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Aquatic and Riparian Effectiveness Monitoring Plan for the Northwest Forest Plan

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Abstract

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The Aquatic and Riparian Effectiveness Monitoring Plan (AREMP) is intended to characterize the ecological condition of watersheds and aquatic ecosystems. It will determine present watershed condition, track trends in watershed condition over time, and report on the Northwest Forest Plan's effectiveness across the region. This Northwest Forest Plan presents options and guidelines for use in pilot testing and implementing an effectiveness monitoring program for aquatic and riparian systems. The base program is designed to evaluate status and trends of watershed, stream, and riparian conditions by using decision-support models. Although the focus of AREMP is on characterizing ecosystem status and trend, implementing the Northwest Forest Plan also will supply information that will be useful in determining causal relations to help explain those trends.

Keywords: Effectiveness monitoring, aquatic ecosystems, riparian ecosystems, decision-support models.

Executive Summary

Under the direction of the Regional Interagency Executive Committee, which oversees the implementation and management of the Northwest Forest Plan (Forest Plan), multiagency federal teams have been developing monitoring programs to evaluate the effectiveness of the Forest Plan. Initial priorities assigned by the federal agencies for monitoring include the northern spotted owl (*Strix occidentalis caurina*), marbled murrelet (*Brachyramphus marmoratus*), late-successional and old-growth forests, and aquatic and riparian ecosystems (Mulder et al. 1999).

The Aquatic and Riparian Effectiveness Monitoring Plan (AREMP) is intended to characterize the ecological condition of watersheds and aquatic ecosystems. It will determine present watershed condition, track trends in watershed condition over time, and report on the Forest Plan's effectiveness across the region. This Forest Plan presents options and guidelines for use in pilot testing and implementing an effectiveness monitoring program for aquatic and riparian systems. The base program is designed to evaluate status and trends of watershed, stream, and riparian conditions by using decision-support models (DSMs). Although the focus of AREMP is on characterizing ecosystem status and trend, implementing the Forest Plan also will supply information that will be useful in determining causal relations to help explain those trends.

The effectiveness of the Forest Plan could be examined at smaller spatial scales; however, the direction for this effort is to describe status and trend of the condition of watersheds at the regional scale. Because the Forest Plan's Aquatic Conservation Strategy (ACS) provides a framework for managing aquatic ecosystems primarily at watershed and landscape (i.e., multiple watersheds) scales, the subwatershed (6th-field hydrological unit) forms the basic geographic unit for monitoring. Sampling a minimum of 50 subwatersheds annually in the Forest Plan area will support regional analyses of ACS effectiveness. Over a 5-year period, a total of 250 watersheds would be sampled (approximately 10 percent of the estimated number of subwatersheds). Postsampling stratification will allow an evaluation at the subregional scale (e.g., provinces, river basins, national forests, Bureau of Land Management districts) after 5 years. The AREMP conceptual framework allows more intense sampling than this if managers wish to dedicate resources to deduce the Forest Plan's effectiveness at smaller spatial scales. Generally, at least 50 units would need to be sampled at the scale desired to provide the necessary statistical rigor.

Under the AREMP conceptual framework, watersheds are stratified into three primary subsystems (channel, riparian, and upslope), each containing an array of physical and biological indicators that define its condition. Watershed condition will be assessed by analyzing indicator values by using a DSM incorporating relations developed by provincial and regional experts. Results will be presented in the form of frequency distributions of the regional aggregation of watershed condition. Status and trend of individual indicator values also will be preserved and reported. The field-sampled indicator data elements are expected to remain the same over time; analysis procedures for those data elements can be revised as new science becomes available (adaptive monitoring). Trend will be assessed by evaluating status of individual watersheds and indicators over time. If the ACS is effective, the frequency distribution of watersheds or indicators should shift toward the better condition categories. Because the watershed processes, on which the Forest Plan is based, operate over long timeframes (decades to centuries), trends may not be observed for 10 to 20 years. Reports on status can be generated every year, but meaningful trends are more likely to be detected on a decadal timeframe. Depending on the intensity of sampling selected by agency managers, insight about ACS effectiveness at subregional scales or on certain management practices could be available sooner.

A pilot effort is proposed for the first 2 years to test protocol and sampling strategies for acquiring data, assess organizational structure, conduct initial analyses, and refine links to existing information and programs. Based on agency experience, spatial and temporal variability in interpreting results is anticipated across the Forest Plan region. The pilot effort will identify sources of variability and will use field-based experience to apply appropriate revisions to refine and improve the process. The AREMP could be fully implemented beginning in the third year after the initiation of pilot testing.

Products will include annual reports and an indepth analysis every 5 years on:

- Assessment of watershed condition
- Database and frequency distribution of watershed scores
- Status of individual indicator elements
- Recommendations to guide research toward topics to improve monitoring and assessment
- Recommendations about potential management changes

The challenges to implementing AREMP reflect the current, relatively poor state of knowledge about aquatic/riparian science including:

- The lack of a current depiction of the expected frequency distribution of watershed condition means that information on reference condition needs to be developed as watersheds are monitored.
- The need to develop the relations between management and watershed (or indicator) condition from watersheds where ACS management practices are being implemented, as a basis for adaptive management.
- Monitoring ACS effectiveness is best directed toward sampling habitat and watersheds, whereas tracking the effects of individual management actions will require supplemental effort.

Summary of Alternatives for Implementation

A variety of alternatives have been considered for implementing an effectiveness monitoring strategy. They include:

Sampling intensity—The recommended number of sample units ranges from 50 to 200 watersheds per year, and the length of return cycle considered ranges from 1 to 10 years.

Complete or composite watersheds—Alternatives considered included sampling only complete watersheds or including both complete and composite watersheds.

Indicator sampling—Ninety indicators being used in different protocols were considered with a smaller number recommended for implementation.

Biological sampling—Alternatives considered focusing on macroinvertebrates, fish, amphibians, or including all three groups.

Management practices—An alternative for consideration would include monitoring the effectiveness of management practices.

Data acquisition—Alternatives considered to acquiring data include the use of:

- A centralized interagency monitoring team.
- Existing agency resources.
- Contracting out to an independent source.
- A combination of these approaches.

Summary of Recommendations

The AREMP team recommends:

Sampling intensity—Monitor 50 watersheds a year over a 5-year repeat cycle for a total of 250 watersheds.

Complete or composite watersheds—Include both complete and composite watersheds in the sampling regime.

Indicator sampling—Measure a core set of 20 indicators.

Biological sampling—Include efficient approaches and shared data for macroinvertebrate, amphibian, and fish sampling.

Management practices—Include this form of monitoring, potentially patterned on the program used by the Forest Service in California.

Data acquisition—Implement the monitoring program with field-sampled indicators collected by using standardized protocols by a centralized interagency team.

Pilot tests—Conduct pilot tests in 2000 and 2001 to work through some of the questions about protocols and logistics.

Characterizing regional aquatic and riparian system status and trend—Use frequency distributions of individual indicator data and frequency distributions of overall watershed condition from the AREMP knowledge-based DSMs.

Decision-support model (DSM)—Use to evaluate watershed condition. A DSM is a tool that aids a consistent and systematic interpretation of acquired data by using the best science available. The information from individual indicators using standardized protocols would be preserved and is not changed by the use of the DSM.

Integrating AREMP and implementation monitoring analyses of watersheds—Will provide information for the adaptive management process.

Contents

Introduction

The Forest Ecosystem Management Assessment Team (FEMAT) developed long-term management alternatives for maintaining and restoring habitat conditions to support well-distributed and viable populations of species associated with late-successional and old-growth (LSOG) ecosystems in the range of the northern spotted owl (*Strix occidentalis caurina*) (fig. 1). Analysis of the FEMAT alternatives in a Forest Service environmental impact statement (USDA and USDI 1994a) led to adoption of the ecosystem management strategy contained in the *Record of Decision for Amendments to Forest Service and Bureau of Land Management Planning Documents Within the Range of the Northern Spotted Owl* (ROD) (USDA and USDI 1994b), commonly known as the Northwest Forest Plan (Forest Plan).

The Aquatic Conservation Strategy (ACS) is designed to restore and maintain the ecological integrity of watersheds and their aquatic ecosystems on public lands. It is a region-wide strategy to retain, restore, and protect those processes and landforms that contribute habitat elements to streams and promote good ecological conditions for fish and other aquatic and riparian-dependent organisms (FEMAT 1993). This approach seeks to prevent further degradation and restore habitat over broad landscapes, as opposed to individual projects or for small watersheds (USDA and USDI 1994b). Specific components and objectives of the ACS are listed in appendix 1.

The ROD also identified the need to develop an effectiveness monitoring strategy for key components of the Forest Plan. Initial priorities assigned by the federal agencies for monitoring include the northern spotted owl, marbled murrelet (*Brachyramphus marmoratus*), LSOG forests, and aquatic and riparian ecosystems (Mulder et al. 1999). As relates to aquatic and riparian ecosystems, the ROD (E-7) specifies that "monitoring will include aquatic, riparian, and watershed conditions and the processes in a watershed to determine if they achieve Aquatic Conservation Strategy objectives."

In response to the direction in the ROD, and in accordance with the effectiveness monitoring planning framework for the Forest Plan, this proposed effectiveness monitoring program for aquatic and riparian ecosystems has been developed by the federal agencies in cooperation with members of the Intergovernmental Advisory Committee (IAC). Specifically, the executives of research agencies (USDA Forest Service, Pacific Northwest Research Station, USDI Geological Survey-Biological Resources Division, and U.S. Environmental Protection Agency-Office of Research and Development) provided direction to an interagency team to guide development of the Aquatic and Riparian Effectiveness Monitoring Plan (AREMP). Direction from research agency executives (app. 2) established AREMP's general goals, limits, and assumptions. The team was specifically directed to provide decisionmakers with a variety of options and associated budgets. Direction from the research agency executives to the work group took into full consideration policy guidance on issues pertinent to the development of AREMP from the IAC. This guidance was obtained at IAC meetings held on August 7 and November 6, 1997, and at an October 31, 1997, IAC subcommittee meeting that was devoted to policy issues associated with effectiveness monitoring of aquatic and riparian systems.

Goal and Objectives

The goal of AREMP is to evaluate the success of the Forest Plan in restoring and maintaining aquatic and riparian ecosystems to desired conditions on federal lands in the Forest Plan area. The primary objective is to determine status and trends of the condition of aquatic ecosystems at the watershed scale. If the Forest Plan is effective, the number of watersheds that improve in condition should increase over time. Specific objectives include:

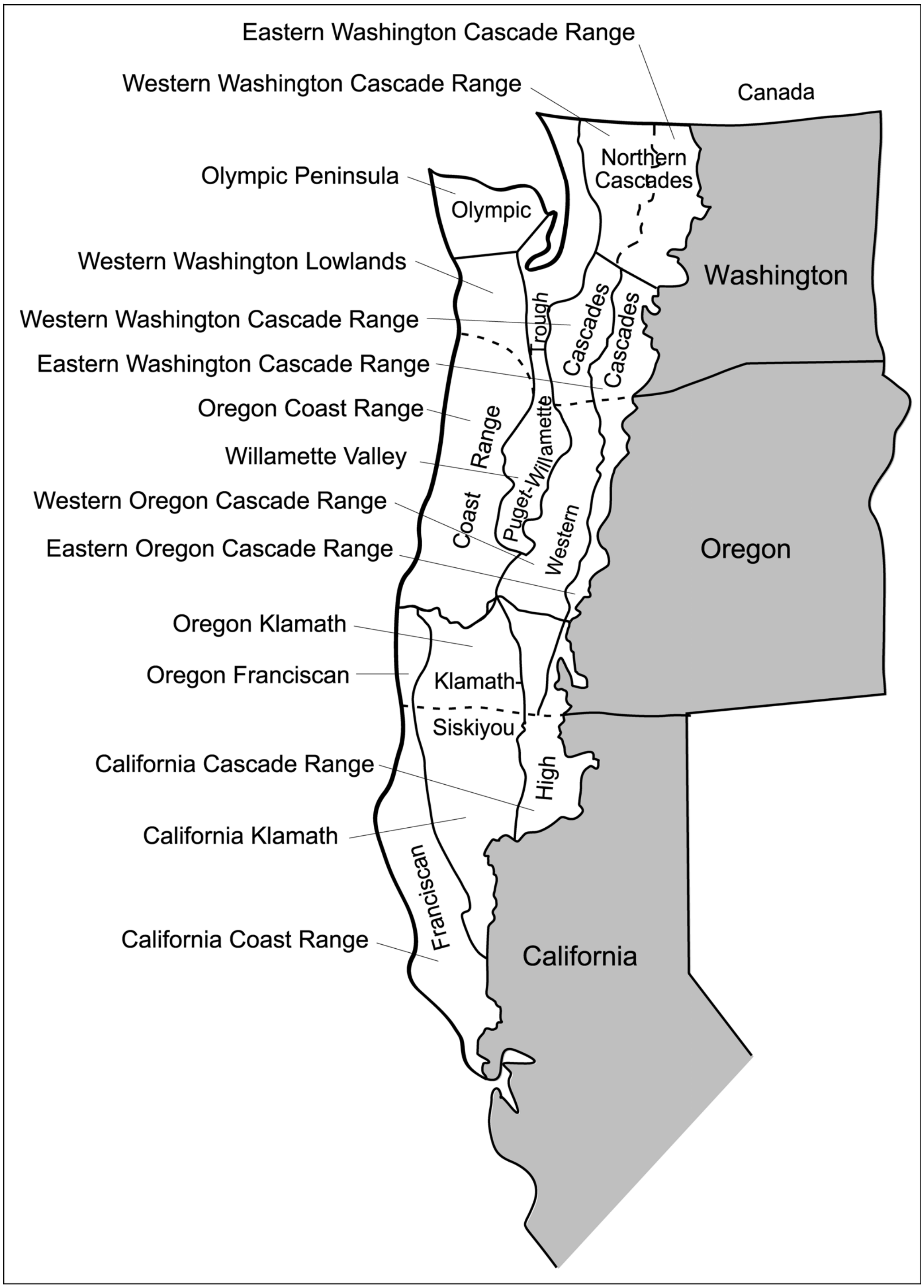

Figure 1—Physiographic provinces in the Northwest Forest Plan region.

- Annually assess the condition of aquatic and riparian ecosystems by estimating the regional distribution of watershed conditions, which is determined by integrating information from various biological and physical indicators measured within the watersheds.
- Develop and validate decision-support models (DSMs) to refine indicator interpretation.
- Develop predictive models to improve use of monitoring data, potentially reduce the number of parameters measured, better anticipate trends, and reduce long-term monitoring costs.
- Provide a framework for adaptive monitoring at the regional scale.
- Provide information for adaptive management by analyzing trends in watershed condition and identifying elements that result in unsuitable or unacceptable conditions. To the extent an understanding of cause and effect in aquatic and riparian habitats is desired, additional information needs can be integrated into this AREMP, or supplemented to the ongoing Forest Plan's Implementation Monitoring Program.

Background

The ACS objectives (app. 1) describe general characteristics of functional aquatic ecosystems and are intended to describe processes needed to create good habitat in the context of geomorphic and ecological disturbance at large spatial scales. The ACS objectives are designed to provide an ecological context for implementing management activities, and all projects are to be consistent with ACS objectives. The ACS is based principally on the relation of watersheds to riparian and aquatic habitat. Although the effectiveness of specific management actions, particularly as they apply to biota, is important to how the function of aquatic and riparian systems is viewed, monitoring of ACS effectiveness must, like the strategy itself, be focused on habitat. The intent of the FEMAT scientists was not for the ACS objectives to be individually monitored, nor were the ACS objectives expected to be met on each portion of the Forest Plan landscape at all times.[1] It was anticipated that watershed condition and habitat would change slowly in response to the implementation of the ACS, across the Forest Plan region. Given this, and the variability inherent in aquatic and riparian systems over time and space, detecting watershed change is likely to be challenging.

The Forest Plan changed the focus of management of habitat for fish and other aquatic organisms from specific in-channel habitat elements (e.g., pieces of large wood and number of pools) to the ecosystem conditions and processes that, if intact, form and maintain habitats. Establishing fixed standards for individual attributes will not necessarily provide metrics appropriate to evaluate ecosystem conditions (Bisson et al. 1997). Basic components of aquatic ecosystems that need to be considered in evaluating ecological conditions include basin geomorphology, hydrologic patterns, water quality, riparian forest conditions, and aquatic habitat characteristics for a variety of aquatic organisms (Naiman et al. 1992). In addition, analysis of aquatic habitat characteristics requires considering the degree to which the key processes that create and maintain

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[1] Reeves, G.H. 1999. Personal communication.
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habitat conditions are intact. These processes include the delivery and routing of water, sediment, and large wood to stream channels (Naiman et al. 1992). Ecologically healthy watersheds possess lateral, longitudinal, and vertical connections between system components as well as the natural, or close to natural, spatial and temporal variability of these connections (fig. 2).

Evaluating fundamental, system-level components of ecologically healthy watersheds is difficult, however (Naiman et al. 1992). Natural variation of individual habitat variables is high (e.g., numbers of pools and pieces of large wood, substrate composition, and water temperature). The interplay among variables is complex and has been difficult to articulate by using traditional methods. Quantifying direct links among processes outside the stream channel to in-channel conditions and biological variables is also difficult. As a result, specifying or setting quantitative expectations of standards for the condition of an aquatic ecosystem is difficult.

The components of the Forest Plan explicitly recognize the complex and dynamic nature of aquatic ecosystems in the Forest Plan region that results from the variety of physical characteristics, natural disturbance events, and climatic features of the region (Benda et al. 1998, Naiman et al. 1992). Because the Forest Plan's approach is long term, and implemented over a widely varying landscape, expected conditions that allow for recovering and maintaining aquatic and riparian habitats will vary greatly. The challenge for the effectiveness monitoring effort will be to detect trends in watershed condition across the Forest Plan region in both the short and long term.

An important implication of an ecosystem- and landscape-scale strategy based on disturbance regimes is that all units, such as watersheds, may not be expected to be in "good" condition at any one time (Naiman et al. 1992, Reeves et al. 1995). As a result, a practical effectiveness-monitoring program for the Forest Plan needs to look at trends in frequency distributions of watershed conditions rather than expect that all watersheds be in good condition at any one time or that they stay in that condition indefinitely. This is similar to evaluation of the amount of LSOG forest in the Forest Plan area (see Hemstrom et al. 1998). It is not expected that all the Forest Plan area will be in late-successional or old-growth forests at any point in time. Success of the Forest Plan will be determined by how much the amount of each of these forest types increases through time up to some level.

The movement to ecosystem management requires examining and considering aquatic ecosystems over larger spatial and temporal scales than was done in previous monitoring efforts. This difference requires boundaries of management decisions and objectives to be at scales congruent with those of ecosystem processes (Grumbine 1994). Consequently, ecological analysis and modeling for such purposes as monitoring must be done at similar scales. Simply scaling-up information from univariate, fine-scale studies will not work for assessment of conditions at larger scales, such as the watershed. Monitoring the effectiveness of management activities in maintaining regional ecosystem processes will require integration of appropriate indicators at multiple scales to define overall ecologic conditions.

Because of the location of federal land in the area of the Forest Plan, the larger river systems and estuaries are generally not included in the monitoring plan. Ongoing coordination with the states may result in links that allow assessment of larger portions of the landscape in the future.

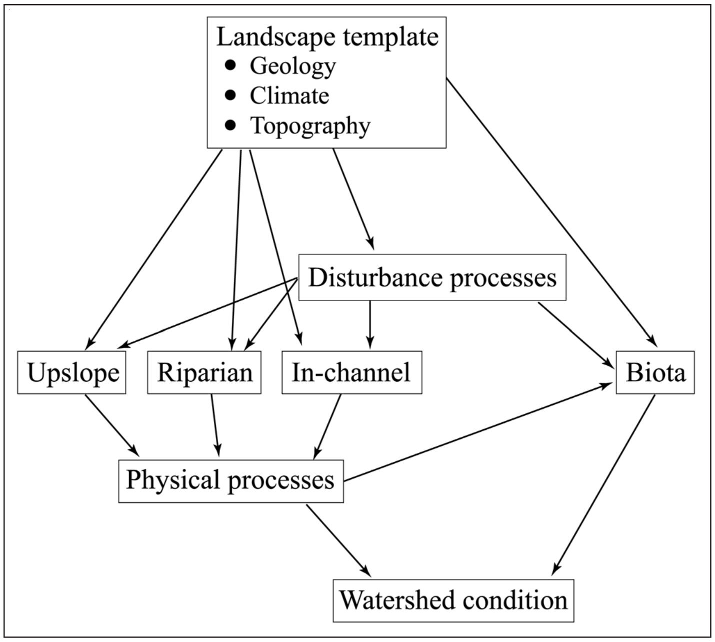


Figure 2—Overview of the conceptual framework.

Monitoring Questions

The primary question arising from implementing the Forest Plan concerns characterizing the ecological status and trends in the condition of watersheds and their associated aquatic systems. Answering this question will require considering watershed and ecosystem attributes, such as:

1. Are the key processes that create and maintain habitat conditions in aquatic and riparian systems intact?

a. What is the status of upslope processes as indicated by vegetation, roads and stream crossings, and landslides in the watershed?

b. What is the status of riparian processes as indicated by vegetation composition, structure, and diversity; roads and stream crossings; and flood-plain connectivity?

c. What is the status of in-channel processes as indicated by pools, sediment flux, substrate, water temperatures, large structure in the channel, and rates of channel movement?

d. What is the status of the fauna as indicated by fish, amphibians, and macroinvertebrates?

2. Has the distribution of these and other key indicators shifted in a direction indicating improved or degraded habitat and biotic condition?

3. How does the aggregate quality of the key indicators used to evaluate watershed condition (i.e., the distribution of watershed condition assessments) change through time under the Forest Plan?

4. Are current management practices (based on the degree to which the Forest Plan's ACS is implemented) at the site and watershed scales attaining the ACS objectives?

Monitoring Approach

Integration of Factors

The condition of the aquatic and riparian ecosystem in any place or time, at any scale, is the integrated product of the ecosystem processes, rates, and attributes reflected in the Forest Plan ACS objectives. The AREMP will look at the aggregate of various physical and biological indicators to evaluate watershed condition.

Conceptual Model

The strategy and design for effectiveness monitoring plans of the Forest Plan were articulated by Mulder et al. (1999). To be meaningful, a monitoring program should provide insights into cause-and-effect relations between environmental stressors and anticipated ecosystem responses. A primary step in developing an effectiveness plan is to recognize the factors that influence the parameter of interest. An overview of the conceptual model for the aquatic and riparian ecosystems is shown in figure 2. The conceptual model illustrates the response of fundamental watershed processes, as influenced by inherent landscape patterns of climate, geology, topography, and soils, to natural and human-caused stressors.

The three physical subsystems (upslope, riparian and flood plain, and stream channel) and related biological components and their interactions are shown in figure 3. The processes occurring in the upslope subsystem (i.e., in the watershed in general) are assumed to affect the riparian and flood-plain subsystem and the stream channel subsystem. The riparian and flood-plain subsystem may, to varying degrees, buffer upslope influences on the stream channel subsystem. Stream channel and riparian and flood-plain subsystems are coupled (i.e., influences are bidirectional) so changes in rates or states associated with the processes and stressors in one of these subsystems will usually affect the linked subsystem (Naiman et al. 1992). In contrast, the influence of the upslope subsystem on the flood-plain and riparian and stream channel subsystems is more strongly unidirectional (downslope). The influence of riparian and aquatic subsystems on upslope processes is assumed to be nearly, but not completely, negligible.

Processes pertinent to aquatic, riparian, and upslope ecosystems affected by the Forest Plan are shown in figure 4. Processes are grouped into those that describe general ecosystem function, with related key processes useful for designing the aquatic and riparian effectiveness monitoring strategy. These key processes are further developed as indicators in table 1.

Aquatic and terrestrial habitat development and the population dynamics of aquatic and riparian biota make up a set of processes that provide a conceptual link between the physical and biotic elements of this monitoring plan. The model depicts habitat development as the composite of the ecosystem processes listed. Thus, habitat development and population or community dynamics are shown as features that integrate general and key ecosystem processes in the stream channel and riparian/flood-plain subsystems (fig. 4). Similarly, habitat distribution, diversity, complexity, and temporal and spatial connectivity comprise a composite of habitat development as affected by natural and human-caused ecosystem stressors.

An integration of processes and stressors provides the functional relations critical to developing conceptual models for monitoring (Noon et al. 1999). In the AREMP conceptual model, specific aspects of each ecosystem process have been identified as stressors that affect the three subsystems. Although natural and human-caused stressors are often difficult to distinguish in practice, the model lists examples of both types. In keeping with the effectiveness monitoring strategy, stressors are intended to be value-neutral (i.e., they can be either positive or negative like roads, which represent both road removal and construction). To simplify the model, many of the stressors have been stated in a

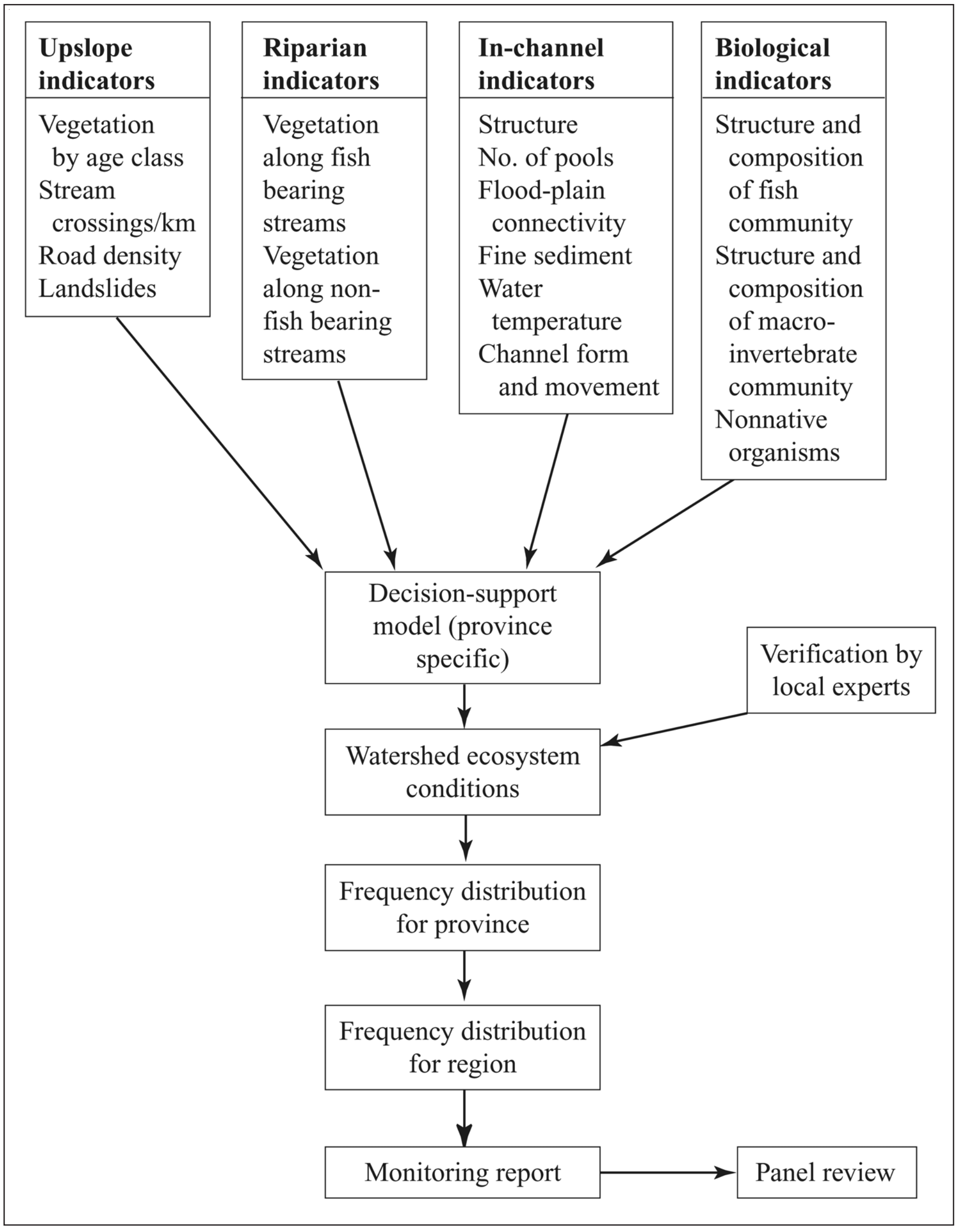
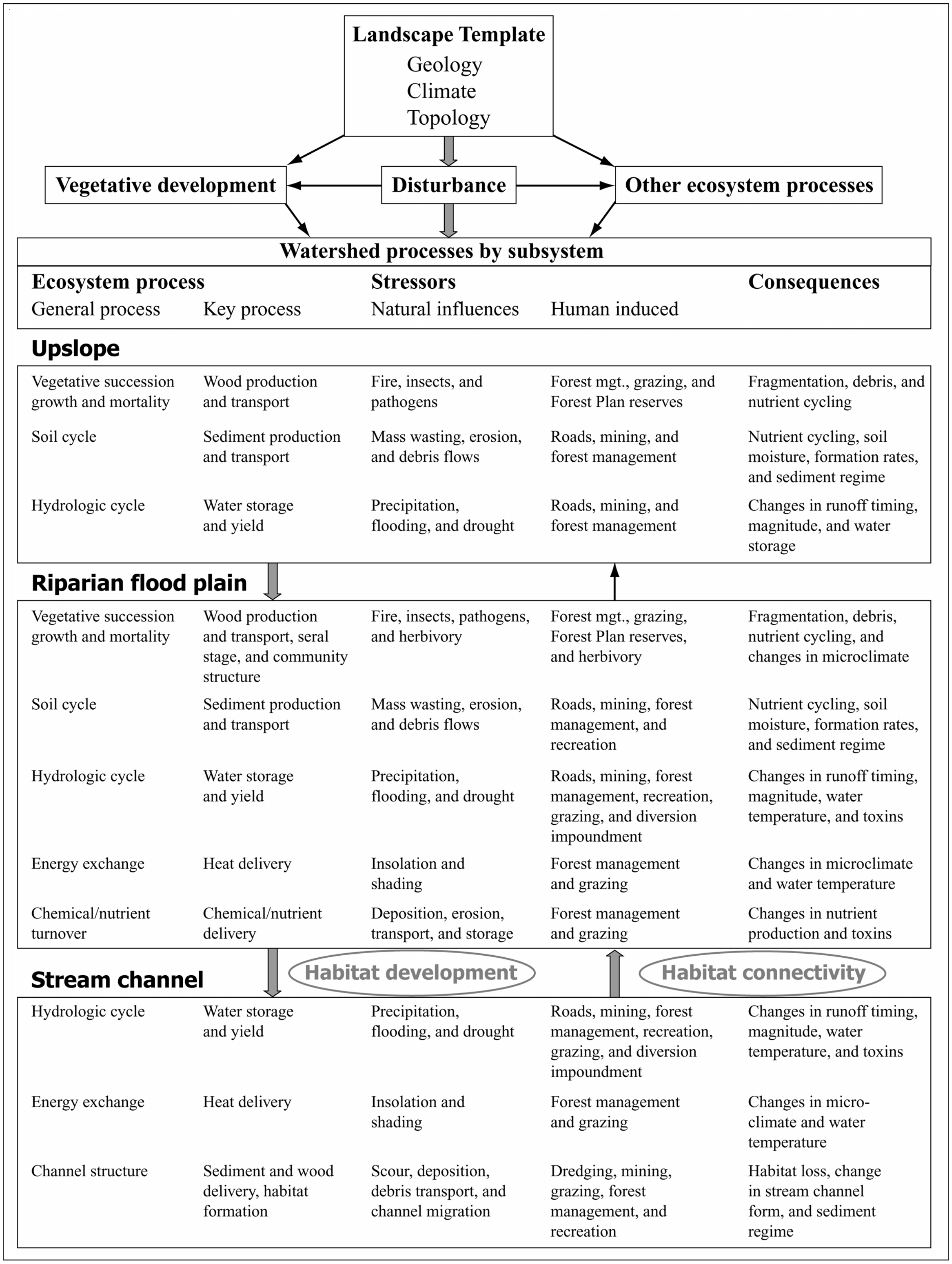


Figure 3—Components of the Aquatic and Riparian Effectiveness Monitoring Plan.



Watershed processes by subsystem

Ecosystem process		**Stressors**		**Consequences**
General process	Key process	Natural influences	Human induced	
Upslope				
Vegetative succession growth and mortality	Wood production and transport	Fire, insects, and pathogens	Forest mgt., grazing, and Forest Plan reserves	Fragmentation, debris, and nutrient cycling
Soil cycle	Sediment production and transport	Mass wasting, erosion, and debris flows	Roads, mining, and forest management	Nutrient cycling, soil moisture, formation rates, and sediment regime
Hydrologic cycle	Water storage and yield	Precipitation, flooding, and drought	Roads, mining, and forest management	Changes in runoff timing, magnitude, and water storage
Riparian flood plain				
Vegetative succession growth and mortality	Wood production and transport, seral stage, and community structure	Fire, insects, pathogens, and herbivory	Forest mgt., grazing, Forest Plan reserves, and herbivory	Fragmentation, debris, nutrient cycling, and changes in microclimate
Soil cycle	Sediment production and transport	Mass wasting, erosion, and debris flows	Roads, mining, forest management, and recreation	Nutrient cycling, soil moisture, formation rates, and sediment regime
Hydrologic cycle	Water storage and yield	Precipitation, flooding, and drought	Roads, mining, forest management, recreation, grazing, and diversion impoundment	Changes in runoff timing, magnitude, water temperature, and toxins
Energy exchange	Heat delivery	Insolation and shading	Forest management and grazing	Changes in microclimate and water temperature
Chemical/nutrient turnover	Chemical/nutrient delivery	Deposition, erosion, transport, and storage	Forest management and grazing	Changes in nutrient production and toxins
Stream channel				
Hydrologic cycle	Water storage and yield	Precipitation, flooding, and drought	Roads, mining, forest management, recreation, grazing, and diversion impoundment	Changes in runoff timing, magnitude, water temperature, and toxins
Energy exchange	Heat delivery	Insolation and shading	Forest management and grazing	Changes in micro-climate and water temperature
Channel structure	Sediment and wood delivery, habitat formation	Scour, deposition, debris transport, and channel migration	Dredging, mining, grazing, forest management, and recreation	Habitat loss, change in stream channel form, and sediment regime

Figure 4—Conceptual framework for the Aquatic and Riparian Effectiveness Monitoring Plan.

Table 1—Core indicators by ecologic process with preferred measures and data fields used in the decision-support model

Subsystem and general process	Key process	Indicator	Protocol	Data used in decision support
Upslope subsystem:				
Vegetative succession, growth and mortality	Wood production and transport	Vegetation seral stage and series	Cover by composition and structure class (Hemstrom et al. 1998)	Proportion of watershed in early-, mid-, and late-seral stages
Soil cycle	Sediment production and transport	Stream crossing density	Density of stream crossings per square mile	Density of stream crossings per mile square (USDA FS 1999)
Soil cycle	Sediment production and transport	Road density	Length and proportion of road network hydrologically connected to the stream channel	Miles of road per square mile within 300 m of streams
Soil cycle	Sediment production and transport	Landslides	Protocol from Swanson addressing frequency, type, and location	Frequency, by type, size, and location of landslide
Riparian flood-plain subsystem:				
Vegetative succession, growth and mortality	Wood delivery, community structural development	Vegetation seral stage and association	Cover by vegetation age class and type categories (Hemstrom 1998)	Proportion of watershed in early-, mid-, and late-seral stages
Soil cycle	Sediment production and transport	Stream crossing density	Density of stream crossings per square mile	Density of stream crossings per square mile (USDA FS 1999)
Soil cycle	Sediment production and transport	Road density	Length and proportion of road network hydrologically connected to the stream channel	Miles of road per square mile by maintenance category
Soil cycle	Sediment production and transport	Landslides	Protocol from Swanson addressing frequency, type, and location	Frequency and size of landslide

Table 1—Core indicators by ecologic process with preferred measures and data fields used in the decision-support model (continued)

Subsystem and general process	Key process	Indicator	Protocol	Data used in decision support
Hydrologic cycle	Water storage and yield	Channel connectivity with floodplain in unconstrained reaches	Entrenchment ratio measured in conjunction with channel cross section and profile (Rosgen 1998)	Entrenchment ratio (valley width divided by channel width)
In-channel subsystem:				
Channel structural dynamics	Sediment and wood delivery	Channel cross section	Monumented cross-sectional profile	Bankfull width and mean depth
Channel structural dynamics	Sediment and wood delivery	Channel movement	Monumented longitudinal channel profile	Water surface slope
Channel structural dynamics	Sediment and wood delivery	Channel sinuosity	Stream length/valley length off aerial photos	Stream length/valley length
Channel structural dynamics	Sediment and wood delivery	Channel pools	Survey of residual pool volume, depth, and frequency in unconstrained reach	Pool depth, volume, and frequency
Channel structural dynamics	Sediment and wood delivery	Structural complexity	Survey of LWD,[a] boulder counts in unconstrained reaches	LWD[a] counts per lineal measure
Channel structural dynamics	Sediment and wood delivery	Substrate composition	Wolman pebble count or Overton et al. 1997	Percentage of fines and D50
Channel structural dynamics	Flood-plain connectivity	Off-channel habitat	Monumented cross-sectional profile	Entrenchment ratio
Energy exchange Chemical/nutrient turnover	Heat delivery Chemical/nutrient delivery	Water temperature Water quality	Water temperature Specific parameter exceedance thresholds – nitrate, phosphorus, etc.	C at outlet measure specific attributes
Hydrologic cycle	Water delivery	Water quantity	Gauge data, water withdrawals, changes in hydrology from historical conditions	Degree of alteration of flow regime (Richter et al.1996)
Biotic community dynamics	Biotic integrity	Biotic indices	Fish, amphibian macroinvertebrates, community, multimetric indices	Numbers of fish, amphibians, and relative abundance of macroinvertebrates

[a] LWD = large woody debris.

general fashion. For example, forest management is meant to encompass a variety of human influences such as land allocations, timber harvest, habitat restoration, and fire suppression. Although this generality was necessary to simplify the conceptual model, these aspects of forest management are further developed as indicators below.

Unit of Evaluation

We use the term "watershed condition" as a concept that represents one aggregate characteristic of aquatic ecosystems. This is a valid concept regardless of the spatial scale of the watershed. Four units were considered and evaluated to select the appropriate unit of interest for AREMP. Two, fifth-field (watershed) and sixth-field (subwatershed) hydrologic units are components of the new U.S. Geological Survey classification of rivers systems, which is based on drainage area. The other, third- and fourth-order watersheds, is based on stream size, following Strahler (1957). Advantages and disadvantages of the various scales are presented in table 2. We selected the sixth-field hydrologic unit because it is conceptually easier to think about than larger units, has less variation within units because of the smaller size while still being a viable geomorphic unit and biologically relevant, and many watershed analyses are done at this scale or small aggregates of this scale. In the remainder of this document, we refer to sixth-field hydrologic units as watersheds.

Regardless of which scale is chosen, "watersheds" will fall into "complete" and "composite" categories (illustrated in fig. 5). Complete watersheds are topographically defined, with no surface inlet and a single outlet; composite watersheds have one or more surface (stream) inlets and can have more than one outlet. Our knowledge of and experience working in larger streams, and consequently composite watersheds, is limited. Size of streams in composite watersheds can differ widely, from small streams to large rivers. As a result, biological and physical attributes and relations among the parameters will vary. Therefore, models that consider the characteristics of composite watersheds will need to be assembled independent of those developed for complete watersheds. We recommend that the pilot testing incorporate a variety of watersheds, both size and type, by using the same key indicators in the composite watersheds to form the database for these systems. Future research efforts need to be directed at gaining understanding of these streams, and the interpretation of the monitoring results will be refined as this information becomes available.

Stressors

Stressors of the aquatic and riparian ecosystem and the primary ecological processes they affect are shown in figure 4. The stressors do not include those that are rare, such as volcanism or other infrequent natural disturbances. Processes are grouped into those that affect general area of the watershed, the upslope areas, the riparian zone and flood plain, and the stream channel. Arrows illustrate the relation between the subsystems and the dominant direction of inputs and outputs, following Naiman et al. (1992).

The conceptual model provides a framework for identifying indicators of dominant processes in each part of the watershed. Data on individual indicators are then integrated in the DSM (described in section VII A of the Forest Plan) to provide an integrated assessment of the watershed condition. The response of individual indicators and stressors may vary greatly among watersheds within the area of the Forest Plan. Such variation is a consequence of inherent differences among or within provinces. The proposed monitoring interpretation program can accommodate virtually any differences that can be articulated.

Table 2—Advantages and disadvantages of different spatial scales for assessing watershed condition

Spatial scale	Advantages	Disadvantages
Hydrologic unit fifth code (watershed:60 to 180 mi^2)	• Used in many watershed analyses	• Difficult to assess because of size and expected large heterogeneity (i.e., variation of conditions among smaller hydrologic units)
	• Relatively small numbers would allow sampling of large fraction over time	• Changes in watershed conditions might be more difficult to detect because a greater extent of change in condition would be required to make shift in condition class
	• Most likely to contain fresh-water habitats needed for all life-history stages of anadromous salmonids	• Likely to end up with frequency distribution in the middle condition category because of heterogeneity
	• Already delineated across region (may not be agreeable to everyone, however)	• Only small portion has large part of ownership in federal lands
		• Sorting out effectiveness of Best Management Practices (BMP) would be more difficult than in smaller units because of larger numbers of potential BMP activities
		• May not include entire watershed (i.e., is composite rather than a true watershed [i.e., has only one outlet])
		• Current understanding of relation between fish and physical features of watershed lacking at this scale at current time
		• Will take longer for expression of trends than at smaller spatial scales
		• Could have variation in sizes that present statistical/interpretive problems
Spatial scale sixth code (subwatershed:5 to 20 mi^2)[a]	• Used in many watershed analyses	• May not include entire watershed (i.e., is composite rather than a true watershed [i.e., has only one outlet])
	• Must be considered when doing watershed analysis in fifth codes	• Will be ecological/biological differences among sixth codes that are attributable to location of stream within stream network—this could be addressed if use "true" watersheds
	• Easier to assess (relatively) than fifth code because of smaller size	• Will include streams of different sizes
	• Changes in watershed conditions might be detected more easily than in fifth code because less extent of change required to see changes	• Will have mainstems and tributaries
		• Will be ecological differences depending on stream size and location within watershed (Could stratify sampling design by size to address this concern)

Table 2—Advantages and disadvantages of different spatial scales for assessing watershed condition (continued)

Spatial scale	Advantages	Disadvantages
.	• Sorting out effectiveness of BMP would be less difficult than in larger units because of smaller size and area	• Delineation within Region inconsistent among states—not all delineated with Region (Could this be done in a reasonable time?)
	• Will provide shorter time for expression of trends than at larger spatial scales	• May not contain all fresh-water habitats needed for all life-history stages of anadromous salmonids
		• Could have variation in sizes that presents statistical/interpretive problems
Intermediate spatial scale (size to be determined) -Discussed 5 to 20 mi^2, but these are on or outside of small end of size for sixth codes recommended by NRCS (or USGS). Klamath NF's were 110 mi^2	• Could be intermediate between fifth and sixth codes • Provides one consistent size class across the region that might meet needs for both detail as with the sixth-code watersheds and broader assessments as needed by fifth-code analyses	• If does not include entire watershed, then could have same problems as listed for the hydrologic unit • Could be inconsistent application of size criteria • Could imply a watershed size not used by any existing programs and entail delineation of new watershed boundaries
Third and fourth order watershed	• Includes entire watershed and is ecologically and biologically complete	• May not match with watershed analysis units of interest (Could be a problem with individual sixth-code hydrologic units but would not be if all sixth-code hydrologic units within a given area are examined)
	• Eliminates need for stratification by stream size or concerns associated with variation in stream size	• Could have variation in sizes that presents statistical/interpretive problems
	• Would be similar to sixth code hydrologic units true watersheds	• Difficult to consistently delineate
	.	• Densification of streams inconsistent across landscape and varies with map scale (1:24,000 more streams than 1:100,000)

[a] This size range is on the lower end of that recommended by the USDA Natural Resources Conservation Service (NRCS) or USGS. The threefold range was identified for statistical concerns about variation with watershed size. If this scale is selected, the agencies will need to make the sixth-field hydrologic units delineation a priority as no consistent coverage presently exists.

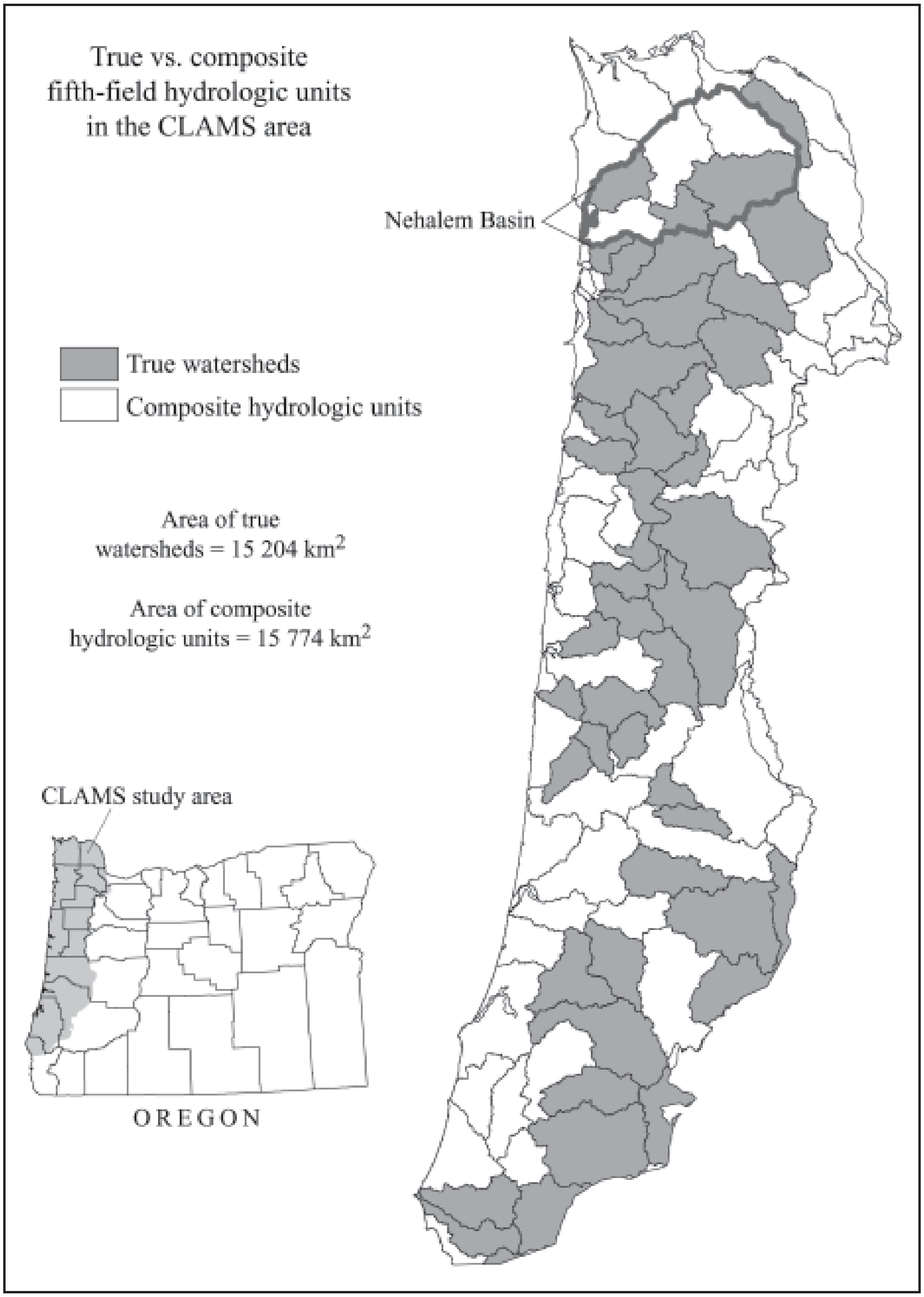


Figure 5—True vs. composite fifth–field hydrologic units in the area considered by the coastal landscape analysis and modeling study (CLAMS).

Indicators

The condition of a watershed is an aggregate measure of the integrity of all ecological processes, which is primarily a reflection of the structure, composition, and rates of system processes. Currently, the information and analytical tools necessary to quantitatively and comprehensively assess rates of watershed processes are lacking. Consequently, the AREMP must rely on physical and biotic variables that individually or collectively act as surrogates or indicators of specific watershed processes. Indicators of watershed condition may represent ecological endpoints of natural or human-caused system stressors or system responses to stressors (Noon et al. 1999). Relevant indicators may be selected to represent processes in each of the three watershed subsystems identified in the conceptual model (fig. 3.). The indicator table (table 1) presents the proposed core indicators, organized by basic watershed processes:

- **Upslope indicators** (such as road density, land use, land cover, and harvest history)
- **Riparian indicators** (such as proportion of channel length with mature, coniferous, riparian forest)
- **Channel indicators** (such as physical properties of the channel such as extent and quality of pools, amount of large woody debris) including water quality indicators (such as water temperature, chemical constituents)
- **Biological indicators** (such as salmonid populations; structure of the fish, amphibian, or macroinvertebrate assemblages; measures of biotic integrity)

Based on the conceptual model, the AREMP team initially identified 90 potential indicators that could be useful to assess watershed condition (app. 3). Candidate indicators representing key functions and processes in each watershed subsystem were evaluated by criteria established following Noon et al. (1999), to distill the various indicators into a core set. The evaluation criteria used were:

- 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.
- The indicator can be accurately and precisely measured or estimated (the signal must be statistically separable from the noise).
- The indicator must have enduring use; i.e., it is generally one of the indicators that experts in the field would use in assessing ecological condition.
- Changes in the indicator must be interpretable in terms of the objectives of AREMP, and they must be distinguishable from changes resulting from natural variability.
- Measurements must be cost effective at the required level of precision and accuracy.

This process resulted in a proposed set of 20 core indicators across the three watershed subsystems (table 1). Indicators require consistent definition, data standards, and measurement protocols to have value and relevance in assessing watershed condition. Many of the indicators are currently part of ongoing agency programs (e.g., the Environmental Monitoring and Assessment Program [EMAP]), or are being developed in other Forest Plan monitoring programs (e.g., old-growth vegetation, riparian vegetation). Greater efficiency can be achieved where sampling protocols, and designs of existing programs can be used or modified to ensure ongoing consistent data collection that jointly satisfies the objectives of the existing program and AREMP. Existing data from the other programs, that demonstrate sufficient quality-control rigor, may be useful in developing relations used in the decision-support assessment model. Coordination with other monitoring or assessment programs will be a key task during the implementation effort.

Biological factors will be incorporated into the initial models developed to evaluate watershed condition. However, for a number of reasons, many agencies that will be responsible for implementing the AREMP do not currently collect or have not previously collected biological data. This makes it difficult to incorporate biological components into the initial DSM. Karr and Chu (1999) question the ability to say something about the condition an environment for which biological information is lacking. They cite examples where failure to incorporate biological criteria into environmental monitoring results in an underestimation of the extent of environmental impairment (e.g., Yoder 1991, Yoder and Rankin 1995). Determining the relation between assessed watershed condition and the associated fauna and identifying potential biological measure should be a primary focus of research evolving from the AREMP.

The current AREMP framework proposes to measure habitat characteristics as surrogates of ecosystem processes. In the aggregate, habitat characteristics define the quantity and quality of the physical structure, or habitat structure, present. Habitat structure is a critical component of ecosystem condition. Habitat assessments provide a useful estimate of ecosystem condition when current conditions are compared against an idealized ecosystem vision.

However, estimates of ecosystem condition based only on habitat condition require acceptance of at least one of the following three assumptions: (1) the condition of an ecosystem is independent of the status and integrity of its resident biota, (2) our understanding of the physical requirements of individual species and their response to changes in those physical characteristics are precisely known, and (3) biological systems respond only to visible habitat alteration. None of these assumptions can bear close scrutiny. The integrity of ecological systems is dependent not only on physical processes such as biogeochemical cycles, energy dynamics but also on the biotic attributes of mutation, demography, biotic interactions, and metapopulation processes (e.g., Naiman and Bilby 1998). Our imprecise knowledge of the relations between biotic response and physical attributes is perhaps most obviously illustrated by the continuing decline of anadromous salmonids in the Pacific Northwest. There is ample documentation of adverse responses of populations where trends in the likely proximal mechanism were not detectable, or where the proximal mechanism was simply not known. Consequently, only monitoring habitat condition can facilitate interpreting data on ecosystem condition but cannot be used to define ecosystem condition (Karr and Chu 1999).

Upslope subsystem indicators—Upslope subsystem indicators—such as vegetation composition, seral stage, and percentage of cover—reflect processes influencing the entire stream network (Naiman et al. 1992) and are relevant indicators over the entire watershed. Data can be gathered largely by existing remote-sensing efforts, such as that established for late-successional and old-growth forests (Hemstrom et al. 1998). The AREMP proposes to incorporate existing vegetation data acquisition, mapping, and analyses into the condition assessments, where appropriate. The LSOG vegetation is mapped at a relatively coarse resolution (25-m pixels); thus, although certain efficiencies in process will be gained by using their data, significant ecological variation at this scale of resolution may not be apparent in the assessment. For each watershed, AREMP proposes that a vegetation map be produced identifying vegetation composition, seral stage, and percentage of cover, as can be acquired from the LSOG monitoring program. The key indicators can be derived from this map and database. Road density and road-stream crossings may be calculated off existing geographical information system (GIS) layers. Landslides may be mapped off aerial photos with a limited amount of ground-truthing by field crews.

Riparian and flood-plain indicators—Riparian and flood-plain subsystem indicators represent processes delivering structure, sediment, and nutrients to stream channels over intermediate spatial scales, and they require finer scale analysis and greater initial sampling intensity for validation than do upslope indicators. It is suggested that riparian indicators be measured throughout the stream network, which includes perennial, fish-bearing as well as perennial nonfish-bearing and intermittent streams. Although materials delivered by riparian and flood-plain subsystems initially affect adjacent stream reaches, they also affect the condition of downstream reaches (Naiman et al. 1992). Consequently, AREMP initially proposes to map (census) riparian indicators throughout the stream network in the selected watersheds. However, in some instances, it may be possible to identify subsets (see examples in Benda and Cundy 1990) to focus sampling on because these streams are more "important" ecologically than are similar streams in this part of the network. Subsampling will be conducted to determine the efficacy of gathering indicator values through a range of sampling intensities.

In-channel subsystem indicators—In-channel indicators will be measured at the reach scale. To understand the spatially explicit pattern necessary to assess the connectivity in the watershed, however, we suggest that every reach in the selected watersheds be monitored. Reach definition is influenced by channel slope, local side slopes, width of the valley floor, riparian vegetation, and bed and bank material (Frissell et al. 1986). Relative width of the valley floor appears to be particularly influential of the physical characteristics of the reach and the resulting biotic response. Reaches can be classified as constrained or unconstrained, depending on whether the width of the valley floor (measured as a continuous variable) is less than or greater than twice the active channel width (Gregory et al. 1989). Constrained reaches tend to have greater channel slopes, higher energy especially during high flows, less habitat diversity, and generally retain fewer nutrients and less debris. Because unconstrained reaches contact a greater area of the flood-plain and riparian area, these reaches generally have greater variation in bed and bank materials, hydraulics, and therefore habitats, and they are considered to reflect the integration of upstream watershed processes (Reeves et al. 1998). For these reasons, unconstrained reaches are considered to be key response reaches (see table 1).

Biological indicators—The composition and structure of biotic communities in streams differs with the characteristics of the reach. In general, because of the greater diversity of habitats and primary productivity, unconstrained reaches produce more macroinvertebrates and salmonids than constrained reaches (Reeves et al. 1998). Consequently, the effectiveness monitoring effort may focus on estimates of indicators that reflect these processes, and rates, in this reach type, although both constrained and unconstrained reach types will initially be included to test their predictive utility. In sampled watersheds without unconstrained reaches, we will measure the relevant indicators in constrained reaches. Both reach types will be available in the DSM evaluating watershed condition. Types of biological indicators are described in appendix 4.

Spatial Distribution of Indicator Measurements

The types and rates of processes that influence aquatic ecosystems differ spatially and temporally within and among watersheds (Naiman et al. 1992). Indicators that are surrogates for those processes have inherently high variability in spatial distribution throughout the watershed, and understanding that distribution may enhance the ability to gauge the effects of stressors on watershed processes. Consequently, documenting the spatial distribution of indicators may increase the precision and reliability of assessing watershed condition. For example, although the total road density in the riparian subsystem may be a relative measure of effects on sediment production and transport, considering spatially explicit attributes of roads, which provide the additional resolution needed to discern hydrologic connectivity to the stream channel increases the accuracy of that measure. Similarly, the distribution of large woody debris or the range of temperature may add value beyond that provided by assessments performed solely through summary descriptive statistics of these indicators. Developing methods and procedures to address this need should be the focus of research agencies.

Watershed Condition Assessment

Coordination With Current Assessment or Monitoring Programs

Evaluating ecosystem condition presents challenges because ecosystems comprised many parameters (e.g., large wood, pools, riparian vegetation). The aggregate of the parameters in a given system must be evaluated to determine ecosystem condition. Previous and current monitoring by the Forest Service and Bureau of Land Management examined parameters individually for a series of watersheds. Consequently, it is not possible to determine the condition of an individual watershed or its associated ecosystem. We are unaware of any systematic, ongoing efforts in the Western United States to assess conditions of watersheds in a manner that is similar to the AREMP proposal, over large spatial scales required by the Forest Plan. Current monitoring or assessment efforts can be summarized as:

1. Most current monitoring programs select sites (reaches or watersheds) subjectively (e.g., because of ease of access, it has a restoration project, etc.). Consequently, aggregating the results from these sites for a provincial or regional evaluation would not give a representative picture of the broader region because the selection of monitoring sites is biased. Sometimes watershed condition is evaluated by aggregating information at multiple sites within a watershed; these watersheds were selected subjectively as well, so aggregating across watersheds would also likely give a biased perception of regional condition.

2. Individual attributes are generally evaluated independently of other attributes to determine site condition. Many agencies establish a single threshold value for an individual parameter or indicator. The condition of the site in relation to the particular parameter is determined by the value of the parameter relative to the threshold. The U.S. Environmental Protection Agency and the state analogs (e.g., Oregon Department of Environmental Quality) have used this approach for their temperature and chemical monitoring. The matrix developed by the National Marine Fisheries Service to evaluate watershed condition is similar to these approaches.

3. Biological attributes have been used separately, or in combination with, physical and chemical attributes to evaluate site condition. Many fish and game agencies monitor population status and trends of individual species or subspecies, but they do not evaluate species responses relative to watershed condition. Some agencies monitor particular biological assemblages (e.g., fish, macroinvertebrates, and periphyton) in combination with physical and chemical attributes. They interpret the assemblage as a whole to evaluate the condition of a site or watershed, particularly where water quality issues are of concern through biological indices, such as those developed by Karr (1991). The index of biotic integrity (IBI) (Karr 1991) is a commonly used procedure to evaluate conditions at a site. This index generally combines biological parameters and is designed to assess conditions of an individual site (Karr and Chu 1999). It does not evaluate ecosystem

condition[2] although it contends to integrate "information from ecosystem, community, population, and individual levels" (Karr 1991, Karr and Chu 1999). Assessments are made by comparing IBIs of individual sites with those established from "pristine" sites (i.e., sites with little or no human influence) (Karr 1991). It is assumed that there is "no or minimal human disturbance" at pristine sites (Karr and Chu 1999).

4. The U.S. Environmental Protection Agency's EMAP uses a statistical sampling approach to select sites on streams at which riparian and channel physical, chemical, and biological measurements are taken. In addition, EMAP defines the watershed upstream of the selected stream locations and obtains relevant watershed attribute data. The data are evaluated both separately and together, to assess "condition" at site and watershed scales. Thus EMAP focuses on the biota as the primary endpoint of interest. One line of argument is that condition should be assessed on the basis of biology, with channel habitat, water quality, riparian condition, and upslope character as diagnostic and classification indicators to interpret the biological measurements (i.e., what explains good or poor biological condition). Results of EMAP can be summarized in relation to watershed condition as the number of kilometers of the stream network that drains watersheds in good or poor condition. Conceptually, the same indicators proposed in AREMP could be used in EMAP, and often the indicators are identical. The primary differences between EMAP's approach and the one proposed by AREMP is (1) EMAP evaluates condition at the site scale (and the catchment above the site), whereas AREMP selects predefined watersheds (sixth-field watersheds); and (2) AREMP uses a decision-support model to integrate the results of various indicators, whereas EMAP compares multiple biological indicators separately.

5. The National Water Quality Assessment (NAWQA) Program of the U.S. Geological Survey focuses on water quality issues (e.g., pesticides, nutrients, volatile organic chemical, and trace elements) but also examines aquatic biology and attempts to make assessments on regional and national scales. The NAWQA is designed to assess historical, current, and future water-quality conditions in representative river basins and aquifers nationwide. One of the primary objectives of the program is to describe relations between natural factors, human activities, and water-quality conditions and to define those factors that most affect water quality in different parts of the United States. The NAWQA Program's design provides consistent and comparable information on water resources in 60 important river basins and aquifers across the country. Together, these areas account for 60 to 70 percent of the Nation's water use and population served by public water supplies and cover about one-half of the land area of the Nation. From these studies, they have developed a model for regional estimation of water-quality named "Spatially Referenced Regressions On Watershed Attributes" or SPARROW. This information may be used in developing the DSM interpretations of field-collected data.

6. A set of aquatic habitat attributes for which data are commonly collected by federal and state agencies was identified as part of what is commonly known as the "Stage I Fish/Hydro Data Standards" (Allen and Guenther 1996). These standards have been useful as a first approximation of the information needed to assess attainment of ACS objectives. The AREMP is more explicit in describing indicators and protocols for monitoring the effectiveness of the ACS, and also goes even further by describing methods for

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[2] Karr, J.R. 1999. Personal communication. Professor, Aquatic and Fishery Sciences, University of Washington, Seattle, WA 98195.

sampling, analyzing, and reporting on the status and trends of watersheds, aquatic ecosystems, and biota. It is anticipated that efforts to expand or improve on the Stage 1 Fish/Hydro Data Standards will be integrated under the AREMP framework.

Knowledge-Based Decision-Support Model

Overview—Assessing ecosystem conditions requires considering multiple variables and the aggregate interaction among them. Several programs have monitored individual attributes (e.g., current Bureau of Land Management and Forest Service stream inventory programs) or an aggregate of attributes (e.g., EMAP). Ecosystems are complex systems, and as a result, the precise relations among variables and relations to ecosystem condition are not fully known. Fuzzy logic (Zadeh 1965) provides a means of developing models that can evaluate conditions of systems where relations between and among variables are not precisely defined.

The condition of sixth-field watersheds in the region of the Forest Plan will be evaluated by using a DSM based on the NetWeaver fuzzy logic knowledge base software (Reynolds 1999b).[3] A knowledge base is a metadatabase (i.e., a large database with multiple variables) that provides a formal logic for interpretation of data (Jackson 1990, Waterman 1986). A knowledge base designer specifies the topics for the problem and the relations among topics. Use of fuzzy logic for ecological assessment and analysis has attracted considerable attention in the past several years as a promising approach to dealing with ecological complexity (Openshaw 1996, Salski and Sperlbaum 1991). Fuzzy logic also has been used in environmental planning (Baas and Kwakemaak 1977, Buckley 1985, Smith 1994, Yager 1977), analysis of fish-stock recruitment relations (Mackinson et al. 1999), analysis of ecological data (Equihua 1990), and assessment of environmental conditions (Meesters et al. 1998). NetWeaver knowledge bases recently have been used for ecological site classification in Great Britain (Ray et al. 1998) and design of biodiversity reserve systems (Bourgeron et al. 2000).

The primary structural element of a NetWeaver knowledge base is the dependency network (hereafter, network), which evaluates a proposition about the state of a unit of interest within the knowledge base. Each network has three basic attributes: the proposition being evaluated, the network's dependency on other networks, and a measure of the truth of the proposition. In AREMP, the measure of truth we use is a subjective probability termed the watershed condition index. The propositional statement is a simple description of the condition to be tested (i.e., watershed condition is suitable to support strong populations of fish and other aquatic and riparian-dependent organisms).

Process for watershed condition assessment—The DSM proposed for the AREMP incorporates a system of fuzzy logic developed by Zadeh (1965). Fuzzy logic is a precise and formal branch of mathematics concerned with the quantification of imprecise information about variables, their interpretation, and the relations between variables. It is especially applicable to categorizing states or conditions of ecosystems. Ecosystems have no arbitrary point at which "fair" condition gives way to "good" condition; a gradient exists, where "fair" transitions into "good." This vague transition or gradient is what fuzzy logic tries to display. Fuzzy logic allows us to retain the concept of classes such as "poor," "fair," and "good" while realizing the vagueness about which watersheds belong in each class. The logic used to construct the DSM relies on general ecological relations, as understood and expressed by subject-matter specialists or expert panels (Reynolds

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[3] The use of trade or firm names in this publication is for reader information and does not imply endorsement by the U.S. Department of Agriculture of any product or service.

and Reeves 2003). We can then derive watershed condition indices for each watershed about which class they belong in rather than saying that the data show, without uncertainty, precisely which class a watershed belongs in. Watershed condition indices are subjective probabilities that a watershed belongs in a given category.

The strength of the model developed for AREMP is that it uses an explicit process for assessing watershed condition and documents the data and relations assumed in the interpretation. This allows everyone to understand and track how a particular result was obtained. Although the model can function with incomplete information, it displays the influence of missing data on the assessment. This information can then be used to improve data acquisition and as part of a sensitivity analysis on how stable the assessments of condition are. Analysis of sensitivity and repeatability of the model will be conducted in the pilot phase. Although the assessment of condition depends on the knowledge base at the time the model is developed, the relations between elements can be refined as our understanding of watershed function increases. The ability to refine the model and rerun data from earlier years to correct deficiencies in the early models is a considerable advantage of this model. The ability to maintain data for the long term and simply recalibrate the model relations between data elements as knowledge improves emphasizes consistent, high-quality data acquisition for elements considered to be enduring data needs for various uses. We have striven to select data elements that experts would use in assessing ecological conditions in watersheds regardless of the program or initiative under which it was collected.

Propositional statements used in the watershed assessments—For the proposed effectiveness monitoring model, the propositional statement is that a watershed is ecologically intact. That means:

- The processes necessary to create and maintain habitat conditions for various native or desired species are intact, particularly in key areas of the watershed.
- Current habitat conditions support the native or desired group of species.
- The system has the potential to recover to desired conditions when disturbed by large natural events or by land management activities.

The meaning of the propositional statement is made explicit by specifying a framework of indicators and their interrelations. In formal logic, a proposition is the smallest unit of thought to which a measure of truth can be assigned (Stillings et al. 1991). Consequently, a key attribute of each network is its measure of truth (or subjective probability index of truth; we will use probability index for brevity). An example of a knowledge base to evaluate watershed condition for the Forest Plan is shown in figure 6 (only a portion of the full logic structure is depicted in the figure). As in figure 6, the probability index of a network often depends on the probability indices of other networks that are embedded in the model. In operational knowledge bases, all pathways eventually depend on links to data (i.e., data links). In addition, NetWeaver uses fuzzy logic operators such as “AND” and “OR” (fig. 6) (Kaufmann 1975; Zadeh 1965, 1968, 1975a, 1975b, 1976) to perform fuzzy math operations (Reynolds 1999b) that combine data elements or networks of elements.

Data links—Data links are simple networks. Like a network, a data link evaluates the truth of a proposition. Unlike a network, the probability index of a data link typically depends on only one data element rather than complex relations between or among data elements. In general, a data link reads one or more data values (i.e., indicators of watershed condition), may perform some mathematical operation on the data, and evaluates the result by comparison to an argument. Examples of data links are shown in figure 7.

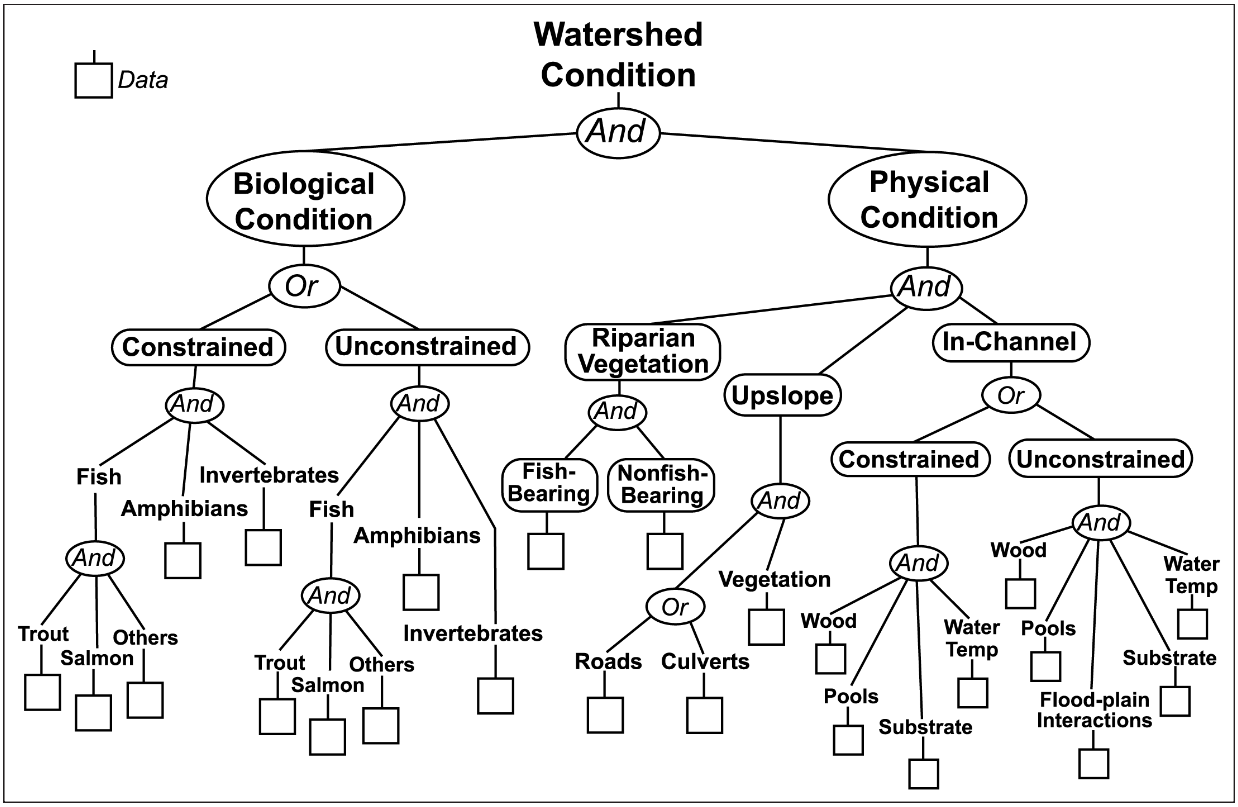
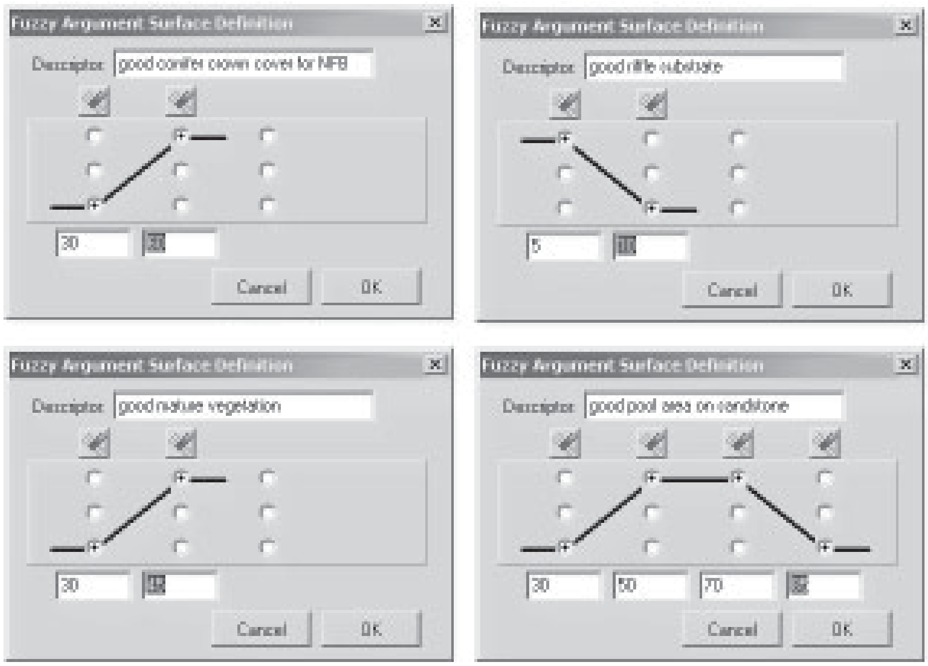


Figure 6—Schematic of the decision-support model for the Aquatic and Riparian Effectiveness Monitoring Plan.



Descriptor: good conifer crown cover for NFB
30 [illegible]

Descriptor: good riffle substrate
5 [illegible]

Descriptor: good mature vegetation
30 [illegible]

Descriptor: good pool area on sandstone
30 50 70 [illegible]

Figure 7—Examples of fuzzy membership functions to evaluate the proposition of interest.

The argument to a data link may be a simple expression (e.g., conifer cover ≤ 10 percent) or a fuzzy membership function (fig. 7) that evaluates an observation's degree of membership in a set representing some concept. Figure 7, for example, illustrates a fuzzy membership function that evaluates the proposition that, for example, the percentage of conifer cover within riparian zones along fish-bearing segments of streams, riffle substrate, or mature vegetation, or pool area in a watershed is within a suitable range. Fuzzy membership functions compute a value on the gradient from –1 to 1, with a value of 1 indicating full membership in the fuzzy set, and a value of –1 indicating nonmembership in the fuzzy set.

Development of indicator relations and functions—Fuzzy membership functions can be developed in two ways. They can be developed from empirical evidence, by using data from published and unpublished sources, or from professional judgment if empirical data are lacking or incomplete. Functions developed from professional judgment typically are developed by consensus among a group of subject matter experts. The NetWeaver knowledge base system provides documentation opportunities for all its components, so functions derived from professional judgment or statistical analysis can be clearly identified as such. More generally, any information relevant to appropriate use of the knowledge base (i.e., explanatory notes, the source of expert judgment, literature citations, and model assumptions) can be embedded in the knowledge base itself as documentation attributes and become readily available to users.

Use of expert panels to define criteria for species use of stream habitats is well established in fish and river management (Angermeier et al. 1991, O'Keefe et al. 1987, Swales and Harris 1994). Assessing watershed condition will rely on expert teams and local knowledge of watershed conditions for several critical activities: reviewing core indicators and validating reference values; adjusting the DSM rule sets for indicator weights and relations; applying the locally adjusted rule set; and verifying results of assessing watershed condition. Regional and provincial teams will be experts that represent interagency and interdisciplinary skills; they will draw on the expertise and knowledge of local research and management field staffs, as necessary.

Relation variability—Relations between indicators and watershed condition will vary among, and possibly within, biogeographic provinces in the Forest Plan region. This variability is the result of differences in such factors as geology, climate, and vegetation that vary spatially within and among provinces. The NetWeaver knowledge base system has two types of components that enable the design of general knowledge bases that accommodate variation in logic structure with spatial context or degree of knowledge. They are switches and complex functions.

Switches—Switches allow selection among multiple alternative logic pathways based on context (fig. 8). In this example, the contribution of in-channel conditions to evaluation of watershed condition is only considered if the variable, lowGradSurvey, is positive, indicating that reach gradient is sufficiently low to make evaluation of in-channel conditions appropriate.

Complex functions—Complex functions allow a knowledge base designer to construct, for example, a logistic fuzzy membership function (or virtually any other continuous membership function) based on theoretical considerations that vary in almost any way imaginable.

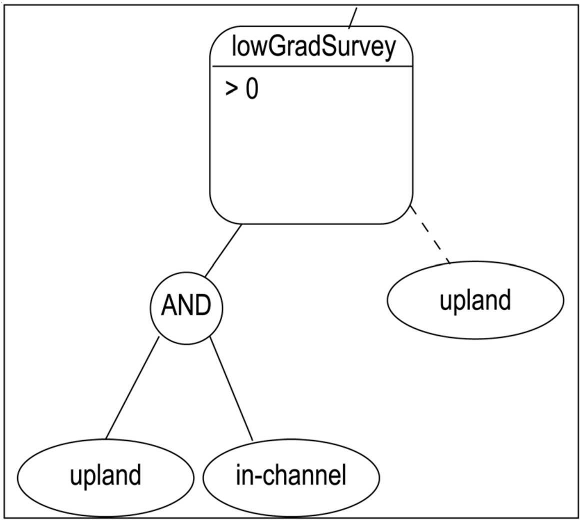


Figure 8—Example of a switch node to control selection of logic pathways based on the context of the situation.

Outputs—NetWeaver knowledge bases can be run interactively, evaluating watershed condition one watershed at a time, or landscape-level analyses of 10, 100, or 1,000 watersheds can be performed with the EMDS ArcView extension (Reynolds 1999b). The EMDS integrates the knowledge-based reasoning methods of NetWeaver into Environmental Systems Research Institute's PC ArcView application, enabling landscape-level knowledge base processing for ecological analyses (fig. 9). The primary outputs of knowledge base analysis are probability indices for all networks involved in the analysis. Probability indices for any knowledge base network can be summarized as frequency distributions for the full Forest Plan region.

Outputs from the model are composite probability indices for each watershed indicating the extent to which the statement that "the watershed is ecologically intact" is true for that area. The probability indices for all watersheds in the region can be graphed in various ways (figs. 10 through 12) to display frequencies. Summary statistics can be calculated to supplement the graphics for each year. Statistical tests also can be run on results from subsequent years to see if the frequency distributions have shifted. Simple graphs such as figure 13 can be developed to visually display progress toward restoration of aquatic conditions. Output summaries are easily performed to identify those indicator variables that contribute most frequently to low probability indices (poor habitat or biological conditions) (fig. 14). This capability allows identification of indicators that need to be addressed to improve watershed condition and provides a basis for further field evaluation of management activities that may influence a particular indicator or a group of indicators.

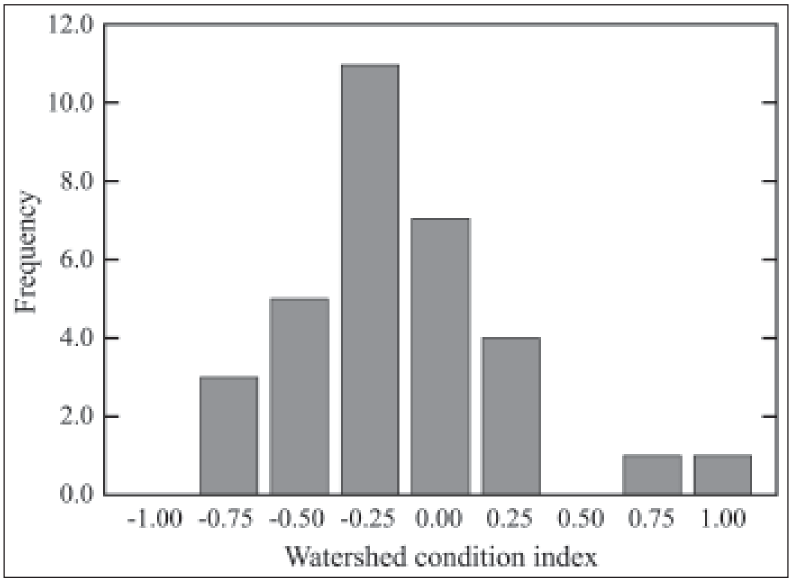


Figure 9—Watershed condition indices summarized by frequency distributions for a hypothetical province.

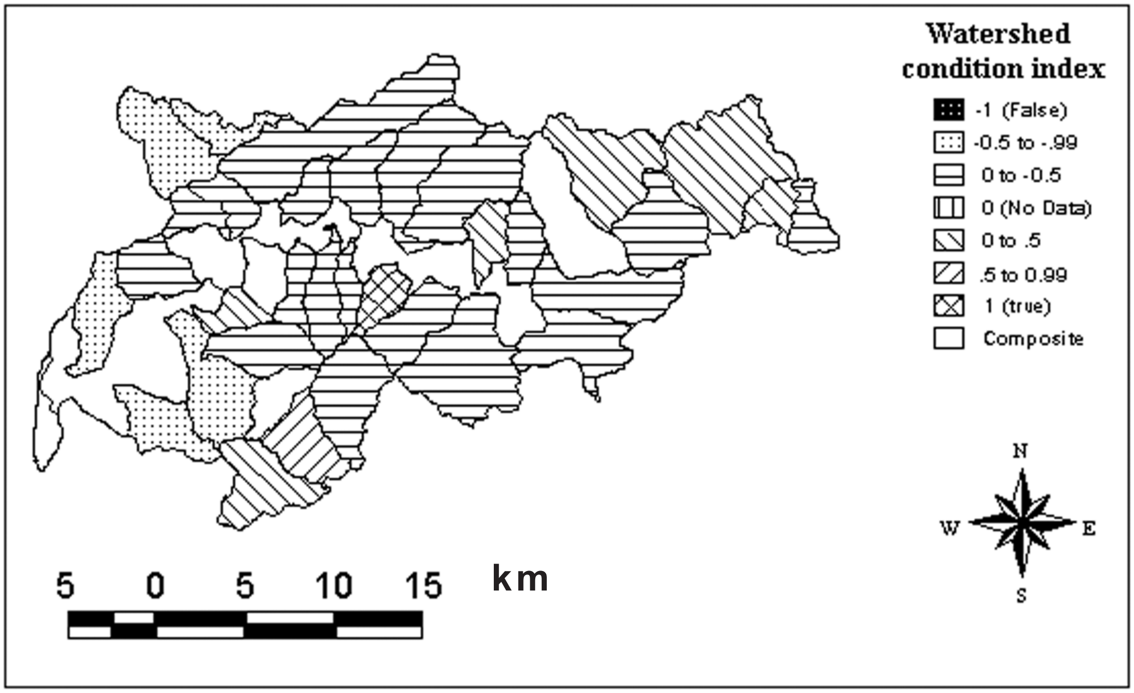


Figure 10—Example of ArcView display of watersheds classed by their watershed condition indices, ranging from dark (good) condition to light (poor) condition.

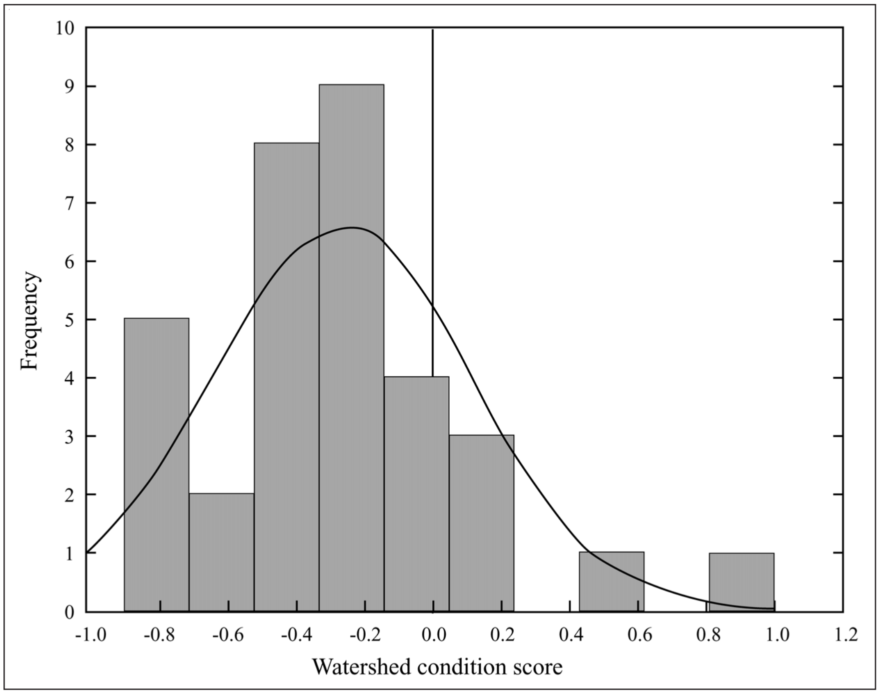


Figure 11—Frequency distribution of watershed condition probability indices for a group of watersheds from the Coast Range of Oregon.

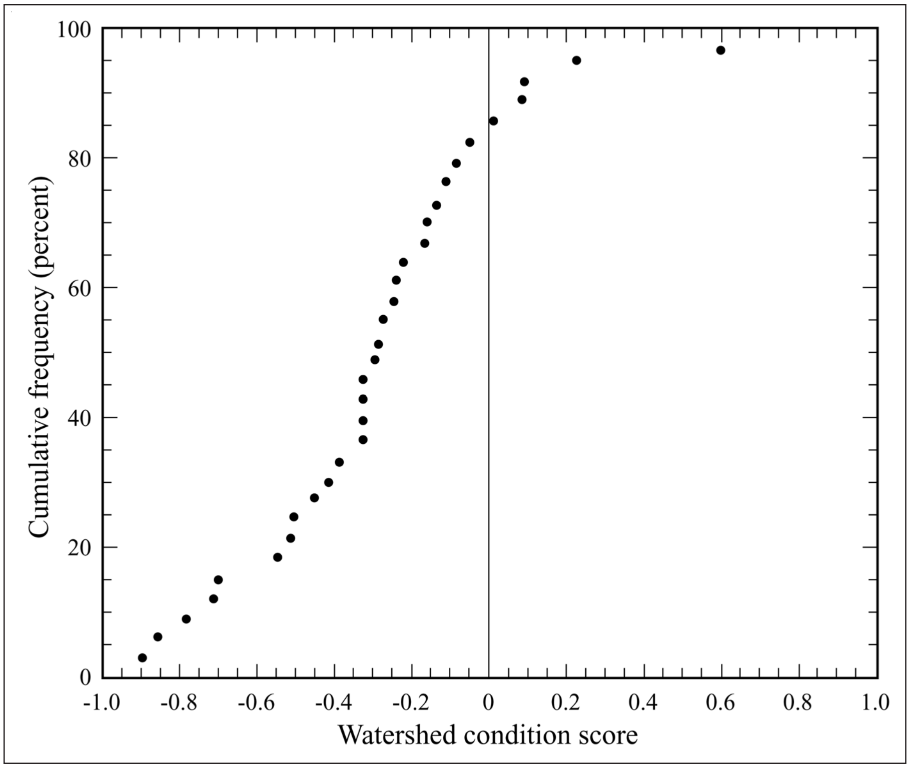


Figure 12—Cumulative distribution functions of condition indices for a group of watersheds in the Oregon Coast Range.

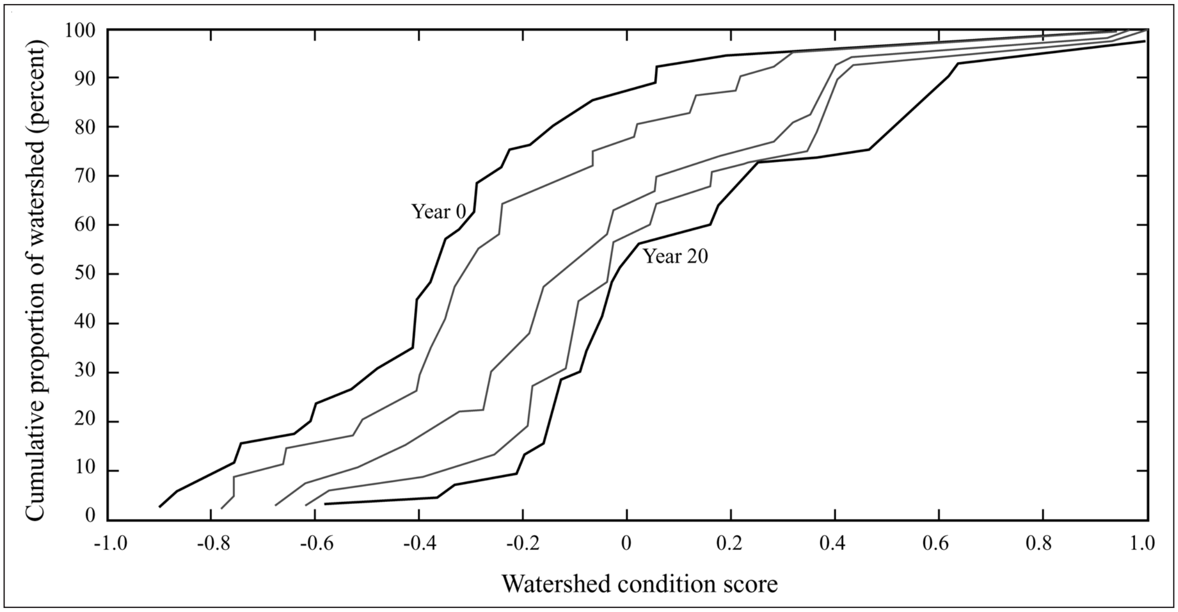


Figure 13—Display of hypothetical regional trends in watershed condition at 5-year reporting intervals for a 20-year period.

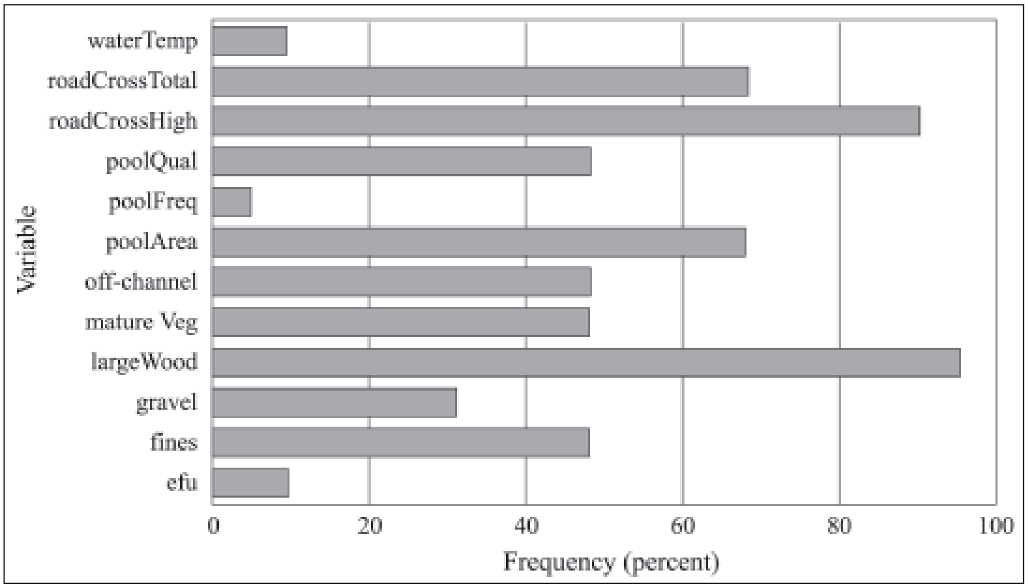


Figure 14—Frequencies that particular indicator variables contributed to low watershed conditions indices in a demonstration area in the Oregon Coast Range.

Summary of the knowledge-based decision support—The proposed knowledge base approach to assessing watershed condition has several advantages for AREMP's use in evaluating watershed condition. The method organizes quantitative and qualitative knowledge about numerous and diverse factors into a single, coherent logical framework that reflects the current state of knowledge about how aquatic systems are believed to be organized, operate, and respond to management. The decision-support model allows us to explicitly disclose how we evaluate the aggregate of indicators for a given watershed. By aggregate, we mean not only the group of indicators as such, but the interdependence among them that together represent "watershed condition." We will be able to disclose what data were used, what relations were assumed, what information or publication was used as a basis for the assumption, and how the aggregate "condition" was arrived at.

Knowledge bases provide consistent data interpretation in a specified framework that is clear and unambiguous. Many current monitoring or assessment efforts do not have an accompanying logic framework that provides for consistent, integrated interpretation of data. This lack commonly leads to differences of opinion about what the data mean and inconsistent conclusions over time (even among the same group of people). Knowledge bases clearly articulate relations between indicators and watershed condition as well as relations among indicators. As a result, calculations of probability indices are consistent and not influenced by successive assessments of individual evaluators.

Regional-scale monitoring, such as that required for the Forest Plan, is complex, must be dynamic and interactive, and must be capable of easy modification over time (Olsen and Schreuder 1997, Vora 1997). It also must allow for incorporating new knowledge and information needs to be successful. Models need to evolve as knowledge evolves. Relations between indicators and watershed condition and relations among indicators are easily modifiable in the knowledge base as new knowledge about watershed condition is acquired. The process of knowledge base design, which specifies relations between indicators and watershed condition, typically leads to identifying or refining research needs and priorities. The specified relations reflect current understanding of how watersheds are organized, operate, and respond to management. At any time, some portions of the model will be better understood than others. Portions for which understanding is weakest suggest a focus for future research efforts to improve understanding of the system and representation of knowledge about it.

Land managers and regulatory agencies will be able to use the knowledge base for more than regional and provincial monitoring. The knowledge base can easily be used to assess the condition of watersheds other than those sampled for the Forest Plan effectiveness-monitoring plan. Additionally, they will be able to identify those indicators most responsible for current watershed condition. This ability, in turn, can assist with (provide decision support for) restoration and management activities.

Establishing Baselines and Evaluating the Results

Baselines—Establishing baselines from which to measure change for monitoring ecosystems can be difficult. All ecosystems change through time. Changes in the biological and physical features of ecosystems result in different ecological or successional states, each with a unique set of features. Terrestrial ecologists recognize that forests move through a series of successional states, each with a combination of fauna and flora (e.g., Huff and Raley 1991). Because of such changes, determining a "normal" state is difficult for ecosystems whose properties are in flux either because of natural disturbance or because of natural ecological mechanisms (Ehrenfeld 1988).

Monitoring ecosystems, particularly across large spatial scales, requires consideration of a frequency distribution of the various ecological states (Noon et al. 1999). At the landscape and provincial scale, a variety of ecological states will be expressed at any given time. The exact combination depends on such attributes as the size and frequency of the disturbances and the range of conditions of the ecological states. At larger spatial scales, the proportion of each successional state may be relatively stable over long periods (i.e., several centuries) (Wimberly et al. 2000). Ecosystems at the landscape and provincial scale are thus characterized by a frequency distribution of different successional states.

The concept of successional states has not been as well recognized or used by aquatic ecologists. A primary reason is the absence of temporal considerations in major paradigms that shape our view and understanding of aquatic ecosystems. For example, the River Continuum Concept (Vannote et al. 1980) describes how biological processes and communities are organized at different points in the stream network. The relations are assumed to be fixed in time and unchanging. Frissell et al. (1986) describe the hierarchical organization of stream systems and identify a temporal component associated with each level. The finer the spatial scale, the shorter the response period. They do not consider how the features of a given level in the hierarchy respond over time, however. Failure to incorporate time into the consideration of aquatic systems can lead to an implied expectation that stream ecosystems experience a limited, if not a single, set of conditions and that this condition (or conditions) can be relatively stable through time.

Some recent papers dealing with aquatic ecosystems have discussed the concept of variation in aquatic ecosystems. Ebersole et al. (1997) discuss the concept in general terms but do not present specifics on features of the individual states. Reeves et al. (1995) described the range of conditions that aquatic ecosystems in the Tyee sandstone formations of the central Oregon coast may have experienced under the natural disturbance regime. Conditions varied widely depending on time since last disturbance. The system that was most recently disturbed (i.e., 80 years ago) had high sediment loads with few pools and pieces of large wood and a salmonid community strongly dominated by coho salmon (*Oncorhynchus kisutch* Wallbaum). Complex habitat conditions with intermediate levels of wood and sediment and a diverse fish community, coho salmon, and steelhead (*O. mykiss* [*Salmo gairdneri* Richardson]) and cutthroat trout (*O. clarki* Richardson) characterize the system that was an intermediate time from last disturbance (i.e., 120 to 160 years ago). The system that was the longest from the last catastrophic disturbance (i.e., 300+ years ago) had simplified habitat conditions; predominantly gravel channels with large amounts of wood. Coho salmon were the only salmonids present. Benda et al. (1998) present frequency distributions of sediment and wood loading for aquatic ecosystems based on simulation models. The distribution varies across a region depending on the magnitude and frequency of disturbance events and local features such as topography and lithology. Focusing on a single set of conditions and failing to place ecosystems in the context of time since disturbance could result in establishing inappropriate standards and misleading interpretation of conditions, particularly at larger spatial scales. It may be impossible at the outset to determine what the expected proportion of Pacific Northwest catchments that should be in various disturbance categories should be.

The baseline for the AREMP can be established in three possible ways. One alternative would be to simply use the results from the first rotation period to establish the conditions that exist presently and evaluate how conditions change in the future. Selecting this as the baseline does not imply that this is the condition that the Forest Plan is striving for. It only provides a baseline from which it is possible to determine if the distribution is changing in an expected direction (e.g., hypothetical frequency distributions of conditions in 2001-5 are presented in figure 13 along with the subsequent frequency distributions of condition for the periods 2006-10, 2011-15, and 2016-20). This baseline obviously reflects current conditions and may not be representative of historical conditions. It would also take 5 years to establish given the current sampling design is accepted and implemented. Nonetheless, because the focus is on the effectiveness of the Forest Plan, we believe that using the conditions at the onset as the baseline may be most appropriate.

Another alternative is to use the historical (i.e., pre-European settlement) distribution of ecosystem states. This baseline would require establishing conditions from early explorer and settler journals and government records (Sedell and Luchessa 1982). However, because descriptions of streams and watersheds generally were restricted to the vegetation and some in-channel features, establishing frequency distributions from such information would be difficult.

A third alternative way of approximating frequency distributions would be through simulation modeling based on minimally human disturbed watersheds. Wimberly et al. (2000) have used such an approach to establish distributions of old-growth forests on the Oregon coast. For aquatic systems, developing simulation models would require an intensive research effort across the region to establish distributions for each province or subprovince. Information for a simulation model could be established from the frequency distribution developed during the initial sampling cycle of AREMP.

Evaluating results—Frequency distributions could be expressed in many ways. One would be to assign the watershed condition index to a condition interval and present the frequency of each interval (fig. 9). An alternative would be to present the condition intervals on a map (fig. 10). The latter alternative would allow the development of criteria to place each watershed into a subjective category (e.g., good, fair, poor). This would require a justification for each category, which at this point is most likely to be subjective. Another alternative display is a density function drawn from the frequency distribution as in figure 12. The last is a cumulative distribution function (fig. 13) that plots the cumulative percentage or frequency of watershed condition indices. The advantage of this presentation is that it is easy to determine various statistics from the graph. For example, to get the median (50 percentile), read up the y-axis to 50, move horizontally until you intersect the curve, then drop down vertically to the x-axis and read off the median watershed condition score. You can do the same for any percentile of interest. With a set of these distributions measured every year, trends can be tracked in the median score or any percentile of interest. The graphs also can be interpreted from the x-axis and ask questions like: What proportion of the total watersheds has condition scores less than zero? This statistic can be tracked to determine if the percentage of watersheds with condition scores less than zero decreases over time as we would expect if the Forest Plan was effective.

Regardless of how the frequency distribution is displayed, conditions and criteria for determining success must be established for the monitoring program (Reeves et al. 1997). One option is to determine if changes in the frequency distribution are statistically significant. Nonparametric statistical procedures such as the Kolmogorov-Smirnnov test (Sokal and Rohlf 1969) or if assumptions are met more robust parametric tests, such a X^2, could be used to determine if changes are significant. The cumulative distribution function from a series of repeat visits can be presented graphically (fig. 14) to visually demonstrate change over time. In any case, we expect that it will take three to four or more sampling cycles (i.e., 15 to 20 years) before shifts in the frequency distribution may be observed. The primary reason for this is that it will take an extended period for degraded watersheds to recover (FEMAT 1993).

An alternative for establishing the criteria for success would be an expected subjective criteria, rather than one based in statistical significance. This alternative could be expressed as the percentage of watersheds with a given range of probability indices or the expected frequency of a condition class of watershed. Such a distribution could be based on professional judgment of resource professionals in management and regulatory agencies.

Survey Design Framework For Monitoring Plan

Overview

Although the ecosystem and adaptive management goals of the Forest Plan are directed at the regional scale (the range of the northern spotted owl), attaining regional goals is based on the collective functioning of each of the 12 provinces (fig. 1). This regional and provincial hierarchy is further built on the “watershed” as the fundamental analysis and management unit (Montgomery et al. 1995; USDA and USDI 1994a, 1994b). Consequently, AREMP focuses on monitoring and assessing the condition of watersheds. The regional evaluation will build from the results of assessments of watersheds in regions of the Forest Plan, which can be thought of as the primary “reporting unit.” The provincial scale can be considered a finer scale reporting unit. The design framework allows for flexibility in the choice of reporting scale and evaluation of relevant costs.

The primary function of the survey design part of a monitoring design is to establish the rules for selecting the watersheds (and sampling within them), the schedule on which they will be monitored and assessed, and the approach for making inferences to the target region. A sound design ensures that results allow a consistent assessment of the reporting region and sets the stage for a regular reporting cycle on which scheduled watersheds are monitored and evaluated, and trends are tracked. Because of the large number of watersheds across the region (approximately 2,500 to 3,000), a census of all watersheds is impractical, and the plan will rely on selecting a statistical sample of the target population of watersheds to monitor and evaluate. The frequency distributions used as a measure of performance will be derived from the statistical extrapolation from the sampled watersheds to the region. Statistical sampling, which incorporates randomization in selecting the sample of watersheds, is increasingly the choice for conducting surveys of this nature. An alternative is to select watersheds based on judgment, for example, on an opinion of what watersheds represent the region as a whole, or on proposed models. In general, unless the region is well understood, or the models well developed and tested, we believe that statistical sampling is the best choice.

The AREMP proposes yearly monitoring and evaluating of a statistically developed sample of the sixth-field hydrologic units (watersheds) with greater than 25 percent federal ownership in the Forest Plan region. This strategy would allow regular status reporting and tracking of trends of watershed condition through time. Trends will be tracked by changes in the frequency distribution of watershed condition across the Forest Plan region over time and by tracking individual key indicators (such as the number of large pools per mile and the amount of large wood per mile). Assessing the selected sixth-field hydrologic unit’s condition also will require that the sampled watersheds not be singled out for special treatment or management that is not carried out in watersheds across the region. That is, that the management of the sampled watersheds cannot be biased; otherwise, the sample will be biased and the trend analysis will not be accurate.

Status Vs. Trends

The primary objective of AREMP from a sampling perspective is to determine the status of and trend in the condition of watersheds. This can be rephrased as: Across the Forest Plan region (or in each province), what proportion of the watersheds is in each condition class? Are the proportions among classes changing? If so, at what rate? **Status** and **trend** questions also can be answered for each indicator as: For indicator ‘x,’ what is the proportion of the landscape, riparian area, or stream channel length exhibiting suboptimal scores? Is that proportion changing? Comparing the trajectories of individual indicators with the watershed or subwatershed trajectories provides a check on the consistency of trends. Contrary trends would indicate some problems with one or more processes, including assessment models, concepts, or missing indicators.

Sampling theory provides useful guidelines to develop and evaluate sampling designs for estimating status and detecting trends (Cochran 1977; Hansen et al. 1983; Kish 1965; Särndal 1978; Stevens 1994, 1997; Thompson 1992; Urquhart et al. 1998). Major considerations can be summarized as:

- The more sample units the better for estimating status.
- Revisiting sample units across years is best for trend detection (analogous to using paired sampling in experimental designs, such as in paired t-tests).
- About 50 sample units (here, sixth-field hydrologic units or subwatersheds) gives a reasonable description of a regional resource of interest when focus is on estimating frequency distributions (see app. 4 for more detailed discussion).
- Inference precision roughly doubles with each fourfold increase in sample size, other considerations being equal.
- Spreading samples evenly across the region of interest better represents the region than does simple random sampling or clustered sampling.
- Stratification does not necessarily improve the ability to estimate status and detect trends and can sometimes be harmful. Benefits of stratification for aquatic and riparian purposes need to be carefully considered by the analysis team. Possible stratifications include stream size, channel type, land allocation, application of key standards and guides, or percentage of federal land.

These guidelines imply that the best design for estimating status (more watersheds) is not necessarily the best for estimating trends (revisiting watersheds). Balancing the status and trends needs is necessarily a focus of the detailed development of a design. In general, to achieve a balance between the sampling needs for estimating status and trends, panel designs that incorporate patterned revisits to watersheds across years are proposed (Urquhart et al. 1998, Urquhart and Kincaid 1999). These designs incorporate a selection of different watersheds each year for a specified number of years (the cycle) and a repetition of the cycle of annual visits.

Use of Rotating Panel Designs

The relative capacity of different sampling designs to detect trend depends on many factors. Often, the criterion of choice for comparisons is the power of detecting a specified trend if such a trend is present. Power can be expressed as the probability or likelihood of detecting a specified trend; for example, we are 80 percent likely to detect a 3-percent-per-year declining trend after 10 years, if such a trend is truly present. The specifications for evaluating trend include sample size, particular design used, structure of variation, specified number of years, and the potential for type 1 errors. The magnitude of trend is one of the primary determinants of the amount of effort that will be required in trend detection. If large trends are present, almost any design will be able to detect them, even casual observations (without any design). The provincial and regional changes likely to be seen as a result of the Forest Plan, however, will be small and detectable only after decades. For example, one of the important strategies incorporated in the Forest Plan is establishing riparian reserves to protect existing mature riparian vegetation, but perhaps more important, to reestablish mature riparian corridors. Tree growth is slow, so the habitat changes likely to result from revegetation of riparian reserves also can be expected to be slow. Sampling designs for trend detection should be based on those that give us the greatest likelihood for detecting these subtle trends. Such designs also will detect the stronger trends. Panel designs serve this purpose well by balancing sample sizes for estimating status and revisiting sites to detect trend (Urquhart et al. 1998, Urquhart and Kincaid 1999). A rotating panel design used by the Forest Health Monitoring (FHM 1994*a*, 1994b) Program is also being considered by the Forest Inventory and Analysis Program (USDA FS 1993).

Uncertainty

Two kinds of uncertainty are relevant when survey designs are considered; one type is strictly associated with sample selection itself. Two random samples of watersheds drawn from the same target population will not be identical. Sampling uncertainty quantifies the expected random variation arising from the sampling, and it is a predictable outcome of design choices. One of the primary variables affecting sampling precision is sample size. The “rule of four” reflects the effect of sample size on sampling uncertainty and basically says that you need to multiple the sample size by four to get twice the precision. For example, conclusions drawn about the proportion of watersheds in poor condition from a sample of 200 watersheds can be expected to be twice as precise as the same conclusion drawn from a sample of 50. Sampling uncertainty also decreases as a greater proportion of the target population is sampled, roughly as (1-*n*/N) 1/2, where *n* is the number of watersheds in the sample and N is the total number of watersheds in the population (Cochran 1977, Kish 1965, Thompson 1992).

A second type of uncertainty quantifies the variation or repeatability in classifying watersheds into their respective condition classes. It incorporates variation in the indicators used as the basis for watershed classification, part of which reflects natural variation, and the other part reflects the variation in measurement and evaluation. Proper designs can provide the data to estimate the magnitude of this type of variation and its influence on estimates.

Design Options

The AREMP recommends monitoring and assessing a statistical sample of complete watersheds each year drawn from the target population of watersheds across the Forest Plan region. As stated in the general considerations, at a minimum, 50 watersheds should be monitored each year. The basis for making inferences about regional watershed condition based on sampling considerations is more fully detailed in appendix 5. The AREMP proposes several options using a basic panel design to achieve a balance between the sampling needs for estimating status and trends (Urquhart et al. 1998, Urquhart and Kincaid 1999). These designs select different watersheds each year for a specified number of years (the cycle); then, the cycle of annual visits is repeated. For example, the recommended cycle is 5 years. In each of the first 5 years, a different random sample of watersheds would be selected for monitoring and assessment; then in the sixth year, the watersheds selected during the first year would be revisited; during the seventh year, the second-year watersheds would be revisited; and so on. This repeating design can be continued for as long as the information collected is useful.

This basic panel design can be modified, for example, by revisiting some of the year 1 sites in year 2, the year 2 sites in year 3, and so on. Incorporating annual revisits into the panel design allows for earlier trend detection than would be possible with other designs and also allows estimation of some key variance components. The basic design can be modified in other ways. For rotating-panel designs, trend cannot be detected until the third rotation begins. Consequently, for a 5-year design, subtle trends would not be detectable until after 10 years.

The following is a brief description of several possible options, which are by no means exhaustive:

1. Monitor the same set of 50 watersheds each year. This design would be most sensitive to detection of trends, but the relatively limited number of watersheds would provide a relatively imprecise estimate of the status of watersheds across the region.

2. Monitor a different set of 50 watersheds each year for 10 years, then repeat the year 1 watersheds in year 11, the year 2 watersheds in year 12, and so on. This option would produce an evaluation of 500 watersheds over the 10-year span, providing a good estimate of regional status. Trend detection would be relatively imprecise until after 20 years when the third cycle of monitoring would begin. The cycle could be reduced to 5 years, with a resultant drop in precision of the status estimation but earlier trend-detection capability.

3. Monitor as in no. 2. above but remonitor some of the watersheds each year. For example, a different set of 50 watersheds could be selected each year for the duration of the cycle; during each year (except the first), a set of 10 watersheds from the previous year could be remonitored. This strategy would increase early trend-detection capability and allow for estimating important variance components. Yearly sample sizes would be 60, except for the first year. This basic plan could be modified by increasing the number of watersheds included in the base sample, by modifying the length of the cycle, or by altering the number of watersheds remonitored in succeeding years.

Final Design

As can be inferred from the options and suboptions outlined, a myriad of possibilities exists for setting up an ongoing monitoring program. After decisions are made on basic design intensity and format (e.g., indicators to be monitored, the level of precision desired for status, and the interval they are willing to wait before being able to make a trend call), the regional implementation team will need to develop an idea of the inherent variability of core indicators before designing the final sampling regime. This will require a rigorous compilation of data from other studies or the results of the first years pilot test. Prior to having this information, we are forced to rely on general design principles and costs to evaluate alternatives.

After a general review and acceptance of the proposed approach for the AREMP by the Regional Interagency Executive Committee, the regional implementation team will convene a group of survey statisticians to develop a final design, given likely costs and other constraints under which the monitoring will be implemented. The primary costs will be data acquisition (field monitoring or remote sensing) for the indicators chosen for characterizing each watershed and assembling and processing the resulting data. Final design will be tested during the pilot effort. The results of the pilot will compare sampling intensities and subsampling strategies for various indicators. Once these costs are established, the final costs of various sampling strategies can be estimated.

Implementing the Aquatic and Riparian Effectiveness Monitoring Plan

Options and Estimated Costs

Watershed condition assessment can incorporate individual or multiple categories of indicators. Potential categories of indicators include those related to physical habitat, biotic condition, and project implementation (e.g., Best Management Practices or BMPs). The general areas of monitoring emphasis and group of indicators used determine the subsequent application of the results. In many cases, the choice of indicators represents a tradeoff between cost and links to management opportunities. For example, watershed condition assessments based solely on physical indicators and management-related indicators will provide documentation of status and trend of habitat over large spatial and temporal scales. Conversely, incorporating management practices into the assessment method can provide the resolution to evaluate specific project activities that facilitate adaptive management at the local scale. Table 3 describes estimated costs for three options that were considered for evaluating the effectiveness of the ACS:

Option 1 considers attributes of physical condition, habitat, and management-related indicators in the three watershed subsystems; i.e., vegetation composition and structure, road density, and in-channel structural complexity. Option 1 provides the basic resolution necessary to document the status and trends of watershed condition and specific watershed attributes over the Forest Plan landscape.

Option 2 includes all indicators found in option 1 and expands these to include indicators of biotic condition. Option 2 increases the precision and accuracy of watershed condition assessments by developing the link between watershed subsystem indicators and biotic components of the watershed. Options 1 and 2 document the status and trends of watershed condition, providing a means of assessing the effectiveness of ACS implementation in terms of habitat and biota.

Option 3 develops the relation between management activities and watershed condition by including project-level monitoring in the study design. In option 3, the effectiveness of local management activities can be evaluated to assess whether they are having the intended effects. Summarized across the selected watersheds, the distribution of management actions and their respective effectiveness will indicate the types of management actions most commonly implemented, and their relative effectiveness (e.g., compliance with BMPs). This information can provide feedback to local and regional managers about whether the Forest Plan, encompassed by its objectives and the Forest Plan standards and guides, is effective, and would facilitate adaptive management at the local level.

Costs estimates portray optional increases above the recommended core alternative for evaluating watershed condition and habitat indicators. The higher option estimates include an “economy of scale” factor so that the cost increases are not linear. The estimates incorporate findings about costs from the first-year pilot testing of AREMP.

Costs could vary depending on answers to the following questions:

- What degree of precision is desired? A minimum is established in this proposal (50 watersheds per year). If the precision of the estimate is to double, sample size will need to be quadrupled (potentially increasing cost three to four times).
- Can the core set of indicators that AREMP recommends change? Over time, investment in remotely sensed data will cost less than field-acquired data, although the type of information that can be derived from the two sources also differs. Biological data (on fish and macroinvertebrates, specifically) are likely to increase costs significantly.

Table 3—Estimated costs for sampling different numbers of watersheds as part of the Aquatic and Riparian Effectiveness Monitoring Plan

	Estimated cost per year by option		
Number of sixth-field subwatersheds per year	**Core physical indicators (remote sensing and field sampling) at $30k per subwatershed**	**Core physical indicators plus biotic indicators at $42k per subwatershed**	**Core physical and biotic indicators plus project-level (BMP[a]) monitoring at $60k per subwatershed**
		Millions of Dollars	
50	1.5	2.1	3
200	5	7	9
800	15	21	27

[a] BMP = Best Management Practice.

- What is the geographic focus of interest? If high-resolution provincial analyses are desired, approximately 50 subwatersheds per province will need to be assessed over the assessment period. District or forest-scale analyses would require similar levels of effort.
- What organizational structure will be selected? Superficially, it would seem that the lowest costs would come through integration with existing programs. However, quality control and quality assurance become increasingly difficult under a decentralized program. Unusable data sets would hinder monitoring status and trends of watershed condition.

The proposed pilot test will provide additional information to assist agencies in determining the best way of optimizing cost and accuracy of information.

Organizational Structure

The AREMP provides the conceptual framework, sample design, core indicators, and DSM to assess watershed condition across the Forest Plan area. It is recommended that a centralized, dedicated monitoring team be responsible for implementing AREMP. This increases the likelihood that AREMP will be successful because the primary focus of this group will be monitoring, whereas teams in a decentralized organization will have responsibilities other than monitoring. Specific responsibilities of the monitoring team are to:

- Implement AREMP.
- Select sample watersheds from the rotating-panel sample design.
- Develop DSMs with assistance of provincial experts.
- Resolve data collection and management procedures.
- Compile and verify watershed-condition results from each province to derive regional watershed frequency distributions.
- Report regional monitoring results annually.
- Analyze and interpret results.
- Make recommendations to adapt monitoring based on results.
- Advise managers on observed effectiveness of management practices on the ACS.
- Review and validate provincial refinement of the DSM.

Local field unit staff will interact with the centralized team to refine local indicators, give relative weighting to indicators in assessments, provide information on management practices implemented, contribute logistical and technical support to data acquisition and interpretation, and work with the regional advisory team in developing the DSMs.

Tasks To Be Completed as Part of Implementation

1. Delineate sixth-field subwatersheds throughout the region of the Forest Plan.

2. Finalize sampling design and select watersheds to be sampled. This requires a compilation of information, either from previous studies or acquiring field information about the variability of the indicator values across the Forest Plan area. This information will allow the refinement of a sampling design to adequately encompass the variability expected. In addition, it is suggested that only watersheds with 25 percent or greater federal ownership be in the sample.

3. Assemble the centralized team. This group will be responsible for developing sampling protocols, sampling scheme, and completing refinement of the DSMs. A team consisting of a representative from each management and regulatory agency, and members of the development team also should be assembled to oversee completion of the DSM, including review of indicator relations. This team would assemble representatives from each province to develop the conceptual model and the data links for the DSM. The prototype model developed for the Oregon coast province could be used as a starting point for more specific models.

4. Establish connection with required geospatial databases. Successful implementation of AREMP will require developing several layers of supporting geospatial information. Standardized hydrographic, elevation, and roads layers will be necessary to evaluate watershed parameters, such as road-stream interactions, as laid out in this plan. The Interorganizational Resource Information Coordinating Council has prioritized the delineation of the Forest Plan hydrological network at a 1:24,000 scale, but the implementing agencies must support this priority to provide the geospatial infrastructure required by AREMP. Similarly, support for the development of digital elevation models (DEMs) and a common road network layer are needed to achieve the objectives of this plan.

Options for Data Acquisition and Management

Several options for collecting and managing data have been discussed:

- Centralized dedicated team. This approach would maximize data uniformity and database simplicity. Data could be stored in a centralized repository for easy access, analysis, and interpretation as has been done for the state of Oregon stream survey program (Moore et al. 1999). This is the method preferred by the AREMP team, primarily because experience has shown that centralized teams provide the substantially higher quality and the lowest cost per watershed successfully analyzed.
- Existing agency resources. Implement within the current agency monitoring programs. This approach would maximize integration with current agency programs but would require significant modification of protocols and guidelines in those programs to meet the needs for consistent data collection, analysis, and management between agencies and regions. Developing and maintaining the database would require additional work if a centralized database were not used.
- Combined options. Implement with some tasks to be completed by a centralized group, others using existing agency resources through existing monitoring program. This approach should combine desirable features from both of the alternatives. Developing, managing, and maintaining the database could either be centralized or decentralized.

Cost, database management efficiencies, consistency, and quality control should all be factors in deciding on the final approach to data management.

Data Quality Assurance and Quality Control

Quality assurance and quality control (QA/QC) measures for collecting field data and assessing watershed condition should be built into the organizational and implementation structure for the monitoring program. Quality-control measures that would be part of a QA/QC plan include:

- Develop and use standardized protocols for data collection.
- Inspect field data collection techniques.
- Be able to repeat tests of a subsample of watersheds by different crews.
- Document data sources, assumptions, and weighting factors used to develop indicator reference relations.
- Coordinate data collecting and assessing watershed condition by the provincial monitoring teams.
- Document the quality of data and information used in the assessments.
- Evaluate redundancies, responsiveness to disturbance, high among-site/indexing variability, high precision.
- Independently review the results by the regional advisory team.

Results of assessing watershed condition may be provided to outside peer reviewers for comment and review. Objectives of outside review are to validate the information and assumptions used in the process, to gain understanding and support of the assessment results and the process used, and to provide feedback on information and research gaps, with suggestions for future work.

Pilot Tests

Although AREMP describes a viable, comprehensive means for monitoring the effectiveness of the ACS, it was impractical to deal with all the issues that will affect Forest Plan implementation during the development of this comprehensive strategy. Key issues that remain to be addressed include:

- Sampling details and how to coordinate them within the regional landscape (i.e., plan for monitoring constrained and unconstrained stream reaches, federal and nonfederal land, etc.).
- Upslope quantification and how to coordinate and correlate it with in-channel data and the DSM.
- Managing information and how this is coordinated with the AREMP analytical process (including DSM), other Forest Plan monitoring modules, and other programs developing related information.
- What are the advantages and disadvantages of monitoring the various taxonomic groups presented as alternatives in AREMP?
- What are viable approaches for integrating either (1) data that are being collected by land management units or (2) data that the AREMP implementation team would collect independently, into Forest Plan implementation.

Evaluation of these issues should consider at least two facets:

- How does a proposed solution support the AREMP framework (i.e., the conceptual model) and AREMP analyses (i.e., the DSM)?
- What are the costs and associated benefits (in terms of information to support adaptive management) of the proposed solution?

The Effectiveness Management Strategy and Design report (Mulder et al. 1999) addresses the use of pilot testing in developing monitoring projects. Pilot testing is particularly relevant to the need to test alternatives prior to making major decisions. The staged AREMP implementation is consistent with what the monitoring program "framers" recommended and RIEC agreed to. Pilot testing of the AREMP is proposed for fiscal years 2000 and 2001. Experience gained in the region-wide pilot will permit necessary changes to the program before extensive capital has been invested. Results of the pilot should allow AREMP to be implemented beginning in fiscal year 2002.

Specific tasks for the pilot include:

- Assemble and evaluate existing information on selected indicators and determine if the data meet minimum quality-control criteria for subsequent analysis by regional teams. This information will be used by the teams to establish expert-panel criteria for ranking relevant indicator data by how useful they are in defining watershed condition.
- Identify and appoint team members with needed technical skills from the agencies to serve on the provincial teams.
- Develop a DSM based on tasks 1 and 2.
- Refine data protocols and develop information forms and formats; both paper and electronic formats can be tested.
- Collect field data on one watershed per province to test protocols and the logistics for acquiring data. This collection will permit evaluating potential variability between teams and provinces and refining protocols where sampling bias or variability is present. In addition, decentralized and centralized management frameworks will be tested.
- Evaluate two approaches for long-term data management to integrate this information into existing agency data platforms (such as the Forest Service IBM or BLM Unix systems), or to develop independent data platforms, which will provide downloading links so indicator information can be available to existing databases. This test will identify and compare strengths and weaknesses of decentralized and centralized data-management programs.
- Analyze data collected through the pilot by using the DSM developed earlier in the test and write preliminary reports on watershed condition.
- Evaluate (late fiscal year 2000) the pilot and recommend any needed changes. If significant problems are identified, the program and its protocols can be refined early in 2001, and limited pilot testing can address corrections later in the year. This schedule should allow full implementation by 2002.

Land Ownership

Integrated with the ROD's focus on the management of federal lands and waters within the Forest Plan region is the ACS concept that watersheds and landscapes are the appropriate scale for maintaining and restoring ecosystem health. The management of federal lands affects stream networks on both federal and neighboring nonfederal land. In monitoring the effectiveness of the ACS, it is important to assess whole watersheds and not have major parts of these systems devoid of information. On a regional basis, it is anticipated that the subset of locales where the ACS influence is greatest should be associated with the greatest positive changes in the indicators monitored, as well as with improvements in overall watershed condition. Issues of (1) how to select subwatersheds to best monitor the effectiveness of ACS implementation on federal lands and (2) how to treat nonfederal lands within the subwatersheds selected for sampling, are key to implementing AREMP successfully.

Forest Service, Bureau of Land Management, and particularly in provinces such as the Olympic Peninsula, National Park Service properties contribute heavily to the condition of watersheds and stream habitats, but nonfederal lands also have strong influences on aquatic and riparian ecosystem condition throughout the region. Connectivity of streams and riparian corridors means that the effects of management activities can extend great distances both upstream and downstream, well beyond jurisdictional boundaries. Relatively few watersheds sampled by using the recommended sixth-code subwater-sheds are likely to contain only federal land. Consequently, a strategy to develop a whole-watershed condition context is required to provide meaningful information on AREMP indicators within sampled watersheds. Information from other watersheds near those selected for sampling also may provide important context for adequate monitoring of ACS effectiveness.

For field-level sampling of many stream and riparian subsystem indicators, access to nonfederal lands is likely to require extensive coordination with landowners. The approach recommended in this Forest Plan is similar to that now widely implemented the procedures outlined in the Federal Guide for Watershed Analysis (USDA and USDI 1995). Like watershed analysis, AREMP is intended to work cooperatively with nonfederal landowners or watershed groups to obtain information on whole watersheds. Field units of the land management agencies will be essential to facilitating coordination with nonfederal landowners and organizations. Voluntary participation is encouraged, as is attention to the proprietary nature of any sensitive information collected from nonfederal portions of watersheds. Forest Inventory and Analysis, the National Wetlands Inventory, EMAP, and the USDC Bureau of the Census provide examples of federal monitoring programs where sensitive ecological information from private sources is used successfully. Where it is impractical to obtain new information from field sampling, the use of publicly available information (particularly from maps or remote imagery) can provide a means of completing the information base from nonfederal portions of sampled watersheds.

The treatment of lands with different ownerships is intercorrelated with geomorphic reach type and location within the stream network, and reinforces the importance of obtaining information from all portions of sampled watersheds. If the unconstrained reaches (i.e., reaches with gradients <2 percent and wide valley floors) cross nonfederal lands that are lower in the network, they will be particularly critical to watershed condition assessments. Unconstrained reaches are natural deposition zones and, as such, are susceptible to impact of land management activities (Gregory et al. 1989). Where such reaches occur lower in the stream network, they will integrate the impacts of upstream land management activities, and their condition is often a surrogate for overall watershed condition. Constrained reaches are more resistant to change from human or natural disturbances than are unconstrained reaches (Gregory et al. 1989). Consequently, they do not integrate the condition of the watershed as well as unconstrained reaches and thus, are less meaningful in assessments of watershed condition.

An important determinant in recommending a watershed monitoring strategy is to sample subwatersheds with varying degrees of ACS implementation to gauge the influence of the strategy. There are places within the Forest Plan region where the federal influence is nil or insignificant to warrant gathering information on the effectiveness of the ACS. At the other extreme, higher portions of systems have large blocks of federal ownership, with complete watersheds and constrained reaches where detecting ACS effects will be difficult. If the screen for the percentage of nonfederal lands within monitored subwatersheds is set too low, sampling will be biased toward complete watersheds in headwater situations and away from composite watersheds lower in the monitored systems. This would result in serious losses of critical information from places where the effects of ACS implementation should be greatest.

Over half of the watersheds (including nearly all Bureau of Land Management land) would be unavailable for analysis if the federal land percentage threshold is set at 50 percent (Regional Ecosystem Office, GIS analysis of fifth-hydraulic unit watersheds in western Oregon). Therefore, it is recommended that watersheds with ≥25 percent federal ownership be used as the population from which subwatersheds are randomly selected. This will emcompass the majority of watersheds with federal ownership, including most where an ACS management effect can be expected. It also will screen out lands where there is little federal land. Although this strategy for determining ACS influence is recommended, pilot testing of these criteria also is advised to refine the percentage of federal land threshold and the sample selection process. To carry out this approach, it will be incumbent on the implementing agencies to develop a unified GIS layer covering sixth-field watersheds throughout the Forest Plan region.

Once subwatersheds are selected for monitoring, there is also a question of how to develop an information base from the entirety of lands sampled. With the realization that mapped or remotely sensed information should be available for characterizing most upslope (and some channel and riparian) subsystem indicators across whole watersheds, there are many methods that collectively could be used to get complete sets of indicator data from nonfederal parcels in a nonintrusive manner. States, tribes and, in some cases, commercial interests have shown a willingness to participate in cooperative ventures to provide mutually beneficial monitoring information from nonfederal lands. Federal land management units often have working relations with private landowners for cooperative data sharing. An “over-sampling” approach is recommended as a means of developing an adequate set of monitoring locales. This approach would use a large set of randomly selected locations, from which those where access is impractical could be dropped with samples from remaining locales available to assure an adequate random sample.

The objective of sampling whole watersheds is to develop a robust set of data on ACS implementation from a large sample (250 over 5 years) of subwatersheds. Although AREMP can provide insight about the effects of management within watersheds, the basic intent of the Forest Plan is to evaluate a large aggregation of watersheds that will facilitate inference about the effectiveness of the ACS across the Forest Plan region. The accumulation of data on indicators of condition from watersheds with various land ownership patterns is required for insight about the effectiveness of the ACS objectives at this scale.

Many options exist for gathering information from whole watersheds. Although it would be desirable, not all options require ground-based data from nonfederal portions of sampled watersheds. Evaluating all parts of sampled watersheds, however, will result in the most meaningful assessment of watershed condition. Options that provide a means for depicting watershed, and stream, condition on all portions of sampled watersheds are best suited for monitoring the effectiveness of the ACS. Viable options are outlined in table 4.

Links To Management and Other Monitoring Programs

Adaptive Monitoring

Management of ecosystems in an adaptive manner requires that the monitoring of the systems monitored also be adaptive (Ringold et al. 1996). Guidance for implementing the effectiveness monitoring program recommends the production of “interpretive reports” at 5-year intervals (Mulder et al. 1999). Provided that this guidance is followed, opportunities for improving the monitoring process will occur over the iterative course of AREMP implementation. Opportunities for improving the monitoring program can be used at key intervals when monitoring results are reported. Federal agencies will cycle through analysis of the same watersheds at a selected interval (recommended every 5 years). Observed information deficiencies and data gaps from the first iteration will be used to improve monitoring efforts and to coordinate between management entities. Both rigor and statistical validity will generally increase over the course of monitoring cycles, and the information and understanding developed in previous years will refine subsequent monitoring efforts.

Adaptive Management

Adaptive management is a central theme of the Forest Plan, including the ACS. As with other forms of Forest Plan monitoring and research, using new information to adapt management strategies is implicit in the successful implementation of AREMP. As AREMP implementation contributes to knowledge about ACS effectiveness in restoring stream and riparian habitat and watershed condition, decisionmakers will have a chance to redirect management in ways that enhance this strategy’s effectiveness.

Adaptive management applies the concept of experimentation to the design and implementation of natural resource strategies by testing clearly formulated hypotheses about the response of the system exposed to the management (Lee 1993). Hypotheses may be tested empirically by using spatial or temporal controls to evaluate resource responses or through system simulation models based on our understanding of ecosystem processes (Walters 1997). Hypothesis testing informs an iterative feedback loop whereby ecosystem responses to management actions are monitored or predicted and those results used to modify management actions (Holling 1978, Walters 1986). Monitoring is intended to assess the effectiveness of management action in maintaining or enhancing ecosystem integrity and fitness. Monitoring strategies are integral to active adaptive management strategies because they provide the feedback to adjust further experimentation. The degree of resolution of monitoring should reflect ecosystem management objectives, the scale of treatments, and spatial and temporal scales of effects.

The three basic adaptive management strategies that have been described are deferred, passive, and active (Walters and Holling 1990). Selection of an appropriate strategy depends largely on the amount of uncertainty associated with the system response and the desired timeframe over which the adaptive management loop will operate. Although in each of these strategies management actions are modified based on an evolving understanding of cause-and-effect relations, the rate at which our understanding evolves and the degree to which actions are accountable to management goals increases from deferred, to passive, to active adaptive management. Under deferred adaptive management, no action is taken until systems are sufficiently understood to predict outcomes with fairly high certainty. Passive adaptive management is based on observation and adjustment based on the assumption that the current management trajectory is correct (Walters 1986). Management actions are not viewed as experimental but as correct until proven otherwise. Passive adaptive management presents difficulties in that ecosystem response is determined for the entire management strategy and, as a result of the scale

Table 4—Advantages and disadvantages to including monitoring of private lands as part of watershed assessment processes of the proposed effectiveness monitoring plan for aquatic and riparian ecosystems covered by the Northwest Forest Plan

Option	Advantange	Disadvantage	Comments
On a cooperative basis, monitor federal and nonfederal lands in sixth-field subwatersheds selected as part of sample	• Allows entire subwatershed to be sampled in the same manner • Will allow analysis of the aggregate effect of the ACS[a] in the Northwest Forest Plan region	• Approach to monitoring nonfederal portions would need to be worked out and could require extensive time and resources to find and develop cooperators	• Would result in the best information for monitoring the condition of whole watersheds • Good precedent for cooperative watershed management
Use remote sensing and mapping for information on nonfederal lands in sampled subwatersheds where ground-based data are impractical to obtain	• Provides important information on all lands within monitored watersheds • Permits analysis of percentage of federal land ownership and other remotely sensed indicators	• Information would not be consistent across land ownerships • Lack of instream information from nonfederal land segments would limit inference	• Although many resources are available, specific procedures remain to be worked out • More emphasis on modeling required to work out instream-upslope habitat relation
Only sample sixth-field subwatersheds that are entirely or almost entirely within federal ownership	• Reduces dependence on nonfederal participation	• Will have a very small popula- from which to draw sample, resulting in a small sample size • Will be restricted mostly to Forest Service and National Park Service lands	• May be difficult to detect an ACS[a] management effect • Bias would not allow the best inference about the various land ownerships represented in the region
Sample seventh-field hydrologic units	• Increases likelihood that the majority of monitored watersheds would be federal • Reduced dependency on nonfederal land • Smaller unit to sample	• Agencies have little experience planning and operating at this scale • Less chance of detecting ACS[a] influence at this scale	• Would need to delineate watersheds in order to establish those to be sampled; no plans to map watersheds at this scale • May be a good strategy for selecting stream reaches for sampling in conjunction with remote sensing of larger watersheds

ACS = Aquatic Conservation Strategy.

of implementation, risks of failure and loss can be high. In contrast, active adaptive management is a process whereby each goal and management action or practice is an experiment. This process tests hypotheses to maximize short-term modifications in management and long-term definition of goals. Alternative management practices can be evaluated for single management emphasis, and multiple hypotheses can be tested simultaneously. Active adaptive management accelerates an evolving understanding of cause-and-effect relations and consequently provides more rapid feedback to modify management actions.

The AREMP, as proposed, will facilitate passive adaptive management. It is intended to characterize the temporal response of watershed condition (status and trend) to the Forest Plan ACS. In the absence of specific links to the cause-and-effect relations between ecosystem response and management actions, the AREMP can only evaluate the degree and rate that the ACS improves watershed condition over time. Currently, after two data-collection cycles, sufficient data will be available to analyze results and display trends in watershed condition within the Forest Plan boundaries. However, if the AREMP is intended to identify components of the Forest Plan management contributing to observed performance and additionally inform modification of these proximate management components, a greater focus on the cause-and-effect relations inherent to the active adaptive management process is necessary. Additional information needed to explain these results will include biophysical data to characterize each watershed (such as soils, geology, and climate), socioeconomic data (land ownership and land allocation), and management data (implementation and effectiveness of the ACS management practices). This information will provide the basis for interpreting observed spatial and temporal variation in the assessment data, and feedback to managers on the effectiveness of Forest Plan actions.

As discussed in the sampling overview, a rotating panel design is based on returning to a series of representative watersheds to obtain a trend for the region as a whole. If sampled watersheds are expected to be targeted for special management actions because of their role in monitoring, then a rotating panel design that includes planned revisits to a watershed will not retain its representativeness and cannot be recommended. However, if the results of the monitoring are used to adaptively define general management principles that will be applied to all watersheds, or specific categories of watersheds, i.e., those within an individual biophysical province, or land management category, then the sample will retain its representativeness.

Monitoring of Management Practices

Although people often think of adaptive management as “learning by doing,” this omits the necessity of experimentation with complex systems to learn from them. Adaptive management is based on a continuing process of action based on planning, monitoring, evaluation, and adjustment. This process, if adequately designed and effectively implemented, will evaluate the effect of management practices (e.g., standards and guidelines) on biological resources and identify whether and how those actions must be modified to meet desired objectives. Because adaptive management potentially imposes change in direction as new information becomes available, it should result in the improvement or refinement of management practices over time (Christensen et al. 1996).

Monitoring is the key component of adaptive management. In this context, monitoring refers to the data gathering and analysis focused on management expectations and is designed to test the success and efficacy of management actions. To provide feedback necessary to fuel the adaptive management strategy, FEMAT (1993) identified the general objectives of monitoring under the Forest Plan as (1) determine if BMPs have been implemented; (2) determine the effectiveness of management practices at multiple scales, ranging from individual sites to watersheds; and (3) validate whether ecosystem functions and processes have been maintained as predicted.

There are two general approaches to monitoring the effectiveness of BMPs: (1) evaluate the aggregate effect of the entire set of BMPs on achieving the goals and objectives, and (2) evaluate the effect of individual BMPs (MacDonald et al. 1991). The results of the two approaches differ in how they can be interpreted and applied. Evaluating the BMPs as a set establishes the aggregate effectiveness of the implemented BMPs in trending toward the desired goals and objectives. This approach, however, does not focus on links between individual management actions and specific indicators of ecosystem response and does little to assess the efficacy of individual management practices on specific indicators of ecosystem response. Consequently, evaluating the effectiveness of BMPs as a set will establish the degree that the management strategy is trending toward stated objectives over time at larger spatial scales but provides little information on the link between specific actions and ecosystem response necessary to fuel the adaptive management strategy. Conversely, monitoring the effectiveness of individual BMPs permits assessment of individual management actions that increases our understanding of the link between specific actions and ecosystem response. Additionally, because of the smaller spatial and temporal focus of the evaluation, it is possible to select specific indicators of ecosystem response that could provide an early estimation of whether individual BMPs are effecting sufficient change to achieve specific goals and objectives.

The proposed AREMP monitoring strategy will allow for evaluation of the efficacy of the Forest Plan management strategy as a whole, treating the overall aggregation of management practices. Options for evaluating the contribution of individual BMPs to achieve desired trends and objectives will need to be selected to refine understanding of the links between management action and ecosystem response at finer spatial scales. For example, the observed trend in watershed condition within the Forest Plan boundaries may not be evident for 20 years. Absent the monitoring of BMPs, the first opportunity to modify the management strategy will be structured around 20 years of data at a scale limited in its usefulness in identifying causal mechanisms.

Understanding fine-scale links between management and ecosystem components is critical to our ability to partition effectiveness between the components of the strategy and identify and refine individual BMPs in a way that effectively guides adaptive management. Additionally, fine-scale evaluations of links between BMPs and specific sensitive ecological indicators could provide early indication of whether management actions are moving the Forest Plan area in the appropriate direction. Without fine-scale analyses that focus on the cause-and-effect relation between BMPs and ecological resources, monitoring and evaluation (1) cannot provide early indication of whether we are on track with our objectives, (2) will be qualitative, (3) will be a speculative (deductive) process, and (4) may result in modifications to BMPs not informed by new knowledge.

Under AREMP, our ability to evaluate the effectiveness of the Forest Plan in aquatic ecosystems will increase as the database becomes larger, and concurrently, so will our capacity to evaluate opportunities for adaptive management. The AREMP can be used to identify the status and trend of watershed condition across multiple spatial scales, i.e., the Forest Plan area, individual biophysical provinces, and management categories, i.e., key watersheds, percentage of federal ownership, etc. Within spatial scales and management categories, AREMP can be used to track the status and trends of the three watershed subsystems as well as the attendant individual habitat indicators, which in the aggregate define condition. Status and trend in the condition of watersheds within specific geographic boundaries or management categories can be evaluated against regional means, other provinces, or other appropriate metrics.

A determination that watershed condition is trending in either an inappropriate direction or at an inappropriate rate over the Forest Plan area, within a biophysical province, or management category, could trigger exploratory examinations to deduce cause. These finer scale analyses would be used to identify first watershed subsystems and then component indicators that are identified by the DSM as constraining watershed condition. Identified indicators can then be evaluated for sensitivities to specific management practices. Modification of identified BMPs and implementation across the relevant spatial or management delineation will complete the adaptive management loop.

Fine-scale monitoring necessary to evaluate the effectiveness of specific BMPs could be incorporated into the existing monitoring framework. Each BMP is in essence an experimental hypothesis describing the relation between management action and ecological response. These hypotheses are based on our current incomplete scientific understanding of ecosystem processes and therefore have inherent uncertainties. Fine-scale studies would evaluate these hypotheses by focusing on the ecological response to implementing individual BMPs. These studies would determine the extent that management actions were moving affected ecosystem indicators toward desired future trends and trajectories. Fine-scale analyses of individual BMPs if based on a rigorous statistical sampling design over a stratified landscape could facilitate partitioning effectiveness between individual BMPs. Partitioning effectiveness, coupled with the refined mechanistic relations between management action and environmental response derived from these analyses, would facilitate more rapid BMP revision and implementation over a spatial scale sufficient to meaningfully inform the adaptive management strategy.

Studies evaluating links between BMPs and ecological indicators could be located on regional reference sites where management actions could be applied as experiments. Alternatively, adaptive management watersheds have been identified as appropriate areas dedicated to the objective of developing and testing new approaches to achieving, in part, new approaches for achieving ecological goals including revision of the Forest Plan standards and guides (USDA and USDI 1994b). The actual studies could be completed through various approaches including paired watershed, repeated measures, or potentially “space-for-time” designs.

The USDA, Pacific Southwest Region, BMP Effectiveness Monitoring Evaluation Program EMEP; (USDA FS 2000) is an example of a BMP monitoring program that could serve as a template for monitoring the effect of management actions on biological resources. This region-wide water quality monitoring effort is intended to test both implementation and effectiveness of BMPs in protecting the beneficial uses of water, including aquatic habitats. The program integrates three components: on-site evaluations (evaluate the implementation and effectiveness of individual practices, such as road drainage and streamside zones); administrative evaluations (subjective group evaluations of sets of practice on a project area); and in-channel evaluations (downstream attempts to detect cumulative effects). This set of protocols needs to be evaluated more carefully before concluding that it can be made compatible with AREMP.

Implementation Monitoring of the Forest Plan

A basic assumption of AREMP is that the Forest Plan is being implemented as envisioned in the ROD. The full potential of AREMP will be realized only if monitoring data can be viewed in the context of how Forest Plan objectives and components are being implemented. Information about implementation of the Forest Plan will be derived principally from the watershed-scale analyses conducted by the land management agencies as part of the Implementation Monitoring (IM) program.

Currently, IM information is collected on fifth-field watersheds from each of the 12 provinces making up the Forest Plan region. The watersheds selected as part of IM must be attuned to the needs of the EMEP program and vice versa. As AREMP is implemented, watersheds selected for IM should correspond to those selected for monitoring in AREMP. Simply knowing the number of projects within a watershed that have been evaluated by using the standards and guidelines contained in the Forest Plan will not be enough. Quantitative information on implementation of each of the Forest Plan objectives and components will be required to fully evaluate their effectiveness in sampled watersheds.

An example of data required to assure that the AREMP evaluation process achieves its potential to deliver information for adaptive management is provided by a recent Regional Ecosystem Office analysis of the attainment of the ACS objective pertaining to roads in key watersheds. To be valuable as input to AREMP analyses, IM outputs should include information on total system and nonsystem road mileages, changes in road mileage over time, and road mileage decommissioned and restored. Similar details should be provided on implementing each of the ACS objectives and strategies.

Watershed Analysis

Monitoring the effectiveness of watershed analysis will be dependent on efficient, integrated implementation of AREMP and IM at the watershed scale. It also will be dependent on some (not necessarily complete) overlap of the watersheds sampled for IM and AREMP. Implementation monitoring is expected to continue tracking the implementation of watershed analysis as described in the ACS and the "Federal Guide for Watershed Analysis" (USDA and USDI 1995). Therefore, it is expected that the IM program will produce a database containing information on the number of watersheds where watershed analysis has been completed, the level of adherence to ACS provisions in sampled watersheds, and the degree to which recommendations for watershed enhancement, as identified in watershed analysis, have been accomplished. The database on watershed analysis implementation can be paired with AREMP databases on watershed condition, as well as databases on individual indicators, for evaluating the effectiveness of watershed analysis in achieving the objectives of the ACS. As with other watershed condition and indicator analyses, the point is not to evaluate the effectiveness of the ACS implementation within individual watersheds but to conduct regional analyses of the correspondence of ACS implementation and its effectiveness. The degree to which watershed analysis has been implemented across the Forest Plan region is thus anticipated to be one aspect of the ACS with which good or improving condition of aquatic and riparian systems will be associated.

Other Effectiveness Monitoring Programs

The success of AREMP will be partially dependent on its integration with other Forest Plan monitoring modules. For example, the watershed condition assessments described in this Forest Plan depend on information on vegetation coverage being developed for the LSOG effectiveness monitoring module (Hemstrom et al. 1998). Likewise, monitoring information on aquatic habitat and biota is likely to be useful in the analyses that will be conducted as a part of the biodiversity effectiveness monitoring module, which is in the process of being developed. Although much of the aquatic and riparian monitoring information will be collected independent of other monitoring modules, interdependencies will be critical when watershed condition is analyzed. Coordination of the actions of the AREMP module lead and the AREMP Regional Advisory Team with Regional Monitoring Team functions in database management, quality assurance and control, and data analysis are important to achieving the objectives of this Forest Plan.

Other Ongoing Monitoring Programs

Many other monitoring efforts, either ongoing or in the process of being developed, are concentrated on aquatic and riparian resources in the range of the Forest Plan. In addition, similar efforts in adjoining areas have a similar focus. To the extent possible, these efforts should be coordinated and linked to assure as much commonality as practical, given the different management goals and jurisdictions. Examples of similar efforts are those being designed in the Sierra Nevada and the interior Columbia basin by the Forest Service, EMAP, Washington State Timber, Fish and Wildlife Monitoring Program, and Oregon's Plan for Salmon and Watersheds.

Other Decision Processes

Results from AREMP will undoubtedly affect decisions beyond those for federal land management planning. With the easy electronic accessibility of information, predicting all possible applications of these data or the decisions they may affect is difficult. An obvious federal decision link is with Endangered Species Act listing. In carrying out their responsibilities to determine whether species should be listed as threatened or endangered under the act, the U.S. Fish and Wildlife Service and National Marine Fisheries Service are required to consider threats to the species' habitats and the adequacy of existing regulatory mechanisms. Watershed status and trend assessments at regional, provincial, basin, and watershed scales may provide relevant information for the U.S. Fish and Wildlife Service and National Marine Fisheries Service evaluation of habitat conditions for aquatic- or riparian-dependent species should they be reviewed for protection under the act. Similarly, the results of effectiveness monitoring of management practice may prove useful to the regulatory agencies when they evaluate the adequacy of existing mechanisms for regulating aquatic and riparian species.

Predictive Model Development

The proposed AREMP relies on the regular and extensive monitoring of various indicators. Here we propose a process that has the potential to make aquatic and riparian monitoring more efficient and cost-effective, the development and use of predictive models. Predictive models would rely on measures of key upslope indicators that have been shown to be empirically (or theoretically) related to key riparian or channel habitat or biotic attributes. It would be less expensive to measure a more limited set of key upslope indicators (e.g., through remote sensing), making the overall process of monitoring much more efficient than complete reliance on extensive ground-level monitoring.

The development of predictive models and their incorporation into the routine monitoring process is foreseen as primarily a research task. Model development, however, should be closely linked with the ongoing monitoring program to improve the objectivity with which watersheds will be evaluated. One way of maintaining this link will be to provide assurances that AREMP indicators cover those parameters most likely to "drive" predictive models of aquatic and riparian ecosystems. Aquatic and riparian system models are envisioned as using upslope factors such as vegetation conditions, amount and character of roads, riparian vegetation conditions, and relating these characteristics to in-channel conditions, such as amount of wood, number of pools, water temperature, etc., and to biotic conditions such as fish populations. The data for model development will be obtained from the AREMP indicators and other available sources, particularly the data on vegetative conditions generated by the LSOG program. Because of the wide diversity of ecological conditions in the area of the Forest Plan, it is likely that a model will have to be developed for each physiographic province or, in some cases, for subprovincial areas.

Model development supporting the implementation of the AREMP can benefit from a number of related efforts. A prototype model of relations between in-channel and upslope features and the ecological conditions of watersheds in the Oregon coast is being developed by the Aquatic and Land Interactions Program of the USDA Forest Service, Pacific Northwest Research Station. Preliminary results are promising. Multivariate techniques and decision tree analysis has been used to predict the status of fish populations from physical features and conditions of watersheds considered in an assessment of the upper Columbia River basin (Lee et al. 1997). The models developed in this effort found strong relations between the status of the fish populations and physical features and conditions of the watersheds. Botkin et al. (1995) developed relations between condition of fish populations and the vegetative conditions of watersheds in the Oregon coast. Further development along such lines will be required to test and put into place the use of models to provide proxy information for monitoring aquatic and riparian systems.

At least initially, model predictions will need to be ground-truthed. Aquatic ecosystem conditions in a watershed will be first predicted by using models and then verified by direct observation and examination of available supporting data through the AREMP indicators. People most familiar with the watersheds will also be consulted to determine whether model predictions match their assessments. Over time, the intent is to reduce the reliance on assessments based on direct indicator measurement and shift to an increased reliance on predictions, relying on less intensive monitoring to verify the models. The degree to which this is done over the long term will depend on the accuracy and utility of the model predictions.

Research Needs

Research will play an important role in implementing, validating, and refining the AREMP process and especially the DSM. Expected tasks include:

- Developing predictive models and incorporating them into routine monitoring.
- Verifying and refining the relations between the parameters identified in the DSM.
- Validating the evaluations of the condition of watersheds.
- Determining the relations of factors within composite watersheds for assessing watershed condition.
- Determining the relation between current biotic measures and assessed watershed condition.
- Refining biotic protocols.
- Developing coarse-scale indicators of watershed condition that may replace finer scale parameters used in the initial phase of monitoring.
- Conducting exploratory data analyses to enhance sampling efficiency and inference capability from monitoring data.

The proposed watershed condition assessment relies on the regular and extensive monitoring of various indicators. Fulfilling the AREMP research agenda is partly designed to make the assessment of watershed condition more efficient and cost-effective. For example, predictive models would rely on measures of a smaller set of key indicators shown to be empirically or theoretically most strongly indicative of watershed condition. Data from this monitoring program, combined with ongoing research, will provide the basis for developing predictive models.

Research efforts should include scientists from all the agencies concerned with AREMP. Scientists should be encouraged to initiate joint studies with colleagues from other agencies and pool resources to reduce costs and integrate the needs of the various agencies.

English Equivalent

When you know:	Multiply by:	To find:
Meters (m)	3.28	Feet
Kilometers (km)	.6125	Miles
Square kilometers (km^2)	.386	Square miles
Mile (mi)	1.609	kilometers
Square mile (mi^2)	2.590	Square kilometers

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Appendix 1: Objectives of the Aquatic Conservation Strategy

The Aquatic Conservation Strategy (ACS) is comprised of four components that, along with the late-successional reserves, are designed to operate together to maintain and restore the productivity and resiliency of riparian and aquatic ecosystems. Its four components are:

- **Riparian reserves** are lands along streams and unstable and potentially unstable areas that provide the various ecological processes and functions that influence the productivity and integrity of aquatic ecosystems and, because of this, are where riparian-dependent resources receive primary emphasis and where special standards and guides direct land use.
- **Key watersheds** are a system of large refugia comprising watersheds crucial to at-risk fish species (Tier 1 watersheds) and providing sources of high-quality water (Tier 2 watersheds). A network of 143 Tier 1 watersheds were designated to ensure that refugia are widely distributed across the landscape; 21 Tier 2 watersheds were designated to serve as important sources of high-quality water. Key, ecologically intact watersheds were assumed to have the best remaining fish habitats and populations, and their protection was the short-term focus of the ACS. Key, but presently degraded watersheds were considered to have altered ecological processes and therefore less likely to be productive habitat for fish. The degraded key watersheds were assumed to be able to recover quickly under a restoration focus.
- **Watershed analysis** is a systematic procedure for characterizing and evaluating geomorphic and ecologic processes operating in specific watersheds. It is designed to guide development of management practices that meet or do not retard attaining the ACS's objectives in specific watersheds.
- **Watershed restoration** is a comprehensive, long-term program to restore watershed and aquatic ecosystem health, including the habitats supporting fish and other aquatic- and riparian-dependent organisms. Three restoration priorities are identified: preventing and controlling road-related run-off and sediment production, restoring riparian vegetation, and restoring in-stream habitat complexity.

The nine specific ACS objectives are:

1. Maintain and restore the distribution, diversity, and complexity of watershed and landscape-scale features to ensure protection of the aquatic systems to which species, populations, and communities are uniquely adapted.

2. Maintain and restore spatial and temporal connectivity within and between watersheds. Lateral, longitudinal, and drainage network connections include floodplains, wetlands, upslope areas, headwater tributaries, and intact refugia. These network connections must provide chemically and physically unobstructed routes to areas critical for fulfilling life history requirements of aquatic and riparian-dependent species.

3. Maintain and restore the physical integrity of the aquatic system including shorelines, banks, and bottom configurations.

4. Maintain and restore water quality necessary to support healthy riparian, aquatic, and wetland ecosystems. Water quality must remain within the range that maintains the biological, physical, and chemical integrity of the system and benefits survival, growth, reproduction, and migration of individuals composing aquatic and riparian communities.

5. Maintain and restore the sediment regime under which aquatic ecosystems evolved. Elements of the sediment regime include the timing, volume, rate, and character of sediment input, storage, and transport.

6. Maintain and restore in-stream flows sufficient to create and sustain riparian, aquatic, and wetland habitats and to retain patterns of sediment, nutrient, and wood routing. The timing, magnitude, duration, and spatial distribution of peak, high, and low flows must be protected.

7. Maintain and restore the timing, variability, and duration of flood-plain inundation and water table elevation in meadows and wetlands.

8. Maintain and restore the species composition and structural diversity of plant communities in riparian areas and wetlands to provide adequate summer and winter thermal regulation, nutrient filtering, appropriate rates of surface erosion, bank erosion, and channel migration and to supply amounts and distributions of coarse woody debris sufficient to sustain physical complexity and stability.

9. Maintain and restore habitat to support well-distributed populations of native plant, invertebrate, and vertebrate riparian-dependent species.

Appendix 2: Directions From Research Executives for Development of the Aquatic and Riparian Effectiveness Monitoring Plan (AREMP)

USDI
Geological
Survey

USDA
Forest
Service

U.S.
Environmental
Protection Agency

MEMORANDUM

DATE: March 20, 1998

TO: Designee

THRU: Supervisor

THRU: Regional Executive

FROM: John D. Buffington, Western Region Chief Biologist, USGS-BRD
Thomas J. Mills, Station Director, FS-PNW
Thomas Murphy, Director, EPA-ORD

SUBJECT: Nomination to Aquatic/Riparian Effectiveness Monitoring Work Group

This memorandum is to confirm your assignment as a member of the work group to produce an Effectiveness Monitoring Plan for aquatic and riparian ecosystems within the Northwest Forest Plan region. The research agency executives have taken the responsibility for directing the production of this plan and for endorsing a scientifically credible plan to the Intergovernmental Advisory Committee (IAC) and Regional Interagency Executive Committee (RIEC). Direction on our expectations with respect to the Plan, and on the participation of work group members, may be found in the enclosed guidance.

We expect that you will need to devote approximately 30 percent *(Karl Stein - 70% for chair)* of your time to this effort over approximately the next 12 months. Your point of contact will be Karl Stein chair of the A/R Monitoring Work Group. Dave Busch of the Research and Monitoring Group is also helping to coordinate A/R Monitoring Plan development.

This program has great potential to influence the way that aquatic and riparian ecosystems are assessed throughout the Pacific Northwest. We wish to express our gratitude at the outset for your participation in this important effort.

cc:
Karl Stein
Dave Busch
Dan McKenzie
Don Knowles

Enclosure

1096/ly

Effectiveness Monitoring of Aquatic and Riparian Ecosystems: Guidance from the Research Agency Executives for Planning an Interagency Program

Guidance for Developing an Aquatic Riparian Monitoring Plan

This document is to serve as the vehicle for providing direction from the Research Agency Executives (RAEs) on the completion of an Effectiveness Monitoring (EM) Plan for Aquatic and Riparian (A/R) ecosystems within the Northwest Forest Plan Northwest Forest Plan region. This guidance stems partly from a process wherein the affected organizations had an opportunity to express their expectations for the A/R Monitoring Plan, based on agency policy, practices, and requirements (Regional Ecosystem Office November 13, 1997, memorandum). The following paragraphs are intended to describe the bounds within which A/R monitoring alternatives should be developed, as well as the targets toward which this effectiveness monitoring effort should be directed.

The ultimate objective of the A/R EM Plan is to evaluate the effectiveness of the Aquatic Conservation Strategy (ACS) in restoring the ecological health of watersheds and aquatic ecosystems contained within them (S&Gs, page B-9). This does not mean that indicators and protocols need to be measured separately for each of the nine ACS objectives. A suite of indicators, biological and physical, will be used to assess the effectiveness of the ACS in achieving its goal. Opportunities to integrate protocols or indicators from other A/R programs (e.g, those for water quality monitoring) should be evaluated. Similarly, opportunities to integrate with other Forest Plan effectiveness monitoring programs should be evaluated (e.g., late-successional and old-growth associated vegetation mapping for landscape and connectivity ACS objectives). Individual protocols or indicators for the Forest Plan A/R program may well apply to several ACS objectives (e.g., if a sediment metric is considered appropriate by the A/R work group, it could potentially help address ACS objectives relating to monitoring physical integrity, water quality, sediment, and habitat). The parameters used in syntheses of watershed condition also may vary geographically.

The A/R work group should draft monitoring plan alternatives that are based at the watershed level, as best defined by the A/R work group. Monitoring should be designed so that data will be aggregated for analysis and reporting at the Forest Plan-region scale. Regional analyses are expected to produce a statistical distribution of data indicating watershed condition. Opportunities should be sought for stratification of the monitoring structure at the provincial level.

While the A/R monitoring plan must have as its basis an evaluation of the results of Forest Plan land management actions, monitoring conducted under related initiatives should be viewed as an opportunity to broaden this basis, or achieve Forest Plan objectives with reduced effort or cost. It is expected that the integration of monitoring efforts will be carried out without awaiting the development by other programs of new protocols or indicator sets that might eventually be common among related monitoring efforts. The A/R monitoring plan should not be so dependent on other initiatives that failure of monitoring conducted under a related initiative would result in a catastrophic failure of the Forest Plan A/R monitoring program. Deriving from agency agreements on other initiatives that include provisions for aquatic and riparian ecosystem monitoring, the plan is expected to identify linkages to related initiatives and should include alternatives for integrating with these initiatives where it would benefit the Forest Plan A/R monitoring program. To assist this process, the Research and Monitoring Group (RMG) has provided a list of potentially related initiatives to the A/R work group for their use. The schedule for plan development will include a midpoint review by the RAEs of the type and intensity of the planned integration with related monitoring initiatives.

Aquatic and riparian systems on federal lands can be affected by nonfederal properties, and vice versa. There is an expectation that opportunities for database consolidation, establishment of common protocols, and comparative analyses will be exploited among Forest Plan and non-Forest Plan monitoring efforts. The A/R work group should continue development of a set of monitoring alternatives that offer a high degree of cooperative opportunity with respect to evaluating A/R ecosystem status and trends. Similar to the approach taken in the Watershed Analysis Guide, part of this charge is to encourage the incorporation of data from nonfederal lands where cooperators are willing to provide it, or where it is otherwise publically available.

Aquatic and riparian monitoring differs from effectiveness monitoring of northern spotted owl and marbled murrlet (*Brachyramphus marmoratus*) in that the latter are explicitly oriented toward individual species and deal with relationships that could, therefore, be considered less complex than those for which A/R ecosystem monitoring is responsible. For these reasons, it is recommended that the A/R monitoring plan be developed and implemented in stages. It will **first** be important to clearly identify the important habitat-population relationships that are fundamental to a conceptual framework linking watershed condition and biotic factors within the context of the ACS and the A/R monitoring plan. **Second**, a plan segment should be drafted specifying how status and trends of watershed condition can best be monitored to evaluate the effectiveness of the ACS. **Third**, given that many of the relationships between watershed condition and aquatic and riparian species population status within the Forest Plan region are presently unclear, a plan segment identifying biotic indicator candidates with the best conceptual or empirical basis for EM of A/R systems should be drafted. This segment also should identify research (or Validation Monitoring) needs that would help strengthen understanding of those habitat-biotic linkages that are most conceptually important to the A/R plan. **Fourth**, based on the plan's conceptual and empirical linking of habitat and key populations, a plan segment should be drafted identifying how biotic indicators can be monitored to evaluate the effectiveness of the ACS.

The RAEs expect that the A/R monitoring alternatives will provide a common set of parameters and protocols to be used for monitoring A/R ecosystems throughout the Forest Plan region. Selection of "core" indicators and protocols will require concerted attention during plan development for the A/R monitoring program. Development of sound alternatives for indicators and protocols should ultimately result in efficiencies in cost and effort when the plan is fully implemented. The possibility of integrating previously-developed or already-implemented sets of indicators or protocols into the A/R monitoring plan for the Forest Plan should be evaluated as the plan is drafted.

The phased approach in the current A/R work group outline lends itself to the development and integration of qualitative and quantitative monitoring aspects. This approach also lends itself to the presentation of alternatives for consideration during the review and approval process. The plan should focus on filling-in the quantitative aspects of the outline and on showing how qualitative, quantitative, and modeling phases will be integrated.

Consistent with the approach embodied in other EM modules, the A/R monitoring plan should remain concentrated on evaluating status and trends. Data on a suite of watershed indicators, plus information from related initiatives and lands, are expected to provide sufficient diagnostic capability to evaluate relationships and draw inferences as to cause, particularly when aggregated at the provincial or regional scale. Therefore, the focus must be on developing a plan that is technically sound with respect to indicators and analyses for a program to monitor A/R system status and trends, and provide information for adaptive management under the Forest Plan.

General Guidance on the Plan Development Process

In addition to the guidance above, the following measures are designed to clarify the task and assist the work group with the A/R plan development process:

- **Technical input**–The RAEs will organize a Technical Sounding Board (TSB) group that can provide input to the A/R work group on technical matters in the same manner that the senior Effectiveness Monitoring Team did for the three completed monitoring modules. The TSB will be available for ad hoc consultation and interim reviews of concepts to be considered for inclusion in the A/R monitoring plan. Nominees for the TSB have been provided by the A/R work group and RMG. The RAEs will charter this group for the duration of the A/R monitoring plan development effort.
- **Institutional input**–There is also a need for feedback about how the proposed A/R monitoring plan meets expectations of the implementing organizations (i.e., cost and other forms of support). A Management Implementation Group (MIG), drawn from the organizations that will be involved with A/R monitoring program implementation, is being formed to help fulfill this need. The MIG will be responsible for representing agency perspectives so that these may be fully considered as the plan is formulated. MIG representatives also will be asked to accept the responsibility of keeping their organizations fully informed about the development of the A/R monitoring plan. Major concerns on the part of the MIG about the A/R plan should be raised to the RAEs.
- **Required effort**–During the period outlined in the schedule below, it is anticipated that work group members will need to devote approximately 30 percent of their time to A/R plan development. The work group leader should be available for approximately 70 percent of their time. Obviously, this level of involvement will not be spread evenly over the course of plan development but will be most intense for formulating and writing alternatives, and for plan revision.
- **Agency support**–The organizations that are represented in the A/R monitoring plan development process must fully support their representation to complete the A/R planning effort outlined in this guidance. In addition to the direction provided in this document, the RAEs will issue charters for the TSB, and MIG to further define the roles and requirements for members of these groups in helping to complete the A/R monitoring plan.

Schedule and Review Process Expectations

A general process for producing the A/R monitoring plan has been laid out (fig. 15). The process is essentially identical to that used for writing, reviewing, and gaining approval for previous EM plan modules. To provide more detailed clarification about requirements and schedules, portions of the process are described here in greater detail:

- **Report dates**–Before a draft is released for review, the work group must internally review and work to agree on the plan to be presented. Where substan-tive differences of opinion as to the monitoring approach exist, plan alternatives should be presented. The TSB may preview portions of the plan to help contribute to it conceptually, but this level of review does not replace reviews by the RAEs, the sponsoring organizations, or independent peer review. An interim A/R monitoring product should be prepared by May 1, 1998. It is expected that this version will thoroughly describe the plan's conceptual framework and alternatives for the habitat (watershed status and trends) monitoring phase of the draft plan. Additionally, this report should portray plans for integrating with related monitoring initiatives, and also should describe

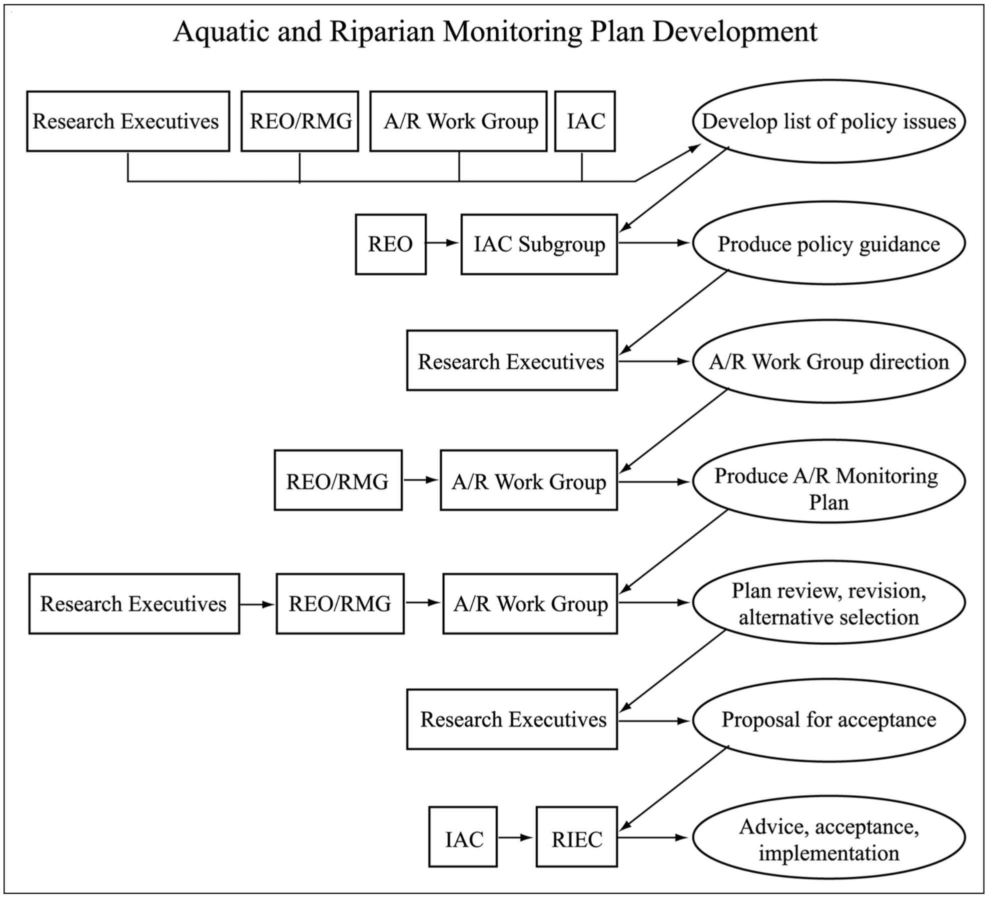

Figure 15—Steps proposed to produce the Aquatic and Riparian Effectiveness Monitoring Plan.

candidates for biotic indicator monitoring. On August 1, 1998, another interim product will be due. It is anticipated that this draft will incorporate comments on the habitat monitoring phase of the plan and will describe alternatives for the monitoring of biota. By November 1, 1998, a complete draft that describes the integration of all monitoring aspects should be completed.

- **Technical review**–Once the work group has produced the above plan drafts, the RMG will facilitate reviews by those individuals and organizations that have been closest to plan development. The TSB, MIG, and RMG will be the principal review bodies for these interim products. The final draft will be formally evaluated by independent peer reviewers selected by the RAEs. It is anticipated that this review will be completed by January 31, 1999.

- **RAE submittal**–Following peer review, it is likely that additional revision will be necessary. When this revision is complete, the plan should be ready for a decision by the RAEs as to their acceptance of the plan. Following this decision, the RAEs will submit the plan with their endorsement to the Intergovernmental Advisory Committee (IAC) for review and acceptance. At this time, recommendations as to the best approaches from among the alternatives included in the A/R monitoring plan should be made by the RAEs.
- **Recommendation and acceptance**–Following IAC review, it is likely that clarification by the RAEs, RMG, and A/R work group will be necessary prior to an IAC recommendation that the plan be accepted for implementation by the Regional Interagency Executive (RIEC). It is anticipated that IAC advice can be concluded and that the RIEC decision on acceptance of the A/R monitoring plan can be made during the first half of the 1999 calendar year.

By meeting this schedule, the plan would be ready for implementation starting in FY 2000.

Appendix 3: Indicators Considered for Inclusion in the Decision-Support Model (DSM) by the Aquatic and Riparian Effectiveness Monitoring Plan (AREMP) Development Team

UPSLOPE

Vegetation:

Percentage of watershed with vegetation 80 to 100 years
Harvest in potentially unstable areas
Proportion of area harvested
Anthropogenic vegetation change
Vegetation seral-stage distribution
Timber disease (insects, pathogens)
Percentage of equivalent clearcut area

Roads:

Road density
Culvert density
Road and culvert failures (density)
Roads on erodible soils and unstable terrain (km/km^2)
Road density above H60 line

Landslides:

Landslides and debris flows (number/frequency)
Anthropogenic landslide and debris flow frequency
Timber harvest in potentially unstable areas

Other:

Percentage of impervious surface

RIPARIAN AND FLOODPLAIN

Vegetation:

Harvest in potentially unstable areas
Proportion of area harvested
Proportion of stream logged
Proportion of fish-bearing stream logged
Shading
Canopy openness
Percentage of riparian zone altered
Anthropogenic vegetation change
Vegetation seral stage distribution
Density of deciduous and coniferous trees> x cm within- meters of active fish-bearing stream channel
Density of deciduous and coniferous trees> x cm within- meters of active nonfish-bearing stream channel
Proportion of fish-bearing stream logged
R/F vegetative connectivity

Roads:

R/F road density within x meters of stream
Road/culvert failures (density)
Roads on erodible soils (km/km^2)

Landslides:

- Landslides/debris flows (number/frequency)
- Anthropogenic landslides/debris flows (frequency)

Other:

- Percentage of impervious surface

IN-CHANNEL

Morphologic and physical:

- Channel complexity
- X-section (incision or aggradation)
- Bank erosion/condition/instability
- Number of large pools (density)
- Pool quality
- Percentage of wood cover in pools
- Residual pool depth
- Residual pool volume
- Wetted Width/Maximum Depth Ratio in scour pools in a reach
- Percentage of stream surface area comprised of pools
- Pool/Riffle ratio
- Bankful Width/Depth ratio
- Density of large wood in active channel
- Density of channel forming wood
- Density of bank stabilizing wood
- Key large woody debris (LWD) (density)
- Debris pieces LWD per channel width
- Key pieces LWD per channel width
- Shading
- “Shade angle” (ODFW indicator)
- Off-channel habitat condition
- Off-channel habitat (change in area)
- Flood-plain/off-channel habitat condition and connectivity
- Change in wetland acreage
- Drainage network (increase in active channel length)
- Length of perennial stream (ratio to intermittent)

Roads:

- Stream crossings (density)

Substrate:

- Composition
- Embeddedness
- Percentage of sand and fines
- Percentage of fines in spawning gravels
- Gravel quality
- Gravel quantity

Water quality:

- Stream temperature
- Nutrients (specific)
- Nutrient (303(d))
- Dissolved oxygen
- Herbicides/pesticides
- Metals
- Turbidity and suspended solids
- “water quality”

Water quantity:

- Withdrawals
- Hydrograph
- Change in peak/base flows
- Peak flow index
- Percentage of stream miles meeting instream water rights, salmonid seasonal flow requirements

Access:

- Dams
- Culverts

Biotic:

- Species/population abundance/trend
- Species growth/survival
- Species life history diversity
- Macroinvertebrate indices
- Community indices
- Percentage of assemblage present

Appendix 4: Potential Biological Indicators

Three different assemblages are typically used to assess the biological integrity or the effects of anthropogenic disturbance: periphyton, benthic macroinvertebrates, and fish (e.g., Hawkins and Norris 2000). These assemblages may be used independently of each other or in consort. Selection of the appropriate assemblage depends on specific project objectives. Although standardized protocols for aquatic and riparian amphibians and other vertebrates have not been developed or widely implemented, the structural/compositional and functional metrics used for fish could be similarly applied and evaluated (e.g., Van Sickle and Hughes 2000).

Periphyton

The periphyton assemblage is useful for water-quality monitoring. Part of the value of the periphyton assemblage is their inherent rapid reproductive rates and short life cycles that make them ideal for evaluating short-term impacts. Algae are directly affected by chemical and physical factors and therefore are sensitive to some pollutants at levels lower than would impact higher trophic levels. Although relatively standard protocols exist for evaluating functional and nontaxonomical structural characteristics of algal communities, few states use the periphyton assemblage in water-quality determinations. Although population and community attributes make periphyton valuable for assessing short-term impacts (i.e., Best Management Practice (BMP) monitoring), the short generation times and rapid response to environmental changes make algae less useful for assessing long-term affects of anthropogenic activities on ecosystem condition. Samples of algal communities are “snapshots” in time and have not yet been successfully used in integrating watershed-scale anthropogenic effects over long periods (Barbour et al. 1997, Pan et al. 2000).

Benthic Macroinvertebrates

Macroinvertebrates integrate the effects of short- and long-term environmental variations. Although most species have complex life cycles of 1 year or more, sensitive live stages respond quickly to stress while the overall community responds more slowly. As a result of limited migration patterns or sessile life histories, macroinvertebrate assemblages are good indicators of local conditions and site-specific impacts necessary for BMP monitoring. Because benthic macroinvertebrate communities are made up of species that constitute a broad range of pollution tolerances, they can be useful in assessing long-term cumulative effects. As a result of shorter life cycles, macroinvertebrates respond faster to environmental change than fish. In many low-order streams (first and second order), where fish are not present, macroinvertebrates may be the highest trophic level available as indicators. Benthic macroinvertebrates also serve as a primary food source to many important fish species. Consequently, macroinvertebrates are good indicators of potential future impacts to fish populations and communities. Most states have well-developed and sophisticated macroinvertebrate monitoring components incorporated into their water-quality monitoring programs (Barbour et al. 1997, Karr and Chu 1997).

Fish (Vertebrates)

The longevity and mobility of fish make them better indicators of long-term effects and broad habitat conditions than other assemblages. Although fish are the most commonly used vertebrate indicators, amphibians have more recently been incorporated into large-scale ecosystem assessments (Van Sickle and Hughes 2000) and may be particularly important indicators of ecosystem condition in riparian areas. As secondary or tertiary consumers, they integrate the effects of lower trophic levels, thus fish community structure is generally considered to be reflective of environmental health. The environmental requirements of fish are generally well established. Water-quality standards are usually characterized in terms of fisheries. Many fish species with high profiles in the Pacific Northwest are affected by management activities. Monitoring these fish provides a direct measure of conservation benefit, making them ideal components of strategies to evaluate status and trends in ecosystem condition (Barbour et al. 1997).

Appendix 5: Rationale for Sampling 50 Watersheds Per Year

An objective of the Aquatic and Riparian Effectiveness Monitoring Plan (AREMP) is to estimate the proportions of subwatersheds in different condition classes as determined by a decision-support model. Given that a statistical probability survey design is used to select a sample of sixth-field units from the entire population of several thousand such subwatersheds, the estimate will have uncertainty associated with it. One measure of the uncertainty is its precision. The estimate is a proportion, p. Under a general assumption the survey design is a simple random sample, we know the variance for the proportion depends only on the true proportion of units meeting the criteria and the sample size n. Because the true proportion is unknown, we can make a conservation estimate of the variance by assuming the true proportion is 0.5, where the variance is a maximum. Under this situation, the precision when 50 percent of units meet the criteria, will be +/- 12 percent with 90-percent confidence. If only 20 percent of the units meet the criteria, then the precision will be +/- 9 percent. This assumes a sample size of 50 units. If only 25 units are sampled, then the precision changes to +/- 17 percent and +/- 13 percent, respectively. If 250 units are sampled over a 5-year period, then the precision changes to +/- 5 percent and +/- 4 percent. It is necessary to assume that conditions during the 5-year period remain constant. Note that for 250 units, the precision is +/- 6 percent and +/- 5 percent with 95-percent confidence.

A critical element in the discussion of precision is the number of subregions of the AREMP study area that are of interest. If estimates are required for each of 12 provinces, then with 25 units sampled in each of the provinces, the precision would be +/- 17 percent and +/- 13 percent (at P = 0.5 and P = 3, respectively) for each province and +/- 5 percent and +/- 4 percent for the entire study area. The subregions do not need to be provinces but could be reserve and matrix land or some other criteria of interest. Another possible grouping of the watershed units may be by percentage of forested land and percentage of federal land ownership. Hence a critical element in determining total sample size will be determining how many and what type of watershed groups will be of management interest. If the 25 samples are obtained over a 5-year period (i.e., sample five units each year in each province), then the precision after 5 years is as stated. For any one year, the precision is +/- 37 percent when P = 0.5.

Precision will be important when a determination must be made on whether the proportion of watershed in given categories meets the criteria between two different periods. If the true proportion changes by 10 percent from 20 to 30 percent, then what is the chance that the monitoring will detect this change. The better the precision, the more likely the change will be detected. The probability of detecting the change depends not only on the sample size but also on the specific survey design to be implemented. Decreasing the sample size decreases the ability to detect the difference. Is 50 a sufficient sample size? That depends on how confident we must be in detecting a change or estimating the true proportion. As an example, if the baseline proportion is 50 percent and after 5 years the proportion changes to 30 percent, then with a sample size of 50, the estimated difference would be 20 percent +/- 16 percent with 90-percent confidence. Because the confidence interval does not include 0, the conclusion is that a significant (at 90-percent confidence) change has occurred. This assumed that the watersheds between the two periods were not paired; i.e., the same in both time periods. If they are the same, then other procedures can be used and are expected to be able to detect small differences between the periods.

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