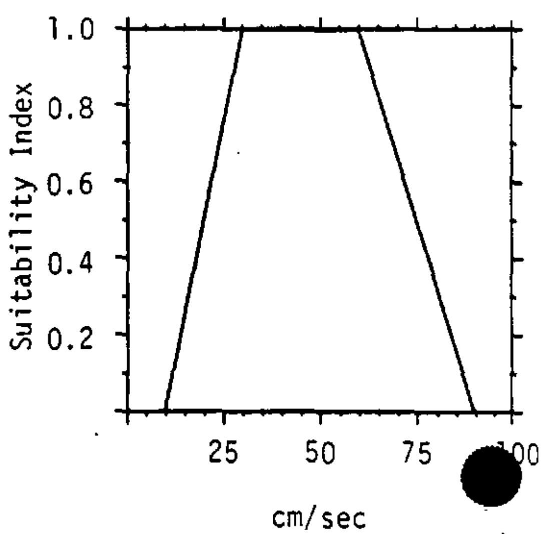


R (V_4) Average thalweg depth (cm) during the late growing season low water period.

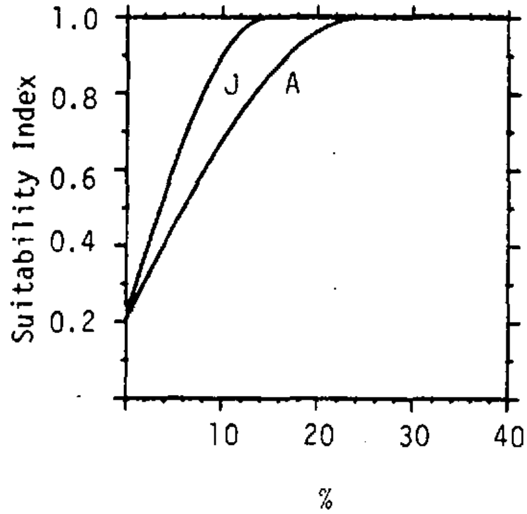
A = ≤ 5 m stream width
B = > 5 m stream width



R (V_5) Average velocity (cm/sec) over spawning areas during embryo development.

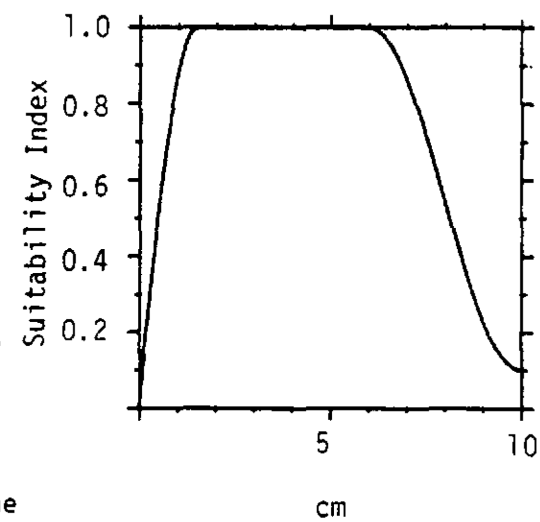


R (V6) Percent cover during the late growing season low water period at depths ≥ 15 cm and velocities < 15 cm/sec.
J = Juveniles
A = Adults

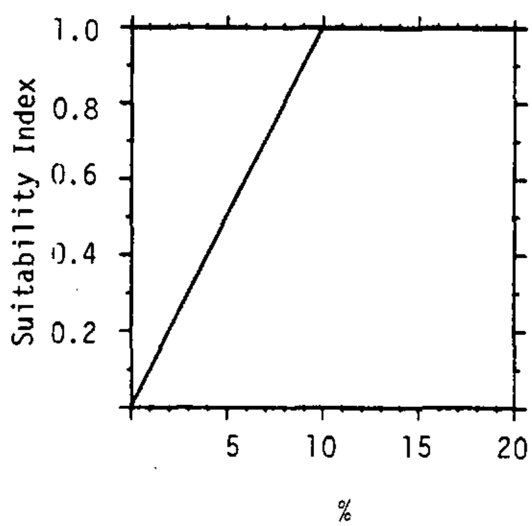


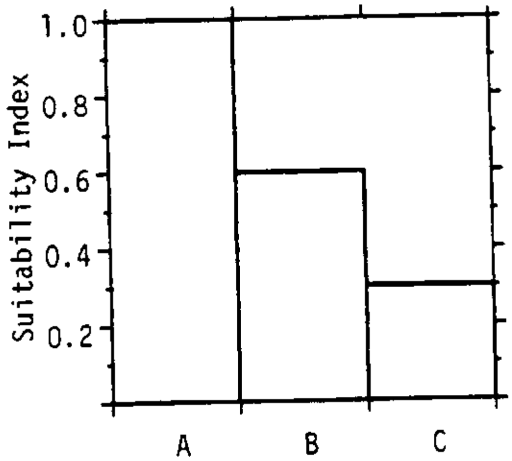
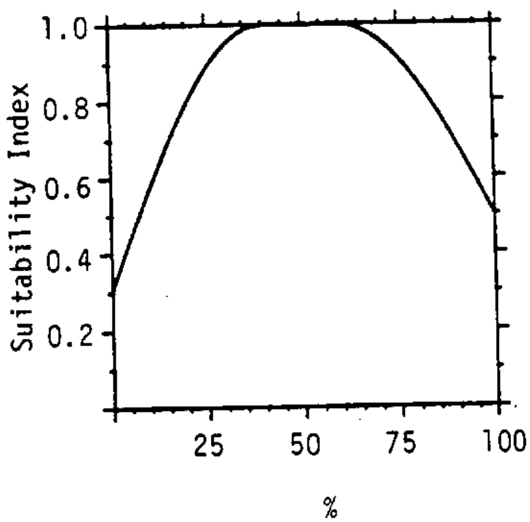
R (V7) Average size of substrate between 0.3-8 cm diameter in spawning areas, preferably during the spawning period.

To derive an average value for use with graph V7, include areas containing the best spawning substrate sampled until all potential spawning sites are included or until the sample contains an area equal to 5% of the total cutthroat habitat being evaluated.



R (V8) Percent substrate size class (10-40 cm) used for winter and escape cover by fry and small juveniles.

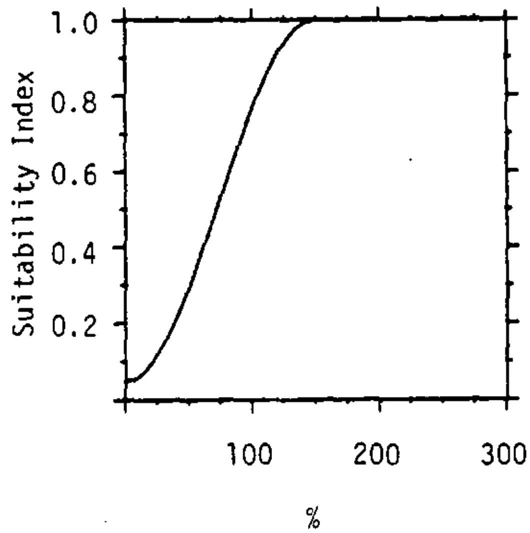


R	(V_9)	Dominant (≥ 50%) substrate type in riffle-run areas for food production. A) Rubble or small boulders or aquatic vegetation in spring areas dominant with limited amounts of gravel, large boulders, or bedrock. B) Rubble, gravel, boulders, and fines occur in approximately equal amounts or gravel is dominant. Aquatic vegetation may or may not be present. C) Fines, bedrock, or large boulders are dominant. Rubble and gravel are insignificant (≤ 25%).	
R	(V_{10})	Percent pools during the late growing season low water period.	

R (V_{11})

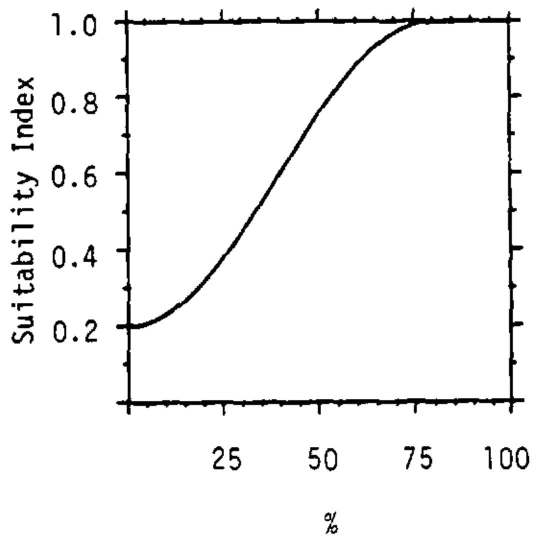
Average percent vegetation (trees, shrubs, and grasses-forbs) along the streambank during the summer for allochthonous input. Vegetation Index = 2 (% shrubs) + 1.5 (% grasses) + (% trees) + 0 (% bareground).

(For streams ≤ 50 m wide)



R (V_{12}) (Optional)

Average percent rooted vegetation and stable rocky ground cover along the streambank during the summer (erosion control).

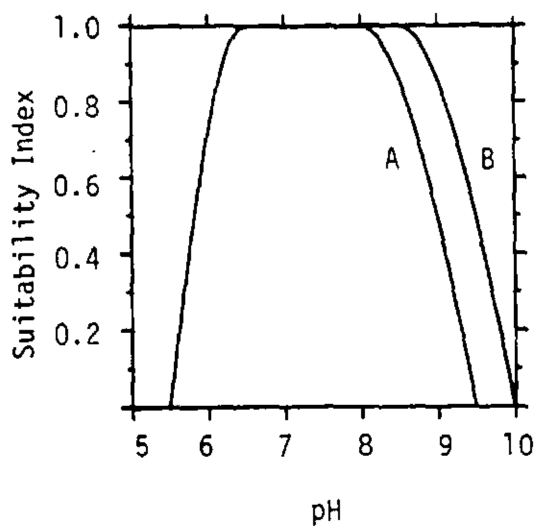


R,L (V_{13})

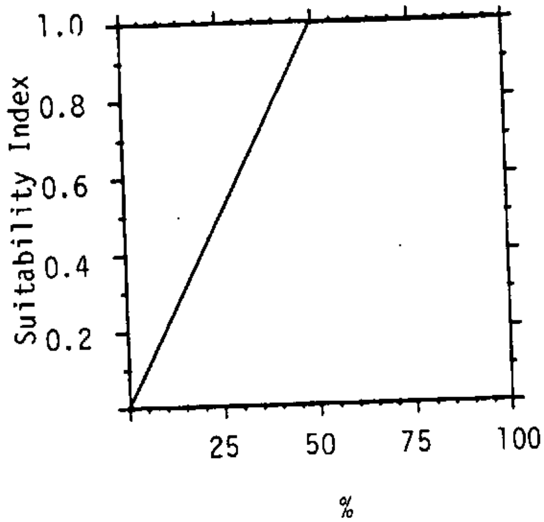
Annual maximal or minimal pH. Use the measurement with the lowest SI value.

For lacustrine habitats, measure pH in the zone of the best combination of dissolved oxygen and temperature.

A = General
B = Lahontan Basin



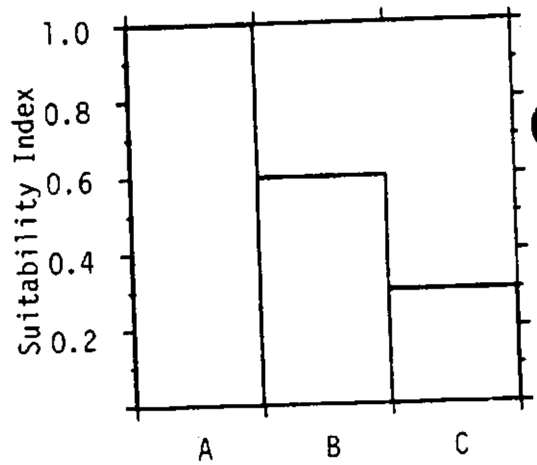
R (V14) Average annual base flow regime during the late summer or winter low flow period as a percentage of the average annual daily flow.



R (V15) Pool class rating during the late growing season low flow period. The rating is based on the % of the area containing pools of 3 classes as described below.

A) ≥ 30% of the area is comprised of 1st-class pools.
B) ≥ 10%-< 30% 1st-class pools or ≥ 50% 2nd-class pools.
C) < 10% 1st-class pools and < 50% 2nd-class pools.

(See pool class descriptions below)



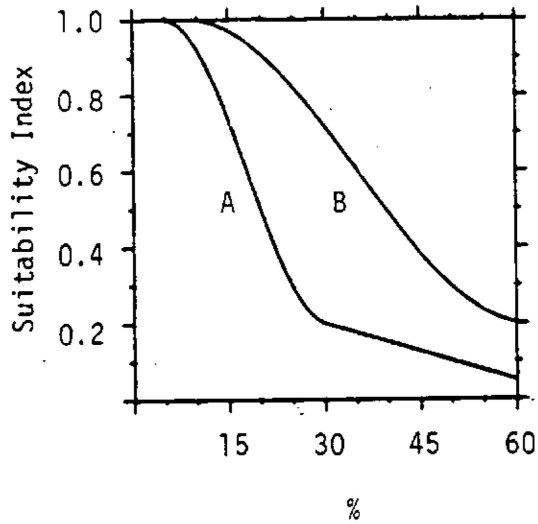
A) First-class pool: Large and deep. Pool depth and size are sufficient to provide a low velocity resting area for several adult trout. More than 30% of the pool bottom is obscure due to depth, surface turbulence, or the presence of structures, e.g., logs, debris piles, boulders, or overhanging banks and vegetation. Or, the greatest pool depth is ≥ 1.5 m in streams ≤ 5 m wide or ≥ 2 m deep in streams > 5 m wide.

B) Second-class pool: Moderate size and depth. Pool depth and size are sufficient to provide a low velocity resting area for a few adult trout. From 5 to 30% of the bottom is obscure due to surface turbulence, depth, or the presence of structures. Typical second class pools are large eddies behind boulders and low velocity, moderately deep areas beneath overhanging banks and vegetation.

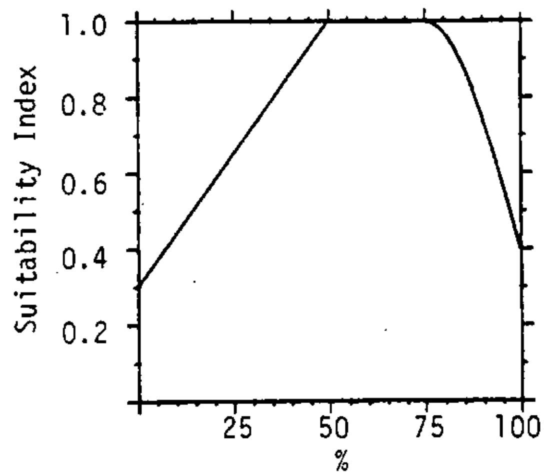
C) Third-class pool: Small or shallow or both. Pool depth and size are sufficient to provide a low velocity resting area for one to very few adult trout. Cover, if present, is in the form of shade, surface turbulence, or very limited structure. Typical third-class pools are wide, shallow pool areas of streams or small eddies behind boulders. Virtually the entire bottom area is discernable.

R (V_{16}) Percent fines (< 3 mm) in riffle-run and in spawning areas during average summer flows.

A = Spawning
B = Riffle-run



R (V_{17}) (Optional) Percent of stream area shaded between 1000 and 1400 hrs (for streams ≤ 50 m wide). Do not use on cold (<18°C) unproductive streams.



References to sources of data and the assumptions used to construct the above suitability index graphs for cutthroat trout HSI models are presented in Table 1.

Table 1. Data sources for cutthroat trout suitability indices.

Variable and source		Assumption
V_1	Needham and Jones 1959 Bell 1973 Behnke and Zarn 1976 Behnke 1979 Dwyer and Kramer 1975	Average maximal daily water temperatures have a greater effect on trout growth and survival than minimal temperatures. The maximal temperature related with the greatest scope for activity is optimum.
V_2	Snyder and Tanner 1960 Bell 1973 Calhoun 1966	The average maximal daily water temperature during the embryo development period related to the highest survival and normal development of the embryo is optimum. Those temperatures that reduce survival are suboptimum.
V_3	Doudoroff and Shumway 1970 Trojnar 1972 Sekulich 1974	The average minimal daily dissolved oxygen level during embryo development and the late growing season that is related to the greatest growth and survival of cutthroat trout and trout embryos is optimal. Those that reduce survival and growth are suboptimum.
V_4	Delisle and Eliason 1961 Estimated by authors	The average thalweg depths that provide the best combination of pools, instream cover, and instream movement of adult trout is optimum.
V_5	Thompson 1972 Hooper 1973 Hunter 1973	The average velocities over spawning areas affect the suitability with which dissolved oxygen and waste products are carried to and from the developing embryos. Average velocities which result in the highest survival of embryos are optimum. Those that result in reduced survival are suboptimum.

Table 1 (continued)

	Variable and source	Assumption
V_6	Boussu 1954 Elser 1968 Lewis 1969	Trout standing crops are correlated with the amount of usable cover present. Usable cover is associated with water ≥ 15 cm deep and velocities ≤ 15 cm/sec. These conditions are associated more with pool than riffle conditions. The best ratio of habitat conditions is about 50% pool to 50% riffle areas. Not all of a pool's area provides usable cover. Thus, it is assumed that optimal cover conditions for trout streams can be reached at < 50% of the total area.
V_7	Bjornn 1969 Phillips et al. 1975 Duff 1980	The average size of spawning gravel that is correlated with the best water exchange rates, proper redd construction, and highest fry survival is assumed to be optimum for average sized cutthroat trout. The percentage of total spawning area needed to support a good trout population was calculated from the following assumptions: 1. Excellent riverine trout habitat will support about 500 kg/hectare. 2. Spawners comprise about 80% of the weight of the population. 500 kg x 80% = 400 kg of spawners. 3. Cutthroat adults average about 0.2 kg each $\frac{400\ \text{kg}}{0.2\ \text{kg}} = 2{,}000$ adult spawners 4. There are two adults per redd $\frac{2{,}000}{2} = 1{,}000$ pairs 5. Each redd covers ≥ 0.5 m² 1,000 x 0.5 = 500 m² per hectare 6. There are 10,000 m² per hectare $\frac{500}{10{,}000} = 5\%$ of total area

Table 1 (continued)

Variable and source		Assumption
V_8	Hartman 1965 Everest 1969 Bustard and Narver 1975a, b	The substrate size range selected for escape and winter cover by cutthroat fry and small juveniles is assumed to be optimum.
V_9	Pennak and Van Gerpen 1947 Hynes 1970 Binns and Eiserman 1979	The dominant substrate type containing the greatest numbers of aquatic insects is assumed to be optimum for insect production.
V_{10}	Needham 1940 Elser 1968 Hunt 1971 Horner and Bjornn 1976	The percent pools during late summer low flows that is associated with the greatest trout abundance is optimum.
V_{11}	Idyll 1942 Delisle and Eliason 1961 Chapman 1966 Hunt 1975	The average percent vegetation along the streambank is related to the amount of allochthanous materials deposited annually in the stream. Shrubs are the best source of allochthanous materials, followed by grasses and forbs, and then trees. The vegetational index is a reasonable approximation of optimal and suboptimal conditions for most trout stream habitats.
V_{12}	Anonymous 1979 Raleigh and Duff 1981	The average percent rooted vegetation and rocky ground cover that provides adequate erosion control to the stream is optimum.
V_{13}	Hartman and Gill 1968 Platts 1974 Sekulich 1974 Behnke and Zarn 1976 Binns 1977	The average annual maximal or minimal pH levels related to high survival of trout are optimum.
V_{14}	Binns 1979 Adapted from Duff and Cooper 1976	Flow variations affect the amount and quality of pools, instream cover, and water quality. Average annual base flows associated with the highest standing crops are optimum.

Table 1 (concluded)

	Variable and source	Assumption
V_{15}	Lewis 1969 Raleigh (in press)	Pool classes associated with the highest standing crops of trout are optimum.
V_{16}	Bjornn 1969 Cordone and Kelly 1961 Platts 1974 McCuddin 1977 Crouse et al. 1981	The percent fines associated with the highest standing crops of food organisms, embryos, and fry in each designated area is optimum.
V_{17}	Sabean 1976, 1977 Anonymous 1979	The percent of stream area shaded that is associated with optimal water temperatures and photosynthesis rates is optimum.

The above references include data from studies on related salmonid species. This information has been selectively used to supplement, verify, or complete data gaps on the habitat requirements of cutthroat trout.

Survey Forms

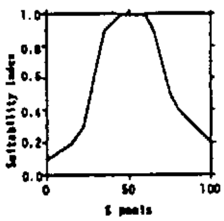
FORM F1

COHO SALMON HABITAT TYPE

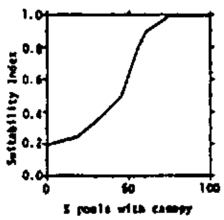
WRIA \ SUBWRIA	DATE
STREAM	SURVEYOR
R.M. TO R.M.	SEGMENT TYPE

HSI	SUITABILITY SCALE
	0.00 1.00 0.00

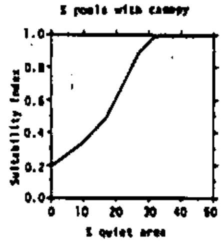
V_{14} Percent pools during summer low flow period.



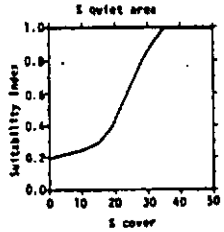
V_{11} Proportion of pools during summer low flow period that are 10 to 80 m² or 50 to 250 m² in size and have sufficient riparian canopy to provide shade.



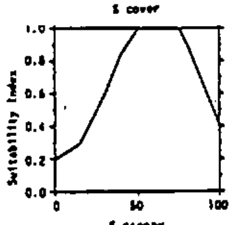
V_{10} Percent of total area consisting of quiet backwaters and deep (≥ 45 cm) pools with dense cover of roots, logs, debris jams, flooded brush, or deeply-undercut banks during winter.



V_{16} Percent instream and bank cover present during summer low flow period.

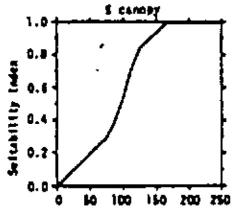


V_{4} Percent vegetative canopy over rearing stream.



V_{5} Vegetation index of riparian zone during summer.

Vegetation Index = 2 (% canopy cover of deciduous trees and shrubs) + (% canopy cover of grasses and forbs) + (% canopy cover of conifers). For measurement techniques, see Terrell et al. (1982), p. A.19 and A.37.



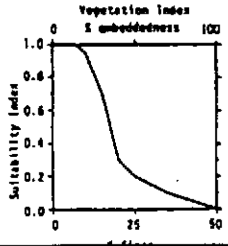
V_{6} Substrate composition in riffle/run areas.

A. Percent of gravel (10 to 60 mm) and rubble (61 to 250 mm) present.

B. Percent fines (< 6 mm) or percent embeddedness of substrate.

$SI = \frac{A + B}{2}$, where B = % fines

or % embeddedness, whichever is



Δ = EXISTING CONDITION

FORM F2

PAST, PRESENT, AND LIKELY FUTURE HABITAT CONDITIONS

WRIA ____________	DATE ____________
STREAM ____________	SURVEYOR ____________
______ TO ______ R.M. R.M.	HABITAT TYPE ____________

Past, Present, Potentential Future HSI	Likely Cause and Rationale
1.00 / 0.00 t	
1.00 / 0.00 t	
1.00 / 0.00 t	
1.00 / 0.00 t	
1.00 / 0.00 t	
1.00 / 0.00 t	
1.00 / 0.00 t	

SUITABILITY (SPECIFIY FEATURE)

△ = EXISTING CONDITION

Attachment 3

HEP Stream Survey Techniques

Stream Survey Method

The field component of Level I analysis is intended to be a rapid assessment of habitat suitablity. The emphasis on the the of the method is on generally quantifying habitat features rather than making an exhaustive survey.

The following techniques are recommended for use with the HEP criteria. Should TFW determine that the suitability criteria are acceptable for use, these field techniques will have to be integrated into a single survey method.

Substrate

Substrate and Sedimentation

Substrate composition can vary in a stream reach, especially between slow and fast water areas. Slow velocity areas generally have more small particles than do fast water areas. The location of the samples taken depends on the purpose of the measurement. If a representative composition measurement is desired, several samples should be taken and divided proportionately between slow and fast water areas. If excessive sedimentation of spawning sites is of concern, as is most often the case, substrate samples from potential or documented spawning sites should be collected.

Surface visual analysis.[2] The composition of the channel substrate (Table 2) is determined along the transect line from streamside to streamside. A measuring tape is stretched between the end points of each transect, and each 1 ft (0.3 m) division of the measuring tape is vertically projected by eye to the stream bottom. The predominant sediment class is recorded for each 1-ft division of the bottom. For example, 1 ft of stream bottom that contains 4 inches of small cobble, 6 inches of coarse gravel, and 2 inches of fine sand would be classified as 1 ft of coarse gravel (if a user elects not to use the predominant sediment class approach, information for all sediment classes can be documented). The individual 1-ft classifications across the transect are totaled to obtain the amount of bottom in each of the size classifications. Reference sediment samples for the smaller classes can be embedded in plastic cubes that can be placed on the bottom during analysis. The classification in Table 2 presents the accepted terminology and size classes for stream sediments.

A rating for embeddedness is given in Table 3. The rating is a measurement of how much of the surface area of the larger sized particles is covered by fine sediment.

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[2]This section is based on Platts et al. (1983).

From:

(Armour & Burnham, 1983)

Table 2. Classification of stream substrate channel materials by particle size from Lane (1947), based on sediment terminology of the American Geophysical Union (based on Platts et al. 1983).

Class name (1)	Size range: Millimeters (2)	Size range: Millimeters (3)	Size range: Microns (4)	Size range: Inches (5)	Approximate sieve mesh openings per inch: Tyler screens (6)	Approximate sieve mesh openings per inch: United States standard (7)
Very large boulders		4,096-2,048		160-80		
Large boulders		2,048-1,024		80-40		
Medium boulders		1,024-512		40-20		
Small boulders		* 512-256		20-10		
Large cobbles		256-128		10-5		
Small cobbles		* 128-64		5-2.5		
Very coarse gravel		64-32		2.5-1.3		
Coarse gravel		* 32-16		1.3-0.6		
Medium gravel		16-8		8.6-0.3	2-1/2	
Fine gravel		8-4		0.3-0.16	5	5
Very fine gravel		* 4-2		0.16-0.08	9	10
Very coarse sand	2-1	2.000-1.000	2,000-1,000		16	18
Coarse sand	1-1/2	*1.000-0.500	1,000-500		32	35
Medium sand	1/2-1/4	0.500-0.250	500-250		60	60
Fine sand	1/4-1/8	0.250-0.125	250-125		115	120
Very fine sand	1/8-1/16	*0.125-0.062	125-62		250	230
Coarse silt	1/16-1/32	0.062.0.031	62-31		270	
Medium silt	1/32-1/64	0.031-0.016	31-16			
Fine silt	1/64-1/128	0.016-0.008	16-8			
Very fine silt	1/128-1/256	0.008-0.004	8-4			
Coarse clay	1/256-1/512	0.004-0.0020	4-2			
Medium clay	1/512-1/1,024	0.0020-0.0010	2-1			
Fine clay	1/1,024-1/2,048	0.0010-0.0005	1-0.5			
Very fine clay	1/2,048-1/4,096	0.0005-0.00024	0.5-0.24			

Recommended sieve sizes are indicated by an asterisk (*).

Table 3. Embeddedness rating for channel materials (gravel, rubble, and boulder) (based on Platts et al. 1983).

Rating	Rating description
5	Gravel, rubble, and boulder particles have less than 5% of their surface covered by fine sediment.
4	Gravel, rubble, and boulder particles have between 5 to 25% of their surface covered by fine sediment.
3	Gravel, rubble, and boulder particles have between 25 and 50% of their surface covered by fine sediment.
2	Gravel, rubble, and boulder particles have between 50 and 75% of their surface covered by fine sediment.
1	Gravel, rubble, and boulder particles have over 75% of their surface covered by fine sediment.

Subsurface analysis.[3] Methods of sampling and analyzing the particle size distribution of gravels used by spawning salmonids have evolved slowly during the past 20 years. The first quantitative samplers to receive general use were metal tubes, open at both ends, that were forced into the substrate. Sediments encased by the tubes were removed by hand for analysis. A variety of samplers using this principle have been developed, but one described by McNeil (1964) and McNeil and Ahnell (1964) has become widely accepted for sampling streambed sediments.

The McNeil core sampler is usually constructed out of stainless steel and can be modified to fit most sampling situations. The sampler is worked into the channel substrate; the encased sediment core is dug out by hand and deposited in a built-in basin. When all sediments have been removed to the level of the lip of the core tube, a cap is placed over the tube to prevent

[3]This section is based on Platts et al. 1983.

~~Small amounts of sorted sediments embedded in plastic (optional)~~

~~Probe for "feeling" sediments in deep water~~

~~D. Training~~

~~One hour to practice accurate recognition of size classes.~~

15.4 Photographic Analysis

Surface sediment size >8 mm is estimated from photographs and related to sieve size by a regression equation. It is useful only at low flows, when much of the substrate is dry, or the water depth is shallow enough to clearly see the substrate. This method will produce more precise data than the visual analysis method but does not require a great deal of effort once it has been calibrated.

Make a 1-m^2 wooden frame and mark each side every 5 cm. String wire every 10 cm from one side to the parallel side so that the interior of the frame is divided into 100-cm^2 squares. Particles to be measured are placed at the intersections of the grid wires; but if the substrate is large and every stone will be measured, the grid is not necessary.

A. Calibration

Lay the frame on dry substrate and paint numbers on each particle in the frame or those that fall beneath a grid intersection. Particles beneath two intersections are counted twice. Position the camera as nearly vertical as possible over the center of the frame and photograph it (Fig. 15.1). Record the photo frame and the film roll number or number the rocks in a unique way for each photo site and document the numbering system. Collect all numbered rocks and place them into a sampling bag labeled with the photo and roll number. Do this at five sites with obviously different particle-size compositions.

Have the film printed as 5-×-7 or 8-×-10 photos. If the numbering of rocks was not unique to each site, be sure that the film is labeled throughout its processing.

In the lab, measure the short axis of each rock or sieve the numbered rocks. Record the smallest sieve size that each rock passes or convert the measured size into a sieve size. Measure the short axis of the numbered rocks in the photographs by using the frame scale in the photograph and a ruler. Convert the measurement to a sieve size. Record the photo measurement with the actual sieve size for each rock. The photo size will probably be less than the actual size because the pebbles in streambeds are tilted, partly concealed by other pebbles or sand, or in shadow.

(Hamilton & Bergerson, 1982)

Fig. 15.1. A 1-m^2 frame with sides marked every 5 cm photographed for analysis of substrate (courtesy J. O'Brien)

Calculate a mean sieve size for the samples from the sieving and the photo data. Compute a regression equation with the sieving data as the dependent (y) variable and the photo data as the independent (x) variable. A regression equation can also be calculated for individual particles, rather than for mean particle size of the sample, if size frequency of particles will be graphed.

B. Sample Measurement

Lay the frame at selected sampling sites chosen according to project objectives (along transects, randomly or uniformly chosen sites, etc.) and photograph it. Record sampling site, date, photograph frame, and roll number.

If part of the frame contains gravel-sand, collect a surface sample and sieve it through standard screens 5 (4-2 mm), 35 (1.00-0.5 mm) and 120 (0.125-0.062 mm); the sediment remaining in the bottom pan is silt. Weigh each fraction or measure water volume displacement to obtain weight (see Chapter 15.6.A-B) and determine mean particle size of the gravel-sand-silt, based on weight of each fraction. This fraction will not be analyzed by photographic analysis but must be accounted for.

Measure substrate particles in the developed photo prints, using the scale on the frame, and calculate a mean photographic particle size. Determine the mean sieved particle size with the calibration equation; or convert each measured, photographed particle to sieve size with a calibration equation for individual particles if you want to display size by frequency or percent.

If part of the frame includes fine gravel and sand or silt, measure its area by planimetry and calculate percent of total frame area. Then mean particle diameter will be

$$\frac{\begin{array}{l}\text{(mean diameter of photo-measured particle size) (percent frame area)}\\ \quad + \text{(sand-gravel sieve size) (percent area)}\\ \quad\quad + \text{(silt size) (percent area)}\end{array}}{100} \quad . \qquad (15.1)$$

If you want to record the fines separately from the large particles, rather than combine them into one mean, percent fines would be the percent of the area in the frame made up of fines (sand and gravel or silt).

C. Accuracy and Precision

When corrected by the regression equation, the photographic results are not significantly different from those obtained by sieving (Adams 1979). How accurately the results reflect the surface sediments of the stream depends on the number and placement of samples.

D. Equipment

Sampling frame marked every 0.5 cm	$ 5.00
35-mm camera or Polaroid	150.00+
Sieves, six to eight	20.00-40.00
Ruler	1.50

E. Training

This method requires a person who can use a 35-mm camera and a planimeter, is familiar with sieving techniques, and can reduce the data into a regression equation for predicting sieve size from photo size.

15.5 McNeil-Ahnell Hollow-Core Sampler

The McNeil core sampler is used to collect sediments from the stream or lake bottom. When time and money are considered, this is probably the most economical method available to obtain estimates of channel substrate particle-size distributions. It is usually constructed of stainless steel and can be modified to fit most sampling situations (Fig. 15.2). Work the sampler into the substrate to a

Pools/Riffles

CHAPTER 11. POOLS

11.1 General Considerations

Pools have slow water velocity and are usually deeper than a riffle or a run with which they alternate (Fig. 11.1). Pool beds are often concave, and the gradient is near zero. Pool surface gradient at low flow is also near zero, but the current direction may be highly variable because of eddies. Pools are often formed around bends or by large obstructions or morphological characteristics that constrict the channel or cause a large drop in the water-surface profile (Fig. 11.2).

Fish habitat is greatly enhanced by deep pools with cover that obscures the bottom, particularly if the pool provides more than one-third of the habitat. Identifying the boundaries of pools to determine precisely and accurately the percent of pool habitat is deceptively difficult because the change from riffle to pool to riffle is usually gradual. Well-defined criteria (such as depth, velocity, width-to-depth ratio) developed by a hydrologist or fish biologist familiar with the study area or study species may be helpful, but it would be best to have an expert identify pools at the study site, if possible.

11.2 Determination of Pool Quality and Coverage of a Stream Reach

Define each category of pool quality. For example, Hickman and Raleigh (1982) defined three quality classes of pools for trout:

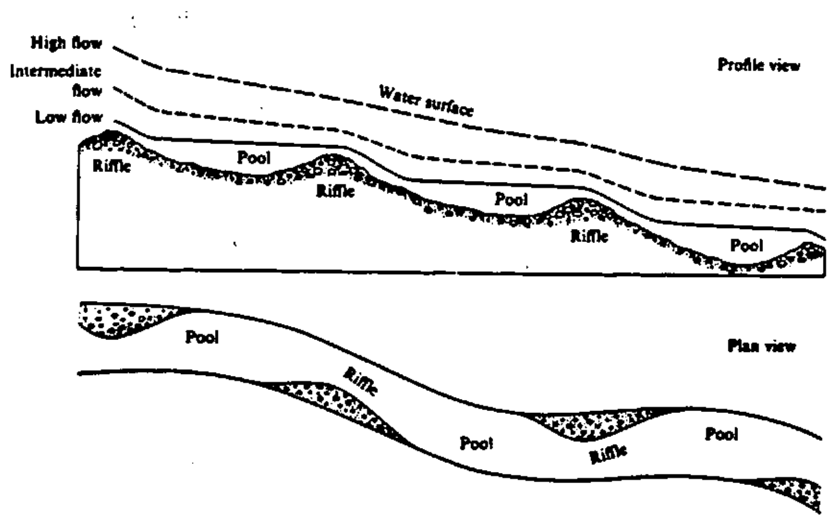

Fig. 11.1. Profile and plane views of typical sequence of pools alternating with riffles. Note that pools are often formed on the outside of stream bends (from Dunn and Leopold 1978, with permission)

(Hamilton and Bergersen, 1982)

a

b

c

Fig. 11.2. (a) Pool created by a boulder cluster. (b) Pool created by water backing up behind a riffle; at high water this pool would not exist as a feature useful to fish. (c) Pool created by bedrock formation and deflection of the run away from the bank.

A. First-class Pool

First-class pools are large and deep. Pool depth and size are sufficient to provide a low-velocity resting area for several adult trout. More than 30% of the pool bottom is obscured because of depth, surface turbulence, or structures (e.g., logs, debris piles, boulders, or overhanging banks and vegetation); or the greatest pool depth is ≥1.5 m in streams ≤5 m wide or ≥2 m deep in streams >5 m wide.

B. Second-class Pool

Second-class pools are moderate in size and depth. Pool depth and size are sufficient to provide a low-velocity resting area for a few adult trout. From 5 to 30% of the bottom is obscured because of surface turbulence, depth, or structures. Typical second-class pools are large eddies behind boulders and low-velocity, moderately deep areas beneath overhanging banks and vegetation.

C. Third-class Pool

Third-class pools are small or shallow or both. Pool depth and size are sufficient to provide a low-velocity resting area for one to very few adult trout. Cover, if present, is in the form of shade, surface turbulence, or very limited structures. Typical third-class pools are wide, shallow areas of streams or small eddies behind boulders. Virtually the entire bottom area is discernable.

Platts et al. (1983) used a five-point pool-rating system developed from needs of catchable-size fish in Idaho streams 20-60 ft wide (Table 11.1) but acknowledged that a productive fishery requires a combination of pool classes.

Methods of obtaining data to rate the quality of a pool depend on stream size and rating criteria. Visual estimation of cover abundance and quality within a pool are usually satisfactory, but more effort will be required to determine depth. On large, deep rivers, sounding methods must be used.

Determine pool area by determining the average length and width of each pool in the study area (Fig. 11.3). Rate each pool for quality while measuring it and record the rating with the pool dimensions. Calculate the area of each pool with geometric equations or by methods described in Chapter 1. Total pool areas in each quality category and divide by the total area of the study reach to obtain percent of the study reach composed of each pool class.

The transect method of estimating pool area requires more calculations but less field work, and the data can be obtained along with other measurements of a cross-sectional profile. Record from the measuring tape stretched across the transect the distance of each side of the pool from the zero point. Assign and record a quality rating to the pool when criteria measurements (e.g., depth, cover, maximum width) are completed. Calculate percent of the study area in each pool quality category:

Table 11.1. Rating of pool quality for streams 20 to 60 ft wide (Platts et al. 1983)

	Description		Rating
1A	If the pool maximum diameter is within 10% of the average stream with of the study site,	Go to 2A, 2B	
1B	If the maximum pool diameter exceeds the average stream width of the study site by 10% or more,	Go to 3A, 3B	
1C	If the maximum pool diameter is less than the average stream width of the study site by 10% or more,	Go to 4A, 4B, 4C	
2A	If the pool is less than 2 ft deep,	Go to 5A, 5B	
2B	If the pool is more than 2 ft deep,	Go to 3A, 3B	
3A	If the pool is over 3 ft deep or over 2 ft deep and has abundant fish cover[1],		Rate 5
3B	If the pool is less than 2 ft deep or is between 2 and 3 ft and lacks fish cover,		Rate 4
4A	If the pool is over 2 ft deep with intermediate[2] or better cover,		Rate 3
4B	If the pool is less than 2 ft deep but pool cover for fish is intermediate or better,		Rate 2
4C	If the pool is less than 2 ft deep and pool cover is classified as exposed[3],		Rate 1
5A	If the pool has intermediate to abundanct cover,		Rate 3
5B	If the pool has exposed cover,		Rate 2

[1]If cover is abundant, the pool has excellent instream cover and most of the perimeter of the pool has fish cover.

[2]If cover is intermediate, the pool has moderate instream cover and one-half of the pool perimeter has fish cover.

[3]If cover is exposed, the pool has poor instream cover and less than one-fourth of the pool perimeter has fish cover.

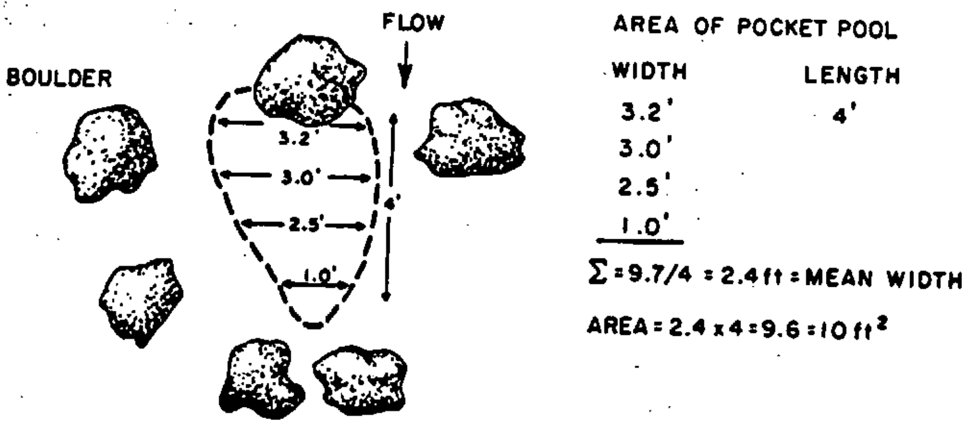

Fig. 11.3. Method of estimating the area of an irregularly shaped pool--in this case, one created by a boulder cluster--by averaging its width and length (modified from Binns 1982)

A. <u>At Each Transect</u>

(1) Calculate total stream width and width of each pool along the transect (Fig. 11:4).

(2) Divide width of each pool by stream width to obtain percent of stream width for each pool.

(3) Multiply the percent width of each pool by the percent of the study area represented by the transect to obtain the percent of the study area represented by each pool.

B. <u>Within each Pool Quality Category</u>

Add the percent of the study area represented by each pool from all the transects to obtain the percent of the study area composed of pools of each quality category.

C. <u>Calculation of Mean Pool Quality</u>

To calculate the mean pool quality for the study area, multiply the total percent area of each pool category by its category number and add them. Divide by the sum of the total percent area of all categories.

Fig. 11.4 illustrates a study reach mapped with pools that are quality rated into one of three categories. Calculations to determine percent study reach of each pool category are in Table 11.2.

Table 11.2. Calculations to determine percent of stream reach of each pool quality category illusted by Fig. 11.4

			Category 1			Category 2			Category 3		
No.	Width (ft)	Total area (%)	Width (ft)	Total width (%)	Total area* (%)	Width (ft)	Total width (%)	Total area* (%)	Width (ft)	Total width (%)	Total area* (%)
1	51.5	33				8.1 22.5	15.1 43.1	5.0 14.4			
2	43.5	22	22.6	51.0	11.4						
3	27.6	12							5.2	18.8	2.3
4	44.9	33	13.4	30.0					7.6	16.9	5.6
Percent of total study area by pool category					11.4			19.4			7.9

*Percent total area = (percent transect width) (percent of study area represented by transect)

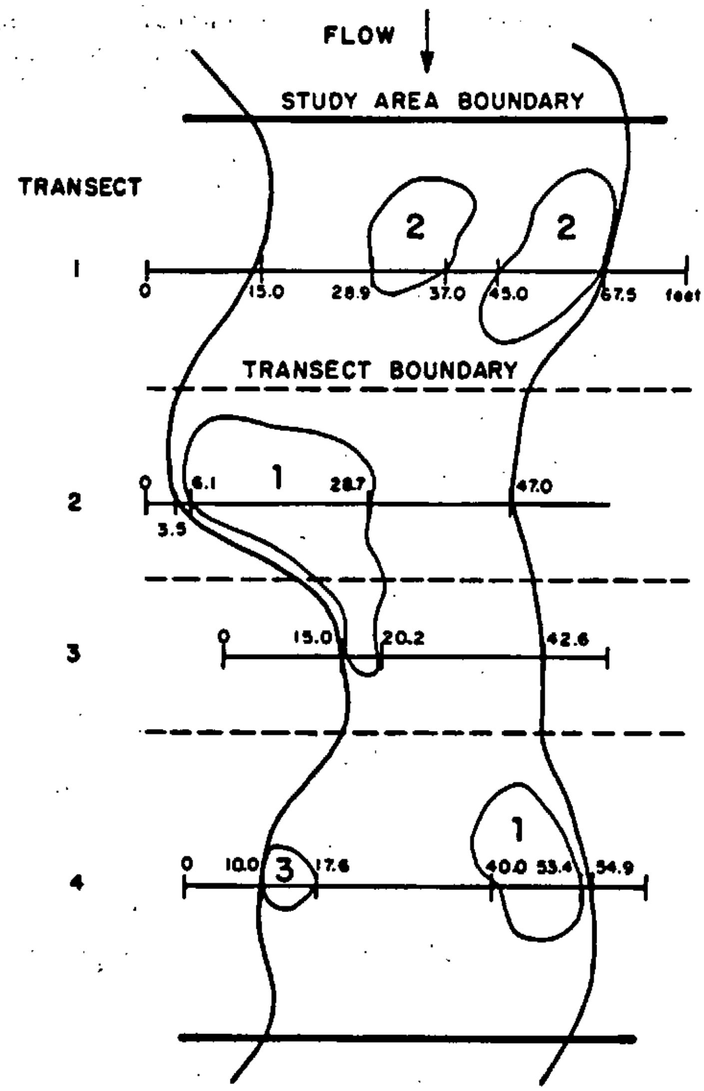

Fig. 11.4. An example of mapping pools within a stream reach to determine percent area of pools in a quality category (1, 2, or 3). See Table 11.2 for calculations.

11.3 Accuracy and Precison

Shepard et al. (1982) reported a 53% error between crews that evaluated the same stream for percent pools and a 31% error between years. Platts et al. (1983) computed 95% confidence intervals (CI) about the mean of data from different observers. He reported 10% and 8% CI for percent pools and pool quality, respectively, but rated year-to-year precision and accuracy as poor. He stated that observers had difficulty discriminating the boundary between pool and riffle. Bias in rating pool quality also occurs when subjective criteria were interpreted differently by observers. Graham (personal communication) found that inaccurate pool coverage and ratings were obtained when the field crew was coding for pools that really were not there.

11.4 Equipment

Measuring tape

30 m	$ 25.00
50 m	36.00
100 m	65.00
Leveling rod, 25-ft, fiberglass	125.00

Or

Marked depth-sounding line or pole

11.5 Training

Allow at least one field trip with a fishery biologist to a stream reach similar to that of the study area to practice identifying important pools and their boundaries and estimating pool quality based on the criteria established for the project. Ideally, a fishery biologist would supervise the data collection as well.

11.6 References

Hickman and Raleigh (1982), Platts et al. (1983), Shepard et al. (1982).

Cover (Instream and Overhead)

CHAPTER 2. COVER

2.1 General Considerations

Places where fish rest, hide, and feed are cover. Cover serves to visually isolate fish, which increases the number of territories in the same space. Less commonly, cover is defined as vegetation growing over the bottom of the stream or lake bed. Although vegetative cover may not provide concealment, it is necessary for reproduction of some species. Morphological features, such as large rocks, pocket pools and deep pools; undercut banks and aquatic and overhanging vegetation; and riparian communities that provide material for brush piles and log jams define the amount and type of potential cover.

The amount of cover significantly affects the production of many fish and invertebrate species, but these species seek cover differentially. Brown trout are negatively phototactic and prefer holes, snags, or undercut banks, against which they press their bodies. Rainbow trout often seek swifter, deeper water instead of overhead cover, while juvenile cutthroat trout prefer deep water with large rubble and boulders. Brook trout and Atlantic salmon fry select shallow water, where adults cannot enter, over pebble substrate, which creates visual isolation (White 1973). Percentage overhead cover was the most important factor affecting mean size of Gila trout in riffles of small streams, but mean depth influenced number and biomass of Gila trout in pools of larger streams (Rinne 1978). The decreased importance of cover may be attributable to the endangered status of Gila trout; their fright behavior has been less affected by fishing pressure than that of other species.

The preceding comparison of preferred cover by trout species illustrates the necessity of knowing preferences of a species and its life stages for which you are conducting a habitat analysis. Although fish will use whatever cover is available, quantification of cover is more accurate if it includes a rating factor to reflect the cover preferences of a particular species. For example, Wesche (1980) developed a simple preference rating for rubble-boulder-aquatic vegetation and overhead bank cover for catchable and subcatchable brown trout.

2.2 Establishing Criteria for Cover

Cover is an ambiguous feature of the aquatic environment, and its evaluation is subjective. Common sense, experience, and familiarity with the natural history of species are required to identify, rate, and estimate the area of their cover sites. As such, there is no standard or commonly used method to quantify cover. Basically, you identify each pocket of cover, measure its area, and calculate the percent cover in the study area.

Establishing criteria that define cover is the key to a successful habitat analysis and the only possibility of obtaining acceptable precision. Wesche (1980) concluded that cover in trout (brown, rainbow, cutthroat, brook) streams must be in areas where the water is at least 0.5 ft deep, the velocity is less than 0.5 ft/sec, and the mean velocity in the water column associated with the cover is less than 1.0 ft/sec. Enk (1977) defined overhead bank cover for trout in Michigan streams as "solid or nearly-solid overhead cover not closer to the bed than 15 cm and extending at least 9 cm from the bank in water that is at least 15 cm deep." He separated overhead bank cover into undercut banks, overhanging vegetation, and log cover. Overhanging vegetation consisting of a mat of tree branches and roots extending into the water and fitting the definition qualified as bank cover. The extent to which overhanging vegetation qualifies as cover must be defined because its value as cover decreases with its height above the water and increases with its density. Enk (1977) further defined log cover as only single logs, deadfalls, or logjams that are firmly lodged against the bank. Rinne (1979) defined instream and bank cover as any "mineral or organic matter that produced shelter, under, at or immediately above the water surface." Examples of cover not always obvious to the casual observer are undercut banks; slow-velocity areas in pools created by a boulder or boulder patch; vegetation suspended over the surface of the water; and deep, slow water.

2.3 Procedure Guidelines

After criteria for defining cover have been established and you have become familiar with the various features that may serve as cover, identify and measure cover at the study site. You may measure cover along a transect concomitantly with other measurements (such as substrate, depth, and velocity) or measure all cover sites within the representative reach.

First, identify a potential cover site, then determine whether it meets the project criteria. It is not always obvious that a site meets the criteria. For example, a deep pool may appear to be attractive cover until velocity measurements show that part of it has a swift current. Enk (1977) used a simple gage constructed of wood doweling and plexiglass with a measuring arm 9 cm wide and 15 cm high to determine whether a bank met his size criteria. If the gage fit beneath an area of potential bank cover, he measured the streamside perimeter of that cover. Wesche (pers. commun.) marks his waders with a 0.5-ft mark to quickly determine whether an area meets his depth criteria.

Determine the percent of the transect area that is composed of cover. One way to determine area is by visual estimation of the percent cover area within transect cells. It may be desirable to break down percent cover into overhead cover and substrate cover or other categories, especially if the quality of the cover will be rated for a particular species. Use categories such as <25%, 25-50%, 50-75%, and 75-100% coded in such a manner that average area of cover or cover types can be determined. Table 2.1 illustrates use of a simple code to estimate average percent cover of a transect.

Table 2.1. Example of visual estimation of cover recorded as a code* applied to cell area to obtain average area of the transect that has cover

Cell position	Cell area (m^2)	Percent cover		Weighted area	
		Overhead	Rubble-boulder	Overhead	Rubble-boulder
1	20	2	1	20 (2)	20 (1)
2	40	1	2	40 (1)	40 (2)
3	40	1	3	40 (1)	40 (3)
4	20	1	2	20 (1)	20 (2)
5	10	3	1	10 (3)	10 (1)
Total	130			150	270

*Code: 1 = <25% cover, 2 = 25-50% cover, 3 = 50-75% cover, 4 = 75-100% cover.

Divide weighted cover areas by total transect area:

Overhead cover = 150/130 = 1.1 ; <25%

Rubble-boulder cover = 270/130 = 2.01 ; 25-50%

Other codes have been devised that combine various cover and substrate types for ease of recording and are often used with computer programs (Tables 2.2 and 2.3).

Quantification of cover is time consuming. Binns (1982) recommended dividing the cover into squares (Fig. 2.1) or obtaining mean widths or lengths to calculate the area of large or irregular patches of cover (Fig. 11.3). He also advocated including a narrow strip of water along an undercut bank to the undercut bank measurement; trout often use this area for resting and feeding, then move back under the bank only when stressed. The width of the strip depends on depth, overhanging vegetation, and amount of debris. A range pole is a convenient tool to probe and measure undercut banks. Measure the slow-velocity area created by a boulder or boulder patch, not the boulder itself. Although a deep pool may be a candidate for cover, parts of it may not fit criteria such as slow velocity. Measure and use only the suitable area. If vegetated areas or areas where specific plants grow were defined as cover, measure those that fit depth, velocity, or other criteria. Figure 2.2 illustrates a reach in which cover and pools are mapped and quantified.

Table 2.2. Example of a cover code that combines overhead cover and rubble-boulder cover and is compatible with a computer program (from U.S. Fish and Wildlife Service Instream Flow Field Methods course)

		Overhead (%)	Rubble-boulder (%)
0	Unused Codes		
1			
	0.2	0	0
	0.3	<25	0
	0.5	25-50	0
	0.7	50-75	0
	0.9	75-100	0
2			
	0.2	0	<25
	0.5	0	25-50
	0.7	0	50-75
	0.9	0	75-100
3			
	0.2	<25	<25
	0.5	<25	25-50
	0.7	<25	50-75
	0.9	<25	75-100
4			
	0.2	25-50	<25
	0.5	25-50	25-50
	0.7	25-50	50-75
	0.9	25-50	75-100
5			
	0.2	50-75	<25
	0.5	50-75	25-50
	0.7	50-75	50-75
	0.9	50-75	75-100
6			
	0.2	75-100	<25
	0.5	75-100	25-50
	0.7	75-100	50-75
	0.9	75-100	75-100
7			

Table 2.3. Example of a cover-substrate code* (Bovee 1982)

Code	% of cell/cover type/substrate/% fines
16.19	<25%/undercut/sand/90-100% fines
36.19	50-75%/undercut/sand/90-100% fines
41.65	75-100%/no cover/small cobble/50% fines
29.28	25-50%/overhanging vegetation with objects larger than 150 mm in diameter/pea gravel/80% fines

*The first integer represents the percent cover in one of four quartile categories: 1 = <25%, 2 = 25-50%, 3 = 50-75%, 4 = 75-100%. The second integer represents one of six cover types: 1 = no cover, 2 = object <150 mm, . . . , 6 = root wad, undercut bank. A decimal point separates cover from substrate rating. The first integer after the decimal point represents one of nine dominant substrate categories, silt through bedrock; the second integer is the code for percent fines.

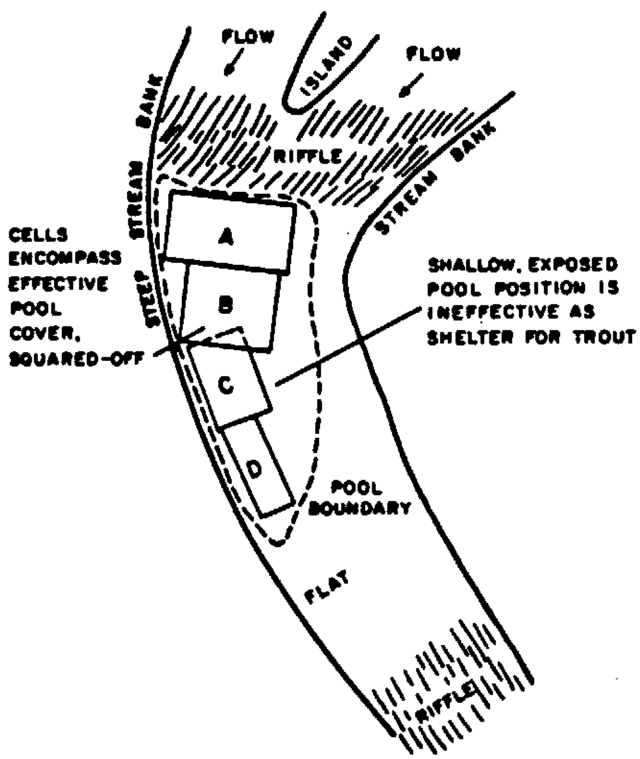

Fig. 2.1. Estimating cover area by dividing it into rectangles whose areas are calculated and summed (modified from Binns 1982)

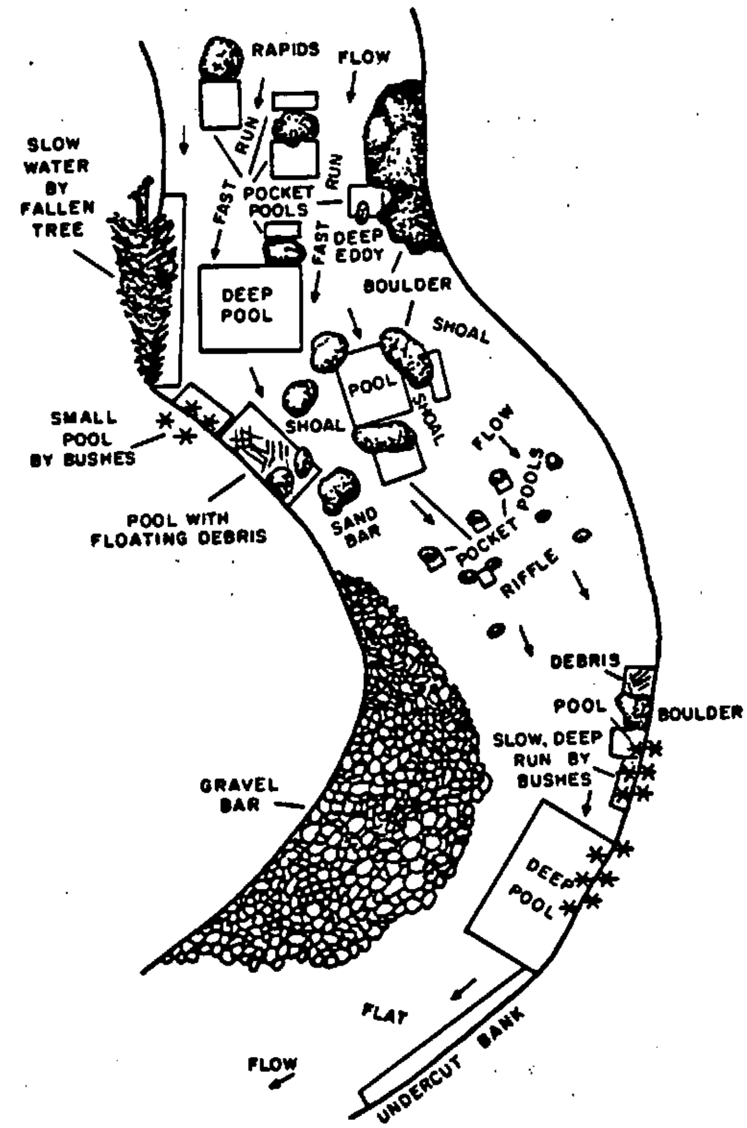

Fig. 2.2. Hypothetical stream reach showing areas of trout cover measured with mean widths and lengths (rectangles). Note strips of cover along the fallen tree and undercut bank; trout use these areas for resting and feeding and move back under overhanging vegetation or banks only when stressed (modified from Binns 1982)

2.4 Accuracy and Precision

Leathe and Graham (1982) evaluated instream and overhead cover in the same areas of two streams with two different crews and found low precision between them (Table 2.4). They decided that more rigorous criteria for defining instream cover would improve cover estimates.

Table 2.4. Mean error between two crews estimating cover in two streams

Parameter	Mean error (%) Lion Creek	Cold Creek
Instream cover	47	36
Logs and debris	43	55
Boulders	34	46
Overhead cover	--	--
Within 1 m	--	13
Undercut bank	--	36
Total overhead	4	10

2.5 Equipment

Fiberglass tape measure	$25.00
Range pole with foot (or 0.1-m) marks	50.00
Criteria definitions	
Common sense	

2.6 Training

Crew members should be familiar with the cover preferences and requirements of the study species and the criteria established to define cover for the project. For a competent and coordinated team, allow one day in the field to demonstrate examples of potential cover and whether they fit the criteria and for the team to practice measuring cover sites.

2.7 References

Binns (1982), Bovee (1982), Enk (1977), Leathe and Graham (1982), Rinne (1979), Wesche (1980), White (1973).