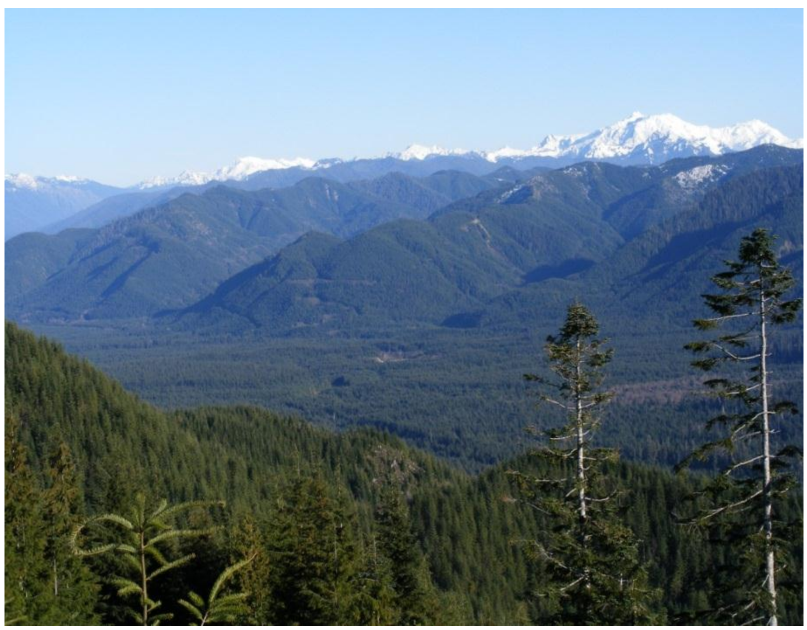
N A T U R A L   R E S O U R C E S

Status and Trends Monitoring of Riparian and Aquatic Habitat in the Olympic Experimental State Forest

Study Plan



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Executive Summary

This study plan describes the design of status and trends monitoring of aquatic and riparian habitat in the Olympic Experimental State Forest (OESF), located on the western Olympic Peninsula in Washington State. The Washington State Department of Natural Resources (DNR) manages this forest with the goal of integrating revenue production (primarily from timber harvest) and conservation across the landscape under the provisions of state trust land Habitat Conservation Plan (HCP) (DNR 1997).

Riparian areas comprise a considerable percentage of state lands in the OESF. An analysis of impacts of planned management activities (DNR 2010) shows gradual improvement of riparian and aquatic habitat over the next 100 years. DNR recognizes these projections are subject to multiple uncertainties. The purpose of this monitoring is to provide empirical data to reduce these uncertainties, to increase confidence in current management practices and to consider management adjustments, if needed. Specifically, the study will assess the in-stream conditions; data to test presumed relationships between riparian, upland, and in-stream conditions; and information to better define "habitat complexity afforded by natural disturbances" - the underlying theme of the OESF riparian conservation strategy.

Data from this project will be used to address several requirements of the HCP including: 1) assessments of baseline habitat conditions and the range of natural variability for use in future HCP effectiveness monitoring (response of riparian and aquatic habitat to management) and HCP validation monitoring (response of salmonid populations to managed landscape); 2) HCP implementation monitoring in the sampled basins; and 3) reliable information for adaptive management.

The monitoring program outlined in this study plan is subject to multiple, inherent challenges. 1) The OESF is large (about 270,000 acres), with rugged topography. 2) The natural disturbance regime varies in both intensity and frequency, and includes windthrow, mass wasting, debris flows, floods, and wildfire. 3) The pattern of ownership is fragmented, and includes a mix of state, federal, tribal, and private holdings. 4) The management history is complex, within both DNR-managed and adjacent ownerships. 5) Available resources are limited, and allocating them must balance the need to estimate status (by sampling many sites) against the need to detect trends (by repeated sampling, at frequent intervals).

The study was designed to: 1) monitor riparian and aquatic habitat conditions at the watershed-scale, the scale considered most relevant to the survival of anadromous salmon species and to management practices in the OESF; 2) measure changes in key habitat attributes as identified by series of conceptual ecological models; 3) capture the dynamic aspects of habitat important to salmonids, across both time and space; 4) monitor a representative sample of watersheds in order to extrapolate monitoring results across the entire OESF; 5) be statistically powerful enough to detect biologically significant changes in both individual indicators and watershed condition scores, and 6) be cost-effective and feasible to implement.

Fifty Type-3 watersheds (basins around the smallest fish-bearing streams DNR manages) were selected for monitoring. Nine aquatic and riparian indicators were identified for sampling at the reach level: 1) in-channel large woody debris, 2) channel morphology (including gradient, confinement, depth, and width), 3) water temperature, 4) stream discharge, 5) habitat units (such as pools), 6) channel substrate, 7) stream shade, 8) riparian microclimate, and 9) riparian forest vegetation. Watershed-level "stressors" such as harvest activities and road use were also identified for monitoring in each of the 50 sample basins.

The temporal study design was based on rotating panel approach (Urquhart et al. 1998) which balances the need for extensive sampling to estimate status with the need for revisiting the samples to estimate trend.

The main hypothesis of this study is that riparian and aquatic conditions will improve, i.e. they will shift towards conditions reflective of natural disturbance regimes as the OESF Forest Land Plan is implemented. This hypothesis will be tested by examining trends in the distribution of the scores of the individual indicators and the overall watershed condition scores across all sample basins in the OESF.

Inferences about management effects on the status and trends of riparian and aquatic habitat will be made using a "model-based inference" analysis (Anderson 2008). To conduct this analysis, ecological models quantifying the relationships between management activities and habitat indicators will be built and later evaluated with empirical data collected through monitoring. The "best-fitting" models will be used to assess management effects.

The implementation of this long-term monitoring project will start with a 3-year pilot phase which includes: field reconnaissance, establishment of sampling installations, 2 years of data collection, and power analysis to assess the indicators' variability and to refine the sampling design. Habitat changes resulting from the ecological processes being monitored manifest slowly. Therefore, a trend may not be detected for 10 or more years. Under the proposed sampling design, the first analysis of trends will be conducted five years after the launch of the full implementation phase (currently estimated as 2019). Subsequent reports on trends will be issued every five years thereafter. The first data on baseline ecological conditions and on ecological relationships between in-stream, riparian and upland systems are expected at the end of the pilot phase (2014).

Project updates will be provided annually to DNR's Forest Resources Division Manager, the Olympic Region Manager and other relevant DNR staff. Reports to research partners, local managers, and interested stakeholders will be presented as appropriate. Project information will be updated on DNR website.

Current DNR funding for this project of $145,000 per year is expected to be sufficient for the monitoring effort described in this study plan. The current priority is characterizing riparian and aquatic habitat condition using the physical indicators described in this plan. DNR will actively seek research collaboration and other forms of partnerships. If additional funding and scientific expertise become available, the following components will be added to enhance the project (listed in order of priority): 1) hire a data manager, 2) monitor additional physical indicators such as turbidity, and 3) monitor biological indicators such as fish and macroinvertebrates.

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Introduction

The Olympic Experimental State Forest (OESF) occupies 270,000 acres of state trust lands on the western Olympic Peninsula in Washington State. The Washington State Department of Natural Resources (DNR) manages this forest with the goal of integrating revenue production (primarily from timber harvest) and conservation across the landscape under the provisions of state trust land Habitat Conservation Plan (HCP) (DNR 1997). The OESF was designated as a place for applied research and monitoring to learn how to better implement integrated management. The intent behind integrated management is to actively manage as much of state trust lands as possible using innovative silviculture, landscape level planning, and quick application of new knowledge. The long-term vision is of a productive, resilient, and biologically diverse commercial forest in which both revenue generation for the trust beneficiaries and ecological health are maintained across state trust lands.

DNR has committed to evaluate the success of conservation strategies described in the state lands HCP as those strategies are implemented. The riparian conservation strategy is one of the three major habitat conservation strategies being implemented in the OESF, along with strategies for northern spotted owl and marbled murrelet habitat. The OESF riparian conservation strategy is designed to maintain and aid restoration of riparian functions in order to support viable salmonid populations. The strategy aims to restore habitat complexity as afforded by natural disturbance regimes, a concept that recognizes dynamic, non-equilibrium conditions and natural variability (Naiman et al. 1992). Under this concept, not all basins are expected to be in good condition at any particular time, nor is any particular basin expected to be in a certain desired condition all the time. Unlike regulatory-based conservation for example Washington Forest Practices Rules (WFPB 2001), which targets a non-site specific, idealized future habitat condition at stream reach scale, the OESF riparian strategy targets restoration of ecological processes such as sediment regime; hydrologic cycle, and wood production required for salmonid habitat at a landscape scale. The OESF riparian conservation strategy is still implemented mainly through applying riparian buffers, however, the placement, width and forest characteristics of the buffers depend on the ecological conditions of the hydrological basin.

DNR is currently developing a forest land plan for the OESF, which will implement the HCP riparian conservation strategy through landscape planning. The OESF Forest Land Plan will provide watershed-specific management recommendations over a 100-year planning period, which includes harvest schedules for ten 10-year periods. The planning process includes analyses of the potential economic and environmental impacts of the proposed management alternatives and projections of habitat conditions including riparian and aquatic habitat.

Purpose

An analysis of impacts of planned management activities in the OESF (DNR 2010) shows gradual improvement of riparian and aquatic habitat over the next 100 years. DNR recognizes these projections are subject to multiple uncertainties. The purpose of the status and trends monitoring described in this study plan is to provide empirical data to reduce these uncertainties, to increase confidence in current management practices and to consider management adjustments, if needed. Specifically, the study will assess the in-stream conditions; data to test presumed relationships between riparian, upland, and in-stream conditions; and information to better define "habitat complexity afforded by natural disturbances" – the underlying theme of the OESF riparian conservation strategy.

Response to DNR Management Needs

Current management uncertainties and information needs for the OESF are identified during the environmental analyses for the OESF Forest Land Plan. These uncertainties are listed and prioritized in Chapter 4 of the OESF Forest Land Plan (DNR, in progress) along with priority research and monitoring projects in the near term.

Riparian status and trends monitoring is identified as a high priority project because it will help reduce number of key uncertainties. Specifically, it will provide direct information on in-stream conditions; data to test presumed relationships between riparian, upland, and in stream-conditions; and information to better define "habitat complexity afforded by natural disturbances" – the underlying theme of the OESF riparian conservation strategy. What further elevates the priority of the OESF riparian monitoring is the fact that riparian areas affected by these uncertainties comprise a considerable percentage of actively-managed state lands in the OESF.

Response to HCP Commitments

The 1997 Habitat Conservation Plan specifies the need for implementation, effectiveness, and validation monitoring in the OESF (DNR 1997, Chapter V) and for adaptive management across HCP-covered lands (HCP Implementation Agreement, Section 24.5). Riparian Status and Trends Monitoring will play a foundational role within the OESF adaptive management cycle for fulfilling these commitments to the HCP (Figure 1) .

Implementation monitoring is defined in the HCP as documenting "whether the Habitat Conservation Plan conservation strategies are implemented as written" (DNR 1997, p. V.1). Implementation monitoring includes documenting both management activities and habitat conditions which occur immediately after these activities are conducted. The majority of information for implementation monitoring comes from operational records and remote sensing. Riparian Status and Trends Monitoring will supply data for implementation monitoring by assessing (in the field or remotely) environmental conditions in the watersheds selected for sampling.

Effectiveness monitoring is intended to "determine whether the implementation of the conservation strategies results in anticipated habitat conditions" (DNR 1997, p. V.1). Empirical data from the Riparian Status and Trends Monitoring can be used for future effectiveness monitoring studies in the OESF, mainly to establish baseline conditions and to provide

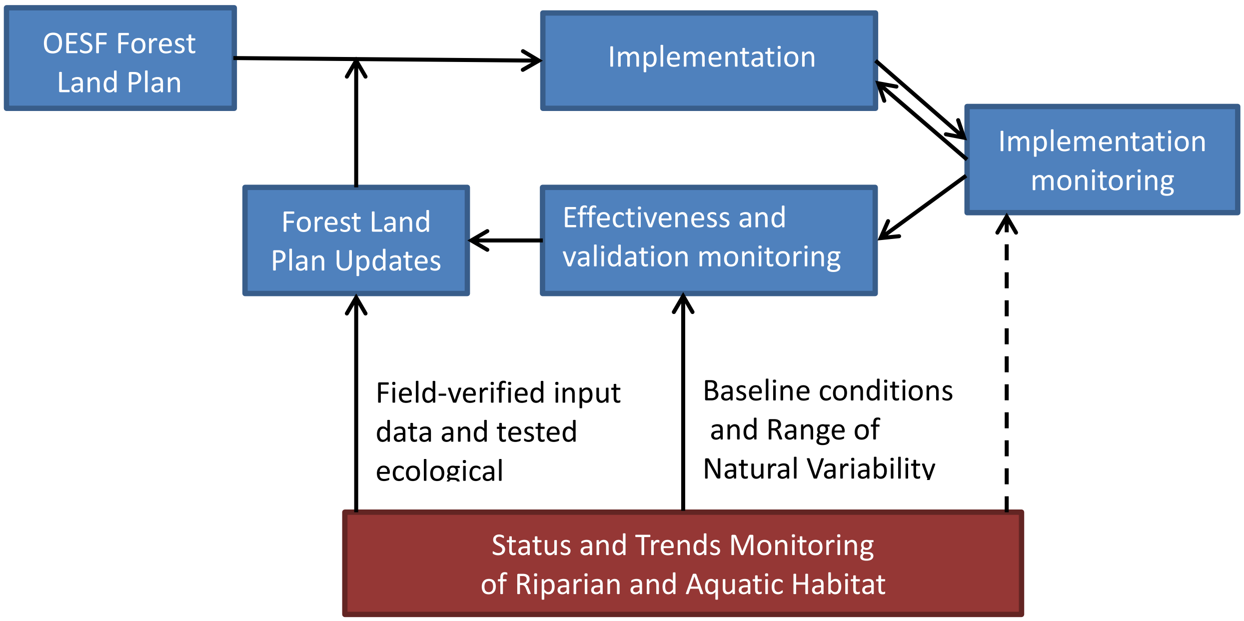


Figure 1. Foundation Role of Status and Trends Monitoringwithin OESF Adaptive Management Process

information about the range of natural variability. In addition, one of the analytical approaches proposed in this plan is intended to provide inference about management effects (refer to section "Analyses to Infer Management Effects").

Validation monitoring is specific to the OESF and its objective is to "evaluate cause-and-effect relationships between habitat conditions resulting from the implementation of the conservation strategies and the animal populations these strategies are intended to benefit" (DNR 1997, p. V.2). Riparian Status and Trends Monitoring will provide information about the variability of sampled habitat attributes. This information can be used in future validation monitoring design.

The results of Riparian Status and Trends Monitoring will be considered for OESF adaptive management following the process described in Chapter 4 of the OESF Draft Forest Land Plan (DNR in progress). Monitoring data will be considered in future updates to the OESF Forest Land Plan and in the reruns of the forest estate model[1].

Collaboration with Research and Monitoring Partners

The OESF is envisioned to be a focal point of environmental research and monitoring in Washington State. Research and monitoring information derived in the OESF is intended to benefit forest management not only on state trust lands but also on other public, private, and tribal lands in the region.

[1] An optimization model which schedules harvest activities across the OESF for the entire planning period.

DNR welcomes cooperation with external research partners to conduct research in the OESF. This Draft Riparian Status and Trends Monitoring Plan is designed to be easily integrated with other ecological studies varying in subject and scale. Suggested additional study modules include monitoring physical habitat indicators in addition ot the ones described in this study plan (for example turbidity); sampling of biological indicators such as fish, macroinvertebrates, and periphyton; silvicultural experimentation in riparian buffers; and assessing sedimentation from road management and use. The field installations and collected data can also be used for studies not directly related to the objectives of the current plan, such as climate change.

Benefits of this status and trends monitoring for collaboration are many: the study will provide long-term empirical data, collected using a statistically valid sampling design and consistent field methods; sampling installations will be distributed and maintained over a large area; ongoing active management and natural disturbances will be documented and the data will be available for analyses.

Additional potential benefits of the OESF as a place for collaborative research include: a large land base amenable to landscape-scale experiments, nearby federal lands to serve as unmanaged control ecosystems, well maintained road network to permit access to research sites, and nonpropriatery land management data such as forest inventory. Participation by OESF in the US Forest Service's nation-wide Experimental Forest and Range Research Network also provides opportunities for scientists working at OESF to perform national-scale cross-site and synthetic research.

A variety of researchers may be interested in collaboration on the status and trends monitoring of aquatic and riparian habitat in the OESF - university scientists (for example from University of Washington), scientists from other state agencies (for example Department of Ecology and Department of Fish and Wildlife), federal agencies (for example the US Forest Service's Pacific Northwest Research Station, US Geological Survey, and NOAA Fisheries), and scientists from tribal natural resource agencies (for example from Quinault, Quilleute, Hoh, and Macah tribes) .

DNR welcomes cooperation with other parties interested in this study. The results of the OESF aquatic and riparian status and trends monitoring may ontribute to improved management of forest and fisheries resources on US Forest Service and National Park Service lands, tribal lands, and private and industrial lands on the Olympic Peninsula and in other areas of western Washington.

Content of This Study Plan

The Draft Riparian Status and Trends Monitoring Plan provides a conceptual framework, monitoring indicators, sampling design, and analytical approaches to evaluate changes in riparian and aquatic conditions across the OESF. It also provides an implementation schedule and describes the organizational structure and budget necessary to conduct the monitoring. This draft does not include monitoring protocols, data management, and quality assurance and quality control procedures. They will be added in the final version of the plan or as stand-alone documents.

Information Sources

The focus on ecological processes (as opposed to desired future conditions) and the necessary consideration of spatial and temporal variability makes it challenging to monitor the effectiveness of DNR management in the OESF. Several monitoring plans have been developed and partially implemented in the OESF over the last decade. Previous DNR monitoring efforts included draft plans for in-stream habitat conditions and trends monitoring (Pollock et al. 2001), riparian forest integrity monitoring (Rose et al. 2001), and riparian validation monitoring (Dominguez and Beauchamp 2001). Implementation of these plans has been incomplete and intermittent. A history of budget and staff interruptions and the complexity of scale, scope, and sampling designs prevented DNR from characterizing the status of the riparian conditions across the entire OESF. The outcomes and field experience from the development and implementation of the previous monitoring plans have been used in the development of this draft.

The Draft Riparian Status and Trends Monitoring Plan incorporates many of the ideas and concepts that have been developed as part of other ongoing regional large-scale monitoring efforts such as Effectiveness Monitoring for the Aquatic and Riparian component of the Northwest Forest Plan (http://www.reo.gov/monitoring/watershed-overview.shtml), PACFISH INFISH Effectiveness Monitoring Program for Streams and Riparian Areas (http://www.fs.fed.us/biology/fishecology/emp), Columbia Habitat Monitoring Program (http://www.cbfish.org/Project.mvc/Display/2011-006-00), Environmental Monitoring and Assessment Program of the Environmental Protection Agency (http://www.epa.gov/emap2/), and DNR Forest Practices riparian monitoring (http://www.dnr.wa.gov/BusinessPermits/Topics/FPAdaptiveManagementProgram/Pages/fp_cmer_active_projects.aspx).

This study plan draws from a number of data sets and analyses developed for the revised Draft Environmental Impact Statement (EIS) for the OESF Forest Land Plan (in progress).

Study Area

The OESF encompasses 270,000 acres (109,265 hectares) of state trust lands on the western part of the Olympic Peninsula (Figure 2). Elevation within the OESF varies from sea level to 3,400 feet (1036 meters), with the majority of state trust lands located between 500 and 1,500 feet (152 and 457 meters). Rugged mountainous terrain at higher elevation changes into gently sloping lowlands towards the coast. Most of the parent rock material in the OESF consists of uplifted marine sedimentary rocks and continental and alpine glacial deposits.

The area is characterized by a maritime climate with high rainfall during the winter. Precipitation averages 140 inches (355 centimeters) per year. Strong winds from the Pacific Ocean are the major natural disturbance force.

Steep erodible terrain and heavy annual precipitation promotes high stream densities. There are 2,785 miles (4,482 kilometers) of streams on state trust lands in the OESF (Source: SHARED_LM.OESF_HYDRO). Watersheds are largely rain-dominated and streams exhibit seasonal fluctuations in flow. A majority of streams have the potential for unstable channel banks and upslope slides (refer to the revised Draft EIS for the OESF).

The Sitka Spruce vegetation zone dominates along the coast. The Western Hemlock zone comprises the majority of the lower elevation inland forest, with western red cedar found in the wetter areas. The Pacific Silver Fir zone is located in higher elevations. Douglas-fir is a seral component in all zones and red alder is a seral component in lower elevations. The area is characterized by a very high tree growth rate. Old growth forests once dominated the landscape and are still present on parts of the OESF. About 50 percent of the OESF is dominated by young stands (refer to the revised Draft EIS for the OESF).

Riparian areas in the OESF provide habitat for eleven resident or anadromous salmonid species (chum, coho, sockeye, chinook, pink salmon, mountain whitefish, pigmy white fish, steelhead, bull trout, Dolly Varden, and cutthroat) and seventeen non-game species such as lampreys, minnows, suckers, and sculpins.

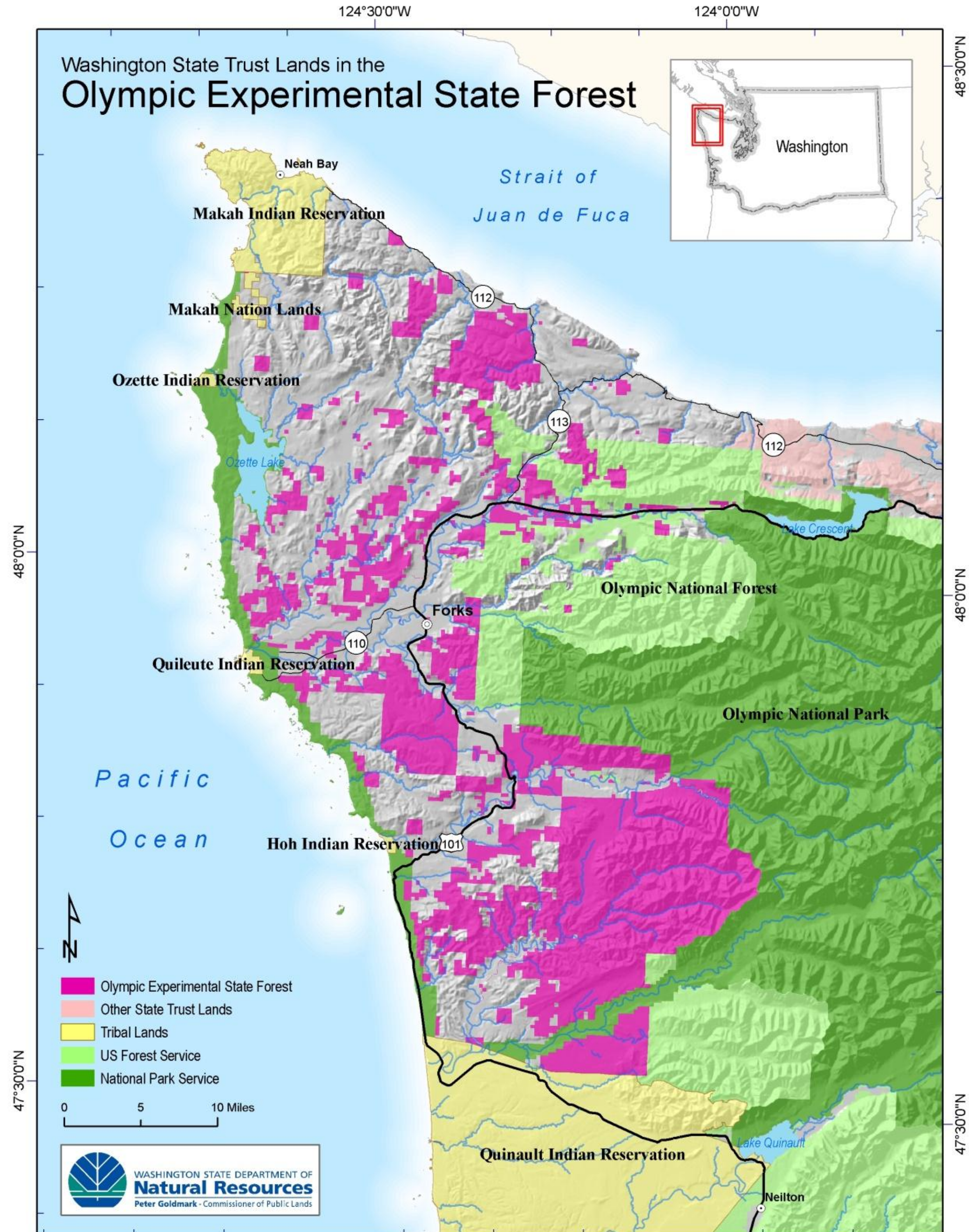


Figure 2. Map of the study area.

Goal and Objectives

The goal of riparian status and trends monitoring in the OESF is to characterize the status and trends of riparian and aquatic habitat across the OESF as the 1997 Habitat Conservation Plan is implemented through the OESF Forest Land Plan.

This monitoring will assess both the status of habitat across the OESF, and the expected habitat recovery from management induced disturbances prior to the adoption of the 1997 Habitat Conservation Plan. Although the primary focus of this monitoring is not on the effect of specific management actions, it will seek inference about management effects on habitat by documenting all operational activities in the monitored watersheds and relating them to sampled habitat conditions. This analysis will be based on likelihood theory and information theoretic approach (refer to review in Hobbs and Hilborn 2006). Ecological models quantifying the relationships between management activities and habitat indicators will be built and later evaluated with empirical data collected through monitoring. The “best-fitting” models will be used to make inferences about management effects (refer to section “Analyses to Infer Management Effects” for more details).

Riparian status and trends monitoring will evaluate the changes in habitat conditions at watershed level and more specifically 3rd order basin (Stream Type 3 basin). This will be achieved by assessing individual monitoring indicators as well as aggregating their values into a single watershed condition score. The empirically-derived indicator values will be integrated through a Decision Support Model (Reynolds 1999) which accounts for indicators’ relative contribution and relationships.

The following monitoring objectives are identified for riparian status and trends monitoring:

1. Document the status and trends in riparian and aquatic conditions in the OESF. The term *trend* describes the continuing directional change in the value (or a distribution) of an individual monitoring indicator or watershed condition score. We use a year as the time interval and trend detection over a period of years, unless otherwise noted.
2. Test the assumptions around the recovery of riparian and aquatic conditions and evaluate the projections of riparian habitat over time as presented in the revised Draft EIS for the OESF.
3. Supply information for implementation monitoring of the OESF Forest Land Plan.
4. Supply information useful for HCP effectiveness and validation monitoring.
5. Supply information for inferences about management effects on habitat as a basis for adaptive management.

Guiding Principles

1. Acknowledge watersheds as the ecologically meaningful scale at which the processes that maintain riparian and aquatic habitat take place.
2. Acknowledge that riparian and aquatic systems are spatially and temporally variable; therefore, it is not appropriate to target habitat conditions which are static and uniform across the OESF.
3. Consider the revised Draft EIS analysis for the OESF Forest Land Plan, including indicators, analysis units, and evaluation approach, when using monitoring data to test assumptions and validate habitat projections described in the revised Draft EIS.
4. Develop a study design that allows detecting change in riparian and aquatic conditions over time.
5. Develop a monitoring study plan that is cost effective.
6. Consider integrating this monitoring with the implementation monitoring for the OESF Forest Land Plan.
7. Conceptually link this monitoring to population processes of salmonids by considering potential limiting factors. Consider integrating this monitoring with future effectiveness and validation monitoring studies in the OESF.

Conceptual Models

Watersheds are a meaningful unit of ecological integration to use when evaluating the status of ecological processes. However the information and analytical tools necessary to quantify and comprehensively assess watershed processes are currently lacking (Reeves et al. 2004). Therefore the OESF Riparian Status and Trends Monitoring Plan, like other, similar monitoring plans (e.g. Northwest Forest Plan monitoring of the aquatic conservation strategy), must rely on physical and biological attributes that act as surrogates or indicators of specific watershed processes.

After identifying monitoring objectives, DNR built a conceptual ecological model of the riparian system to be monitored. A carefully developed conceptual model is a key step in designing an ecological monitoring plan. The model can be helpful for 1) selecting monitoring indicators; 2) formulating hypotheses to be tested in the monitoring study; and 3) conceptually linking this monitoring to effectiveness and validation monitoring studies. The last can be achieved by identifying relationships of habitat attributes to management stressors and limiting factors for species of interest (in this case salmonids).

DNR developed one global conceptual model for the entire riparian system (Figure 3) and then more detailed models that are specific to several monitoring indicators (Figures 4 through 10). The global model identifies physical indicators to be sampled and summarizes processes and mechanisms important to the indicators' status and trends. The indicator-specific models provide a more detailed view of mechanisms of influence to these indicators. The models illustrate the physical and biotic processes, including natural and management-related disturbances. The conceptual models are informed by literature on riparian ecology, local knowledge about OESF biophysical conditions, and existing riparian monitoring models (e.g. Kershner et al. 2004, Reeves et al. 2004).

The global conceptual model (Figure 3) lists recognized ecological processes in riparian and aquatic systems and specific mechanisms that result in riparian and aquatic habitat (the first two columns of the diagram). The resulting riparian and aquatic habitat conditions are characterized by their key physical attributes and then monitoring indicators are selected to measure changes in these attributes. The shaded boxes in the last column of the model show the indicators that will be sampled in the field with the funding and staff planned for this project. The non-shaded areas show physical indicators which will be sampled when additional funding and expertise are available.

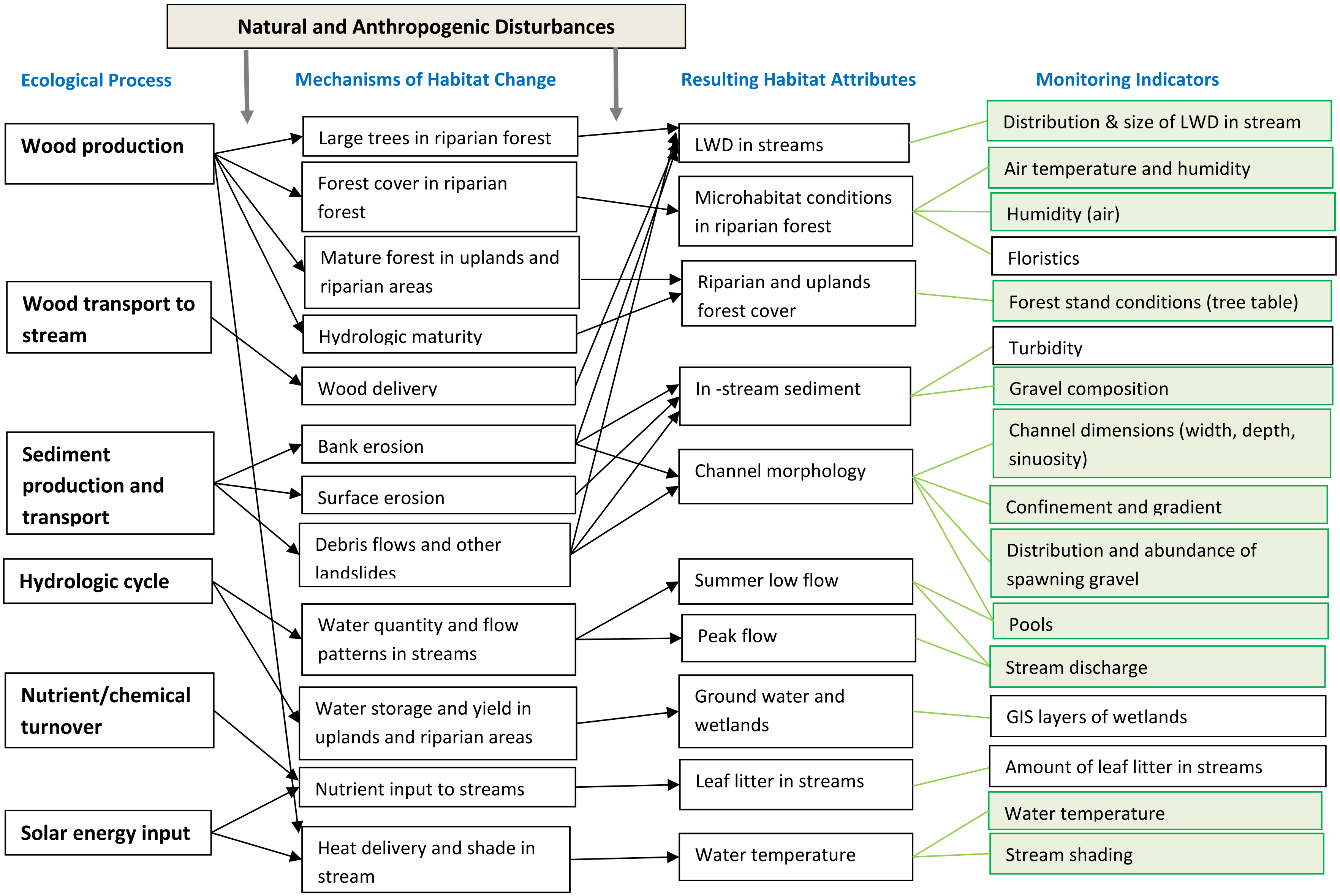


Figure 3. Global conceptual model for monitoring in-stream and riparian conditions in the OESF. Shaded indicator boxes denote indicators that will be sampled in the field.

INDICATOR-SPECIFIC MODELS

Indicator-specific models were developed for six of the indicators DNR expects to sample in the field: water temperature, in-channel large woody debris, pools, availability of spawning habitat, gravel composition, and gravel stability. A brief explanation of the other four indicators are presented at the end of this section. Due to the complexity and multiple interactions in these systems, many relationships are presented in summary fashion through graphical representations (Figures 4 through 10). The models are neither fully comprehensive nor mutually exclusive. Implicit in these models are hypotheses of causal relationships between environmental influences and indicators. DNR intends to use these models as the conceptual foundation for making inferences about the effects of forest management on riparian and aquatic habitat (refer to Analytical Methods for more details).

Figure 4 illustrates how forest and road management activities influence natural processes, which in turn affect key indicators of riparian function in the OESF. Forest management in riparian and wetland areas can interrupt, maintain, or restore natural processes important to the function of riparian ecosystems. These processes include water storage and yield, particularly through interaction with evapotranspiration in forested wetlands (Richardson 1994); filtering of surface flow; provision of large trees in streamside forests and uplands that can be delivered to channels (Gregory et al. 2003); and provision of structural support for stream banks. Upland forest management influences overall hydrologic characteristics in watersheds (Grant et al. 2008), and management practices on unstable slopes can influence the dynamics of coarse and fine sediment in watersheds (Swanson et al. 1987). Forest roads and their drainage systems can alter hydrologic regimes through mechanisms that include increased runoff from impervious surfaces and interception and channelization of surface and shallow groundwater (Beechie et al. 2005). The location and continued management of forest roads and their drainage systems also influence the production and delivery of coarse and fine sediments to riparian and aquatic habitats. The primary mechanisms of influence are alteration of frequency and severity of mass-wasting events and erosion from road surfaces (e.g., Wemple et al. 2001, Reid and Dunne 1984).

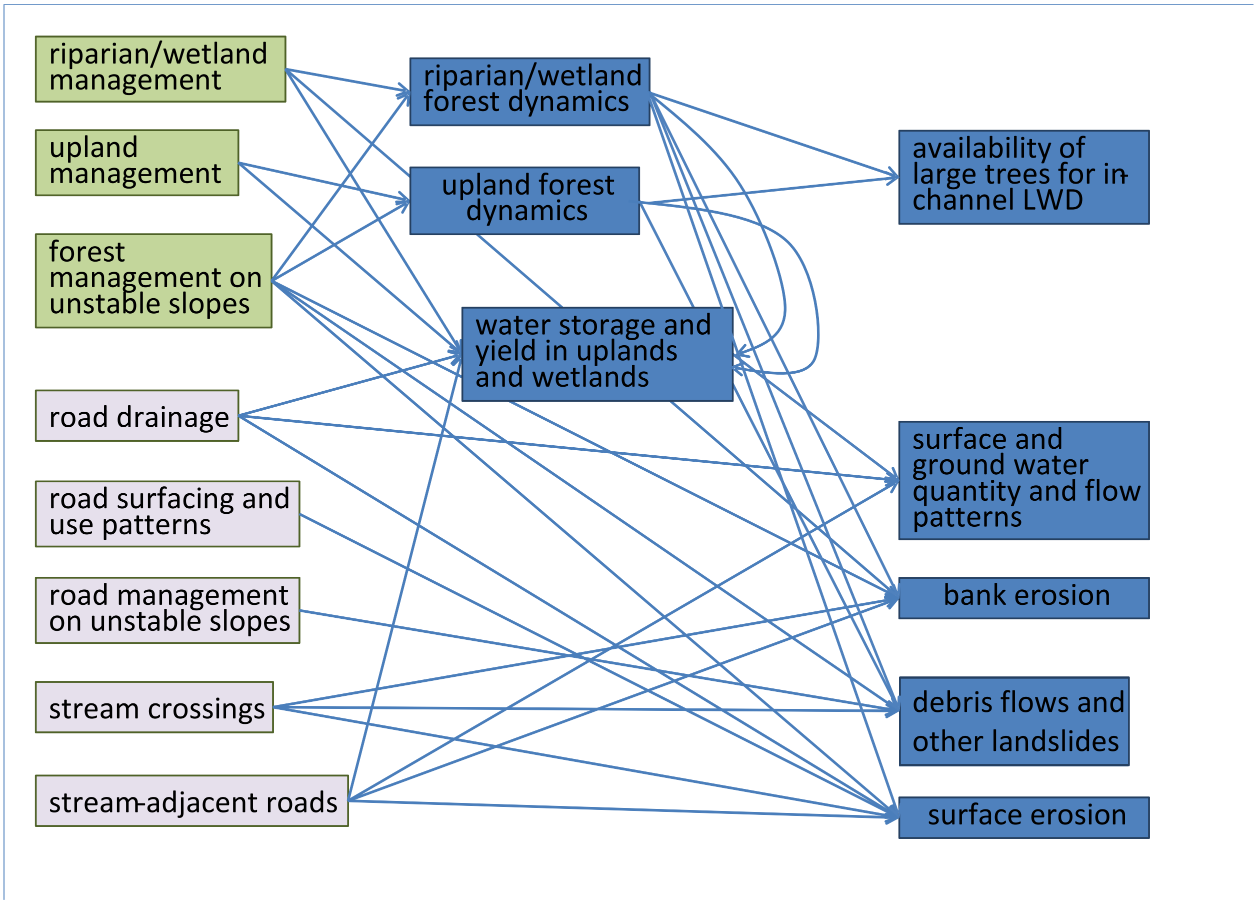


Figure 4. Summary of the management influences on environmental mechanisms that affect key indicators of riparian function in the OESF. Boxes are color-coded to reflect similarities among processes: green, forest management; gray, road management; and dark blue, indirect influences on indicators.

The 1997 Habitat Conservation Plan and OESF Forest Land Plan include specific management objectives for maintaining and restoring natural processes to conditions more reflective of natural disturbance regimes (DNR 1997, 2011). The influences of forest and road management on natural processes are illustrated graphically in summary form in Figures 5 through 10.The following sketches and narratives are presented as "multiple working hypotheses" (Chamberlain 1897). These hypotheses can provide a framework for analyses that strengthen our understanding and communication of how environmental and management influences result in the indicators' status and trends.

Water Temperature

Water temperature is the result of dynamic interactions of energy and water exchanges across the water surface, streambed, and banks (Poole and Berman 2001, Moore et al. 2005). Important processes and their interactions are illustrated in Figure 5. Heat exchange occurs through four physical processes: convection, conduction, advection, and radiation. Ensuing stream temperature regimes are the result of solar energy and water mediated by hydrologic and riparian processes; these processes variously insulate and buffer water temperature. Historic management influences interrupted many of those processes, resulting in elevated temperatures in many OESF streams even though riparian shade had recovered in many areas (Pollock et al. 2009). Understanding status and trends in stream temperature in the OESF will likely require a more encompassing interpretation of temperature regimes in the context of this broad suite of hydrologic and riparian processes.

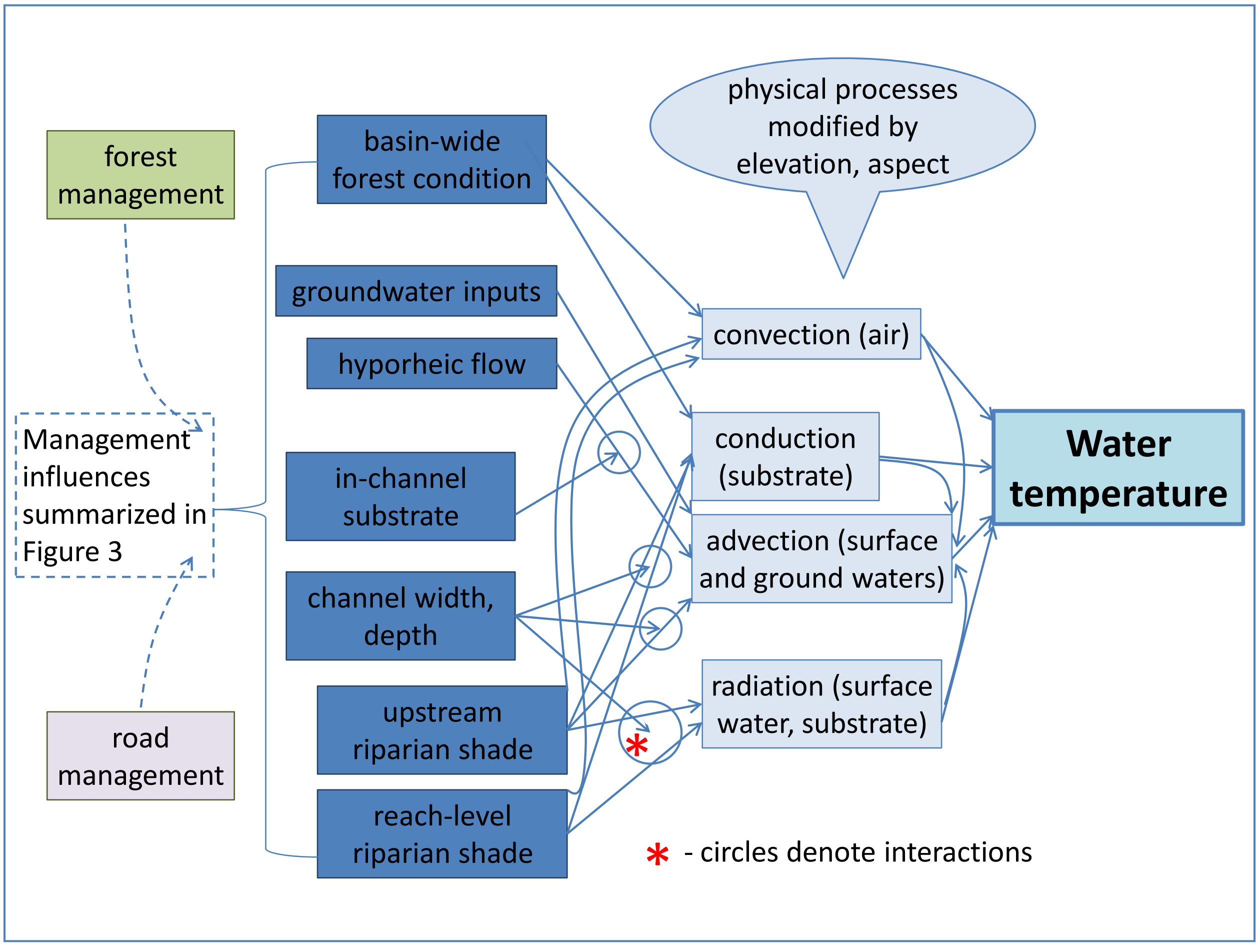


Figure 5. A schematic representation of hypothesized relationships among management influences, riparian processes, and hydrologic processes resulting in status and trends of stream temperatures in the OESF. Boxes are color-coded to reflect similarities among processes: green, forest management; gray, road management; dark blue, indirect influences on indicators; and light blue, direct influences on indicators. Indicators are shown in turquoise.

Large Woody Debris

Large woody debris is a critical element of functional aquatic and riparian ecosystems in Pacific Northwest streams (Gregory et al. 2003). Hydraulic functions of large woody debris are important to patterns of sediment transport, which result in structural and habitat complexity in streams; and to connections of streams with their floodplains (Montgomery et al. 2003).

In-stream large woody debris originates in riparian and upland forests and is delivered to streams by the mechanisms illustrated in Figure 6. Historic management practices reduced riparian and upland large woody debris sources; these practices also altered the rate and severity of disturbances that delivered large woody debris to channels and transported it within and throughout the riparian system (Martin and Benda 2001). DNR hypothesizes that status and trends in large woody debris in the OESF stream channels are the result of the interplay among these stream-reach and watershed-level processes and factors.

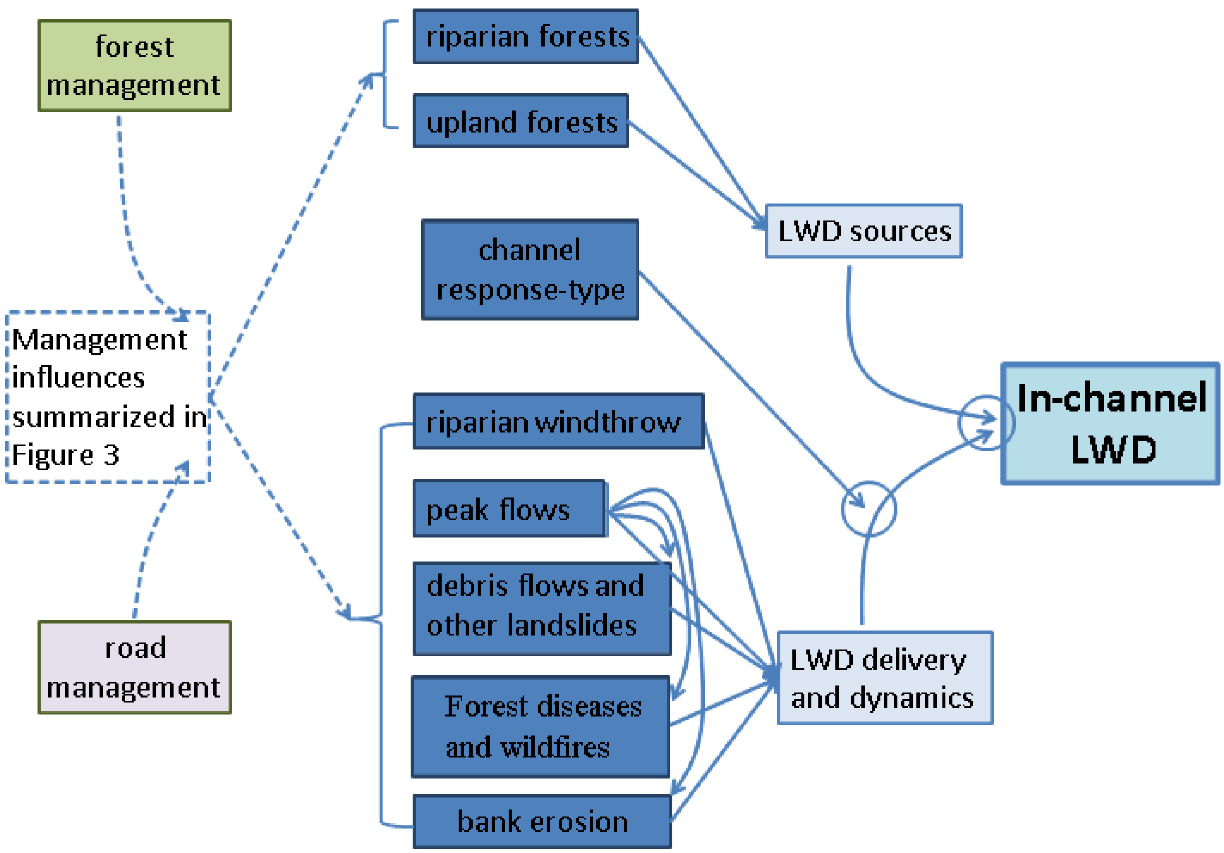


Figure 6. A schematic representation of hypothesized relationships among management influences, riparian and upland forest dynamics, and geomorphic and hydrologic processes resulting in status and trends of in-stream large woody debris in the OESF. Boxes are color-coded to reflect similarities among processes: green, forest management; gray, road management; dark blue, indirect influences on indicators; and light blue, direct influences on indicators. Indicators are shown in turquoise.

Availability of Spawning Habitat

Spawning habitat varies among the four salmonid species common in the OESF, based mainly on the species' size. Larger fish utilize larger gravel, often in areas of deeper water and higher flow (Reiser and Bjornn 1979). As shown in figure 3, three attributes of spawning habitat are considered indicators: gravel composition, abundance and distribution. Collectively, these indicators describe habitat availability and quality. The availability of spawning habitat depends on gravel distribution and abundance relative to flow patterns during the spawning seasons of native salmonid stocks. The quality of this habitat depends in large part on gravel composition, which permits sufficient interstitial space to allow oxygenating water movement and refugia for newly-hatched alevins; and on the stability of the spawning beds during high flow events, such that scouring does not cause mortality.

The distribution and abundance of suitable spawning habitat results from the interaction of supply and movement of coarse and fine sediment within channels (Buffington et al. 2004). Fine and coarse sediment enters streams from hill slopes, stream banks, and floodplains through a variety of geomorphic processes. Sediment is then redistributed by hydraulic forces as summarized in Figure 7. In-stream large woody debris and other roughness elements create a variety of conditions that allow spawning gravel to occur in channels that might otherwise be inhospitable (Buffington and Montgomery 1999). Gravel of the appropriate size and quality becomes available according to flow patterns during the fall through spring spawning seasons and is utilized by various species and stocks (Reiser and Bjornn 1979). Forest and road management has altered the supply and in-stream dynamics of sediment as summarized in Figure 4. Understanding the relationship of management with restoration objectives with status and trends in the availability of spawning gravel will require analyses that encompass the complex relationships outlined in Figure 7.

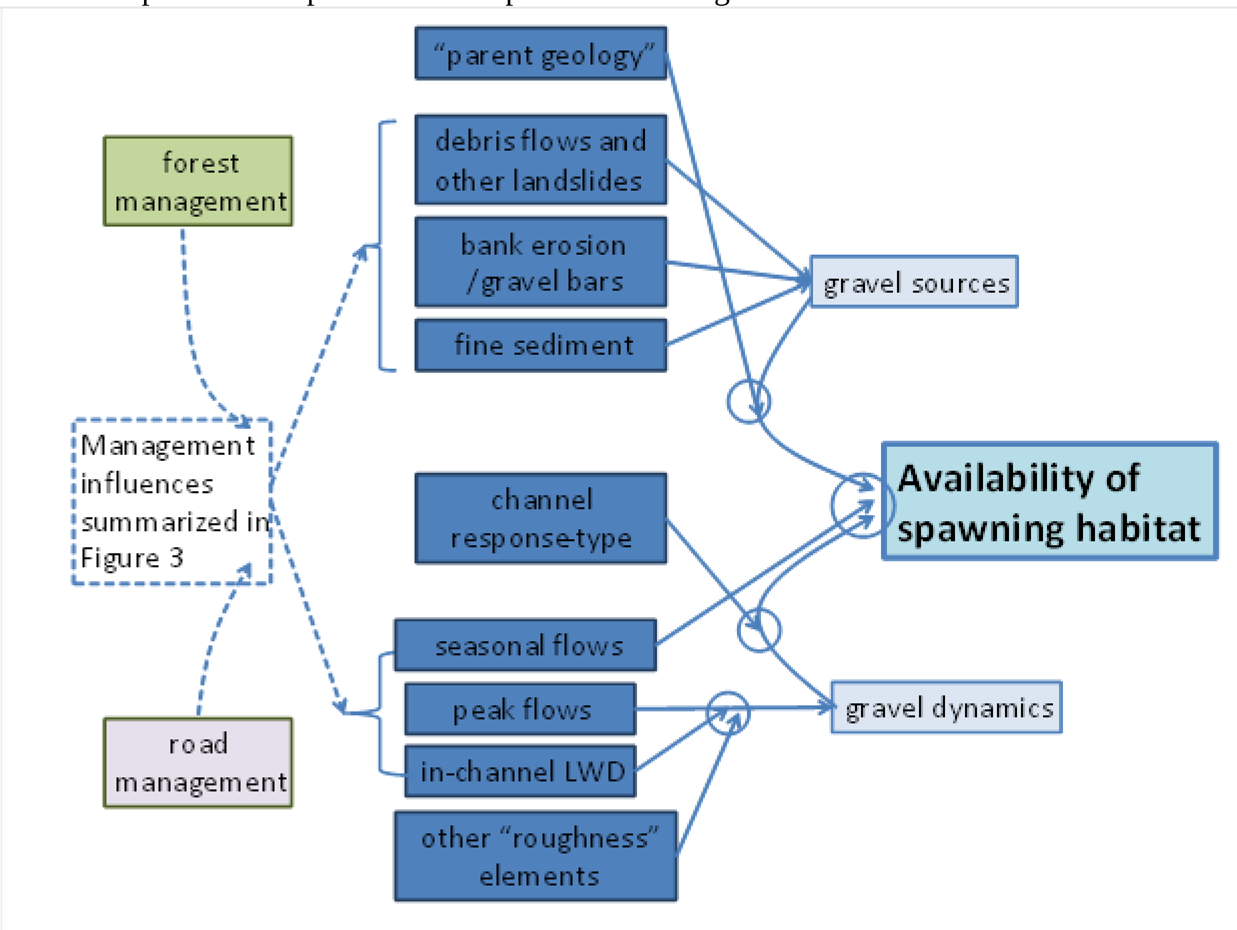


Figure 7. A schematic representation of hypothesized relationships among management influences, riparian and upland forest dynamics, and geomorphic and hydrologic processes resulting in status and trends of the distribution, abundance, and availability of spawning gravel in OESF. Boxes are color-coded to reflect similarities among processes: green, forest agement; gray, road management; dark blue, indirect influences on indicators; and light blue, direct influences on indicators. Indicators are shown in turquoise.

Spawning Gravel Composition

Fine sediment in spawning gravel is detrimental to the survival of eggs in redds and of newly hatched alevin before they emerge from the gravel as fry (Jensen et al. 2009). Thus the composition of spawning gravel is an important indicator of habitat quality. Fine sediment enters streams through a variety of geomorphic processes and is re-distributed by hydraulic forces; however, it responds to those forces differently than coarse sediment (Beechie et al. 2005. Lisle and Hilton 1999). Figure 8 summarizes those processes. Forest and road management has altered the supply and in-stream dynamics of fine sediment; in particular, timber haul on logging roads can be a chronic source of fine sediment (e.g., Cederholm et al. 1980). DNR hypothesized that status and trends in spawning gravel composition, i.e., the proportional representation fine sediment, is the result of the interaction of the multiple factors summarized in Figure 8, including the direct influence of spawning salmon on gravel composition ("biotic factors" in Figure 8, Kondolf et al. 2008).

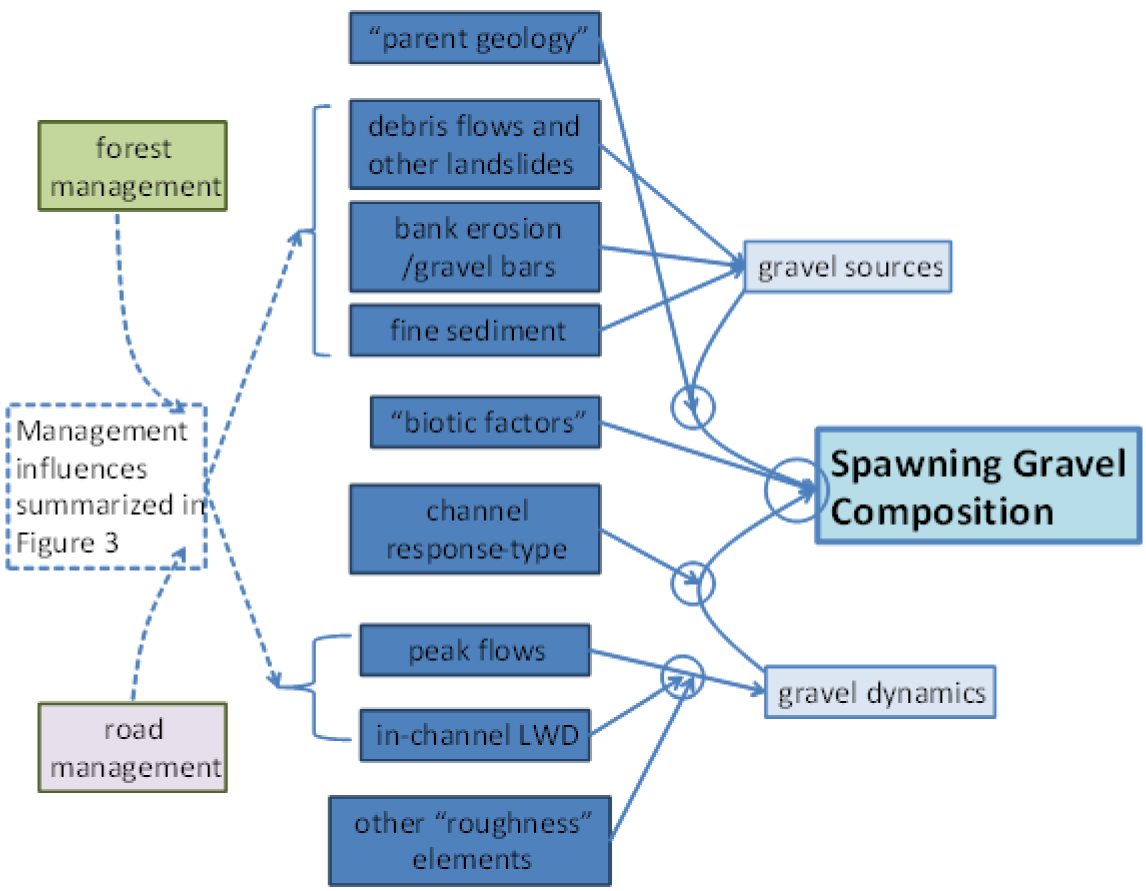


Figure 8. A schematic representation of hypothesized relationships among management influences, riparian and upland forest dynamics, and geomorphic, hydrologic, and biotic processes resulting in status and trends of the composition, i.e., proportion of fine sediment spawning gravel in the OESF. Boxes are color-coded to reflect similarities among processes: green, forest management; gray, road management; dark blue, indirect influences on indicators; and light blue, direct influences on indicators. Indicators are shown in turquoise.

SPAWNING GRAVEL STABILITY

High stream flows can transport bedload and otherwise influence channel morphology. Forest and road management can alter hydrologic processes in watersheds affecting in the frequency and intensity of peak flows that fall outside the range of natural variability, although elevated peak flows are "likely much less significant" than other management impacts on channel dynamics (Grant el al. 2008). Elevated peak flows can directly influence salmonid habitat in a variety of ways; for example, scouring spawning gravel causes mortality of eggs and alevins (summarized by Schuett-Hames et al. 1999). The locations, depth, and frequency of stream bed scour are influenced by the interaction of sediment and hydraulic characteristics of streams (Montgomery and Buffington 1997) as summarized in Figure 9. The stability of potential spawning gravel is an indicator that integrates peak flows, other influences on hydraulics, and characteristics of in-channel sediment.

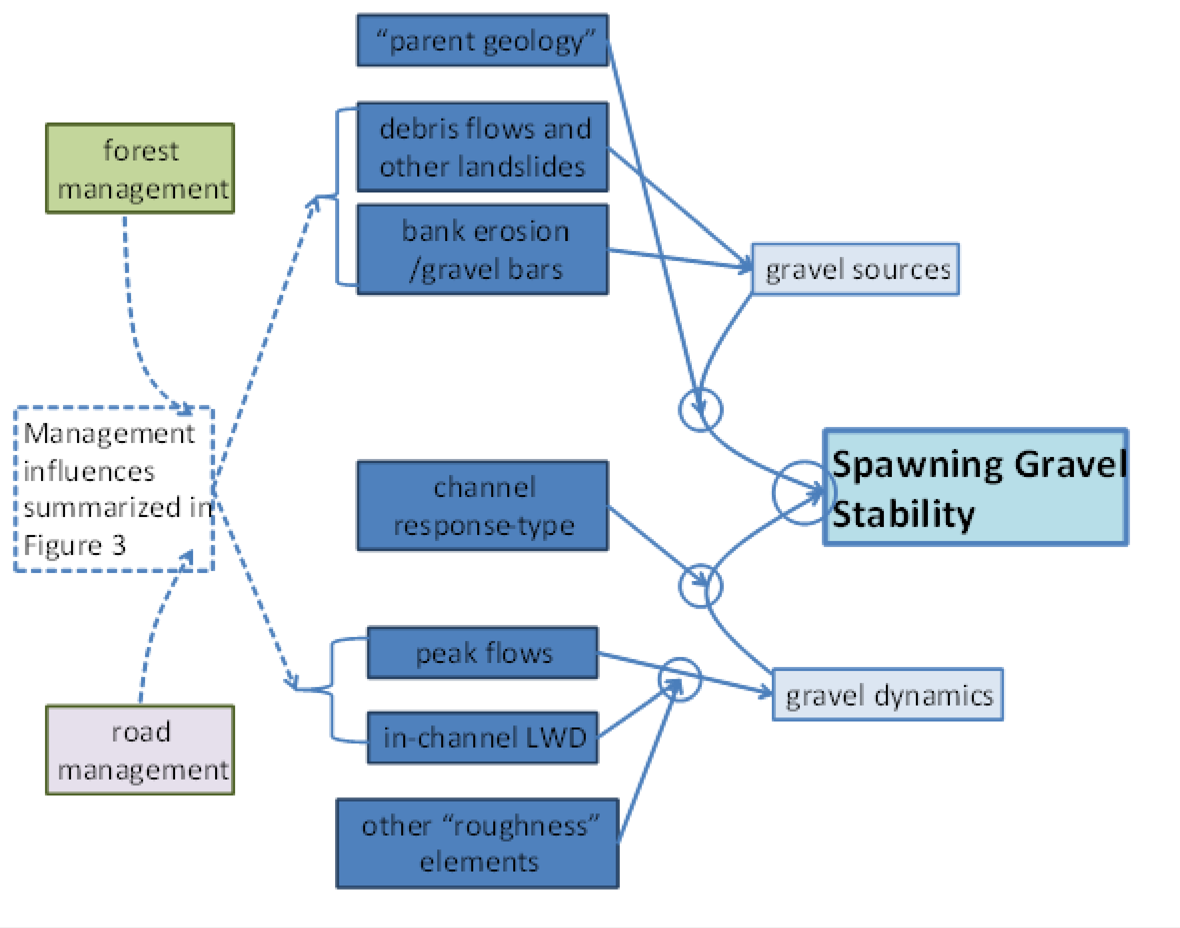


Figure 9. A schematic representation of hypothesized relationships among management influences, riparian and upland forest dynamics, and geomorphic and hydrologic processes resulting in status and trends of the stability of spawning gravel in the OESF. Boxes are color-coded to reflect similarities among processes: green, forest management; gray, road management; dark blue, indirect influences on indicators; and light blue, direct influences on indicators. Indicators are shown in turquoise.

Pools

The quiet, often deep water found in pools is recognized as an important element of salmonid habitat (e.g., Bisson et al. 1988, Reeves et al. 1989). Pools in the lower gradient stream reaches provide high-quality habitat for anadromous salmonids, and largely result from large woody debris and other obstructions to flow. These obstructions cause complex patterns of sediment trapping and local scouring (Montgomery et al. 1995). Both riparian and upland sources of large woody debris are important to pool formation (Montgomery et al. 2003) and are influenced by forest management (Sedell et all 1988). The complex interactions that result in pools are summarized in Figure 10, and form the basis of our hypotheses about the status and trends of pools in OESF streams.

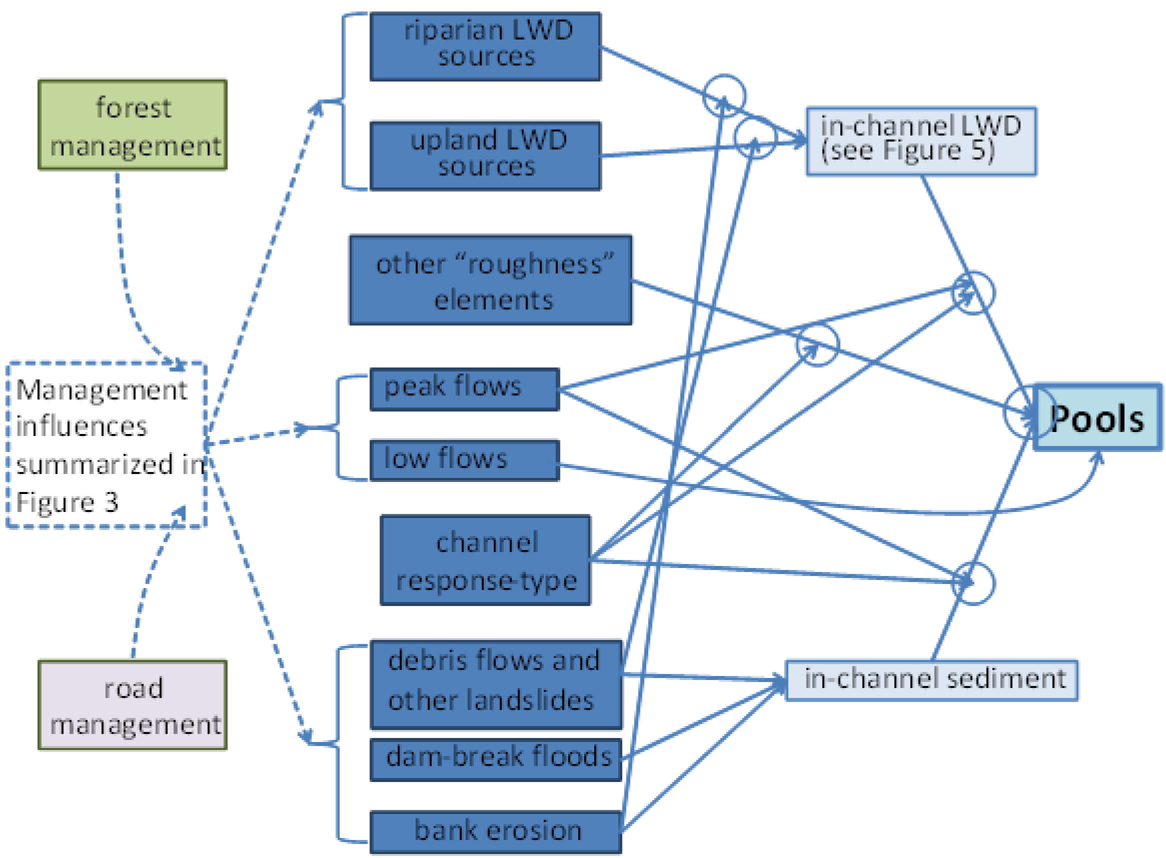


Figure 10. A schematic representation of hypothesized relationships among management influences, riparian and upland forest dynamics, and geomorphic and hydrologic processes resulting in status and trends of pools in OESF streams. Boxes are color-coded to reflect similarities among processes: green, forest management; gray, road management; dark blue, indirect influences on indicators; and light blue, direct influences on indicators. Indicators are shown in turquoise.

OTHER KEY INDICATORS

DNR did not develop ecological models for stand conditions, channel sinuosity, channel-floodplain connectivity, or stream shading as part of this plan.

Stand conditions are a result of tree growth and mortality, which is caused by the interaction of site-level factors such as soil productivity, aspect, and moisture with initial stand characteristics such as species composition and stocking and the influence of silviculture and/or natural disturbances (refer to the revised Draft EIS for the OESF). Because silvicultural science has well-developed models to characterize and study these processes in uplands and because, in large part, these processes do not directly relate to objectives of the current monitoring plan, an indicator-specific model was not developed for stand conditions. An exception is the effect of windthrow in riparian buffers, which is addressed in Table 3 on p. 22. The authors recognize that little modeling has been done on riparian forest stands in the Pacific Northwest and it might be worthwhile to include riparian modeling at some point in the future, especially to frame the hypothesis that thinning riparian areas accelerates the growth of dominant conifers.

Characteristics of channel response-type, sinuosity, and connectivity with floodplains are relatively static in the constrained channels that are typical of the Type 3 watersheds within the sampling frame[2] for this monitoring plan. These characteristics will be measured and incorporated as covariates in modeling responses of several of the indicators described in the previous section.

Stream shading is an important component of processes that determine stream temperature (Figure 5). Shading will be monitored and its relationship to riparian stand conditions will be investigated as part of stream temperature modeling.

The above models (Figures 4 through 10) outline processes which result in status and trends of monitoring indicators. We suggest strengthening the multiple working hypotheses implicit in the models as sets of explicit, quantitative models that represent our current understanding of these systems. These models should be based on the literature, the collective experience of DNR staff, and consultations with a strong pool of local and regional experts. As data are collected on the indicators and their covariates, "model-based inference" (Anderson 2008) can be used to improve our understanding and communication of how environmental and management processes interact in restoring aquatic and riparian ecosystem functions. More details on this approach are provided in the section Analytical Methods.

Main Hypothesis

DNR's central hypothesis is that as the OESF Forest Land Plan is implemented, riparian and aquatic conditions will improve, i.e. they will shift towards conditions reflective of natural disturbance regimes.

[2] Sampling frame – a listing of the elements in a population from which a sample is drawn.

To test this hypothesis, we will measure individual riparian and aquatic indicators such as stream temperature and will develop a watershed condition score. The score will be calculated from the values of the individual monitoring indicators identified in the global conceptual model. The construction of watershed conditions model is described in the section Analytical Methods. The main hypothesis will be tested by examining trends in the distribution of the scores of the individual indicators and the overall watershed condition score across all sample basins in the OESF. It is hypothesized that, over time, the distribution of scores will approximate that found under an unmanaged condition, resulting in a larger proportion of Type 3 watersheds with higher watershed condition scores (refer to Figure 16d).

Monitoring Questions

Six main monitoring questions were identified based on monitoring objectives:

1. What is the status of the individual monitoring indicators (habitat attributes) across the OESF?
2. What is the status of Type 3 watersheds as characterized by aggregations of the selected monitoring indicators (i.e., the watershed condition score) across the OESF?
3. Has the distribution of individual indicator scores shifted in a direction indicating improved or degraded condition?
4. Has the distribution of watershed condition scores shifted in a direction indicating improvement or degradation?
5. How do empirically-derived indicator scores and watershed condition scores compare to the scores projected in the revised Draft EIS analysis for the OESF Forest Land Plan?
   5.1. Is the large woody debris recruitment potential recovering as projected?
   5.2. Is the sediment regime recovering as projected?
   5.3. Is peak flow recovering as projected?
   5.4. Is stream shade recovering as projected?
6. How do forest and road management influence indicator scores?

Monitoring Indicators

The term *indicator* is used throughout this study plan in a loose sense of a measurable factor that reflects the structure, composition, or functioning of an ecological system. When developing monitoring protocols later, indicators, metrics, and measurements will be described following the framework described in www.monitoringadvisor.org:

<u>Measurement</u> - refers to the value resulting from a field data collection event at a specific site and temporal period, i.e. what is actually measured/estimated in the field at a site (or within a site). An example is measuring the thalweg depth at one point on the sampled stream reach.

Metric refers to the aggregation of measurements to characterize a site (when a single measurement doesn't capture what we are trying to characterize at a site). For example, the mean thalweg for the sample reach derived from all thalweg measurements in the sample reach. In some cases, a site's metric comes from a single measurement, e.g. peak flow.

Indicator refers to the aggregation of metrics across the set of sites in a study, meant to characterize a domain's condition by inference from the set of site measurements. E.g. an indicator might be the proportion of the stream network that exceeds a thermal threshold.

Under this framework, the process of determining an indicator based on metric values is defined as inference design. This component of the project will be developed together with the monitoring protocols.Using the terminology above, what we indicate in this study plan as indicators are rather indicator categories.

Most of the habitat attributes in our global conceptual model can be assessed by more than one indicator. We considered a longer list of potential indicators then the one presented in Fig. 3. The reduction to the final list was done by applying a set of criteria modified from Kershner et al. (2004), Reeves et al. (2004), and Schueller et al. (2006). These criteria are listed in Table 1.

Table 1. Criteria for selecting monitoring indicators.

	Criterion	Description
1	**How relevant is the indicator to our objectives, and questions?**	Changes in the indicator must be interpretable in terms of the objectives of the monitoring plan.
2	**How sensitive is the indicator?**	Changes in the system being monitored are likely to be reflected in measurable changes in the indicator; the indicator must respond quickly enough to disturbance or recovery to provide results in the chosen timeframe
3	**Are there existing methods available to measure the indicator?**	It is desirable to have the following in advance: existing protocols, agreed-upon standards or threshold values of the indicator, available baseline data, and analyses of the accuracy and precision of the measurements or estimates
4	**Does the indicator have enduring use?**	Widespread use of the same indicator allows for comparison across sites and scaling up from local to regional assessments.
5	**Can the indicator data be easily interpreted?**	It is preferable to have the signal statistically separable from the noise, i.e. the indicator to have low or understood levels of background variation and human measurement error so that these variations and errors can be distinguished from changes of interest. This is difficult to achieve for many fish habitat attributes, especially in disturbance prone environments in the western Olympic peninsula and there may be value in retaining highly variable indicators. Application of emerging analytical techniques can help overcome the difficulties presented by high variability.
6	**Is the indicator feasible and cost-effective to obtain?**	The indicators should be accessible at low cost and feasible to collect and analyze It should be feasible to collect data repeatedly in a way that is not overly destructive. The use of data collected by other DNR programs will increase efficiency and reduce cost.
7	**Is the indicator integrative?**	The indicator should provide information about multiple levels or aspects of the system, e.g. useful for future effectiveness and validation monitoring.

The indicators in our model are commonly used in riparian and in-stream monitoring. In forested watersheds where streams are managed to limit impact of forest harvest on fish species of concern, key attributes typically revolve around stream water temperature (or stream shade), availability of large wood (for structuring in-stream habitat), and the intrusion of fine sediment into streambed gravels (Bisson and Wondzell 2009).

Several less common indicators ended up in our conceptual model and therefore deserve explanation. Wetlands are included in the list of indicators for several reasons reflective of their functions: they ameliorate damaging peak flow, provide habitat, and participate in nutrient cycling. At this phase of the project we do not have the expertise and the resources to measure this indicator directly. Six geographic information system (GIS) datasets, currently used by DNR, will be used to provide wetlands baseline conditions: DNR Forest Resource Inventory System, DNR hydrology layer, DNR soils layer, USFWS National Wetlands Inventory, and National Resource Conservation Service's layer. Tracking changes in wetlands will depend on updates of these GIS layers. Field verification of wetlands will take place incidental to other field monitoring.

Shade is included as an indicator in addition to the direct indicator "water temperature" because it is a widely used parameter in regulatory documents. Also, it is an indicator in the EIS riparian analyses and can be used to test relationships between riparian forest, shade, and water temperature, as described in the EIS analysis.

Measuring peak flow directly through stream flow gauging may be cost prohibitive. DNR will continue exploring field protocols and newly available technology. An alternative is to use a surrogate indicator for peak flow (gravel stability) which will be measured as stream bed scouring.

Since aquatic and riparian-dependent species are the ultimate response variables to forest management, the lack of biological indicators in our list is a noticeable omission. The importance of in-stream and riparian biological indicators has been recognized in the literature (refer to discussion in Karr and Chu 1999). The three main groups for biological indicators commonly used to assess aquatic conditions are fish, stream benthic macroinvertebrates (a heterogeneous assemblage of animals inhabiting the stream bottom), and periphyton (a mixture of organisms attached to substrates, including algae, bacteria, microinvertebrates, and associated organic materials) (US EPA 2002b). DNR excluded biological indicators from this monitoring plan for budget reasons. Also, DNR has little experience in this type of sampling. Expertise in this area and information about biota cannot be obtained through routine business operations, as it can for some physical indicators (e.g. inventory of riparian vegetation). Adding biological indicators to the sampling design is strongly recommended and DNR will seek collaborators for this work.

The areas of sampling and the potential data sources for each indicator are identified in Table 2. The areas of sampling for the riparian indicators (riparian forest stands and microclimate) are the same as those areas used in the riparian analyses found in the Revised Draft EIS for the OESF Forest Land Plan (DNR, in progress). The areas used in the Revised Draft EIS were largely based on interpretations of the literature summarized in preparation for the Northwest Forest Plan (FEMAT 1993). The area of sampling for the aquatic subsystem is a stream reach whose length is determined as 20 times the bankfull width (refer to the sampling design section of this document for more details). Additional details on sampling area and data sources will be provided in the sampling protocols either in an appendix of the final version of this study plan or in a stand alone document..

Table 2. Areas of sampling and data sources for monitoring indicators of riparian and aquatic conditions.

Monitoring indicator	Sampled area	Data sources
Distribution and size of large woody debris in stream	Stream reach	Field sampling
Turbidity	Stream reach	*No sampling at this stage*
Spawning gravel composition	Stream reach	Field sampling
Availability and stability of spawning gravel	Stream reach	Field sampling
Channel dimensions (width, depth, sinuosity)	Stream reach	Field sampling
Pools	Stream reach	Field sampling
Stream discharge	Stream reach	Field sampling
Amount of leaf litter in streams	Stream reach	*No sampling at this stage*
Stream temperature	Stream reach	Field sampling
Stream shade	Stream reach	Field sampling
Confinement	Floodplain of sampled stream reach	Field sampling
Gradient	Stream reach	Field sampling
Riparian forest stand conditions	Both banks of the stream reach within 150 feet from stream*****	Field sampling Riparian forest inventory
Riparian microclimate: **temperature** **humidity**	Both banks of the stream reach within 150 feet (46 meters) from stream ***** within 150 feet (46 meters) from stream *****	Field sampling
Wetlands	Entire type 3 watershed	*No sampling at this stage*

*****The distances from the stream are measured outward from edge of the channel migration zone.*

The models in Figures 4 through 10 provide the conceptual foundation for making inferences about the effect of management activities on riparian and aquatic habitat conditions. Data on management activities (mainly harvest and road management) and natural disturbances in the monitored basins will be derived from operational records and remote sensing. The procedures for collecting and recording this information will be described in an appendix of the final version of this study plan or in a stand-alone document (currently under development). To the extent possible, the riparian status and trends monitoring will utilize DNR operational and compliance data collected as part of DNR timber sales and road management programs. Additional data on natural disturbances need to be collected. DNR will develop a document that will provide details on the type, format, and permanent location of this new data.

Table 3 lists the indicators for management and natural disturbances and available data sources.

Table 3. Area of sampling and data sources for monitoring indicators of management and other disturbances influencing riparian and aquatic habitat.

Disturbance	Monitoring indicator	Sampled area	Data sources
Timber harvest	Percent harvested area by type of harvest	Entire type 3 watershed	Forest management GIS layer, planning and tracking database
	Hydrologic maturity	Entire type 3 watershed	Hydrologic maturity GIS layer
	Windthrow effects on riparian buffers (buffer width and forest cover)	Entire type 3 watershed Riparian buffers on both banks of all streams	Aerial photos
	Post-harvest site preparation (slash burning and herbicide application)	Entire type 3 watershed	Records on timber sales compliance Forest management GIS layer, planning and tracking database
Road management	Road density by status and public access	Entire type 3 watershed	Regional road management layer
	Road use	Entire type 3 watershed	Regional records on road use
	Road maintenance and repair	Entire type 3 watershed	Regional road management layer
Other disturbances	Landslides/debris flows (extend and frequency)	Entire type 3 watershed	Forest practices GIS layer on landslides; aerial photography including historical aerial photosequence; timber sales geotech reports; regional records on landslides and debris flows
	Windthrow (not related to edges created by timber harvest)	Entire type 3 watershed	Aerial photography including historical aerial photosequence Regional records windthrow
	Flood damage, including dam-break floods by culvert blowouts	Entire type 3 watershed	Regional records, regional road management layer; local knowledge

All instances of riparian windthrow, landslides, fire, floods, and debris flow in the sampled basin will be documented regardless of their cause. To the extent possible, analyses will attempt to classify "natural" vs. timber harvest vs. road-related disturbances. When these disturbances are identified, they will be analyzed through field visits or records review to decide which basins to revisit for data collection.

Monitoring protocols will be selected for each of the monitoring indicators that will be sampled in the field. For the indictors that will be measured through remote sensing or operational records, we will develop sampling procedures and list the available GIS sources and analysis software. The sampling methods will be described in an appendix of the final version of this study plan or a stand-alone document (currently under development).

Conceptual Link to Validation Monitoring

To the extent possible, field installations and data from riparian status and trends monitoring should be used in future riparian validation monitoring. The purpose of validation monitoring is to document and assess fish response to habitat changes resulting from management activities. Through validation monitoring DNR will test the assumptions behind the 1997 Habitat Conservation Plan riparian conservation strategy for the OESF (DNR 1997) and will provide compelling evidences for the effectiveness of the conservation strategy.

In order to conceptually link the status and trends monitoring effort with a later validation monitoring effort, it is important to describe how habitat attributes identified for sampling under riparian status and trends monitoring affect the life history requirements of salmonids in the OESF. There are several widely used models of limiting habitat factors for salmonids, e.g., Ecosystem Diagnosis and Treatment (EDT) and the Shiraz Model, which could utilize habitat monitoring data from the OESF. Model outputs could be used to develop testable hypotheses concerning management effects. These hypotheses are then tested by implementing effectiveness and validation monitoring studies.

To date, DNR has only conducted planning for riparian validation monitoring. A draft riparian validation monitoring plan (Dominguez and Beauchamp 2001) was published in 2001. It described scope, challenges, and a phased approach to implementation. In 2008, DNR renewed its efforts by launching an assessment phase for validation monitoring, which consisted of three workshops attended by DNR staff and the federal services. Coho salmon was identified as the likely monitored salmon species in the OESF. The assessment phase also identified coho life stages that are most influenced by DNR forest management: spawning and egg incubation, juvenile rearing, migration of juveniles to salt water, and adult migration to their spawning grounds.

Findings from the earlier planning efforts narrow our description of salmonid habitat relationships and potential limited to four life stages of a single species. The brief discussion below is at conceptual level. A conceptual framework for riparian validation monitoring is presented in an appendix of the Draft OESF Forest Land Plan (DNR, in progress). A future study plan for validation monitoring is expected to provide the necessary level of detail.

In-channel large woody debris affects all of the coho life stages listed above. The direct mechanism of influence is protection from predation (hiding cover). The indirect mechanisms include pool availability, food availability of drifting and benthic invertebrates, and slowing of the water flow.

Pools affect the juvenile rearing stage of coho salmon by providing rearing space.

Riparian forest stand structure and composition affect the juvenile rearing stage directly by providing protection from predation, and indirectly by providing nutrient input into the food chain and affecting light availability, which influences in-stream productivity. Riparian forests influence all life stages indirectly by providing shade, which affects water temperature.

Peak flow affects all life stages of coho salmon mainly indirectly through destabilizing and transporting large woody debris and scouring the stream bed.

Stream temperature has direct physiologic effects on all life stages. Its indirect influence includes changes in the amount of dissolved oxygen.

Spawning gravel availability, stability, and composition affect the spawning of coho salmon by providing refuge from flow events. The influence on juvenile rearing is mainly through protection from predation.

Sampling Design

The complexity of aquatic and riparian systems, the magnitude of their spatial and temporal variation, and the insufficient understanding of the ecological processes that maintain habitat make it challenging to develop a sampling design that is capable of characterizing status and detecting trends in aquatic and riparian habitat conditions. This section begins by listing the requirements for the sampling design, followed by a brief review of literature on implemented or proposed sampling designs for detecting trends in salmonid habitat. The rest of the section describes the sampling frame, the allocation of sampling units, and the sampling size and frequency, which are appropriate to the stated design requirements and the project's monitoring objectives.

Requirements for the Sampling Design

The sampling design for monitoring the status and trends of riparian and aquatic conditions in the OESF should meet the following requirements:

1. The sampling design should be driven by the monitoring objectives and the monitoring indicators for habitat conditions and management stressors described earlier in this document.
2. The watersheds selected for sampling must be representative of OESF watersheds in order to confidently extrapolate about riparian and aquatic conditions across the entire OESF. "Defining characteristics" of these watersheds, i.e. the characteristics that have the greatest influence on their disturbance and recovery processes, include topography (slope gradient), geology, stream size, vegetation zone, and management history (harvest and hauling methods).
3. The sampling design should be powerful enough to detect biologically significant change in both the individual indicators and basin-wide conditions.

4. The sampling design should balance the need to estimate status with the need to detect trend. Status in our case is defined as the average condition of a monitoring indicator or basin-wide conditions across the OESF at a given point of time. Sampling more units is better for estimating status. Revisiting sampling units across years is best for trend detection.
5. The sampling design should be cost effective and feasible to implement.

LITERATURE REVIEW

In the monitoring section of their riparian synthesis for the OESF, Bisson and Wondzell (2009) suggest referencing several years of past regional monitoring surveys when developing a monitoring program for the OESF. DNR reviewed one national and several regional monitoring designs for guidance on the spatial and temporal framework of the design and sample size. The findings are summarized below.

Urquhart et al. (1998) described several regional monitoring designs and evaluate their relative power for detecting trends. The authors recognized that variation can have substantial effects on power to detect trend and break variance to several important components to assess their influence on trend detection. Different temporal designs were compared for their ability to simultaneously provide precise estimates of status and good power to detect trend. Rotating panel design was described as a survey design that includes site visits on alternative years, with a subsample of the selected monitoring sites visited every year. This design balances the need to estimate status by sampling as many sites as possible across the broadest geographic distribution, with the need to detect trend by repeated sampling of the same set of sites over time. Revisit designs gave adequate power to detect moderate trends in 10–15 years, even when revisits were less frequent than annually.

Larsen et al. (2004) examined four components of variability (inter-site, yearly [synchronous yearly variation among sites due to region-level factors, e.g. storms], interaction between site and year, and residual [measurement error, observer's error etc.]) in four indicators (pools, large woody debris, riparian canopy cover, and fine sediment) from six surveys in the Pacific Northwest. The authors concluded that a network of approximately 50 sites, monitored annually, can provide sufficient statistical power to significantly detect trends of 1–2% per year (i.e. relatively small trend) within one to three decades. Lowering the number of sites for some of the indicators did not decrease the power of the analysis and the authors recommended a sample size of 30–50 annually visited sites for regional-scale monitoring. The power of trend detection was clearly sensitive to the duration of the study; it improved substantially with the passage of years. Rotating panel designs did not hamper trend detection sensitivity significantly; they only delayed trend detection by a few years. However, these designs allow a greater number of sites to be monitored, increasing confidence in overall estimates of the status of indicators and watersheds.

Stevens and Olsen (2004) described a type of spatial design that blends simple random sampling (which tends to clump the sample sites) and systematic sampling (which is difficult to implement for streams because of their uneven distribution). The design is called Generalized Random Tessellation Stratified design. It was developed for and used in the

Environmental Monitoring and Assessment Program Aquatic Monitoring, managed by US EPA.

Reeves et al. (2004) developed a monitoring framework for the aquatic strategy of the Northwest Forest Plan which focused on status and trends of watershed conditions across 24 million acres of federal land. The selection of monitoring sites followed the Generalized Random Tessellation Stratified design (Stevens and Olsen 2004). The temporal allocation of the sampling effort used a rotating panel approach of Urquhart et al. (1998).

Bowes et al. (2011) developed a scientific protocol for salmonid habitat surveys within the Columbia Habitat Monitoring Program as part of Columbia River basin-wide habitat status and trends monitoring plan. The proposed spatial design was based on Generalized Random Tessellation Stratified design (Stevens and Olsen 2004) and the temporal approach was a split rotating panel design (Urquhart et al. 1998) with revisits of each panel every fourth year.

Sampling Frame

The geographic area subject to this monitoring is all state trust lands within the Olympic Experimental State Forest Habitat Conservation Plan Planning Unit (Figure 2).

The type 3 watershed is selected as the sampling unit for this monitoring because it is the smallest hydrologically complete unit relevant to both the riparian ecological processes that provide salmonid habitat, such as sediment production and transport, wood production and transport to streams, and the hydrologic cycle; and to DNR management activities in the OESF, primarily timber harvest and road management. The type 3 watershed is also the spatial unit selected for the environmental impact analyses of the OESF Forest Land Plan and the scale at which the Forest Land Plan provides management recommendations over a planning period of 100 years. Thus, the target population for monitoring is all type 3 watersheds encompassing state trust lands in the OESF as identified by DNR's GIS watershed boundary dataset (SHARED_LM.OESF_WATERSHED). In the OESF, 601 type 3 watersheds entirely or partially overlap state trust lands.

Watersheds are categorized as either "true" or "composite" based on topography and flow patterns, using modified guidance from the Federal Standards and Procedures for the National Watershed Boundary Dataset (USGS and USDA NRCS 2011) and Reeves et al. (2004). True watersheds are topographically defined, with no surface inlet. True watersheds are typically defined as having only one surface outlet. An expanded definition for true watersheds used for this study includes "frontal" watersheds – those watersheds located along the coastline of a lake or ocean. These frontal watersheds may have more than one surface outlet. Only frontal watersheds with no surface inlet are classified as true watersheds. Composite watersheds have one or more surface inlets and may have more than one outlet. Composite watersheds, as delineated in the current DNR hydrology dataset, are often comprised of the small triangular wedges between adjacent drainage areas after true watersheds are delineated (Figure 11).

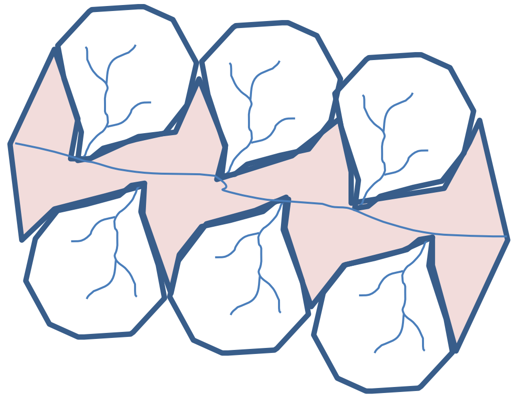


Figure 11. Illustration of true basins (white polygons) and composite basins (shaded polygon) as delineated in DNR corporate layer.

Of the 601 type 3 watersheds in the OESF, 446 which include some portion of DNR trust lands are classified as true watersheds.

According to DNR's GIS hydrology dataset, there are 10,730 miles (17,268 kilometers) of streams within the OESF planning unit, including all ownerships. A total of 2,785 miles (4,482 kilometers) of streams are located on DNR-managed trust lands in the OESF. The average stream densities in the OESF are 0.33 mi/mi^2 for type 1 waters, 0.12 for mi/mi^2 for type 2 waters, 1.06 mi/mi^2 for type 3 waters, 0.92 mi/mi^2 for type 4 waters, 4.07 mi/mi^2 for type 5 waters, and 0.08 mi/mi^2 for type 9 (unclassified) waters (refer to the Revised Draft EIS for the OESF, in progress). Also, 16,287 stream reaches across the OESF were identified through the Salmon and Steelhead Habitat Inventory and Assessment Project (SSHIAP) (SHARED_LM.OESF_HYDRO[3]) and analyzed in the OESF Forest Land Plan EIS. With such an abundant stream network, a decision had to be made which streams in type 3 watersheds will be sampled.

The status of type 3 watersheds will be characterized by the aquatic conditions in the most downstream section of the type 3 stream in the watershed, and by conditions in the adjacent near-stream riparian area. The sampling reach starts at the outlet of the watershed and continues upstream for a length equal to 20 times the average bankfull width (see review of field protocols by Bowes et al. 2011). These downstream reaches are the sampling locations, which will be fixed and permanent.

The most downstream reach is selected for sampling since its conditions should represent the response to changes in the entire watershed. Also, the most downstream reach is most likely to be unconstrained and to have the lowest gradient. Therefore, the most downstream reach is expected to have greater variation in stream morphology as a result of sediment delivery, debris inputs, and peak flow compared to upstream reaches within the basin. Montgomery and McDonald (2002) recommend sampling stream reaches with gradient less than 3% since they represent pool-riffle channels that should have the greatest sensitivity to sediment supply and peak flow.

[3] Hydrologic dataset was clipped to the OESF boundary. SSHIAP stream segments identified where "WB_LLID_NR" is null and "WC_HYDR_FTR_CD" in ('ST', 'SC', 'WT') and SSHIAP_SEG <> 0.

After the true type 3 watersheds in the OESF were identified as the pool for sampling, two additional screening steps were performed, as described below.

Since monitoring will track habitat conditions as the OESF Forest Land Plan is implemented, sampling should be performed in type 3 watersheds where DNR manages the majority of the watershed. Selecting these watersheds reduces the variability associated with mixed-ownership management. To select a threshold for DNR ownership per type 3 watershed, land ownership patterns in these watersheds (Figure 12) were reviewed and a threshold of at least 50% DNR ownership per watershed was selected, which captured 70% of DNR's land base. This screening process reduced the pool of type 3 watersheds available for sampling from 446 to 244.

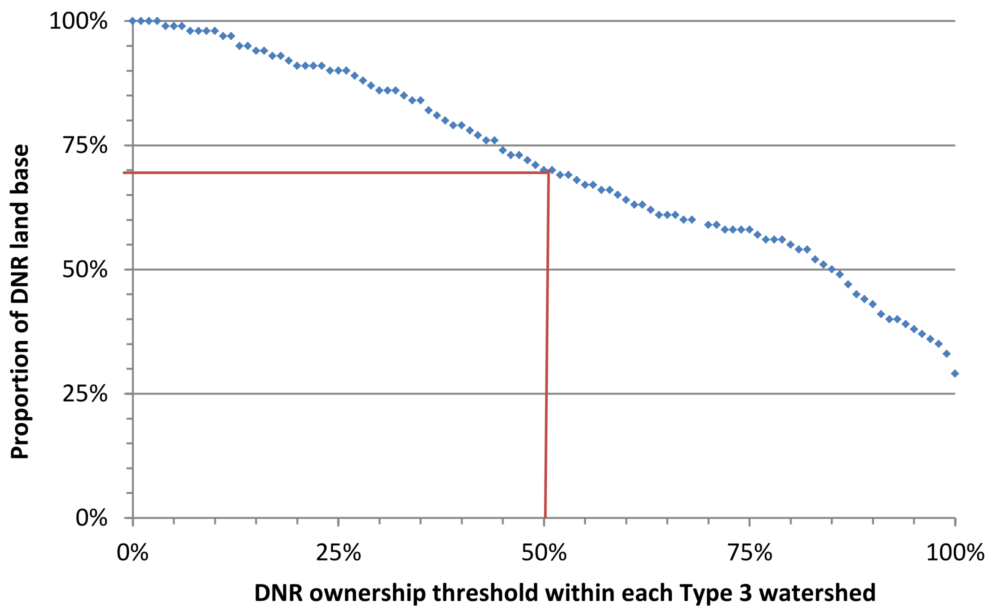
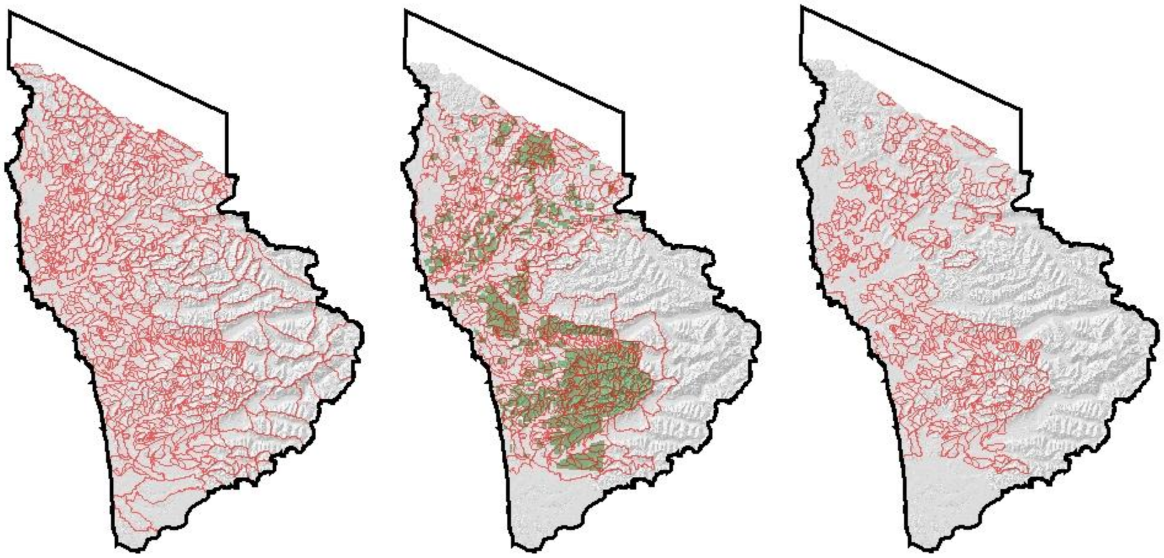


Figure 12. Proportion of DNR land base within the OESF represented as a function of percent of DNR ownership within each type 3 watershed.

Watershed size was used as an additional screening criterion. In the current hydrology dataset, it varied between 14 and 3,530 acres for the 244 type 3 watersheds classified as true watersheds with at least 50 percent DNR trust lands. As watershed size was not normally distributed, a logarithmic transformation was applied. Outliers were defined as those watersheds whose log transformed size was greater than or equal to 2 standard deviations from the mean; those watersheds were excluded from further consideration.

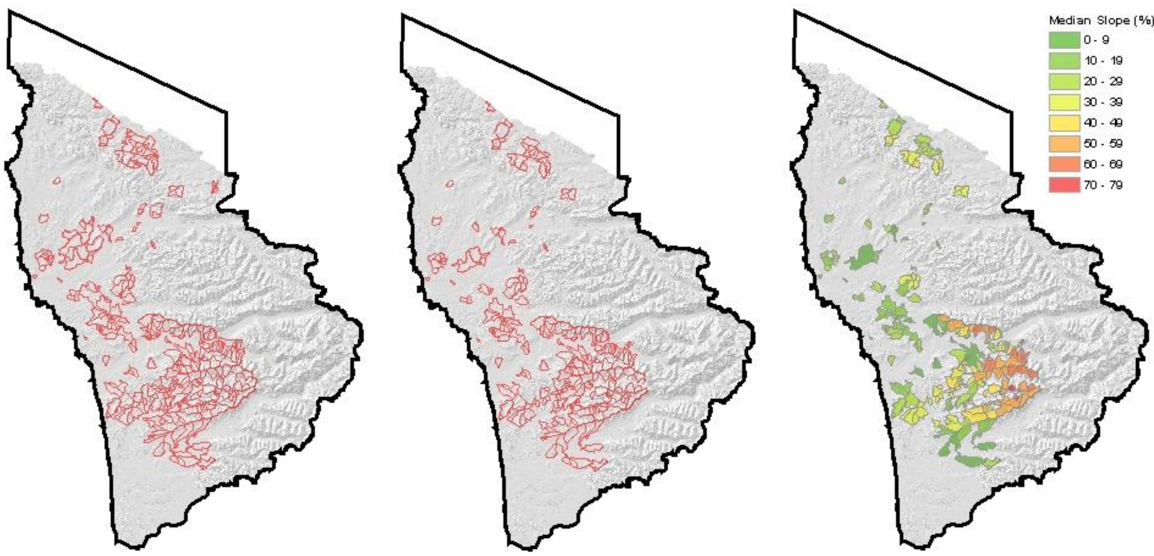
A total of 236 watersheds met these screening criteria and ranged in size from 49 to 2,799 acres (20 to 1,132 hectares). This is the sampling frame, i.e. the listing of the type 3 basins from which the sample will be drawn. The reduction of the target population to the sampling frame as a result of the screening process is illustrated in Figure 13 (a-d) and Table 4.



a) Type 3 watersheds located within the OESF. N = 848.

b) Type 3 watersheds containing DNR ownership. N = 611

c) Type 3 watersheds classified as true basins. N = 446.



d) Type 3 watersheds with ≥ 50 % DNR ownership. N = 244.

d) Type 3 watersheds with total basin size within 2 standard deviations of the mean. N = 236.

e) Selection set stratified by median basin slope (%).

Figure 13. Selection criteria applied cumulatively to identify the sampling frame (maps a through d) and results of stratification by slope (map e).

Table 4. The effect of screening on the pool of basins available for sampling.

Screening criterion (applied cumulatively)	Number of type 3 watersheds
Within the boundary of the 1997 Habitat Conservation Plan planning unit	848
Contains any DNR ownership	611
True basin	446
At least 50% DNR ownership	244
Log_{10} watershed size within 2 standard deviations of the mean	236

REFERENCE SITES

Reference conditions will be sampled as part of this monitoring plan. They are defined as essentially unmanaged watersheds subject only to natural disturbances. The value of recording reference conditions is in providing a picture of what unmanaged basins look like and how they respond to natural disturbances over time.

The reference basins are not envisioned to be controls for the managed basins in the OESF. Neither will they be used characterize temporal and spatial range of natural variability in local ecological conditions. The sample size is too small for that. Any comparisons with managed basins are expected to be largely qualitative.

The only completely unmanaged type 3 watersheds in the western Olympic Peninsula are located in Olympic National Park. The majority of these watersheds are located at higher elevations and are characterized by steeper topography. We selected three lower-elevation areas that are expected to have biophysical conditions similar to the OESF. These areas are located within the Queets, Hoh, and Bogachiel River basins (Figure 14).

A total of four type 3 watersheds will be selected across these three areas. The number of reference sites was chosen for practicality – less than 3 is too few to be able to analyze the conditions in the reference basins and more than 4-5 will be very difficult to access and sample in the remote and largely inaccessible western portion of the Olympic National Park. The initial screening of the three selected river basins showed several type 3 watersheds with gradient, size, elevation comparable to the managed watersheds. Final selection of the four reference watersheds will require extensive office and field reconnaissance. Access to the most downstream reach of the watersheds will be a major factor in selecting the reference watersheds since the areas are predominantly roadless. DNR staff will contact Olympic National Park for permission to establish reference sites with non-destructive sampling.

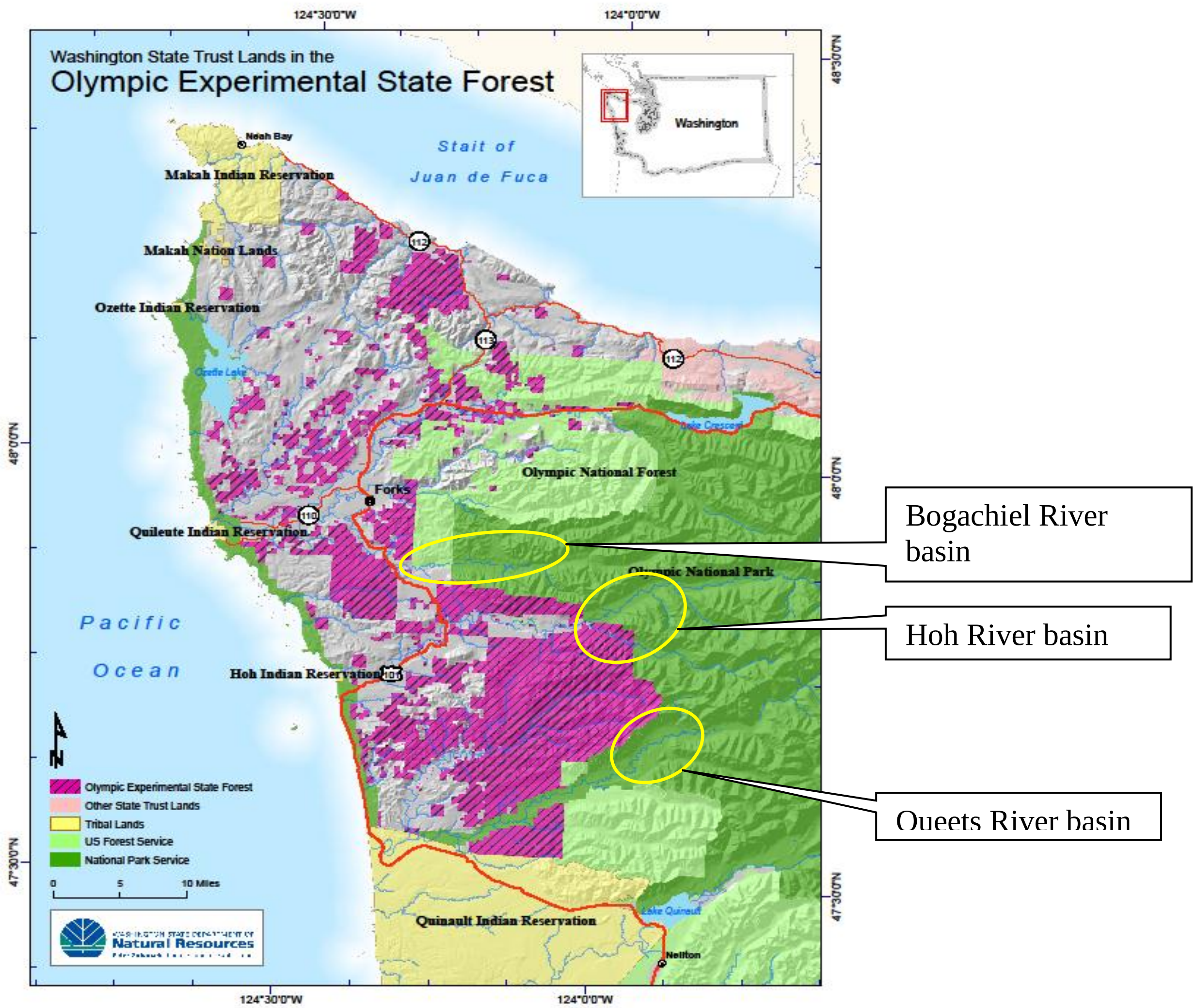


Figure 14. Location of the three areas for selection of reference watersheds.

Allocation of Sample Units

As already described in the requirements for the sampling design, a monitoring sample is needed that fairly represents the population as a whole. Given the high variability of the attributes of interest (see section Literature Review above), a completely random sampling across the sample frame will require a very large sample to reliably estimate the status and trends of ecological conditions. Completely random sampling is also unlikely to represent biophysical characteristics and management history in the OESF (unless a very large sample is selected) because they are spatially uneven – a relatively small part of the OESF is in a low elevation flatter area.

To ensure that biophysical conditions in the OESF were represented, a stratification process was applied. The "defining characteristics" of the OESF, i.e. the characteristics that have the greatest influence on the disturbance and recovery processes, were identified as slope gradient, geology, stream order, vegetation zone, and management history. It is likely that these characteristics are largely correlated within type 3 basins and that a basin-wide slope gradient provides a reasonable description of basin characteristics. Thus the distribution of basins in the sampling frame was evaluated relative to their median gradient in order to achieve a sample that was representative of the range of conditions across the OESF.

The sampling frame of 236 type 3 watersheds was placed in strata of 10% gradient increments ranging from 10 to 80% median slope. The data source for this stratification was the 10-meter Digital Elevation Model (DEM) (Source: \\snarf\database\grids\dem10w). This process yields 8 strata shown in figure 15.

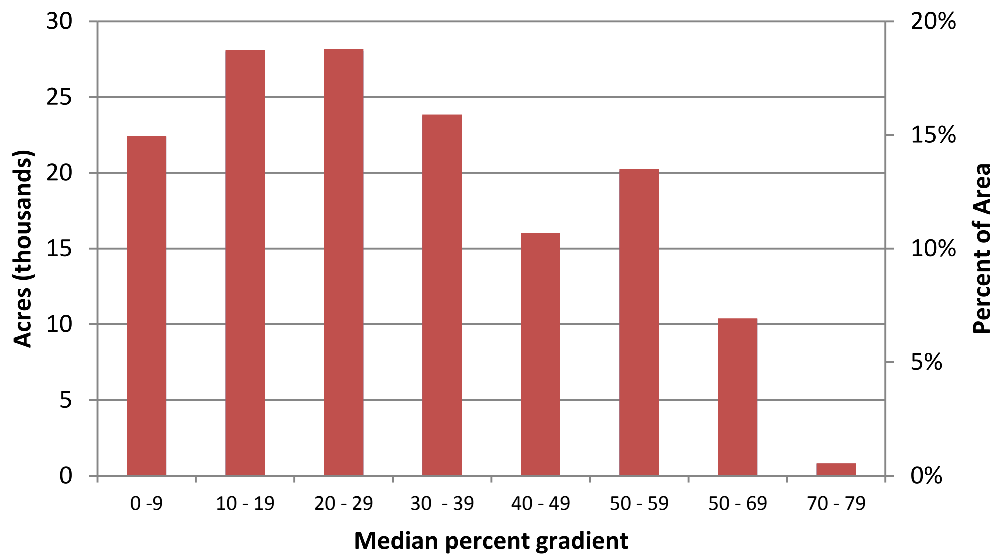


Figure 15. Distribution of the OESF land base by gradient strata.

Sampling units were selected from each stratum in proportion to the area of the stratum (Table 5). A sample size of 50 basins was used to calculate the proportions (see the next section for the rationale behind n=50).

Table 5. Allocation of the 50 sampled watersheds across eight gradient strata (slope classes). The proportion of sampled basins in each stratum corresponds to the percent land base in each gradient. The four reference sites are not included.

Slope class (median % slope)	Acres in each gradient strata	Percent of area in each slope class	Number of watersheds to be sampled in each slope class from a total of 50
0 - 9	22,338	15%	**8**
10 - 19	27,995	19%	**10**
20 - 29	28,047	19%	**10**
30 - 39	23,746	16%	**8**
40 - 49	15,949	11%	**5**
50 - 59	20,150	13%	**6**
60 - 69	10,338	7%	**3**
70 - 79	812	1%	**0**

Sample units within each stratum were drawn randomly. An ordered list of sample units was generated for each stratum in order to support additions and/or omissions while retaining spatial balance. For example, if during the reconnaissance process, one of the selected basins was determined unsuitable, the next watershed in the list would be selected.

The purpose of this stratification was to ensure representation of OESF biophysical conditions. It was not designed to reduce variation, since collected data will be analyzed across the entire OESF.

The final list of 50 selected watersheds is presented in Table 6 and illustrated spatially in Figure 16.

Table 6. List of type 3 watersheds selected for sampling on state lands in the OESF.

	Basin ID	Type 3 watershed	Percent DNR ownership	DNR acres	Total acres	Median gradient	Gradient stratum
1	698	True	77%	201	261	0	0 – 9%
2	627	True	67%	480	718	4	0 – 9%
3	846	True	100%	1,791	1,791	4	0 – 9%
4	642	True	100%	263	263	5	0 – 9%
5	550	True	53%	246	464	6	0 – 9%
6	630	True	89%	1,228	1,379	8	0 – 9%
7	658	True	72%	550	764	9	0 – 9%
8	568	True	100%	463	463	11	10 – 19%
9	796	True	88%	1,552	1,764	11	10 – 19%
10	721	True	66%	807	1,215	15	10 – 19%
11	192	True	64%	473	738	16	10 – 19%
12	463	True	53%	61	115	17	10 – 19%
13	583	True	62%	934	1,509	18	10 – 19%
14	523	True	100%	2,037	2,037	18	10 – 19%
15	582	True	100%	181	181	19	10 – 19%
16	498	True	93%	1,473	1,585	19	10 – 19%
17	467	True	60%	43	71	20	20 – 29%

	Basin ID	Type 3 watershed	Percent DNR ownership	DNR acres	Total acres	Median gradient	Gradient stratum
18	460	True	100%	128	128	21	20 – 29%
19	370	True	54%	276	511	21	20 – 29%
20	544	True	100%	126	126	21	20 – 29%
21	834	True	74%	36	49	23	20 – 29%
22	597	True	67%	565	837	24	20 – 29%
23	608	True	82%	339	415	24	20 – 29%
24	65	True	54%	285	524	26	20 – 29%
25	158	True	100%	519	519	26	20 – 29%
26	763	True	78%	342	439	31	30 – 39%
27	497	True	87%	433	499	33	30 – 39%
28	488	True	54%	171	318	33	30 – 39%
29	798	True	100%	327	327	34	30 – 39%
30	136	True	75%	257	341	36	30 – 39%
31	712	True	100%	475	475	38	30 – 39%
32	790	True	100%	849	849	39	30 – 39%
33	717	True	100%	150	150	42	40 – 49%
34	577	True	83%	821	992	44	40 – 49%
35	724	True	100%	177	177	46	40 – 49%
36	776	True	100%	176	176	48	40 – 49%
37	625	True	100%	537	537	49	40 – 49%
38	576	True	71%	646	908	50	50 – 59%
39	773	True	100%	414	414	53	50 – 59%
40	654	True	100%	1,503	1,503	53	50 – 59%
41	697	True	100%	1,434	1,434	55	50 – 59%
42	750	True	100%	298	298	56	50 – 59%
43	687	True	100%	736	736	57	50 – 59%

	Basin ID	Type 3 watershed	Percent DNR ownership	DNR acres	Total acres	Median gradient	Gradient stratum
44	635	True	100%	318	318	60	60 – 69%
45	639	True	100%	327	327	61	60 – 69%
46	653	True	100%	149	149	64	60 – 69%
47	844	True	99%	700	709	4	0 –9%
48	542	True	100%	382	382	17	10 – 19%
49	443	True	51%	183	359	20	20 – 29%
50	730	True	87%	775	895	39	30 –39%

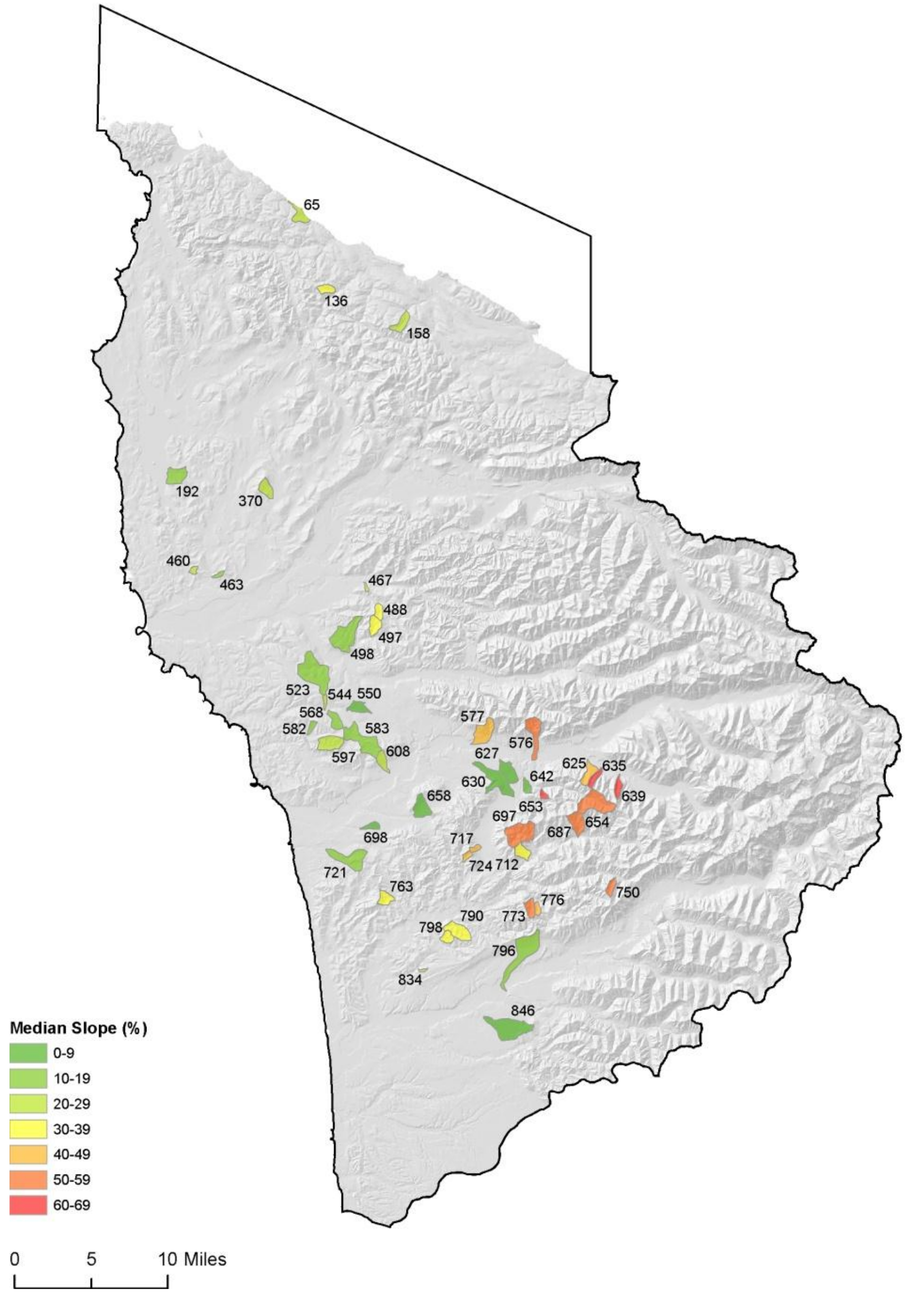


Figure 16. Type 3 watersheds selected for sampling (n=50). Each type 3 watershed is labeled with its watershed identifier.

SAMPLING SIZE, SAMPLING FREQUENCY, AND DURATION

The literature review at the beginning of this section indicates that a sample size of 30-50 type 3 watersheds should be reasonable to describe both status and trends across the OESF. DNR is suggesting a sample size of 50 watersheds recognizing that this is only a starting point until a power analysis is performed to determine the sampling size for the full implementation phase (refer to analytical methods on p. 36 of this document for more details).

Starting with a pilot project or having a phased approach (partial implementation) is a standard practice in ecological monitoring. In the first phase, the goal is usually to determine the feasibility of the proposed sampling design, assess the variability of the sampled attributes, and determine the sample size for full-scale implementation.

Re-sampling all 50 sampling units (type 3 watersheds) annually is not practical. The literature review found the rotating panel approach (Urquhart et al. 1998) is most appropriate for DNR's objectives. This approach balances the need for extensive sampling to estimate status with the need for revisiting the samples to estimate trend.

Rotating panel designs have increasingly been used in natural resource monitoring. A rotating panel design is currently being implemented in the effectiveness monitoring of the Northwest Forest Plan's aquatic conservation strategy (http://www.reo.gov/monitoring/watershed-overview.shtml), the US Forest Service's PACFISH INFISH Effectiveness Monitoring Program for Streams and Riparian Areas (http://www.fs.fed.us/biology/fishecology/emp), and DNR's Forest Practices' monitoring (http://www.dnr.wa.gov/BusinessPermits/Topics/FPAdaptiveManagementProgram/Pages/fp_cmer_active_projects.aspx); this design is planned for the Columbia Habitat Monitoring Program (http://www.cbfish.org/Project.mvc/Display/2011-006-00).

We suggest a modified (split) rotating panel design with five panels. A panel is a group of sites which is revisited following the same schedule. Four of the panels will be revisited every fifth year and one of the panels will be sampled annually (Table 7). The annually sampled sites, called sentinel sites, will provide information on trend faster, although with lower level of confidence because of the small sample size. The data from the sentinel sites will also provide information about the inter-year variability of the monitoring indicators. According to Reeves et al. (2004), when using panel rotation, trends will not be detectable until the third rotation of sampling begins, which under the proposed design will be after at least nine years.

Table 7. Split rotating panel design with 10 sample units in each panel.

	Pilot phase		Full implementation phase											
Year	**1st**	**2nd**	**3rd**	**4th**	**5th**	**6th**	**7th**	**8th**	**9th**	**10th**	**11th**	**12th**	**13th**	**14th**
Sentinel sites	5	10	10	10	10	10	10	10	10	10	10	10	10	10
Panel 1		5	10				10				10			
Panel 2				10				10				10		
Panel 3					10				10				10	
Panel 4						10				10				10

Under the proposed phased approach, DNR will have a pilot phase which will consist of one year of reconnaissance and two years of data collection. Five sentinel monitoring sites will be sampled in the first year of data collection. In the second year, the five sentinel sites will be revisited, an additional five sentinel sites will be sampled, and five sites from Panel 1 will be sampled. After the second year of sampling, power analysis will be conducted to establish appropriate sample size. The full implementation of the project will start in the third year.

The ten sentinel sites will be drawn randomly across the seven gradient strata. The remaining 40 watersheds will be randomly assigned to the four panels. For the pilot phase of the project, DNR will consider the watersheds that are scheduled for harvest activities in the next two years as high priority for inclusion in the sentinel panel and Panel 1, so that baseline conditions in these watersheds maybe sampled before management takes place.

Sampling frequency for the reference sites will follow the schedule for sentinel sites.

Field sampling will take place during the low-flow summer index window, generally between mid-June and mid-September. Records of management activities and remote sensing data will be collected continuously.

The proposed sampling design will be representative only if the management activities implemented in the sampled basins are the standard management practices intended in the OESF Forest Land Plan. If the sampled basins are targeted for special management actions (e.g. localized restoration actions, recreational management, and urban development), the monitoring results cannot be used to report the state of habitat conditions across the OESF, or to inform about the effectiveness of the OESF Forest Land Plan across the OESF. If an experimental manipulation takes place in one of the sampled basins, this basin may be excluded from the analyses used to characterize the effects of standard management practices under the OESF Forest Land Plan.

Analytical Methods

Five types of analyses are suggested for addressing objectives for riparian status and trends monitoring. The rationale and general approach for each analysis type is described in this section. The detailed methodology and necessary software for conducting these analyses will be presented after the pilot phase of the project is completed and will be part of the recommendations for the full implementation phase of the project.

POWER ANALYSIS

After the first two years of data collection, the five sentinel sites will have been visited twice and an additional five sentinel and five panel sites once (Table 7). The data from all 15 sampled sites will provide information about inter-site variability, measurement error (due to instruments, observers, and protocols), sampling cost, feasibility of field protocols, and logistics. The data from the five revisited sentinel sites may provide information about the inter-year variability of some indicators although, given the short period, this information will be considered cautiously.

In order to determine sample size for the full-implementation phase of the project, data will be needed not only on the attributes' inherent variability, but also on the required level of confidence in the findings (level of significance) and expected magnitude of the trend (effect size) for both individual attributes and watershed-wide conditions. Deciding how much change is biologically meaningful, and thus necessary to detect, is important because the sampling design should be developed to maximize the power of detecting a change of that magnitude should it occur (Uzarski and Otieno 2008). It is recommended that consultation with regional and local experts, statisticians, and literature sources as well as professional judgment is employed to make these determinations. Once variability, significance level, and effect size are determined, statistical power analysis (Gerrodette 1993) should be conducted to estimate the sampling size. The agency budget for long-term implementation of the program will be considered when making the final decision.

DECISION SUPPORT MODELS FOR WATERSHED CONDITION

Conditions of the sampled type 3 watersheds will be evaluated through a single watershed condition score (habitat index). The score will be derived from a hierarchical model expressing the values of and relationships between individual monitoring indicators.

Assessing ecosystem conditions requires consideration of multiple variables and the aggregate interactions among them (Reeves et al. 2004). Riparian ecosystems are complex and, as a result, the precise relationships among variables and relations to ecosystem conditions are not fully known. Fuzzy logic (Zadeh 1965) provides a means of developing models that can evaluate conditions of systems where relationships among variables are not precisely defined. One framework for building these ecological assessment models is provided by Reynolds (1999) and is called "Ecosystem Management Decision Support" software.

DNR has used this approach before and has adapted the modeling process to use customized geoprocessing of spatial and tabular data with Python-based GIS applications. This approach is used in the revised Draft EIS for the OESF to project changes in watershed conditions over the planning period. The decision support models for this monitoring study will be built after the pilot phase of the project.

ANALYSIS TO DETERMINE STATUS AND TRENDS

The traditional monitoring approach is to identify desired future conditions and measure progress against this goal. In this approach, thresholds are identified for parameters of interest, such as stream temperature or peak flow. Often these thresholds are arbitrary and not based on solid scientific evidences (Reeves et al. 2004). The objectives of the OESF Riparian Conservation Strategy do not include specific thresholds, but instead call for restoring or conserving "habitat complexity afforded by natural disturbance regimes on the western Olympic Peninsula" (DNR 1997, HCP IV. 107). Given the lack of a set target value, the traditional monitoring approach is not applicable here. Instead, the scores of the individual indicators and the entire watersheds will be represented as frequency distributions across all sampled watersheds. The shift in these distributions will be evaluated over time. The range of conditions in managed and in reference (unmanaged) watersheds will be reported and analyzed separately.

According to DNR's main hypothesis, the distributions of watershed conditions and individual indicators should move towards improved conditions, i.e. towards ecological conditions in unmanaged systems[4]. This means that the proportion of type 3 watersheds with a higher watershed score will increase. If habitat conditions across the OESF resemble the natural variability in an unmanaged landscape, this distribution is also expected to widen, covering a broader range of habitat scores. The expected change in the distribution shape and the shift in the distribution over time are schematically represented on Figure 17 d.

[4] *As already stated earlier the data from the 4 reference sites will not be used to define the range of natural variability –they are two few to provide comprehensive picture of unmanaged systems.*

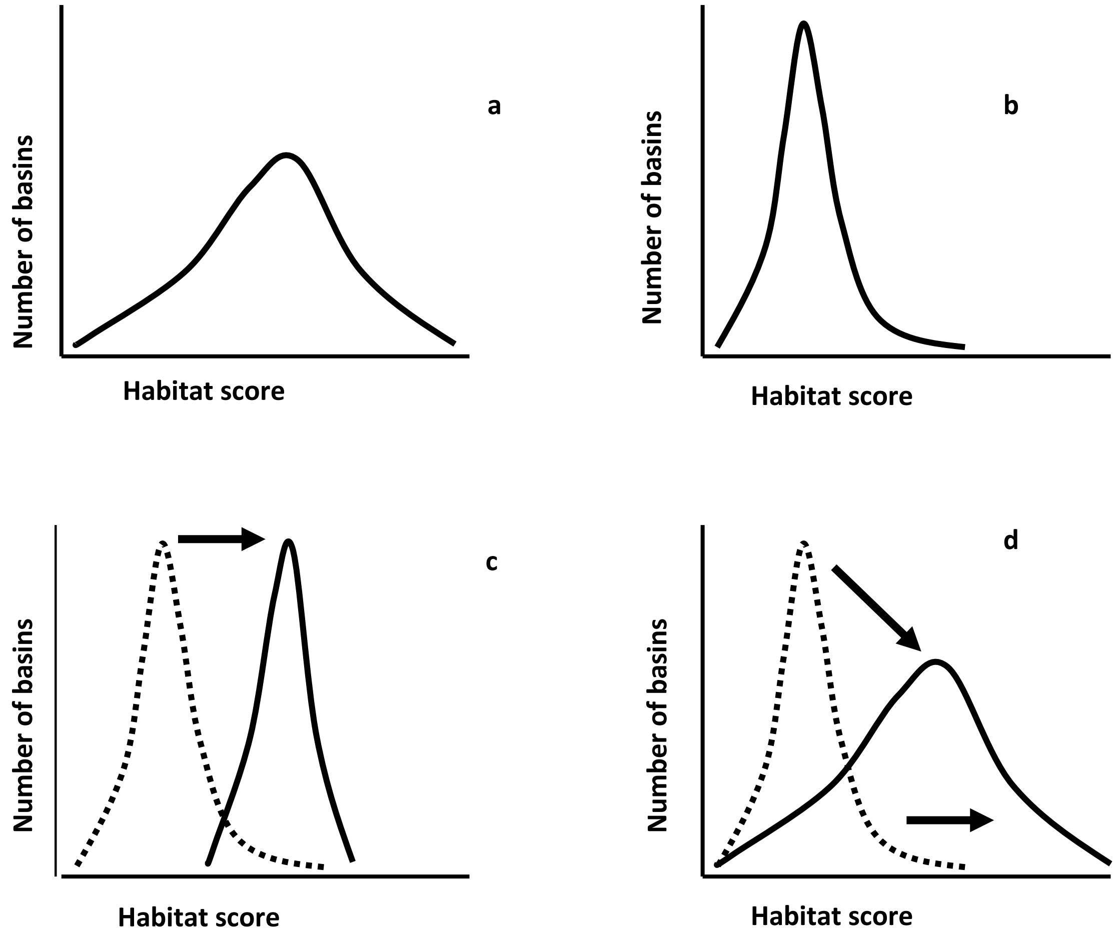


Figure 17. Expected change of the range of habitat conditions (modified from Bisson and Wondzell 2009): a) distribution under historic range of variability; b) majority of basins in poor habitat condition, c) shift towards standardized idealized condition, d) shift towards historic range of natural variability.

Frequency distributions of the scores for both individual indicators and entire watersheds will be plotted and summary statistics (mean and variance estimators) will be calculated. Statistical significance tests like χ^2 could be run on results from subsequent years to evaluate whether the distributions have shifted over time. An alternative approach is to use professional judgment to assess the change.

An exception of the above approach will be the comparison of the OESF water temperature data to the set of state surface water quality standards for water temperature (WAC 173-201A). Water temperature is measured by the seven-day average of the daily maximum temperatures (7-DADMax). Table 8 lists the temperature criteria for each of the aquatic life-use categories. Most likely, field data on temperature will be compared to the criterion for core summer salmonid habitat.

Table 8. Aquatic Life Temperature Criteria in Fresh Water (WAC 173-201A-200).

Category	Highest 7-DADMAX
Char Spawning	9°C (48.2°F)
Char Spawning and Rearing	12°C (53.6°F)
Salmon and Trout Spawning	13°C (55.4°F)
Core Summer Salmonid Habitat	16°C (60.8°F)
Salmonid Spawning, Rearing, and Migration	17.5°C (63.5°F)
Salmonid Rearing and Migration Only	17.5°C (63.5°F)
Non-anadromous Interior Redband Trout	18°C (64.4°F)
Indigenous Warm Water Species	20°C (68°F)

In the past 70 years, management activities have altered a large proportion of OESF watersheds. Recovery processes can take decades or centuries. Therefore, the effects of implementing the OESF Forest Land Plan will not be evident in a short period of time. Reeves et al. (2004) expect three to four sampling cycles of a rotation panel design, in DNR's case 12-16 years, before shifts in frequency distributions can be observed.

The ecological meaning of the identified trends should be interpreted in the context of the entire landscape. Validation monitoring, i.e. the response of salmonids to habitat change, is envisioned by the 1997 Habitat Conservation Plan (DNR 1997) as the ultimate indicator that integrates these changes at a landscape level. The changes in the sampled managed watersheds should also be interpreted in the context of the temporal variability of the reference sites.

Analyses to Test the Assumptions and Evaluate the Projections in the OESF Forest Land Plan

OESF Forest Land Plan alternatives are analyzed by using a number of assumptions and by modeling several environmental indicators over a 100-year planning horizon (refer to chapters 1, 2, and 3 of the revised Draft EIS for the OESF).

Examples of assumptions used in the EIS analyses include the amount of large woody debris recruitment and stream shade as a function of riparian stand conditions; the amount of fine sediment in streams as a function of road density and road management practices; and the level of background sediment delivery (not caused by management). DNR will not be able to specify which assumptions will be tested using the empirical data collected through this monitoring until the Final EIS and the OESF Forest Land Plan are completed. A detailed description of the selected, specific assumptions, including methods for testing them, will be presented in the recommendations after the pilot phase of the project.

The following environmental indicators were qualitatively or quantitatively assessed in the EIS for their response to proposed management actions: large woody debris recruitment, stream shade, water quantity (peak flow), riparian microclimate, leaf and needle litter recruitment, fine sediment delivery to streams, and windthrow susceptibility. Coarse sediment delivery was included as a parameter in the watershed condition score, but was not expected to vary temporally or by the proposed management alternative. Streambank stability was discussed as an important indicator of riparian function, but was not analyzed as adverse impacts were not anticipated under proposed management activities. The riparian status and trends monitoring will provide empirical data for the status of all the indicators listed above with the exception of microclimate and leaf and needle recruitment.

The comparison of empirical data to EIS habitat projections will be conducted not only for the individual habitat attributes but also for the status of watershed-wide conditions. Decision support models for watershed conditions are currently being built for the EIS analyses. These models will likely differ from the models built to analyze the status of the monitored watersheds because of the difference in the available data. For this reason, the comparison of the watershed condition scores from the EIS analyses to those from the monitoring data will likely be qualitative.

Analyses to Infer Management Effects

Experimental or “design-based studies” offer powerful methods to infer cause and effect relationships. Although riparian status and trends monitoring will collect data on both habitat conditions and management activities, the high levels of natural variability and complex interactions among physical and biotic processes in OESF watersheds do not allow a monitoring design that can reasonably distinguish effects due to management from those due to extrinsic factors. Thus, traditional hypothesis testing such as analysis of variance are unlikely to be useful in demonstrating statistically-significant management effects (e.g., Grant et al. 2008). Instead, an alternative approach, “model-based inference” (Anderson 2008), will be used to make inferences about management effects on the status and trends of riparian and aquatic habitat. This approach is expected to be more amenable to the proposed monitoring design and the questions related to management effects. This approach evaluates the relative strength of evidence in data for hypotheses represented as ecological models. It is recommended and increasingly used in addressing complex scientific and management issues (Hobbs and Hilborn 2006). It is particularly useful when the data is not collected through manipulative experiments with treatments and controls.

Under this approach, the conceptual indicator-specific models presented in figures 5 through 10 will be used to develop a set of explicit, quantitative models representing multiple hypotheses about the interaction of management with the physical and biotic processes that contribute to the status and trends of each indicator. These models will be developed prior to accumulation of monitoring data and will be based on scientific literature, consultations with experts, observations, and experience. After sufficient empirical data are collected, the *a priori* statistical models will be fitted using maximum-likelihood methods by comparing the model predictions to observations (Burnham and Anderson 2002). The strength of evidence in data for alternative ecological models is typically evaluated through Akaike Information Criterion, or AIC (Burnham and Anderson 2002). This technique also allows assessing the relative importance of the environmental and management covariates to status and trends of indicators, and the uncertainty that the chosen "best" model would emerge as superior given a different dataset (Burnham and Anderson 2002).

Detailed work on building the *a priori* models for the indicators of interest can begin relatively soon, although results from the pilot phase of monitoring will be helpful. It will likely take several monitoring cycles through the sample watersheds to collect enough empirical data to evaluate the models; e.g., at least three data points are necessary to evaluate whether or not a trend exists.

Reporting and Expected Products

Annual Monitoring Reports

The OESF research and monitoring manager will produce annual reports and submit them to the Forest Resources Division Manager, the Olympic Region Manager, and other relevant DNR staff. The reports will also be posted on the OESF webpage.

The annual monitoring reports will describe the collection of field data and the analyses of field and remote sensing data. The status of the watersheds and individual indicators sampled that year will be reported and discussed. All management activities conducted in the OESF for that year will be reported including timber harvest, road management, site preparation, vegetation management, special forest products, and gravel pits. Management activities that take place in type 3 watersheds selected for status and trends monitoring will be described in detail. Maps and reports from the compliance foresters will be included in the report.

Report on the Pilot Phase of the Project

The report will be developed after the completion of data collection and analyses scheduled for the pilot phase of the project. It is recommended that the document includes the following information:

- Critical review of the implemented sampling design and the field protocols including feasibility (time and effort to obtain the required metrics), sampling cost, measurement error (due to instruments, observers, protocols), and logistics.
- Power analysis to establish appropriate sample size for the full implementation phase of the project. The analysis will include discussion on inter-site and annual variability of sampled attributes, the expected magnitude of change in watershed conditions, and the level of confidence in the results as required by DNR managers.
- Decision support models to evaluate the watershed-wide condition using empirical data.

- Detailed description of the analytical methods to detect trends in habitat conditions, compare the empirical data with the habitat projections described in the revised Draft OEFS EIS, and infer management effects on riparian and aquatic conditions.
- Review of the cost estimates and project structure.

Reports on Trends in Aquatic and Riparian Habitat Conditions

The processes DNR monitors are slow; therefore, a trend may not be detected for 10 or more years (Reeves et al. 2004). The first analysis on trends under the proposed sampling design will be conducted five years after the launch of the full implementation phase (currently estimated as 2019), with reports on trends issued every five years thereafter.

Adaptive Management Recommendations

The intended use of monitoring results is to provide recommendations for adaptive management changes in the OESF and, if the scope of inference permits, on other DNR-managed lands. Adaptive management is a core principle for the OESF. Recommendations to DNR managers for adaptive management changes will be made if indicated by interpretation of the monitoring results.

The 1997 Habitat Conservation Plan described adaptive management as “a process for integration of intentional learning with management decision making and course adjustments” (DNR 1997). The adaptive management process is described in detail in the Adaptive Management Chapter of the OESF Forest Land Plan (DNR, in progress) and is further formalized through an adaptive management procedure for the OESF (currently under development).

The proposed status and trends monitoring will facilitate passive adaptive management; the assumption is that the current management trajectory is correct until proven otherwise. The management actions taking place during the monitoring period are not designed as experiments—no alternative management practices are monitored and compared. As a result, the acquired knowledge does not provide a tested alternative for better management if the current course is proved inefficient.

Expected Products

The implementation of the OESF riparian status and trends monitoring plan will provide the following products:

- Description of status and recovery trends of riparian and aquatic conditions in the OESF obtained through scientifically-defensible monitoring.

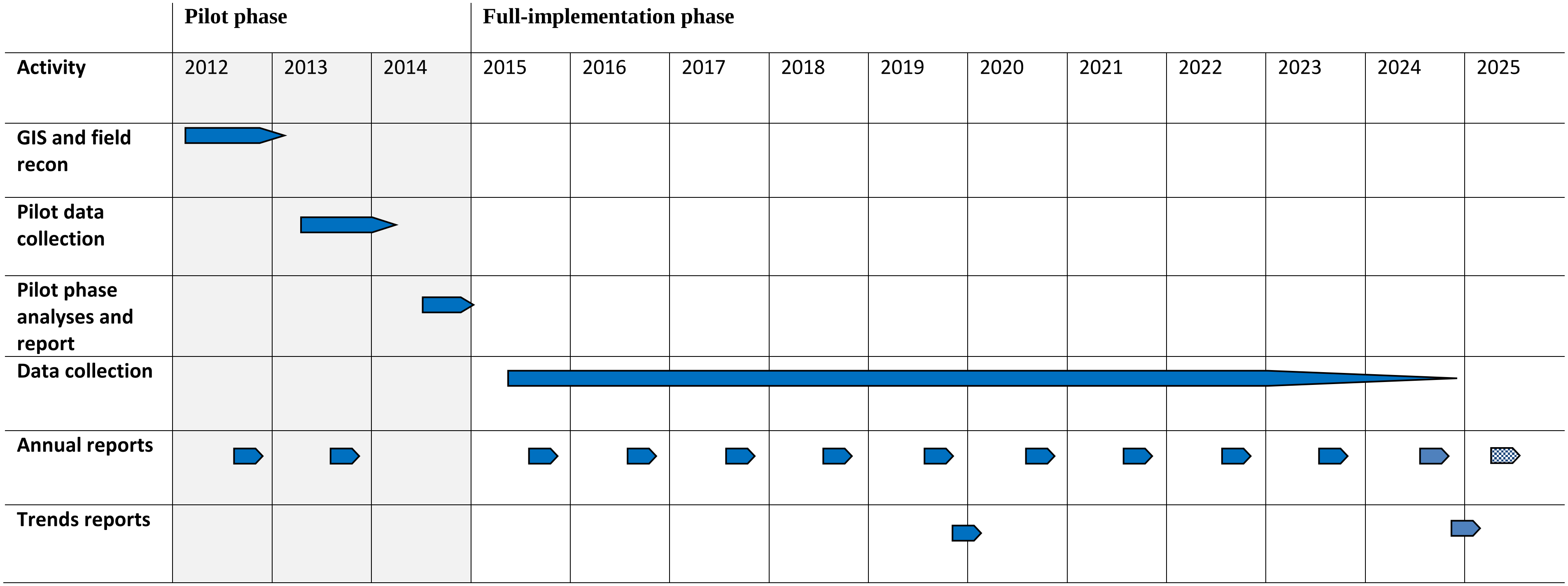
- Updated and/or field verified data for DNR regional and corporate datasets such as riparian forest inventory and hydrology GIS layers.
- Information for assessing the effectiveness of the OESF Forest Land Plan in achieving 1997 Habitat Conservation Plan commitments.
- Recommendations for adaptive management changes including future updates of the OESF Forest Land Plan.
- Data, experience, and field installations for effectiveness and validation monitoring studies.
- Leverage for research collaboration.

As part of the pilot phase of the project from 2012 to 2014, DNR will try to form data-sharing partnerships with other organizations engaged in biological monitoring on the peninsula. Potential partners include Olympic National Forest, University of Washington, NGOs, or local tribes.

Implementation Schedule

The project will start in the spring of 2012 (Table 9) before the final Environmental Impact Analyses for the OESF Forest Land Plan is completed. The first task will be reconnaissance work in the office. This work will include exploration of available remote sensing data, exploration of available GIS data (corporate and regional), and assessment of the projects information management needs (operational activities records, timber sale compliance reports, road management updates, etc.). Olympic National Park will be contacted about the possibility of establishing reference monitoring sites in the Queets, Hoh, and Bogachiel River basins. The available field equipment will be inventoried and the necessary field equipment will be purchased.

Table 9. Implementation schedule.



Field reconnaissance of the selected monitoring sites will start in the summer of 2012 (Table 9). The establishment of the first five sentinel monitoring sites may start the same season.

Much of the preparation work needed to launch this project has already been completed as part of the OESF forest land planning process. For example, available GIS datasets were identified and assessed, management activities were modeled, and habitat conditions were projected for the next 100 years. The analyses of the environmental impacts prompted building decision support models for watershed conditions. Assumptions about the relationships between habitat attributes were researched and documented. Spatially-explicit harvest schedules were suggested for each type 3 watershed at the spatial resolution of timber sale management units. Major uncertainties, current assumptions, modeling rules, and, in some cases, sensitivity analyses were documented. Information management gaps and needs for the OESF Forest Land Plan implementation and monitoring were identified.

Data collection for the two-year pilot phase will take place in 2013 and 2014. Those type 3 watersheds selected for sampling that have timber harvest or road management activities scheduled within the first two years will be sampled first to ensure availability of data on baseline conditions. Indicators that are expected to show high temporal variability (e.g. stream temperature) will be sampled first to ensure availability of data for testing inter-year variability at the end of the pilot phase.

A report on the pilot phase, including recommendations for the full implementation phase of the project, will be developed in the winter of 2015.

The full-scale implementation of the status and trends monitoring will start in 2015 and is expected to continue for at least a decade. After the first decade of full-scale implementation, DNR will assess the benefits of the status and trends monitoring data and will make a decision whether to continue, modify, or terminate the project. Delays in funding will delay implementation of the monitoring efforts and push full implementation and results out a corresponding amount of time.

Organizational Structure

DNR will manage and conduct the implementation of this monitoring plan.

PROJECT OVERSIGHT

An oversight committee consisting of a DNR riparian expert, a DNR environmental analyst, an Olympic region biologist, and two external riparian experts will provide guidance for data interpretation and analyses, modification of field protocols, and changes in the entire study design. The committee will help interpret the monitoring results for DNR managers and stakeholders.

Project Management

The OESF research and monitoring manager will be responsible for managing the implementation of the project including overseeing the field work and preparing reports. These responsibilities include hiring and supervising field techs, coordinating field work, coordinating remote sensing and GIS analyses, overseeing information management (field data management, management of operational records, etc.), consulting with the oversight committee, reporting to DNR managers, and posting information on the OESF webpage.

The OESF research and monitoring manager will seek collaboration with external organizations and opportunities for additional funding.

Reconnaissance Work

Office and field reconnaissance work will be conducted by the OESF research and monitoring manager and the Olympic region biologist. Other DNR staff, including division GIS analyst and Olympic region foresters, are expected to provide support.

Field Surveys

Initial data collection (years two and three of the pilot phase) will be conducted by two field technicians who will be hired seasonally for up to six months per year for the period of May to October. It is expected that a two-member field crew will continue to collect data for the full implementation phase; however, this estimate may change after the analyses from the pilot phase.

Information Management

A designated information manager, working out of the Olympic Region, will manage and verify (through spot checking) the records on management activities, remote sensing data, and field data. Depending on the workload, the same person may analyze remote sensing data and provide GIS support.

Data Analyses

The analyses of remote sensing data as well as analyses of trends, management effects, and comparison with OESF Forest Land Plan EIS projections will be conducted by DNR staff in consultation with external experts.

Reporting

The OESF research and monitoring manager will write annual progress reports, recommendations for adaptive management changes based on monitoring results, and other reports or presentations as requested by DNR managers.

Budget

OESF riparian status and trends monitoring, as described in this plan, will be funded and implemented by DNR. Partnership with external organizations will be actively sought in terms of expertise and additional funding. This collaboration will allow DNR to increase the scope and sampling intensity and to integrate status and trends monitoring with effectiveness and validation monitoring projects.

The estimated minimum annual budget for the pilot phase and the first decade of the full-implementation phase is presented on Table 10. This budget estimate includes fieldwork, field data management, and equipment costs. GIS support, data analyses, and reporting are not included in the cost estimate because existing DNR staff will provide these services.

Table 10. Annual budget (in thousand dollars).

	Pilot phase			**Full-implementation phase**										
Activity	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
Recon	In-kind													
Pilot data collection		90	120											
Consultation		10	10				10				5			10
Equipment		50	20	10					10			5		
Data collection				120	120	120	120	120	120	120	120	120	120	120

Information management is not included in the above cost estimate. The information manager will have the critical role of collecting and managing information on operational activities and natural disturbances in the OESF in addition to monitoring data from this project. This information will also contribute to the implementation monitoring and future updates of the OESF Forest Land Plan. Since current DNR staff cannot absorb this workload, additional staff has to be hired. A minimum of 0.5 FTE will be needed to meet these information needs which adds an estimated $56,000 per year.

DNR has allotted $145,000 for FY 2013 (July 1, 2012 - July 1, 2013). The majority of this funding will pay for field technicians. Technicians will receive training in May, conduct field sampling between June and September, and organize and manage the data in October.

The current budget estimate is $290,000 per biennium starting in FY 2014 without additional funding for OESF information manager. The budget estimate with the information management expenses is estimated at $362,000 per biennium. The project will continue for as long as the information is useful to DNR. This funding estimate may change after the recommendations from the pilot phase are completed.

Conclusion

One of the largest issues with monitoring plans of this type is the truncation of monitoring before enough data is gathered for interpretation (Reid 2001). At the same time, research indicates that the continuance of a consistent monitoring program over years is crucial for successfully detecting habitat trends. Trend detection increases dramatically with time; the actual details of the temporal designs do not matter as much as a commitment to the long-term integrity of the survey (Larsen et al 2004).

The Riparian Status and Trends Monitoring Plan should be viewed as a “living” document and should evolve as new information becomes available. Field protocols, mechanistic models, and analytical methods will be continuously refined. Revisions will be driven by the cost to implement the plan, the time it will take to detect changes, and the power to detect changes (Gallo et al. 2005). While continuous improvement of this monitoring plan is envisioned, the basic sampling scheme should remain intact to allow the use of previously collected data.

As more funding becomes available, additional modules will be added. Modules for identified physical indicators not included in the current plan (refer to Figure 3, the global conceptual model) are the highest funding priority. These physical indicators include riparian microhabitat attributes (air temperature and humidity), stream water turbidity, and amount of leaf litter being carried to streams. The next priority is adding biological monitoring indicators such as fish, macroinvertebrates, and periphyton.

The intent of the Riparian Status and Trends Monitoring Plan is to provide information that will help DNR managers understand whether riparian and aquatic habitat is being restored and maintained as the OESF Forest Land Plan is implemented. The Forest Land Plan can succeed in this goal only if the riparian status and trends monitoring results are delivered to managers in a timely manner and if managers consider responding to the provided information. While the ability to detect changes over time is a measure of the monitoring plan’s success, the measure of success for DNR will be a demonstrated use of monitoring results in management decisions and policies.

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