Establishing a Network of Intensively Monitored Watersheds in the Pacific Northwest

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Pacific Northwest Aquatic Monitoring Partnership

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Introduction

The U.S. Congress, the Northwest Power and Conservation Council, and state Legislatures allocate hundreds of millions of dollars each year to aid recovery of salmonid species listed under the Endangered Species Act, and enhancement of other non-listed anadromous and resident fish. There is a tremendous need to document the contribution that these efforts are making to improvements in watershed condition and listed species.

Basic questions about how fish respond to well-intended actions cannot be answered unless a significant amount of existing and new information is obtained and rolled up in a manner that, to date has typically not been done (IAC 2002, ISP 2002, Bayley 2002). There is a growing realization and risk of losing significant funding for salmon and habitat recovery if the region does not demonstrate the coordinated monitoring necessary to answer basic questions posed by appropriators (GAO 2002).

Along with other complementary monitoring activities, the Pacific Northwest Aquatic Monitoring Partnership (PNAMP), a consortium of entities with a common interest in coordination of monitoring, has recommended establishing a regional network of “Intensively Monitored Watersheds” (IMWs) to evaluate the effectiveness of restoration projects, programs and policies at the landscape scale (PNAMP 2004). Effectiveness monitoring at the IMW scale addresses the following general questions:

> *Does the collective effect of restoration and/or management actions result in improved watershed condition and fish response? Why or why not? What are the causes of those responses?*

The PNAMP Strategy (PNAMP 2005 v2/23/05) contains specific objectives and actions associated with effectiveness monitoring objectives aimed at IMW outcomes that are excerpted below.

> “**Objective 4. Coordinate Pacific Northwest effectiveness monitoring efforts**”
>
> “**Outcome G. Develop a network of Intensively Monitored Watersheds (IMW) and reach specific studies for effectiveness monitoring.**
> Intensively monitored watersheds are designed to address key questions in a disciplined scientific manner. All possible factors need to be considered: accurate measures of fish populations including spawners entering the watershed and juvenile migrants leaving the watershed, and accurate estimates of mortality factors such as marine conditions, harvest, hydro, predation, and other factors directly affecting salmon abundance and survival. Without a holistic approach, it will not be possible to determine the response of salmon to habitat restoration and other management efforts.

Action item 1. *Recommend a strategy for placing IMWs throughout the Pacific Northwest to monitor and evaluate "cause and effect" relationships between habitat restoration and management actions, and changes in fish population responses and other viable salmonids population criteria.*

Action item #2. *Develop a regional map with agencies identified geographically that will be responsible for funding and implementing intensively monitored watershed monitoring*.

The IMWs should be coordinated to reflect differing ecoregions, species, and treatments. Selection of IMWs should be a cooperative process between federal and State agencies, and local watersheds.

Action Item 3. *To reduce the risk of not being able to detect a change resulting from habitat improvements, PNAMP will encourage federal and state governments that select and fund habitat restoration projects to cluster them in the identified intensively monitored watersheds so that the amount of habitat improved can be at a scale measurable in terms of migrant salmonids produced*."

Distinguishing features of the IMW approach, in contrast to other PNAMP effectiveness monitoring recommendations, are that IMWs will provide:

- integrative watershed-scale evaluations,
- assessment of fish population responses to habitat actions evaluated at the watershed scale in terms of causal or correlative relationships, and
- results from rigorous designs used to adequately address confounding factors and experimental controls or reference conditions.

There may be ongoing or future research or investigations in intensively "studied" watersheds that do not meet all of the distinguishing features of IMWs listed above. Although that research would not be part of the PNAMP IMW network, it is likely that mutual benefits would accrue from improved coordination and information exchange.

Although the emphasis of the PNAMP IMW network is on monitoring the responses of fish to habitat projects or habitat management actions, there may be IMWs in the network whose experimental design emphasis addresses fish related management questions (e.g., supplementation) in a watershed scale context with broad implications for habitat management activities.

Broad interpretation of results from IMWs will be most effective if information from concurrent status and trend monitoring of specific ecosystem components, including watershed habitat conditions, water quality, stream morphology, riparian condition, and the viability of salmonid populations is available. Status and trend information provides a context within which results of IMWs can be interpreted and extrapolated beyond the local IMWs. IMWs need to be designed to assess the relative contribution of restoration and management actions in the context of other factors or ecological stressors.

This document outlines the PNAMP strategy and action plan for the implementation of a network of IMWs across the Pacific Northwest. Implementation activities will involve interactions within and between a number of ongoing watershed monitoring efforts in the PNAMP area (e.g., Federal Columbia River Power System pilot watersheds (Jordan et al. 2003), Washington IMWs (WSRFB 2003; Bilby et al. 2004). Where appropriate, existing efforts will be incorporated as part of the IMW network either in the early or later phases of this work.

Conceptual Framework

The basic premise of Intensively Monitored Watersheds is that the complex relationships controlling salmon response to habitat conditions can best be understood by concentrating and integrating rigorous monitoring and research efforts at a few locations. Intensively Monitored Watersheds reduce the complications of monitoring project effectiveness, increase the comprehensiveness of monitoring, and increase efficiencies through shared responsibilities.

Addressing the complications

The types of data required to evaluate the response of fish populations to management actions that affect habitat quality or quantity are difficult and expensive to collect and analyze. Evaluating biological responses is complicated, requiring an understanding of how various management actions interact to affect habitat conditions and how system biology responds to these habitat changes. The response of fish is dependent on the relative availability of the habitat types it requires, which changes through the period of freshwater rearing, and the manner in which these habitat types are influenced by application of a management action. Further complicating the issue is the fact that the relative importance of each habitat type in determining fish survival changes from year-to-year due to variations in weather and flow, the abundance of fish spawning within the watershed and other factors. For example, smolt production can be dictated by spawning habitat availability and quality during years when flood flows occur during incubation and greatly decrease egg survival. However, during years of more benign flow conditions during egg incubation, population performance may be more influenced by the availability of food during spring and summer or adequate winter habitat. Furthermore, changes in habitat are often linked with large disturbance events and/or may occur slowly over long periods of time, necessitating a significant time commitment to the IMW strategy to see results. Untangling the various factors that determine performance of the salmon and how these factors respond to land use actions or restoration efforts can only be accomplished with an intensive monitoring approach (Hillman 2003).

The ultimate objective of most habitat restoration efforts and land management programs aimed at salmon is to increase the abundance of naturally spawning fish. As a result, the most meaningful measure of program effectiveness for anadromous species is the survival of the fish from adult spawning through smolting of their offspring. Because salmon use multiple habitat types during their freshwater residency, the spatial and temporal scales at which evaluations are conducted should be large enough to encompass all the habitats required for the salmon to complete this phase of their life history and of sufficient duration to allow changes to occur. The size of the area required to capture the full range of habitats needed to complete freshwater rearing will vary by species.

Individually, and most importantly, collectively IMWs may be the most efficient method of achieving the level of sampling intensity necessary to monitor the response of salmon to management actions (ISP 2002).

Addressing the comprehensiveness of monitoring – constraints

Implementing an intercommunicating, coordinated network of IMWs is a critical step in the region's ability to respond to fundamental policy and public questions about results and accountability. However, there will be limits to what IMWs will be able to deliver. For example, technical feasibility, funding constraints, and political realities will inevitably preclude some hypotheses from being tested. Development and implementation of the approach outlined here will help clarify those limitations.

Finally, availability of funding will likely constrain the extent to which the IMW network can be fully implemented. The PNAMP IMW strategy represents a phased approach, where initial implementation will be followed by additional analysis, review, and refinements as needed.

Addressing the efficiencies – an IMW network

Development of individual IMWs will require considerable effort for scoping, assessment, analysis, design, implementation, analysis, and eventually multifaceted integrated syntheses and reporting of results. Because of differences in ecological and geological circumstances, and management contexts among IMWs, each IMW will be able to address only a part of the general question stated above. **However, the systematic development and implementation of a distributed "network" of IMWs is intended to address a range of species, ecological contexts, and management scenarios that are most relevant to policy interests, and that are technically feasible.** It will provide a framework to facilitate coordination and sharing of common interests, technical resources, fiscal impacts, and communication needs (Figure 1).

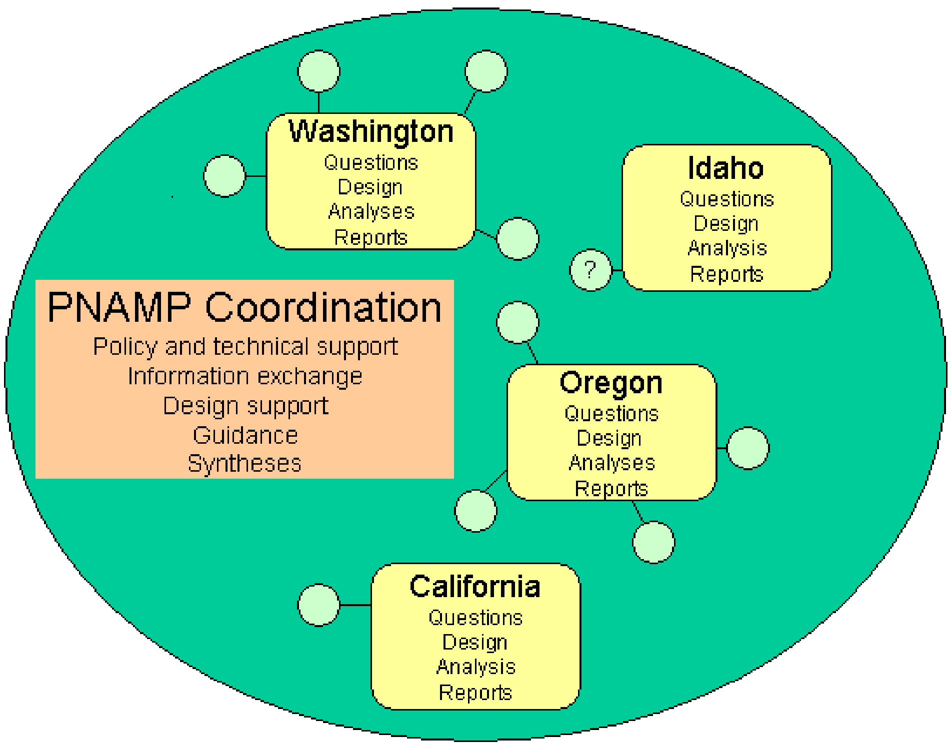

Figure 1. Network of PNAMP IMWs (small circles) and functions across geographic areas of the Pacific Northwest.

The network of IMWs will be based policy needs, technical considerations and practical opportunities (e.g., funding). Emphasis will be placed on achieving efficiencies through use of a hierarchy and diversity of IMWs deployed in a network across the PNAMP area.

Importantly, because monitoring in an IMW context is just getting underway, the relationships among them – the degree to which they will constitute a unified network – is a work in progress. However, in the same way that PNAMP encourages its members to do compatible, comparable status and trend monitoring, we also encourage interested parties to design their IMW activities so that direct comparisons can be made for different watersheds throughout the Northwest. Ideally, all IMWs would sample and measure the same fish and habitat indicators using similar protocols. If this can be done, or if reasonable “adapters” can be developed that allow different approaches to be understood and reconciled, it should be possible to make credible comparisons between the effects of similar habitat actions in different areas (e.g., interior Columbia and the Oregon coast).

A range of practical problems will make implementation and direct comparisons difficult. For example, although many IMWs measure juvenile output using traps or weirs, high spring flows will make this type of measurement impossible in many watersheds where it would be desirable. Juvenile life-stage survival rates can be estimated easily in some streams but not others. Similar constraints will probably apply to direct counts of adult spawners entering a watershed. It may be possible to perform near-census level habitat inventories in smaller watersheds, while larger areas will require EMAP-style random sampling. In some cases, IMWs may be located in the same areas with other long-term monitoring and research, increasing the type and extent of coordination issues.

It remains to be seen to what extent these and other problems will make direct comparisons between IMWs difficult or impossible. Without a clearly elucidated design template, however, useful comparisons across watersheds are almost guaranteed to be impossible. This is the motivation behind the PNAMP IMW design: to increase the odds that one can use results from a network of many IMWs in such a way that the sum of the combined results is more informative than the sum of the individual IMW analyses.

Addressing applicability – extrapolation of results

The PNAMP area is being classified based on physical and biological characteristics to enable identification of strata to aid prioritization of candidate IMW locations for implementation. However, it is possible that IMWs will be unable to be implemented in all identified strata. Extension of results from a limited number of IMWs to other watersheds cannot be accomplished by the traditional method of increasing the sample size (number of watersheds monitored) until a sufficient level of statistical certainty is achieved. The applicability of results will be determined using classification information based on similarity of physical and biological characteristics in relation to the watersheds included in the IMW network. Watersheds, which have biophysical characteristics and patterns of human activities comparable to IMWs, will be locations where IMW results can be extended with the greatest degree of certainty. A brief description of the classification analysis to be used in identifying candidate IMWs and extrapolating IMW results is found in Bilby et al. (2004).

The initial goal of the IMW extrapolation exercise is to classify and group watersheds with similar physical, biological and anthropogenic impact characteristics in relation to IMWs. Ultimately, the classification process will:

- support the extrapolation of expected results from restoration projects between monitored and non-monitored watersheds,
- inform the design and distribution of future restoration and monitoring projects, and
- support the interpolation of data across areas not monitored as intensively as the IMWs.

Briefly, to generate landscape classification schemes for this purpose requires choosing biophysical variables that capture most of the information pertinent to salmonid productivity. The choice of these variables is therefore critical to the success of this exercise. Variables will be chosen based on the current understanding of fish-habitat relationships available in the literature. The two main assumptions underlying this exercise are that the variables used are: (1) some of the most important determinants of the overall characteristic of a watershed, and (2) important determinants of salmonid population processes.

The basic list of variables currently thought to correlate to fish productivity includes climate, geology, watershed topology, vegetation, channel confinement and gradient, land-use/cover, ownership, and wetlands. In addition, recent work shows that channel size (e.g., drainage area or some regionally calibrated estimate of discharge) and elevation are also important. A variety of studies have shown empirical correlations between fish numbers and these variables. It is feasible to simply seek correlations between the distribution (histograms, cumulative distributions) of these attributes and fish species and population sizes, which would allow extrapolation to other basins that lack monitoring data. However, it will also be useful to look at how these attributes affect fish directly, which may provide a more powerful means of extrapolation.

Ultimately each attribute included in the extrapolation process somehow affects aquatic habitat and these effects occur point by point through the channel network. Thus, it is the combined suite of variables at each point that is important. For example, the relationship of channel gradient and valley width for a reach is lost when the distribution for each variable is viewed independently. A measure of basin productivity requires a method of assessing the effects and interaction of all variables point by point and then aggregating that information over the basin. A number of recent examples of constructing similar geomorphically based watershed intrinsic potential metrics have been very useful for the management and recovery planning of listed anadromous salmonids.

Existing approaches to classifying landscapes for the purpose of managing and recovering anadromous salmonid populations have not included parallel assessments of immutable characteristics of watersheds and human land-use impacts on the watersheds. Therefore, to extend the current understanding of and approaches towards landscape classification specific to aquatic resources, similar methods must be applied to both the geomorphic and anthropogenic determinants of watershed intrinsic potential. Human activity over the past 100 years in the Pacific Northwest has dramatically altered the region's land- and waterscapes. As such, human activity has impacted the productive potential of most of the region's aquatic systems. In fact, some of the immutable factors used above to describe the inherent potential of aquatic systems have been changed by human activities (e.g., channel confinement, local climate). However, the primary mode by which human activities impact aquatic ecosystems is indirectly through land use practices (e.g., agriculture, urbanization). Therefore, any exercise to characterize broad scale patterns of aquatic productivity would be naïve to ignore the impacts of these activities. Thus, the effect of human activity on the landscape will be assessed through a parallel effort to develop a regional classification of watershed condition as a function solely of human activity. The potential list of human land use practices and activities that have the potential to alter relevant physical and biological processes will include: agricultural activities, forest practices, livestock activities, transportation, channel alteration, mining, urbanization.

Further IMW design development will identify the strata into which initial IMWs occur, explore the desired number of IMWs per targeted strata, and explore the implications of the extrapolation on implementation approaches.

Criteria for inclusion in the network

A number of policy and technical criteria will be used to delineate IMWs during implementation of the PNAMP network. In at least the near term, it will be important to identify and capitalize on opportunities in watersheds where there is an existing body of suitable scientific knowledge from which to address other criteria and design issues. Categories of policy criteria for which priorities may be identified include: cooperator support, species, type of ecological community, class of management action, geographic or political area(s) of concern, desired level of certainty or confidence in results, and costs. In its earliest phases, delineation of IMWs will tend to be opportunistic, whereas in subsequent phases candidates will be identified to fill gaps, through deliberate policy and technical analyses.

By definition, smolt and adult monitoring are essential for inclusion in the IMW network. Moreover, drawing upon existing smolt and adult monitoring resources and programs will lower costs and shorten startup time. To the extent that the precision of the fish abundance estimates is known, much effort will be saved that would otherwise need to be expended in finding suitable locations, installing new traps and sampling schemes, and verifying the accuracy of the estimates. Issues related to differing scales of fish sampling will be resolved as part of experimental design development for each IMW.

Primary technical criteria include:

1. *Activities in the IMW can be controlled to the extent necessary to maintain the integrity of the experimental design throughout the life of the project.*
2. *Suitable control or reference streams exist to provide comparisons to the treatment stream(s) that will remain adequately unaffected by the restoration actions of management actions being evaluated.*
3. *The degree of certainty with which management/monitoring questions are to be answered is known or will be developed, affecting design, sampling frequency, and feasibility.*

Secondary technical criteria include:

1. *Size is sufficient to be able to detect significant changes in the context of the management scenario(s) (or treatments) being evaluated.*
2. *The desired time frame for study results is known.*
3. *Multiple, similar watersheds with contrasting land management are preferred.* While true experimental ‘control’ watersheds may not be available, insight into the relative effects of different land management or habitat restoration strategies can be evaluated by comparing basins which are similar in all respects but the management scenario.

In summary, the above criteria are recast below as initial policy and technical criteria to form the basis for inclusion in the IMW network over time.

The IMW network:

a. shall capitalize to the extent possible on the pre-existing availability of suitable scientific knowledge
b. shall have long term commitments to juvenile, outmigrant, and adult fish monitoring
c. shall support important management questions of PNAMP members

d. shall be distributed across areas/ecoregions, species, and categories of project and/or management activities consistent with (a)

e. shall have sufficient type and duration of management actions for reliable implementation of long term experimental designs

f. shall apply experimental designs with appropriate and viable controls

g. shall have broad base of support in the locally affected area

Initial opportunities

A number of IMWs have been or are currently being planned for implementation and form the ***first phase*** of implementation of the PNAMP IMW strategy. These IMW efforts are intended to take advantage of existing opportunities, and include local support. The extent to which they meet all PNAMP criteria for inclusion as IMWs is being analyzed as part of Phase 1. This analysis will also include development and/or refinement of management hypotheses, monitoring questions, experimental design and implementation plans. Phase 1 IMW opportunities are identified in Table 1 with locations shown in Figure 2.

Appendix 1 provides more detail on individual IMWs.

Table 1. Phase 1 IMW network opportunities

Washington	Puget Sound: - Skagit River estuary - Straight of Juan de Fuca: Deep Creek, East and West Twin rivers - Hood Canal: Big Beef, Little Anderson, Seabeck, Stavis creeks
	Lower Columbia: Germany, Abernathy, Mill creeks
	Upper Columbia: - Wenatchee River: Nason, Peshastin, Chiwawa creeks - Entiat River (lower) - Methow River: Libby, Gold, Beaver creeks
	Snake: Tucannon River (potential)
Oregon	Coast: - Nehalem-Coos River area (6 basins) - East Fork and Upper Lobster creeks - Cummins and Tenmile creeks - Trask River
	Cascades: Hinkle Creek
	Lower Columbia: North Fork Scappoose
	Middle Columbia: - John Day River: upper Middle Fork and Lower South Fork
Idaho	Lemhi River in Salmon River drainage
California	Hollow Tree Creek in South Fork Eel River drainage

Based the information in Appendix 1, over 80% of the Phase 1 IMWs in Table 1 address species listed under the ESA. The remainder of the IMWs address many of these same ESA species but in areas that are not currently listed. Phase 1 IMWs are located in areas having a variety of land use types (Figure 3) and efforts will address management and monitoring questions associated with a range of management activities (Figure 4).

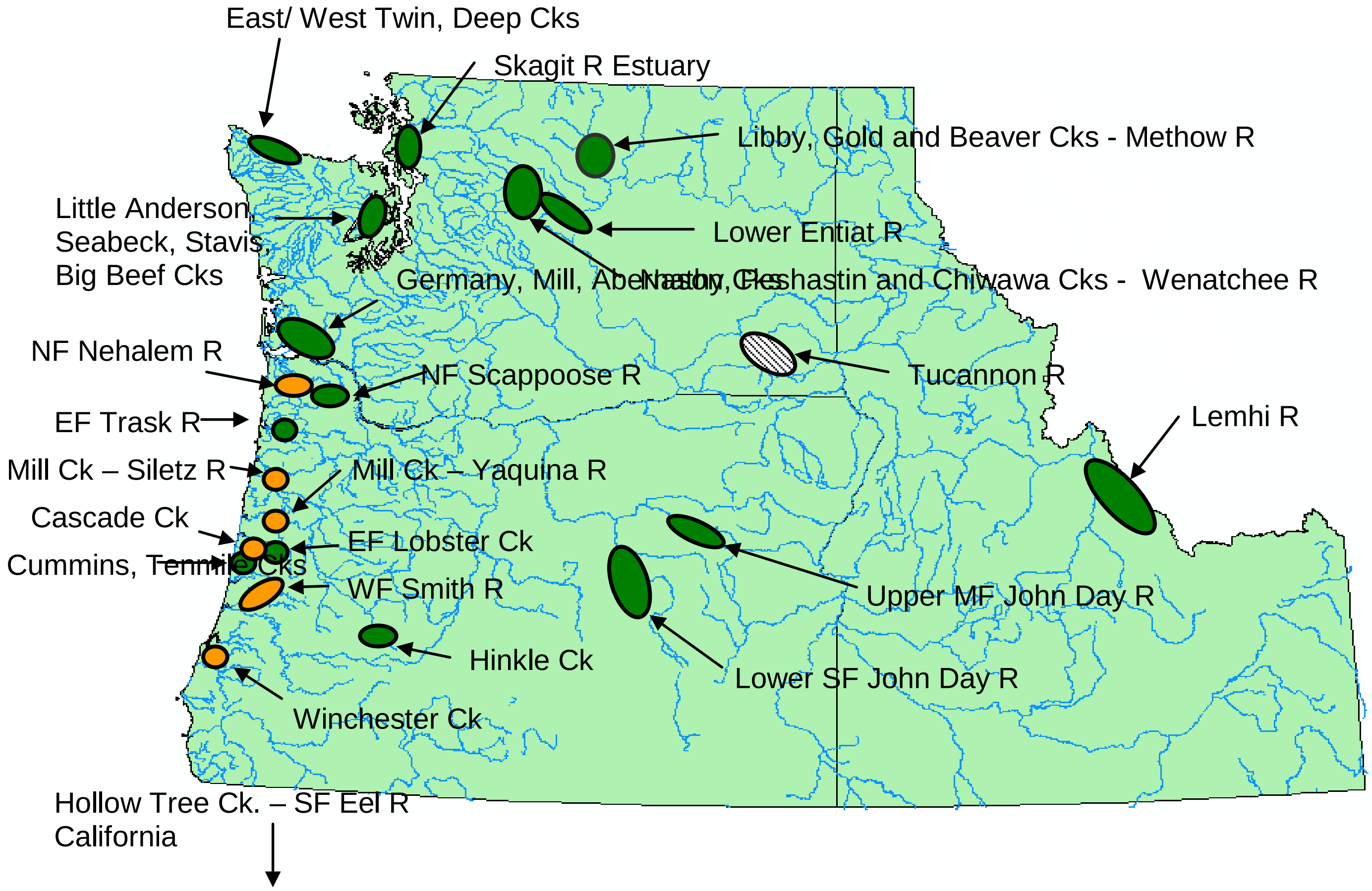

Figure 2. Map of watersheds in Phase 1 of the PNAMP IMW network described in Appendix 1. Locations shown with diagonal pattern are under consideration for inclusion in Phase 1.

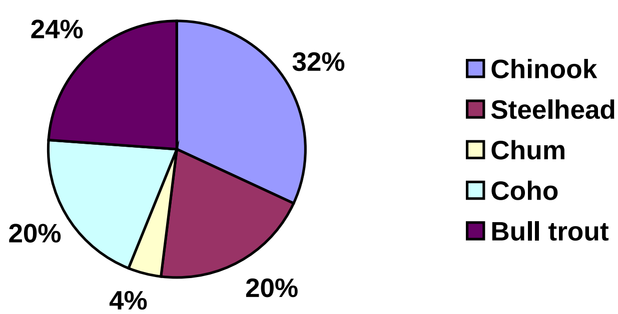

Figure 3. Distribution of ESA-listed species in Phase 1 IMWs.

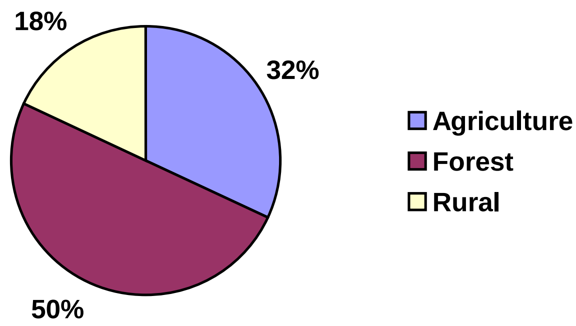

Figure 4. Land use types in Phase 1 IMWs.

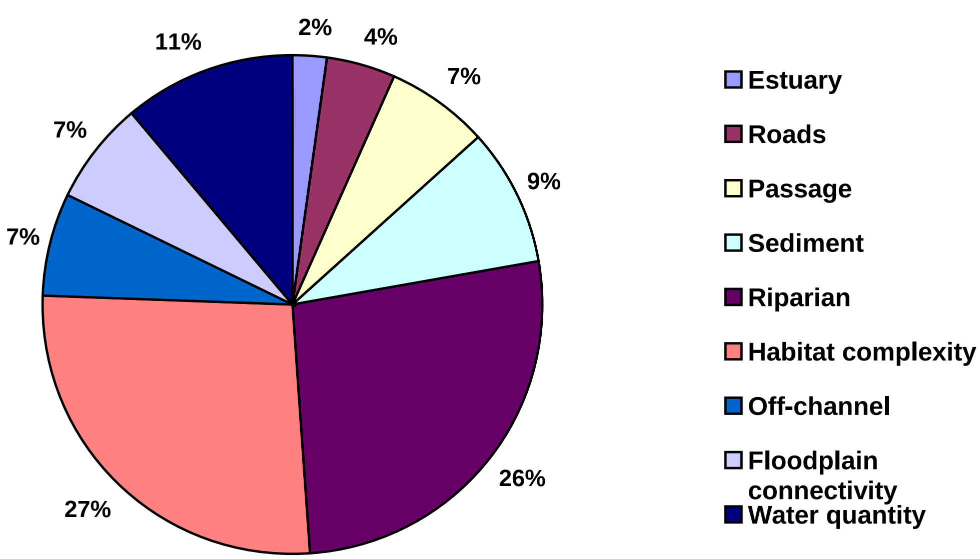

Figure 5. Habitat protection and restoration efforts addressed in Phase 1 IMWs.

Implementation Plan

The action plan outlined here identifies key tasks using a phased strategic approach. Implementing in phases will allow IMWs identified in initial work to be further reviewed and analyzed, and changes will be made to refinements or modify subsequent phases.

Phase 1: identify and evaluate initial IMWs guided by and in the context of stated policy and technical criteria and classification information

1. describe initial IMW opportunities based on criteria
2. stratify/classify PNAMP area
3. review placement of initial IMWs in context of criteria and classification
4. identify preliminary limits to extrapolation of results based on initial opportunities
5. assess and review policy implications of Phase 1 IMW network with Executives

Phase 2: review/refine initial IMW selection criteria as needed, including changes in policy context, possible refinement of policy-relevant statistical and other criteria (e.g., number of IMWs per target strata; meta-design and analyses; timeframes)

1. identify gaps in coverage consistent with refined criteria
2. identify and prioritize candidates to address gaps
    a. perform scoping or feasibility analyses, etc as needed
3. identify final IMW priority candidates
4. identify work needs for subsequent phases
5. assess and review policy implications of Phase 2 IMW work with Executives

Phase 1 and beyond: (ongoing implementation and integration of IMW products)

- support development and refinement of experimental designs for individual IMW efforts
- support development of cross-network design guidance and implementation
- identify/expand collaborators and partners
- identify technical and policy gaps in implementation of current and/or new IMWs
- identify funding needs and assist development of funding strategies
- bring policy issues to the attention of the PNAMP Steering Committee and Executive Network

PNAMP IMW products:

- Host annual IMW reviews (separately, or as part of larger PNAMP information exchange efforts) to (1) summarize progress, (2) identify key results, and (3) identify and address coordination issues within the PNAMP IMW network, and regarding other PNAMP activities (project effectiveness monitoring, status and trend monitoring, etc). This may include coordination those performing focused studies in watersheds outside the PNAMP IMW network.
- PNAMP IMW Implementation Reports

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Appendix 1. Overview of the Phase 1 Intensively Monitored Watershed network

State	Region	Watershed or stream complex	Species – ESA listed species indicated by *	Adult and smolt counting (past/present)	Scale(s) and potential for controlled experiments	Types of habitat protection/ restoration problems (hypotheses) to be addressed	General land use, predominant limiting factors to salmon	Funding status, sponsors, cooperators, and lead PNAMP contact
Washington	**Puget Sound: Northern** **(WRIA 3: Lower Skagit)**	Skagit River estuary	Chinook*	Chinook smolt counts upstream of estuary. Adult Chinook	Project scale (10-100s ha) experiments planned. Evaluate the relative frequency, spatial distribution, growth, and survival of identified life history strategies as a function of estuary restoration.	Estuary restoration, including dike removal, and restoring distributional channels within the estuary	Agriculture and hydrological modifications to the estuary	Phase 1 funding (2003-04) from SRFB to WA Depts of Ecology, and Fish and Wildlife. Other partners include Weyco, NWFSC, EPA, UW, with local support from Skagit System Cooperative, Skagit Watershed Council Lead PNAMP contact: Bill Ehinger (WA Dept of Ecology)

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Washington	**Puget Sound: Eastern Hood Canal** (WRIA 15 – Kitsap)	Big Beef, Little Anderson, Seabeck, and Stavis creeks; all drain directly into saltwater	coho steelhead cutthroat fall chum summer chum*	WDFW: coho, steelhead, and cutthroat production measured annually since 1978 in Big Beef, 1992 in Anderson, and 1993 in Seabeck and Stavis creeks Adult coho, chum, and Chinook trapped since 1976 in Big Beef Creek Coho and chum spawner surveys conducted in some but not all years	Small: 3,000 to 9,000 acres Paired control and treatment streams	Big Beef Creek: Reservoir rehabilitation, control sediment delivery/routing, temperature, low summer discharge, habitat complexity L Anderson Creek: Habitat complexity, sediment routing, water delivery/routing, off-channel habitat, LWD Seabeck Creek: Low summer discharge, sediment routing, habitat complexity Stavis Creek: Control All to monitor the effectiveness of land-use regulations and forestry rules	Mix of forest and residential development FPB Watershed Analysis (1998) Kitsap Refugia Study (2003) Mass wasting, erosion High/low flows exacerbated by development and forest practices	Phase 1 funding (2003-04) from SRFB to WA Depts of Ecology, and Fish and Wildlife. Other partners include Weyco, NWFSC, EPA, UW, with local support from Hood Canal Coordinating Council Technical Committee, Kitsap County, and the Hood Canal Salmon Enhancement Group Lead PNAMP contact: Bill Ehinger (WA Dept of Ecology)

State	Region	Watershed or stream complex	Species – ESA listed species indicated by *	Adult and smolt counting (past/present)	Scale(s) and potential for controlled experiments	Types of habitat protection/ restoration problems (hypotheses) to be addressed	General land use, predominant limiting factors to salmon	Funding status, sponsors, cooperators, and lead PNAMP contact
Washington	**Coast: (Strait of Juan de Fuca)** (WRIA 19–Lyre/Hoko)	Deep Creek, and East Twin and West Twin rivers; all drain directly into saltwater	coho steelhead cutthroat chum	Lower Elwha Klallam Tribe and WDFW	Small Paired control and treatment streams	Passage, road improvements, large wood, riparian plantings, off-channel habitat creation	Mix of private, state and federal forest. Watershed analyses are available. Watersheds are recovering from past forest practices.	Funding through EPA (RARE grant). Also includes Phase 1 funding (2003-04) from SRFB to WA Depts of Ecology, and Fish and Wildlife. Other partners include Weyco, NWFSC, EPA, Lower Elwha Klallam Tribe. Lead PNAMP contact: Bill Ehinger (WA Dept of Ecology)
Washington	**Lower Columbia** (WRIA 25 - Grays – Elochoman)	Germany, Abernathy, and Mill creeks; all drain into the lower Columbia River estuary	steelhead coho cutthroat	WDFW: Juvenile steelhead, coho and cutthroat production annually measured since 2001 Adult enumeration options are being explored for Abernathy Creek	Small to medium: 14,000 to 19,000 acres Paired control and treatment streams	The following were derived from a LCFRB initiated EDT analysis: Delivery and routing of water and sediment, riparian management, LWD, temperature, channel stability/complexity, floodplain connectivity Intend to validate hypotheses and site potential projects through habitat surveys in 2004	Forest Private and state timber lands with some agriculture in lower reaches State limiting factors analysis (2002) Riparian condition, large wood, pools, floodplain connectivity	Phase 1 funding (2003-04) from SRFB to WA Depts of Ecology, and Fish and Wildlife. Other partners include Weyco, NWFSC, EPA, with local support from Lower Columbia Fish Recovery Board Technical Advisory Committee and the Wahkiakum Conservation District Lead PNAMP contact: Bill Ehinger (WA Dept of Ecology)

State	Region	Watershed or stream complex	Species – ESA listed species indicated by *	Adult and smolt counting (past/present)	Scale(s) and potential for controlled experiments	Types of habitat protection/ restoration problems (hypotheses) to be addressed	General land use, predominant limiting factors to salmon	Funding status, sponsors, cooperators, and lead PNAMP contact
Washington	**Upper Columbia Region** (WRIA 45 - Wenatchee)	Nason, Peshastin and Chiwawa Creeks - Wenatchee River system; drains into Columbia River mainstem	Chinook* steelhead* bull trout* westslope cutthroat Pacific lamprey sockeye	Adult and juvenile counts WDFW USFWS Chelan PUD YN USFS	Large Multiple "independent" watersheds w/differing levels of impact	Road decommissioning, water quantity, water quality, off-channel habitat, floodplain and riparian restoration, passage obstructions Protection of ecosystems in the upper basin (e.g., White, Little Wenatchee, Chiwawa)	Forestry in upper watershed, agriculture in lower Roads, culverts, diversions Habitat overall in reasonably good shape in the upper portions of the basin	BPA funding as part of the FCRPS BiOp pilot RME projects. Other partners include Upper Columbia Fish Recovery Board Regional Technical Team (state, federal, tribal members and contractors), and PUDS through HCPs Lead PNAMP contact: Chris Jordan (NWFSC)
Washington	**Upper Columbia Region** (WRIA - 46 Entiat)	Lower Entiat River; drains into Columbia mainstem	steelhead* Chinook* bull trout*	Adult and juvenile WDFW USFWS	Medium Single unreplicated treatment with control reaches	Habitat complexity restoration (off channel and in-channel)	Agriculture Rural development Channel confinement and simplification	BPA funding as part of FCRPS BiOp pilot RME projects. WA SRFB Other partners include Upper Columbia Fish Recovery Board Regional Technical Team (state, federal, tribal members and contractors). Lead PNAMP contact: Chris Jordan (NWFSC)

State	Region	Watershed or stream complex	Species – ESA listed species indicated by *	Adult and smolt counting (past/present)	Scale(s) and potential for controlled experiments	Types of habitat protection/ restoration problems (hypotheses) to be addressed	General land use, predominant limiting factors to salmon	Funding status, sponsors, cooperators, and lead PNAMP contact
Washington	**Upper Columbia Region** (WRIA - 48 Methow)	Libby, Gold and Beaver Creeks – Methow River system; drains into Columbia mainstem	steelhead* Chinook* bull trout*	Adult and juvenile WDFW **USFWS** USFS Douglas PUD YN	Small Multiple projects	Habitat access modification (push up dam replacement)	Agriculture Rural development Water withdrawal structures	US Bureau of Reclamation Lead PNAMP contact: Chris Jordan (NWFSC)
Washington	**Snake**	Tucannon River	Spring and fall Chinook* Bull trout* steelhead*	WDFW via LSRCP	Under examination	Floodplain and channel function Riparian Instream habitat Upland sediment	Forestry in upper watershed; Dryland farming in uplands; Irrigated agriculture in bottomlands	Lower Snake River Compensation Program funding as part of a Lower Snake mitigation program. WDFW leads monitoring efforts. Local Lead: Mark Schuck Lead PNAMP contact: Chris Jordan (NWFSC)
Oregon	**Lower Columbia**	NF Scappoose	*coho* cutthroat steelhead	Adult and smolt trapping since 1998	Medium Potential? yes IMW basins at appropriate scales being identified	Riparian, instream	Forest, rural residential Habitat complexity	Funded by ODFW, OWEB Other support from USFWS Lead PNAMP contact: Jeff Rodgers (ODFW)

State	Region	Watershed or stream complex	Species – ESA listed species indicated by *	Adult and smolt counting (past/present)	Scale(s) and potential for controlled experiments	Types of habitat protection/ restoration problems (hypotheses) to be addressed	General land use, predominant limiting factors to salmon	Funding status, sponsors, cooperators, and lead PNAMP contact
Oregon	**Coast**	"Life Cycle Monitoring" from Nehalem River to Coos River: NF Nehalem R Mill Creek (Siletz R) Mill Creek (Yaquina R) Cascade Ck (Alsea R) WF Smith R (Smith/Umpqua) Winchester Ck (South Slough-Coos Bay)	coho* cutthroat steelhead	Adult and smolt trapping since 1998	Small to medium Potential? yes IMW basins at appropriate scales being identified	Riparian, instream	Forest Habitat complexity	ODFW and OWEB funding Other cooperators: private timber, State forest, USFS, USFWS Lead PNAMP contact: Jeff Rodgers (ODFW)
Oregon	**Coast**	EF and Upper Lobster Creek	coho* cutthroat steelhead	Smolt trapping and adult spawning surveys since 1988	Small Potential? Yes IMW basins at appropriate scales being identified	Riparian, instream	Forest Habitat complexity	BLM funding Other partners: ODFW, USFWS Lead PNAMP contact: Jeff Rodgers (ODFW)

State	Region	Watershed or stream complex	Species – ESA listed species indicated by *	Adult and smolt counting (past/present)	Scale(s) and potential for controlled experiments	Types of habitat protection/ restoration problems (hypotheses) to be addressed	General land use, predominant limiting factors to salmon	Funding status, sponsors, cooperators, and lead PNAMP contact
Oregon	**Coast**	Cummins and Tenmile Creeks	coho* cutthroat steelhead	Smolt trapping since 1991	Small, medium Potential? Yes IMW basins at appropriate scales being identified	Riparian, instream	Forest Habitat complexity	ODFW funding Other cooperators: USFS, USFWS Lead PNAMP contact: Jeff Rodgers (ODFW)
Oregon	**Coast**	Trask River: EF or the SF	coho*	Smolt trapping since fall 2004	Medium Currently evaluating potential for paired watersheds in the headwaters	Riparian protection State and private forest management strategies	Forest Habitat complexity	ODF and ODFW funding Lead PNAMP contact: Liz Dent (ODF)
Oregon	**Cascades**	Hinkle Creek	cutthroat steelhead	Adult and juvenile sampling since 2001	Small/medium Paired control and treatment watersheds	Riparian protection and management around small headwater streams; effects on aquatic habitat and biota	Forest	Private, state and federal funding on a biennial basis Partners include private forest landowners, multiple state agencies, counties, BLM Lead PNAMP contact: Liz Dent (ODF)

State	Region	Watershed or stream complex	Species – ESA listed species indicated by *	Adult and smolt counting (past/present)	Scale(s) and potential for controlled experiments	Types of habitat protection/ restoration problems (hypotheses) to be addressed	General land use, predominant limiting factors to salmon	Funding status, sponsors, cooperators, and lead PNAMP contact
Oregon	**Middle Columbia**	Upper MF and Lower SF of the John Day River system; drains into Columbia River mainstem	Chinook* steelhead bull trout*	ODFW, CTWSR Long-term spawning indices for spring Chinook (almost census) and steelhead (sparse) Systematic EMAP juvenile and adult monitoring beginning	Large Multiple "independent" watersheds w/differing levels of impact IMW basins at appropriate scales being identified	Forestry practices (past), riparian vegetation restoration Intensive irrigation, flow augmentation Grazing Barrier removals or modifications Stream complexity	Ranching, with associated agriculture and water withdrawals. Summer rearing temperatures Winter survival due to poor summer conditions Sedimentation	BPA funding as part of the FCRPS BiOp draft RME plan. Bureau of Reclamation funding Cooperators: ODFW, NWFSC, OWEB Lead PNAMP contact: Chris Jordan (NWFSC)
Idaho	**Central**	Lemhi River in Salmon River drainage	steelhead* Chinook*	Adult and juveniles IDFG	Small, medium Single uncontrolled treatment, or multiple small watersheds	Water quantity and habitat connectivity issues addressed with managed hydrograph	Agriculture Water withdrawals	BPA funding as part of the FCRPS BiOp RME pilot projects. Lead PNAMP contact: Chris Jordan (NWFSC)
California	**Northern**	Hollow Tree Ck (SF Eel River)	Chinook* coho* steelhead*	Adult, juvenile and some smolt counts since 1980s	Small to medium; Potential: perhaps (private land)	Responses to upslope, riparian, and instream treatments	Forest Sediment, Habitat complexity	CDFG and private restoration funding: (no monitoring funds at this time) Lead PNAMP contact: Scott Downie (CDFG)

Appendix 2. Approach to design and implementation of IMWs

General guidance

Multiple experimental designs will be utilized in IMWs, depending upon the questions being addressed and the scale at which the assessment must be conducted. Analyses have been used to investigate the relationships between stream flow and smolt production and these analyses should also be used in IMW investigations to the extent possible. Many of the objectives of IMWs can be addressed by before-after/control-impact (BACI) experimental designs. This type of design enhances the ability to differentiate treatment responses from responses due to variations in weather or other factors not directly affected by the treatments.

The principal value of BACI in experimental design is in isolating the treatment from relevant spatial and temporal controls. However, BACI does not constitute a statistical test; it is but one element of experimental design. Other considerations for experimental design will include the details of the statistical test performed-- the "analysis design". For example, it is anticipated that habitat data collected in parallel with fish abundance data will be used to create sensitive tests of the effectiveness of restoration projects. This will likely result in the use of multivariate analyses of covariance to discriminate the more subtle and diverse impacts of projects. On the other hand, there may be situations where a straightforward t-test will be sufficient to discriminate the effect of habitat projects. These alternatives place different demands on the type and quantity of data collected, and consequently the design of the monitoring plan. In another example, if the inferences reached in the effectiveness evaluation of projects in a single IMW are to be extended to other watersheds rather than made only with respect to the IMW itself, then sample sites for treatments and controls may be chosen with a different criteria-resulting in different sites being selected. Clearly then, the choice of test will be dependant on the specific features of the question being asked and the characteristics of the system being evaluated. In this way the analysis design used once the data are collected places demands on data acquisition. From the previous example, if the analysis will depend on habitat data that is spatially and temporally correlated with the fish response data, then clearly sampling designs and protocols for habitat data must be identified that preserve temporal and spatial associations with the fish data. Thus, the diverse and strong relationship between the analysis design and the monitoring design must be appreciated at all steps in the development of a monitoring plan for IMWs. The vehicle for maintaining this association will be clear and complete articulation of the technical questions that the data collection is designed to address. The articulation of the question must include spatial and temporal scales, species of interest and all other features of the monitoring plan design, as will be outlined later in this appendix.

All approaches will benefit from:

- the evaluation of two or more basins in each IMW study complex.
- at least one basin that will serve as a reference site where no experimental treatments are implemented during the period of IMW work
- a calibration period prior to applying treatments is required to determine how the reference and treatment basins compare and establish stable and predictable relationships for the key response variables prior to any habitat manipulation. The length of time required to develop this baseline will vary among IMWs. The calibration period for sites with existing information on spawner abundance and smolt output would be much shorter than for IMWs where these data have not been collected.

Treated and untreated sites can be paired at a multiple spatial scales within the IWM design, the scale dependent on the question being addressed. In fact, reference sites for some reach-level projects could be within the basin designated for treatment. These reference sites would consist of portions of the basin comparable in initial condition to the location where a restoration action is applied but where no habitat manipulation would occur during the period of evaluation. Questions that can be addressed at this finer scale include life-history specific biological responses or physical habitat responses to management actions. For evaluations of effects at the scale of the entire basin, a comparison with a nearby basin that is not undergoing treatment is required. Notably, **the IMW approach requires sufficient management discipline to ensure that reference sites remain untreated through the duration of study. This does not imply that any and all management activities in the reference watershed will compromise the integrity of the study. The validity of the study design will be maintained provided that the management activities not directly related to the restoration actions being evaluated are comparable at the reference and treated locations.** For example, the effectiveness of restoration actions can be evaluated in watersheds being actively managed for wood production provided that the type and intensity of forest management activities in the treated and reference watersheds are comparable.

Experimental treatments applied in the treated basins will vary depending upon their initial condition, the perceived factors limiting fish production, and the feasibility of applying treatments. The identification of the most effective treatments should be based on assessments of current conditions. Many IMWs will have had some type of watershed assessment already conducted (e.g., limiting factors analysis, Washington State watershed analysis, EDT). Working in conjunction with local watershed or sub-basin groups, these analyses will be used to identify the suite of habitat restoration efforts most likely to positively influence the salmon and trout production.

An example

Fundamental to the IWM approach is the establishment of a set of overarching objectives, which provide the context for the application of ecological restoration and to which individual projects and activities can easily be related. As the goal of most habitat restoration efforts for salmon and trout is to improve the survival of the fish through their entire period of freshwater residency, goals that relate to this outcome should be a component of the objectives. Individual restoration projects should collectively contribute to the attainment of the watershed level objectives. To determine whether this is occurring, projects applied at the reach scale should be nested within and related to the watershed-level objectives for habitat condition and fish populations. Such nesting creates an interconnectedness among projects that is critical to assessing the ultimate efficacy of the restoration effort.

Implementation of an IMW effort should begin with assessments of the current condition of the watersheds to be monitored. There are a number of tools that are appropriate for this task. The information generated by these assessments will indicate the factors that are likely limiting fish production in the watershed. For example, if the assessments identify a lack of large wood in the streams in the watershed, the hypothesis could be posed that lack of pool habitat is limiting available rearing space. An experiment to evaluate this hypothesis might involve deliberate addition of wood to channel segments and measurement of the change in pool habitat and summer and winter rearing populations at these sites relative to populations at untreated reaches (reach-level evaluation). However, even if this analysis indicates an increase in the number of fish rearing at treated sites, it does not provide information about the effect that these projects have had on the overall productivity of the fish population. In order to determine whether the wood addition has actually changed system productivity, rather than simply attracted fish to the treated reach that would have reared elsewhere, measures of watershed-level productivity are required.

The specifics of the biological, physical and habitat attributes measured in an IWM effort will vary depending on the questions being addressed. It will take a number of fish generations to get definitive results about the effectiveness of habitat restoration. However, by implementing these evaluations with clear objectives, careful consideration of experimental and statistical design, disciplined adherence to the experimental constraints at the treatment and reference sites, and patience, results can be produced that will greatly improve our ability to promote salmon recovery.

To evaluate watershed-scale responses, the treatments (e.g., wood additions) need to be applied at enough locations so that a population response can be detected. If the initial hypothesis proves correct and rearing habitat does have a controlling influence on fish production in the watershed, the number of smolts produced or survival rate from egg-to-smolt should increase. The number of treatment sites required to detect a watershed-level response can be evaluated as wood-addition projects are successively implemented. Due to the expense and labor involved in wood additions to channels, application of treatments will occur over a period of years. Small increases in density of rearing fish at the reach level would indicate that watershed-scale responses would only be discernible when a large number of sites had been so treated. A very dramatic density response at the site level might suggest that changes in population should be measurable with treatment of fewer sites.

At a minimum, information on number of spawning adult fish and smolt output are required to evaluate watershed-level responses. Counting fences or weirs at the downstream end of a watershed provide the most accurate measure of adult salmon returning to spawn. This method is very accurate but labor intensive and provides no information about spawner distribution within the watershed. Counts of fish on the spawning grounds or mark-recapture estimates of spawning fish or carcasses conducted periodically during the time of spawning is not as accurate as counts at weirs in determining total number of fish but does provide data on distribution. The application of statistically valid techniques of reach selection and frequent, consistent surveys of each reach can improve the accuracy of estimates of spawner abundance.

Such a method has been developed and implemented on the Oregon coast for coho salmon. Smolts leaving the sampling area must be sampled using some type of trap. Typical trap types include fences or weirs that capture all smolts exiting the watershed (although fences may become inoperable at high flows), or scoop or screw traps that capture a portion of the fish. Partial sampling traps are easier to maintain and can be utilized in channels too large for fences. However, these types of sampling devices require frequent calibration to determine the proportion of smolts being captured. ***With adult and smolt data it is possible to calculate the survival of the fish from spawning through smolting. The objective of nearly all salmon habitat restoration efforts (although often unstated) is to increase this value. Therefore, regardless of the methods selected to measure adult salmon and smolt abundance, these measures are critical to any comprehensive effort to evaluate fish response to restoration and must be included at all IMW sites.***

Augmenting the smolt and spawner data with information on egg survival and the distribution, abundance and survival of juvenile salmon from emergence from the gravel through smolting can enable salmon response to individual restoration projects to be linked with response at the scale of the whole watershed. Capturing fish seasonally (spring, late summer, winter) by electrofishing, seining or trapping at multiple locations across the watershed would enable an estimate of fish distribution, abundance, growth rate, species, and age class composition. An alternative to capturing fish is a visual survey using an extensive sampling approach like Hankin-Reeves (Hankin and Reeves 1988) although this method does not provide information on fish species and size that is as accurate as methods that involve capturing fish, it is rapid and would enable sampling of the entire stream network in a sampled watershed. A combination of the two approaches, a complete survey coupled with subsamples at selected sites where the fish are captured and measured, would provide the most complete information. The method selected will depend on how critical the measurement is, the characteristics of the site, and the resources available to be dedicated to obtaining the measurement.

Differential tagging of salmon captured during the sampling of different stream reaches and subsequent capture at smolt traps could provide additional information on survival rates of fish rearing in different areas of the watershed and the effectiveness of individual restoration projects. Differences in survival among reaches or habitat types may provide an indication of key mortality factors operating in the river and aid in the identification of restoration efforts likely to have the greatest effect on salmon populations. There are numerous tagging technologies available. Passively induced transponder (PIT) tags, which are appropriate for larger fish (>70mm) have been used extensively on the Columbia River and enable individual identification of fish. Visible implant (VI) tags also can be used to identify individual fish although reading the tags is more difficult than with PIT tags. The injection of colored dyes or polymers into various transparent tissues of the fish enables determination of the location where a fish was tagged but cannot be used to identify individual fish. However, this type of tag may be very appropriate for addressing many of the questions related to restoration effectiveness.

The collection of data on fish populations must be coupled with information on the habitat attribute, habitat-forming watershed processes, and climatic conditions. As fish are very sensitive to variations in flow, temperature and other factors that might not be directly influenced by restoration treatments, interpretation of the fish data can be enhanced by the collection of this information. At a minimum, a recording flow gauge is required at the mouth of the reference and treatment watersheds. In addition, if some of the restoration efforts are attempting to alter flow patterns, secondary flow gauges should be installed at the locations where these efforts are undertaken. A weather station collecting data on precipitation and air temperature should be located near the downstream end of the watershed. Water temperature also should be recorded year round at each gauging station and at all sites where one of the purposes of a restoration action is to alter water temperature. Instruments to record flow, weather and water temperature information data have improved dramatically in the last decade and costs have decreased. Thus, costs are reasonable for installing this equipment. However, maintaining the instruments and the database are labor intensive.

Data on habitat can be collected concurrently with fish sampling. These data are especially important at sites where restoration projects will be implemented. Habitat data can include physical characteristics of the channel (e.g., pools, riffles etc.), riparian area condition, levels of sediment deposited in pools and in spawning gravel, water quality (e.g., temperature, suspended sediment), nutrient levels and trophic productivity. The variables measured will depend on the objectives of the restoration actions. For example, projects designed to increase pool habitat will focus on the physical attributes of the channel while measures of nutrient levels and trophic production would be the most appropriate measures of a salmon carcass addition project.

Pre-treatment data should be collected for a period of one or two years. No treatments would be applied at any of the sites during this time. Pre-treatment data would be collected on sediment production and delivery, habitat conditions in the stream and fish populations.

Treatments would commence in year 2 and could extend over a period of several years if the plan is to sequentially treat multiple tributary watersheds. Treatments might include reconfiguration of drainage systems to divert ditch flow onto the forest floor, paving bridge approaches and utilization of harder surfacing materials.

Assessments implemented at the reach level would focus on the effect of sediment-reduction efforts implemented at a single location on sediment production and input to the channel. These site-specific assessments would not be conducted at every project site. Several representative examples of each project type would be assessed. Sediment input can be assessed with periodic grab samples or pump samplers deployed above and below the treatment location. The corresponding habitat attribute of interest at this scale would be the level of fine sediment in gravel or the amount of sediment deposited in pools. Measurements of these attributes would be taken annually at the project site and at a reference site in an untreated tributary watershed.

There are numerous methods for determining fine sediment levels in streambed gravel. Residual pool depth or closely spaced cross sections at pools could be used to determine changes in pool volume. The only relevant biological attribute at this scale would be the survival of eggs in the gravel before and after implementation of the sediment reduction measures and how this value compares with a nearby, physically comparable but untreated reach. There are a number of methods for measuring egg survival.

Types of monitoring questions and responses at appropriate spatial scales.

Scale	**Response Type**		
	Physical	Habitat	Biological
Reach	Do individual treatments reduce sediment delivery to the channel?	Does reduction in sediment input correspond to a reduction in sediment in streambed gravel and/or a reduction in deposited sediment in pools immediately downstream from the project area?	Does a reduction in sediment in streambed gravel correspond to an increase in egg survival at the project site?
Tributary Watershed	Does the application of multiple treatments result in lower suspended sediment export at the mouth of the treated tributary?	Is there an increase in the volume of pools in the treated watershed?	Are there increases in the density of rearing juvenile salmon in the treated watershed?
Watershed	none	none	Is there an overall increase in the number of smolts produced or egg-to-smolt survival rate following application of treatments?

The next relevant spatial scale for this analysis is the tributary watershed. At this scale, a reduction in suspended sediment export at the mouth of the treated tributary would be the physical attribute most sensitive to the application of multiple sediment reduction treatments. Suspended sediment can be measured with grab samples or pump samplers at the downstream end of the tributary watershed. Changes in pool volume through time in the treated tributary watershed would be compared with changes in pool volume in a reference tributary watershed. Various survey techniques have been developed that are appropriate for extensive assessment of pool volume. Increased pool habitat and increased survival of eggs in the gravel should correspond to an increase in the abundance of rearing salmon in the treated tributary watershed. This response can be addressed by conducting an extensive survey of fish abundance (e.g., snorkel survey) in all areas supporting fish in the treated and reference tributary watersheds.

If sediment input to fish-bearing streams is truly a factor of consequence in determining the survival of salmon from spawning through smolting, an increase in smolt output should be detectable, provided that a sufficiently large area of the watershed is treated. Changes in smolt output would be judged relative to smolt production from a reference watershed. There are a number of ways to evaluate smolt response. Change in the total number of smolts produced per unit area or unit stream length from the watershed where the treatments were applied relative to a corresponding measure from the reference watershed is the most straightforward approach. With accurate counts of spawning adults, the smolt data can be used to generate estimates of egg-to-smolt survival. This measure may be more sensitive than simple smolt production as it does provide some ability to account for differences in the abundance of spawning adult salmon, which could be impacted by factors other than sediment levels. If sediment input was correctly identified as a factor limiting the production of salmon in the treated watershed, an increase in survival should become apparent as progressively larger areas of the watershed undergo treatment.

Comparable approaches could be used to assess other types of restoration projects. Regardless of the type of restoration approach being applied, treatments and assessments must be applied in integrated manner that allows biological and physical responses at each spatial scale to be connected.

Additional statistical and experimental design guidance

The following is adapted from the Washington Comprehensive Monitoring Strategy (IAC 2002).

The ability to draw inferences from IMWs depends on framing hypotheses as clearly as possible, with clearly defined controls and/or references, and collecting the data in a manner having the least possible uncertainty.

In general, an example principal hypothesis is: recovery action X will make fish response of life stage Y higher in area Z. In this case, “fish response” reflects fish characteristics, such as abundance, productivity, and diversity. A specific application is: use of agricultural diversion screens has increased the numbers of salmon yearlings in river Z. How much action is needed to test these hypotheses and to have confidence in the answer obtained? Alternatively, how much uncertainty can we tolerate?

To illustrate, how critical is it to detect a 5% change in a population within a 4-year period, 19 times out of 20? If that power of resolution is critically needed, then a corresponding level of effort can be calculated and applied, and its associated cost can be determined. These issues pertain to statistical power analysis, which involves knowing four critical things:

1. **Sample size** (if measurements can only be taken for four years, how many sites/projects need to be monitored?)
2. **Confidence** (can we afford to be wrong one time in 20? Can we tolerate being wrong half the time? Most of the time?)
3. **Variability** in the data (what is the reliability of the measurements we are making?)
4. **Effect size** (what difference do we need to see? ±5%? ±50? ±150%?)

All four of these parameters are interdependent: specifying any three of them affects the fourth. In reality, some parameters will be set by available resources, variability of the population, and other factors which will be out of the control of the parties conducting the monitoring.

If features of the analytical process are viewed as statistical planning tools, then both policy and science need to influence this process at different points to affect the implemented monitoring plan. For example, if it is going to take 125 years to see a small effect size (e.g., 5%) that may have been specified, the cost is likely to be prohibitive. On the other hand, if being "wrong" in population abundance monitoring is equivalent to extinction of the salmon we are trying to monitor, are we willing to be "wrong" half the time (i.e., confidence of 0.5)?

Articulation of testable hypotheses will involve identifying biological effects of the management action and appropriate controls. The hypothesis should also identify the geographic area of influence of the action. Further details of specific experimental design choices are presented in MacDonald et al. (1991) and Conquest and Ralph (1998).

Generic design planning questions

A significant challenge in implementing IMWs is balancing the different levels of technical expertise of those conducting the monitoring with the diversity of demands of monitoring to be performed across the range of management actions implemented and the environments that salmon occupy. Crafting a "cookbook" of specific IMW monitoring plans that contains recipes for every management action in each habitat type across the PNAMP area would be prohibitive. Outlined below is an approach that if followed, will result in custom-made adequate IMW monitoring plans. Importantly, this will generate data that is useful both within the context of individual recovery actions, and also in the context of broader (i.e., regional, cross-regional) comparisons within classes of recovery actions.

Those developing IMW plans should address the generic technical questions below. If these questions were collectively answered adequately, a high degree of confidence would exist that the IMW monitoring plan would produce useful results. It is particularly important to evaluate the sources of uncertainty in IMW plans to maximize the probability that data from various IMWs can be usefully compared, and classes of recovery management actions identified.

Generic scientific questions that address issues common to all actions:

1. What are the scientific questions that are framed by the management action(s)?
2. What are the management questions?
3. What is the hypothesis(es) to be tested? (If the hypothesis is explicit it is easier to evaluate the choice of controls and indicators.)
4. What are the controls?
5. What is being measured?
6. Are measures primary or correlated indicators, and how does the measurement being made relate to the specific question?

7. What are the connection between what is being measured and the biological result that is desired? This is another way of defining the assumptions implicit in the choice of monitoring strategies—for example, are you measuring actual fish numbers, or a surrogate figure such as carcasses or redds?
8. Explicitly, what are the assumptions of the monitoring plan?
9. What is the spatial area of effect of the management action? Is the extent of the area incorporated into the monitoring plan? How? If not, why?
10. Are inferences from this IMW intended to be extended to other watersheds, or are inferences intended for the IMW only?
11. How long into the future is the need for updated answers?
12. Are the consequences of being wrong or failing to fully examine a hypothesis understood?

Variability:

1. What is the measurement error of the technique used to make the measurement?
2. What is the net accuracy of the measurement technique, sampling design, and experimental design?
3. What is the net precision/variability of the measurement technique, sampling design, and experimental design?
4. To what degree is the data collected spatially explicit?
5. What is the largest and smallest spatial scale over which the data are expected to vary?
6. What is the largest and smallest temporal scale of which the data are expected to vary?
7. What level of statistical power is desired? In other words, what level of biological response (fish numbers, growth rate, diversity, etc.) is desired, and, given the obtainable accuracy and precision of our measurements, how long must one monitor to obtain this level of result?

Effect size:

1. How have estimates of historic fish densities or possible carrying capacity been addressed?
2. Does the program monitor year-round, seasonally, or just for a few weeks in a particular season(s)?
3. If it is presumed that the action is expected to result in $\mu > 0.0$, what value of μ is required? Is this answer based on biology, or based on politics? Was this value arbitrarily determined?
4. Do you know beforehand how precise you need to be about estimating μ?
5. What technique was used to calculate μ? Why was that technique chosen?

Sample size:

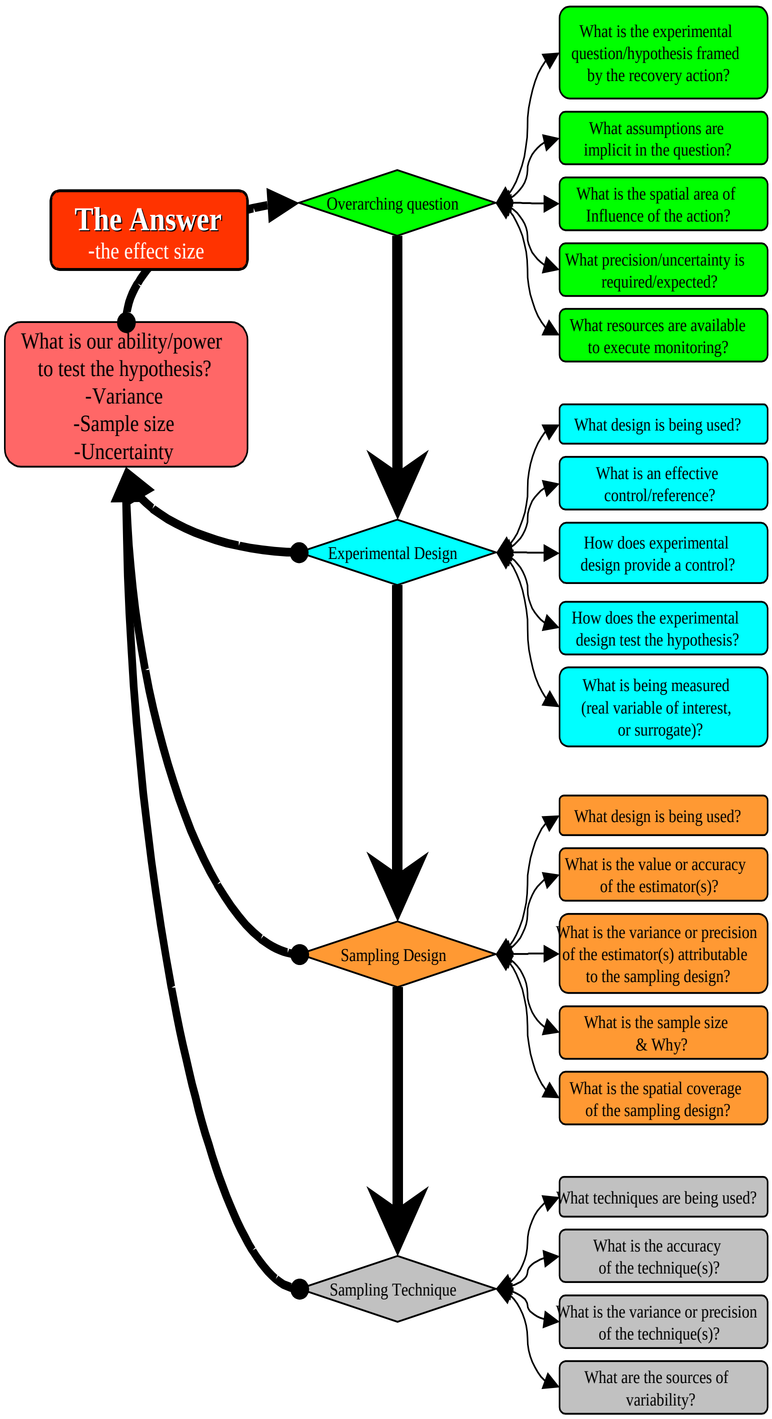
1. How does the duration of the monitoring correlate with the generation period of the salmonids affected by the management action?
2. What technique was used to determine sample size?
3. What set of protocols were used that will lead to cost savings?
4. Is there an historic/legacy data set being used, continuity with which needs to be preserved?

Confidence:

1. What level of confidence is being used?
2. How was this value derived?
3. What are the implications or consequences of being wrong?

Fish ecology questions:

1. What is the fish response to the management action?
2. What species and life stages use the affected area?
3. What is the change in salmonid egg-fry survival with the action?
4. What is the change in salmonid fry-smolt survival with the action?
5. Are there changes in juvenile salmonid density with the action?
6. Which life-history change shows the largest response to the action?
7. Are there changes in non-salmonid densities with the action?


The Answer
-the effect size
What is our ability/power to test the hypothesis?
-Variance
-Sample size
-Uncertainty
Overarching question
What is the experimental question/hypothesis framed by the recovery action?
What assumptions are implicit in the question?
What is the spatial area of Influence of the action?
What precision/uncertainty is required/expected?
What resources are available to execute monitoring?
Experimental Design
What design is being used?
What is an effective control/reference?
How does experimental design provide a control?
How does the experimental design test the hypothesis?
What is being measured (real variable of interest, or surrogate)?
Sampling Design
What design is being used?
What is the value or accuracy of the estimator(s)?
What is the variance or precision of the estimator(s) attributable to the sampling design?
What is the sample size & Why?
What is the spatial coverage of the sampling design?
Sampling Technique
What techniques are being used?
What is the accuracy of the technique(s)?
What is the variance or precision of the technique(s)?
What are the sources of variability?