Columbia River Estuary Habitat Monitoring Plan

DRAFT

August 31, 2004

Prepared by the Lower Columbia River Estuary Partnership

with funding from
the Bonneville Power Administration

and technical support from
the Pacific Northwest National Laboratory,
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Overview

The purpose of the Lower Columbia River Estuary Partnership's habitat monitoring plan is to provide a detailed, statistically valid sampling plan for status and trends monitoring of salmon habitats. This monitoring plan will also support restoration action effectiveness research in the Columbia River estuary ecosystem by generating baseline habitat data. Monitoring of the status and trends of salmon and their habitats in the Columbia River estuary is currently incomplete: it does not include representative samples of the entire 243-km tidal reach below Bonneville Dam, is not coordinated and integrated across multiple monitoring efforts, and is not meshed with action effectiveness research for habitat restoration projects estuary-wide (Johnson et al. 2004). The Estuary Partnership's habitat monitoring plan is consistent with the Action Agencies/NOAA Fisheries Research, Monitoring and Evaluation Plan (RME Plan 2003; Johnson et al. 2004). The study area for this plan covers the tidally influenced portion of the Columbia River below Bonneville Dam.

The habitat monitoring *program* that will implement this *plan* is intended to supplement existing research and monitoring efforts in the estuary, without being duplicative. Coordination with the following three existing projects will be especially important, for example, sharing sampling sites to the extent possible: 1) the Estuary Partnership's Toxic Contaminants and Water Quality Monitoring Program funded by the Bonneville Power Administration (BPA); 2) National Oceanographic and Atmospheric Administration (NOAA) Fisheries' Historic Habitat Opportunities and Food-Web Linkages of Juvenile Salmon in the Columbia River Estuary funded by BPA; and 3) NOAA Fisheries' Estuarine Habitat and Juvenile Salmon study funded by the Corps of Engineers (COE) through the Anadromous Fish Evaluation Program and the Columbia River Channel Improvements Project. Furthermore, this plan is designed to serve as an umbrella for sampling designs that will be generated as new issues of significance in the estuary emerge. Thus, the sampling design described in this plan involves sampling measurable attributes of estuarine habitats (e.g., vegetative cover), while measurable attributes of salmon habitat usage (e.g., spatial and temporal distribution) are being addressed by other projects.

The Estuary Partnership proposes a two-phased approach to sample habitats in the study area. *Phase I: Inventory* sampling will serve to a) characterize variability throughout the 243-km estuary; b) validate the designation of "complexes" and other strata in the habitat classification project; c) ground-truth cover type analyses from remotely sensed imagery; and d) field-test sampling protocols. *Phase I: Long-Term Monitoring* sampling will a) systematically collect data on estuarine habitats at a discreet set of sites; b) track long-term changes in habitats, including geomorphology and cover type; c) evaluate an established set of null hypotheses (to be determined at the outset of Phase II, based upon data collected in Phase I); and d) provide information about the effects of restoration actions that can be used to evaluate and refine management measures in the estuary.

Monitoring Framework

Goals and Objectives

The habitat monitoring program has the following objectives, with the goal of providing a long-term data set to assess the status and trends of aquatic habitats, including those used by listed salmonid populations, and applying these data as appropriate to action effectiveness research on estuary habitat restoration.

1. Status Monitoring—Landscape and estuary ecosystem
    a. Inventory, classify, and describe the Columbia River estuary ecosystem using the appropriate spatially explicit data sets available for the study area.
    b. Establish a baseline of existing connectivity between habitats, including an assessment of passage barriers for salmon, and assess trends in connectivity through time.
2. Status Monitoring—Estuarine habitats
    a. Describe physical and biological characteristics of estuarine habitats.
    b. Describe salmon species composition, age/size structure, spatial and temporal distribution, and other metrics that are relevant to salmonid dependence on estuarine habitats (see comment below).
3. Action Effectiveness Research
    a. Associate project sites and reference sites with specific classification strata to provide a framework for action effectiveness analysis.
    b. Designate status monitoring sites that are appropriate for use as reference sites for restoration project effectiveness research conducted by others.

Objective 2b, while a part of the framework for the monitoring program, is not addressed in the sampling design provided in this plan. It is currently being addressed by NOAA Fisheries research described in Section 1.3, Coordination, and if data gaps are identified, salmon monitoring may be addressed in future sampling designs under the auspices of this program.

Habitat Classification

A classification system based on existing hydrogeomorphic-structured classification systems is being developed for use in this habitat monitoring program. It will be unique in that very few of the available classification systems address complexes in tidal freshwater and floodplain portions of estuaries. The classification system will use a variety of spatial datasets—including hydrologic, geomorphic, bathymetric, land cover and other comprehensive data—to delineate ecosystem structure. In this habitat monitoring plan, Level 3 of the five levels in the classification method is used to stratify habitat sampling.

Statistical Design

The field sampling program will have two phases, in order to take full advantage of the habitat classification system being developed concurrent with the first phase. *Phase I: Inventory* is designed such that its output, combined with the output of the classification system, will support specific refinements to the sampling design prior to the initiation of *Phase II: Long-Term Monitoring*.

Phase I: Inventory sampling will serve to a) characterize variability throughout the 243-km estuary; b) validate the designation of "complexes" and other strata in the habitat classification project; c) ground-truth cover type analyses from remotely sensed imagery; and d) field-test sampling protocols.

Phase II: Long-Term Monitoring sampling will a) systematically collect data on estuarine habitats at a discreet set of sites; b) track long-term changes in habitats, including geomorphology and cover type; c) evaluate an established set of null hypotheses (to be determined at the outset of Phase II, based upon data collected in Phase I); and d) provide information about the effects of restoration actions that can be used to evaluate and refine management measures in the estuary.

Both phases involve a stratified rotational sampling design and incorporate both fixed and randomly selected sites. Site selection will occur within the classification of the study area currently being developed on a geographic information system (GIS) platform, which will be empirically based on available spatial data. This statistically based field sampling design will permit variability within and between habitats to be measured, thus complementing the classification system and providing an opportunity to verify it. A rotational design has many advantages: it entails sampling more sites than other designs given the limited resources of a long-term habitat monitoring program and it will result in a greater ability to measure change over time. By incorporating fixed sites, data will be produced that can also be used for a) comparative studies of the development of habitat restoration project sites, and b) studies of the range of variability within sets of reference sites of a particular type (e.g., swamp) throughout the estuary. Fixed sites may also represent existing sampling stations from other estuary monitoring programs and would thus provide long-term and more comprehensive suites of data and increase the efficiency of sampling investments in the estuary.

Following Phase I, the analysis of field-collected data will be used in conjunction with the habitat classification system to refine the sampling design for Phase II as follows: a) produce the target statistical population, b) provide defensible sampling strata, c) generate appropriate null hypotheses, and d) identify the sampling frequency and distribution suitable to the variability associated with specific attributes of the system. The null hypotheses to be tested during Phase II: Long-Term Monitoring will be dependent on the variability of the system that is quantified during Phase I: Inventory. Strata for the sampling design of Phase II will be selected based on the variability of the system identified in Phase I.

Action Effectiveness

Data gathered in the Estuary Partnership's habitat monitoring program will contribute to restoration project implementation and effectiveness monitoring. Some of the data generated will be from fixed sites selected from shallows/flats, swamp, and marsh habitat types that are relatively undisturbed (i.e., not separated from the estuary by dikes or other barriers, although altered by the engineered nature of the system). A list of potential sites is provided to facilitate planning. These sites can serve as "reference sites" for comparative studies at restoration project locations. Data will be made available for analyses evaluating changes at restoration project sites, where suitable pairing between restoration project habitats and reference site habitats exists.

Implementation

Monitored Attributes

The sampling design addresses status and trends in the physical and biological characteristics of estuarine habitats. Monitoring of other important attributes of the estuary, including habitat usage by salmon, water quality, and toxics, is underway or planned in related studies (see Section 1.3, Coordination). The potential attributes for estuarine habitat monitoring include those of high importance to salmon and those most useful for the evaluation of restoration project action effectiveness. In this way, the habitat monitoring design provides for status and trends monitoring of estuarine habitats in general, with particular emphasis on those attributes supporting salmon populations, and provides information from reference sites for comparison to restoration project monitoring results. The list of example attributes presented in Table O.1 below will be refined for the second phase of the habitat monitoring project once hypotheses have been developed and variability of habitats has been assessed in Phase I. More information specific to each monitored attribute described in Table O.1 is provided in Section 3.1 of this plan, including data acquisition method, scale of application, protocol citation, and frequency of sampling in Phase I and Phase II.

Table O.1. Monitored Attributes of the Estuary Partnership's Habitat Monitoring Plan, Organized by Sampling Category and Characteristic within Each Category

Sampling Category	Characteristic	Monitored Attributes
Physical Features and Structure	Site features	site area, tidal channel area, total edge tidal channels, elevation, bathymetry, channel cross sectional profiles, large woody debris
	Hydrology	water elevation, lateral extent of flooding, velocity
	Sediments	grain size analysis, organic content analysis, accretion rates, pore water salinity
	Landscape	patch, mosaic and landscape metrics: e.g., shape, fragmentation, heterogeneity, connectivity, etc.
Water Quality	Parameters	temperature, turbidity, salinity, dissolved oxygen, ph, nutrients
Biological Features	Consumers and predators	species and life history composition, abundance, size structure, temporal presence, diet
	Macro-invertebrates	*benthos:* species and life history composition, density, standing stock
		zooplankton: species and life history composition, density, standing stock
		insects: species and life history composition, density, standing stock
	Vegetation	*emergent:* species composition, frequency, and % cover
		scrub-shrub and woody: species composition, frequency, stem density, and percent cover
		submerged aquatic: species composition, frequency, and percent cover

Data Management

The commencement of on-the-ground monitoring intended for long-term analysis requires that vast amounts of data be catalogued for future use. We recommend a data clearinghouse be established, whereby one organization is responsible for managing metadata. Metadata management will be of increased importance for action effectiveness research, as it is likely that several parties will be collecting data at diverse restoration sites. The data collected from this program should be highly organized in a format that is adaptive to changing technology (i.e., on a 20+ year scale). Generated data will consist of site locator data, as well as data from each monitored attribute. Feedback to the GIS model under development concurrently will contribute to fully developing a classification system for Phase II sampling. Data from reference sites established as part of status and trends monitoring should be made available to restoration project managers in a format relevant for restoration project comparisons.

Among the parties working in the Columbia River estuary, the need for data sharing and coordination has been expressed as being of paramount importance. Because no standardized system for data management currently exists and projects are piecemeal based upon sponsor, results rarely get broadly disseminated. The Estuary Partnership is currently evaluating web-based data reporting systems to determine if a similar system could be used in the Columbia River. To facilitate better cooperation and increased value of collected data, we recommend annual meetings as a platform for sharing data and reporting on projects. Additionally, biennial reports would synthesize work from multiple years, while sharing results in a timely manner. Data should be archived according to an established protocol, and voucher specimens, data sheets, raw computer files, processed and analyzed data, and reports should all be maintained to allow for re-evaluation of data at a later date should new information or new research questions arise.

Management Implications

Management implications fall into five main topic areas: ecosystem health, habitat restoration, Federal Columbia River Power System (FCRPS) operations, federal basin-wide RME, and recovery planning.

Status and trends in *ecosystem health* reveal whether the quality of the Columbia River estuary ecosystem is deteriorating or improving. The Habitat Monitoring Program is one of several that will provide data applicable to assessment of estuary ecosystem health. Data from the Habitat Monitoring Program especially relevant to ecosystem health are the inventory of habitat classes and the measurements of habitat connectivity. Results from the Habitat Monitoring Program will be incorporated into the Estuary Partnership's periodic assessments of ecosystem health mandated because the Columbia River estuary is in the National Estuary Program.

Research on the effectiveness of *habitat restoration* actions in the Columbia River estuary will use monitoring data collected at reference sites as part of the Habitat Monitoring Program. Reference site monitoring data, e.g., vegetation cover, sediment grain size, and bathymetry, will be compared periodically with habitat restoration site data. The trend in similarity between the two sites will be one indication to managers of the effectiveness of the restoration action. In addition, the Habitat Monitoring Program's habitat classification system, coupled with the routine inventories of estuary habitats, will provide key information to help managers prioritize habitat restoration actions.

Monitoring data from the Habitat Monitoring Program would be applicable in evaluations of any future *FCRPS operations* designed to affect shallow water habitats in the Columbia River estuary. Hydrodynamic modeling showed that reductions in the magnitude of the spring freshet due to FCRPS operations could have contributed to the loss of shallow water habitats thought to be important for juvenile salmon survival (Kukulka and Jay 2003). Some entities, e.g., the Columbia Intertribal Fish Commission in Portland, Oregon, have called for increased flows in spring to closer resemble the historical hydrograph. Such an operation would affect the Columbia River estuary habitats, and could be monitored at the sites in the Habitat Monitoring Program.

The Habitat Monitoring Program in the Columbia River estuary complements and is consistent with *Federal Basin-Wide RME* (RME 2003) as mandated in the Biological Opinion on FCRPS operations (NMFS 2000). The management implication of this is that the estuary is included along with tributary and mainstem habitats in deliberations on allocation of resources to implement RME basin-wide. That is, decision-makers will have information on the status and trends of estuary habitat conditions and the effectiveness of estuary habitat restoration actions to compare and contrast to similar data from areas above Bonneville Dam. The relative importance of management actions in these respective areas may be weighed and resources allocated accordingly.

Recovery planning for salmonids listed under the Endangered Species Act will incorporate the best scientific data available on status and trends of habitats supporting listed populations in the estuary. The NOAA Fisheries' Technical Recovery Team for the Willamette and Lower Columbia River, which covers the evolutionarily significant units for lower Columbia River Chinook and steelhead, among others, will be especially interested in the data from the Habitat Monitoring program as it formulates recovery plans for these listed species. In addition, as data from the Habitat Monitoring Program is used in research on the effectiveness of habitat restoration action (see above), recovery planners will be able to identify and prioritize habitat improvements designed to aid recovery of listed stocks.

In sum, the Habitat Monitoring Program will characterize existing conditions in the estuary using a hierarchical classification system and a statistically valid sampling design; measure change in estuarine habitats through time; and provide baseline data to decision-makers to improve estuarine habitat conditions through restoration actions.

Preface

This project was funded by the Bonneville Power Administration (BPA Project No. 2003-007-00) as part of the Northwest Power Planning Council (NPCC) Fish and Wildlife Program and its fiscal year 2003 review cycle for the Columbia River estuary. The project has two parts, Water Quality Monitoring and Habitat Monitoring; the plan contained herein pertains only to Habitat Monitoring. During the provincial review process, the Independent Scientific Review Panel (ISRP) examined the project proposal (No. 30015) submitted by the Lower Columbia River Estuary Partnership. The Review Panel deemed the project “fundable” contingent upon its review of the habitat monitoring plan to be developed under initial tasks in the project’s scope of work. Accordingly, the Estuary Partnership submits this draft Habitat Monitoring Plan to the ISRP after the project period ends on August 31, 2004.

The Estuary Partnership (Deborah Marriott, Executive Director) manages and directs this project through its Technical Programs unit (Scott McEwen, Director, and Jason Karnezis, Monitoring Coordinator). The Estuary Partnership receives technical support from the following subcontractors: the Pacific Northwest National Laboratory’s (PNNL) Marine Sciences Laboratory in Sequim, Washington (Val Cullinan, Heida Diefenderfer, Gary Johnson, Kathryn Sobocinski, Ron Thom, and Greg Williams); the University of Washington (UW) in Seattle (Jennifer Burke and Charles Simenstad); and the U.S. Geological Survey (USGS), Biological Resources Division in Cook, Washington (Tim Counihan and Jim Hatton) and the Water Resources Division in Portland, Oregon (Ian Waite). Statistical consultation was provided by John Skalski of the University of Washington’s Columbia Basin Research Institute. BPA’s contracting officer’s technical representative is Tracey Yerxa, who succeeded Jessica Wilcox.

This document was the result of a team effort. Under guidance and oversight from the Estuary Partnership, PNNL had the lead to write the main body of the Habitat Monitoring Plan, with input from the UW and USGS. Similarly, the UW and USGS had the lead to develop the Habitat Classification appendix, with input from PNNL. It is anticipated that the Habitat Classification piece will become its own technical publication; it is included here because of its strong relevance to the Habitat Monitoring Plan.

This project is currently being integrated with ongoing monitoring and research in the estuary. Monitoring efforts include the U.S. Army Corps of Engineers’ Columbia River Fish Mitigation Project, the Columbia River Channel Improvements Project, and the Columbia River Estuary General Investigations Study; the U.S. Environmental Protection Agency’s Environmental Monitoring and Assessment Program; the Oregon Watershed Enhancement Board’s monitoring program; and the Washington Salmon Recovery Funding Board’s monitoring program. This project also may be of interest to the Pacific Northwest Aquatic Monitoring Partnership. Research important to the subject matter in this plan is being conducted by Oregon Health Sciences University, Oregon State University, NOAA Fisheries, Portland State University, and University of Washington.

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1.0 Introduction

A comprehensive habitat monitoring program in the Columbia River estuary[1] is needed to inventory and evaluate the status of existing habitats and make well-informed decisions regarding future management actions. The Columbia River estuary is a complex ecosystem with strong and weak interactions among numerous species across several trophic levels and various scales. The relationships between hydrologic and landscape processes and the aquatic biota that are critical for the long-term survival of sensitive species and the ecosystem in general are complex and not well understood. A broad understanding of the lower Columbia River ecosystem is critical to ensure the perpetuation of sensitive species and to predict and mitigate the effects of introduced species and further landscape alterations in this system. A broad knowledge is also critical for better planning and implementation of the diverse array of restoration activities that will occur in the near future.

No species or habitat can be understood in isolation without a broad understanding of its role in the ecosystem. While the focus of the sampling plan described herein (Section 2.4 below) is on tidally influenced aquatic habitats supporting juvenile salmon, its framework encompasses the entire tidally influenced portion of the lower Columbia River, extending landward to the extent of the historical floodplain and including deep water habitats. Designing the habitat monitoring plan for the estuary in its entirety ensures that it will accommodate additional sampling plans as species of interest change or new funding becomes available.

Monitoring of the status and trends of salmon and their habitats in the Columbia River estuary is currently incomplete. It does not include representative samples of the entire 243-km tidal reach below Bonneville Dam, is not coordinated and integrated across multiple monitoring efforts, and is not meshed with action effectiveness research for habitat restoration projects estuary-wide (Johnson et al. 2004). The purpose of this document is to provide a detailed, comprehensive plan for long-term habitat monitoring[2] in association with action effectiveness research in the estuary.

1.1 Background

The Columbia River estuary serves as a migration corridor, a physiological transition zone, a rearing area, and a refuge from predators for all 12 salmon and steelhead species in the Columbia River Basin listed under the Endangered Species Act. Until recently, however, the estuary had received scant attention in the extensive basin-wide effort to recover listed salmonid stocks and mitigate for the effects of the federal hydrosystem, because funding priority was placed on the dams and tributary subbasin habitats.

Attention to the role of the estuary in salmon recovery is presently increasing. Bisbal and McConnaha (1998) made a strong argument for decision makers to consider estuarine and ocean conditions in salmon management. The Northwest Power Planning Council (now called the Northwest

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[1] For the purpose of this plan, the Columbia River estuary includes the tidally influenced portion of the mainstem river from Bonneville Dam downstream to the mouth (see Section 1.2, Study Area, for more details).

[2] Habitat monitoring, as used herein, implicitly means monitoring of abiotic and biotic attributes in an ecosystem context.

Power and Conservation Council) convened a symposium on ocean conditions, which also encompassed the estuary (NPPC 1999). The Council's Independent Scientific Advisory Board (ISAB) supported actions in the estuary to aid salmonid stocks basin-wide (Bisson et al. 2000). Karieva et al. (2000) concluded that improvements to juvenile survival in the estuary could help reverse salmon population declines. Brodeur et al. (2000) offered a rationale and plan for research on juvenile salmonids in the estuary and ocean. These and other assessments resulted in an increased emphasis on actions in the estuary in the Council's 2000 Fish and Wildlife Program (NPCC 2000) and the NOAA Fisheries 2000 Biological Opinion on hydrosystem operations (NMFS 2000). Like Columbia River tributary and mainstem habitats, these actions primarily involve habitat restoration,[3] with associated research, monitoring, and evaluation.

Research, monitoring, and evaluation (RME) activities are essential to fulfill the Reasonable and Prudent Alternative in the 2000 Biological Opinion (NMFS 2000). Since early 2001, the Action Agencies[4] have been working with NOAA Fisheries and federal, state, and tribal fisheries agencies to develop a comprehensive RME plan for the Columbia River Basin (called the basin-wide plan and cited as RME Plan 2003). In addition, the 2000 Biological Opinion includes a RME action focused specifically on the Columbia River estuary. Action 161 states "Between 2001 and 2010, the Corps and BPA shall fund a monitoring and research program acceptable to NMFS and closely coordinated with the LCREP monitoring and research efforts (Management Plan Action 28) to address the estuary objectives of this biological opinion." Accordingly, the BPA supported a planning effort by the estuary/ocean RME subgroup that resulted in a plan for research, monitoring, and evaluation in the Columbia River estuary (Johnson et al. 2004).

In the meantime, the Lower Columbia River Estuary Partnership (Estuary Partnership) received funding from BPA to develop and initiate a monitoring program for the Columbia River estuary. The estuary/plume RME plan (Johnson et al. 2004) provides goals, objectives, performance indicators, and general methods for status monitoring, action effectiveness research, and uncertainties research, and specific recommendations for phased development of an RME program. However, because of scope constraints, the estuary/plume RME plan does not include specific details on where, when, which, and how samples should be collected within a statistically rigorous sampling design using state-of the-science habitat classifications, nor does it include details on data management and analysis essential to the monitoring program. To fill this need, the goal of the Estuary Partnership's habitat monitoring plan is to provide a detailed, statistically valid sampling plan for status and trends monitoring of salmon habitats that also supports restoration action effectiveness research in the Columbia River estuary ecosystem.

The Estuary Partnership's Monitoring Program is consistent with the RME Plan 2003 and involves "status monitoring" and "action effectiveness research." Status monitoring is the "measurement of environmental characteristics over an extended period of time to determine status or trends in some aspect of environmental quality" (from Suter 1993, cited in Noon 2003). Action effectiveness research is the

[3] In this document, the term "restoration" generally refers to any or all of the five fundamental restoration approaches commonly reported in the literature: creation, enhancement, restoration, conservation, and protection (NRC 1992).

[4] The action agencies are the Bonneville Power Administration, the Bureau of Reclamation, and the U.S. Army Corps of Engineers

evaluation of how effectively actions specifically designed to aid listed salmon produce desired biological and physical response. Finally, just as the estuary/plume RME plan was included by reference in the Columbia River estuary subbasin plan (Lower Columbia Fish Recovery Board 2004), it is also anticipated that the Habitat Monitoring Plan contained herein will become part of the estuary subbasin plan.

1.2 Study Area

The study area for this plan covers the tidally influenced portion of the Columbia River below Bonneville Dam (Figure 1.1). The BPA-funded portion of the habitat monitoring program requires clear linkages to salmonid habitats. Hence the study area for the habitat monitoring program must include those shallow aquatic and adjacent tidally influenced habitats directly linked to juvenile salmon feeding, refuge and migration. However, we recognize that habitats (including non-tidal wetlands) not directly linked to salmon may none-the-less be important to the formation and maintenance of salmonid habitats, as well as maintenance of biodiversity in the estuary system; therefore, these habitats must be included in a comprehensive monitoring program for the system. The study area is further described in the subbasin plan (Lower Columbia Fish Recovery Board 2004), Salmon at River's End (Bottom et al. 2001), and the estuary/plume RME plan (Johnson et al. 2004).

Figure 1.1. Columbia River Estuary Study Area from the Mouth to Bonneville Dam (243 km upriver). The inset shows the study area relative to the Columbia Basin.

1.3 Coordination

The habitat monitoring program described here is intended to supplement existing research and monitoring efforts in the estuary, without being duplicative. The design of this habitat monitoring program is built on recommendations in the Research, Monitoring and Evaluation (RME) Plan for the estuary (Johnson et al. 2004), which in turn was designed to be integrated with the tributary RME and hydrosystem RME plans in the basin-wide RME effort. One of the needs identified for the estuary is a coordinated effort to gather baseline data about estuarine resources (Johnson et al. 2004). This habitat monitoring plan will address some of the data gaps for the mainstem estuary evident in the NPCC sub-basin plan (2004) and will contribute to the database available for the Corps General Investigation study.

Data acquisition and management for this habitat monitoring study will be available to the Pacific Northwest Aquatic Monitoring Partnership and other ongoing efforts to standardize data systems in the region. Data collected at those relatively pristine habitat monitoring sites suitable to serve as reference sites will be made available to restoration project managers for comparative studies of restoration trajectories and performance. It will also be made available to the Corps' Anadromous Fish Evaluation Program's Cumulative Ecosystem Response study team for evaluation of the cumulative effects of multiple restoration projects in the estuary.

This habitat monitoring study may also utilize existing sampling locations from current and planned research and monitoring projects, such as EPA's Environmental Monitoring and Assessment Program (EMAP), in addition to fixed reference sites and randomly selected sampling sites specific to this project. This strategy will provide data sets on multiple metrics for several locations throughout the estuary: for example, vegetation cover type, fish genetics, fish toxics, and water and sediment toxics. We will attempt to identify shared sampling sites to facilitate analyses and to coordinate extensively with the three projects summarized below:

1) BPA/Estuary Partnership -- Toxic Contaminants and Water Quality Monitoring Program

As part of the Lower Columbia River Ecosystem Monitoring Project, the USGS and NOAA Fisheries are teaming to study water quality and fish toxicology in the estuary. USGS is coordinating the water quality monitoring component and collecting extensive data at a number of sites already established as part of an ongoing long-term monitoring project. NOAA Fisheries' Ecotoxicology program will be sampling juvenile salmon in coordination with the water quality study. Fish will be sampled for a variety of analyses, including chemical analyses (PCBs, DDTs, aromatic hyrdrocarbons), stomach content analyses for chemical compounds, blood samples for vitellogenin, otolith collection for age/growth studies, and fin clips taken for genetics. Sites for the fish collection effort have been established in coordination with other USGS and NOAA Fisheries projects.

2) BPA/NOAA Fisheries -- Historic Habitat Opportunities and Food-Web Linkages of Juvenile Salmon in the Columbia River Estuary

The BPA-funded portion of this project, specifically the NOAA Fisheries effort, samples salmonids using beach seine and trapnet methods. Sampling points include a variety of sites and salmon habitats throughout the lower portion of the estuary (Figure 1.2). Objectives of this project are as follows: 1) Reconstruction of Historic Conditions: Reconstruct the historic extent of estuarine and tidal-floodplain habitats (Columbia River mouth to Bonneville Dam) and historic changes in climate, river flow, and sediment transport from Astoria to Bonneville Dam; 2) Simulation of Habitat Change: Evaluate effects of cumulative changes in bathymetry and flow on habitat opportunity for juvenile salmon; 3) Food web and Life-History Responses to Habitat Change: Evaluate effects of habitat change and flow regulation on historic and current estuarine food webs that support diverse juvenile salmonid estuarine life histories; and 4) Implications for Estuary Restoration: Evaluate implications of historic habitat change for flow management and habitat restoration efforts in the estuary. This project also utilizes stable isotope analyses to evaluate contemporary and historic food web linkages and evaluate how food web linkages have changed through time and with modifications in the estuary.

3) Corps/NOAA Fisheries -- Estuarine Habitat and Juvenile Salmon.

This project is funded through the Anadromous Fish Evaluation Program and the Columbia River Channel Improvements Project. NOAA Fisheries is sampling several sites (Figure 1.2) in the lower estuary for salmon and salmon habitats with the aim of assessing fish-habitat linkages. Salmon stomachs, scales, and otoliths are being collected for this effort.

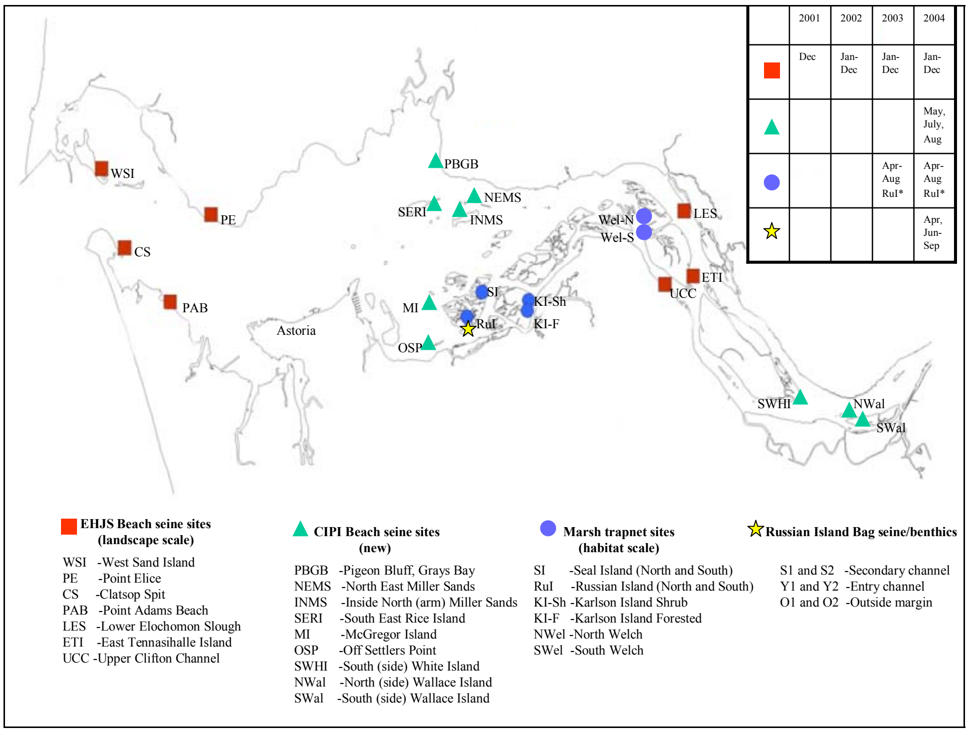


Figure 1.2. NOAA Fisheries monitoring project sampling locations. (EHJS=Estuarine Habitats for Juvenile Salmon, CIPI=Channel Improvement Project Investigation)

1.4 Organization

This plan is organized into seven sections: 1) Introduction, 2) Monitoring Framework, 3) Implementation, 4) Management Implications, 5) Literature Cited, 6) Appendix A Habitat Classification, and 7) Appendix B Potential Reference Sites. The content of this plan resembles that recommended by Hillman (2004) for the upper Columbia River. The Monitoring Framework provides the basis for successful implementation, while the details for monitoring are provided in the Implementation section. The section on Management Implications addresses the fundamental uses of the data from this habitat monitoring program in future decision-making.

2.0 MONITORING FRAMEWORK

2.1 Goals and Objectives

2.1.1 Goal

The goal of the Estuary Partnership's habitat monitoring program, as proposed under the Northwest Power and Conservation Council's Fish and Wildlife Program, is to provide a long-term data set to assess the status and trends of aquatic habitats, including those used by endangered salmon populations, and apply these data as appropriate to action effectiveness research on estuary habitat restoration. This program covers the tidally influenced reach of the Columbia River (river mouth to 243 km upriver at the Bonneville Dam).

2.1.2 Objectives

The objectives of the Estuary Partnership's habitat monitoring program, which are organized into three hierarchical levels, are as follows:

1. Status Monitoring—Landscape and estuary ecosystem
    a. Inventory, classify, and describe the Columbia River estuary ecosystem using the appropriate spatially explicit data sets available for the study area.
    b. Establish a baseline of existing connectivity between habitats, including an assessment of passage barriers for salmon, and assess trends in connectivity through time.
2. Status Monitoring—Estuarine habitats
    a. Describe physical and biological characteristics of estuarine habitats.
    b. Describe salmon species composition, age/size structure, spatial and temporal distribution, and other metrics that are relevant to salmonid dependence on estuarine habitats.
3. Action Effectiveness Research
    a. Associate project sites and reference sites with specific classification strata to provide a framework for action effectiveness analysis.
    b. Designate status monitoring sites that are appropriate for use as reference sites for restoration project effectiveness research conducted by others.

Objective 2b, while a part of the framework for the monitoring program, is not addressed in the sampling design provided in this plan. It may be addressed in future sampling designs under the auspices of this plan, and is being addressed by NOAA Fisheries research described in Section 1.3, Coordination.

2.2 Habitat Classification

The University of Washington (UW) and U.S. Geological Survey (USGS) are developing a hierarchical classification system for the estuary. It is based on existing hydrogeomorphic-structured classification systems but will be unique in that very few of the available systems address complexes in tidal freshwater floodplain portions of estuaries. The classification system will use a variety of spatial datasets—including hydrologic, geomorphic, bathymetric, land cover and other comprehensive data—to delineate ecosystem structure. The classification system will be relevant at multiple scales, all of which will be useful to various management actions.

Because the development of this classification system is co-occurring with the development and employment of the habitat monitoring plan and various sampling exercises, the plan will continue to evolve and be validated as the classification system matures. The classifications will be used in refining the sampling designs under this habitat monitoring plan and in the interpretation of data generated by the habitat monitoring program.

We anticipate that the habitat classification system under development will include five hierarchical levels (see Appendix A):

1. Ecosystem Province
2. Ecoregion
3. Hydrogeomorphic Reach
4. Ecosystem Complex.
5. Primary Cover Class

This habitat monitoring plan will use Level 3, Hydrogeomorphic Reach (see Section 2.3, Statistical Design). Ultimately, the Ecosystem Complex level is expected to be especially useful as a monitoring template for analyzing trajectories of change in juvenile salmon habitats because its definition integrates both geomorphology and cover type. Descriptions of the levels, the framework for the current classification system, and other supporting materials are presented in Appendix A, as prepared by UW and USGS.

2.3 Statistical Design

2.3.1 Rationale and Phased Approach

The habitat monitoring program is designed to provide a description of *status and trends in estuarine habitats;* in addition, data generated by status and trends monitoring of estuarine habitats must support evaluations of the *effectiveness of restoration actions* designed to benefit salmon populations. Most generally, the program will involve sampling measurable attributes of estuarine habitats (e.g., vegetative cover), and measurable attributes of salmon habitat usage (e.g., spatial and temporal distribution) (see Section 2.5). However, the program is designed to serve as an umbrella for sampling designs to be generated as new issues of significance in the estuary emerge. The sampling design presented here addresses estuarine habitat attributes, not salmon usage, which is currently being investigated by NOAA Fisheries (see Section 1.3). If data gaps regarding salmon habitat usage are identified, they may warrant the development of a sampling design under the auspices of this habitat monitoring plan.

The monitoring program has been designed in two phases (described in Section 2.4, Sampling Design), in order to take full advantage of the classification system being developed concurrent with the first phase (see Section 2.2 and Appendix A). Phase I is designed such that its output, combined with the output of the classification system, will support specific refinements to the sampling design prior to the initiation of Phase II. Both phases use a stratified rotational sampling design. The classification of the study area currently being developed on a GIS platform (Appendix A) is empirically based on available spatial data. The statistically based sampling design in this habitat monitoring plan will permit variability within and between habitats to be measured, thus complementing the classification system and providing an opportunity to verify it. The analysis of field-collected data will be used in conjunction with the habitat classification system to refine Phase II as follows: a) produce the target statistical population, b) provide defensible sampling strata, c) generate appropriate null hypotheses, and d) identify the sampling frequency and distribution suitable to the variability associated with specific attributes of the system.

2.3.2 Description of Statistical Design

Habitat Monitoring *Phase I: Inventory* aims to describe habitat types in the estuary, provide data for comparison/ground truthing with remote sensing-based project components (specifically the classification system), and measure variability in estuarine habitats so that an adequate population can be identified for sampling in subsequent efforts. The statistical design for both Phase I and II is a stratified rotational sampling design incorporating fixed and randomly-selected sites. The stratification selected for Phase I sampling is based on the level three hydrogeomorphological stratification (Figure 2.1) produced for the habitat classification system (Section 2.2, Appendix A). This selection will provide continuity between Phase I and Phase II, whether the strata for Phase II are the same or on a different level of the system.

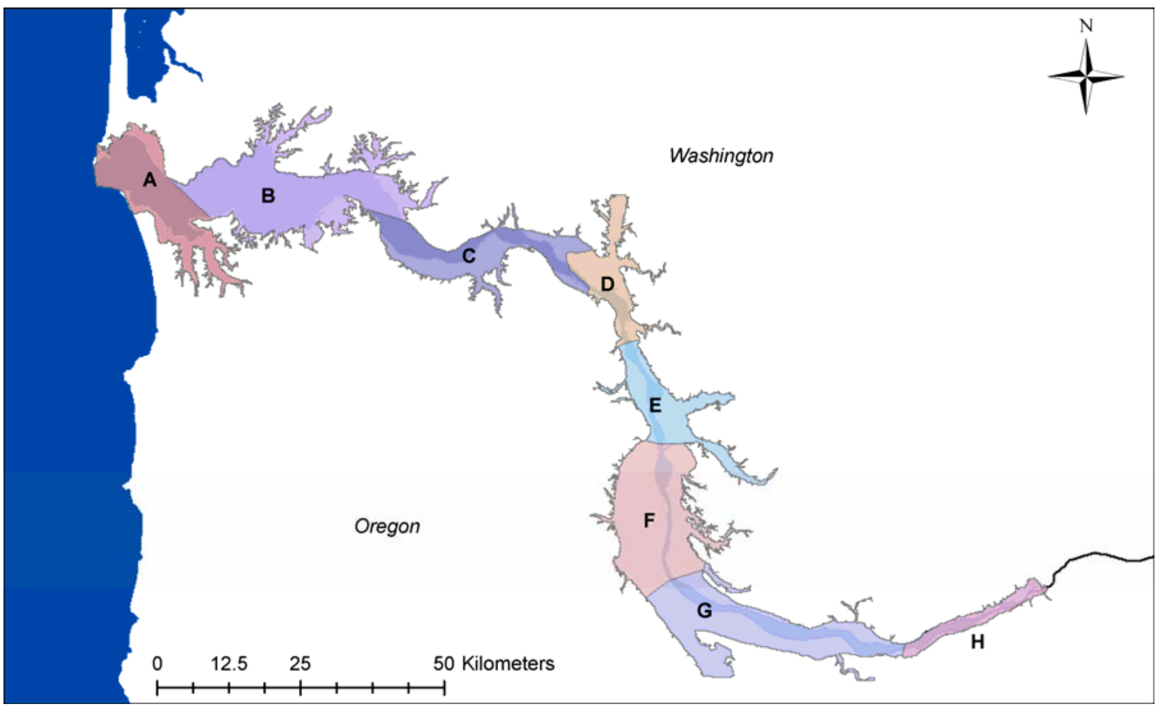
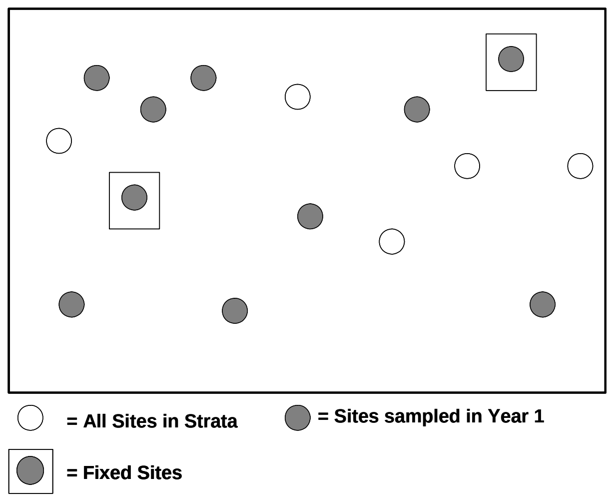


Figure 2.1. Lower Columbia River estuary landscape classification level 3 strata, as developed in the preliminary classification system prepared by UW and USGS.

A rotational design (Figure 2.2) has many advantages as described by Hillman (2004) and Rice et al. (In Press). According to Rice et al., "rotational designs that monitor 'status and trends' can be especially useful to help increase the total area that can be sampled over time, to help reduce the variance of estimates of change over time, to separate spatial and temporal variability, and to develop time series of long-term trends that represent the entire site. Rotational designs preserve inference about the full extent of a population by continually including new samples in the design and reduce the variance of estimates of change if there is correlation, over time, in repeatedly sampled units." A rotational design will sample more sites than other designs given the limited resources of a long-term habitat monitoring program and will result in a greater ability to measure change over time (Tear 1995). By incorporating fixed sites, data will be produced that can also be used for a) comparative studies of the development of project sites, and b) studies of the range of variability within sets of reference sites of a particular complex type throughout the estuary. Fixed sites may also represent existing sampling stations from other estuary monitoring programs and would thus provide long-term and more comprehensive suites of data.

a.



b.

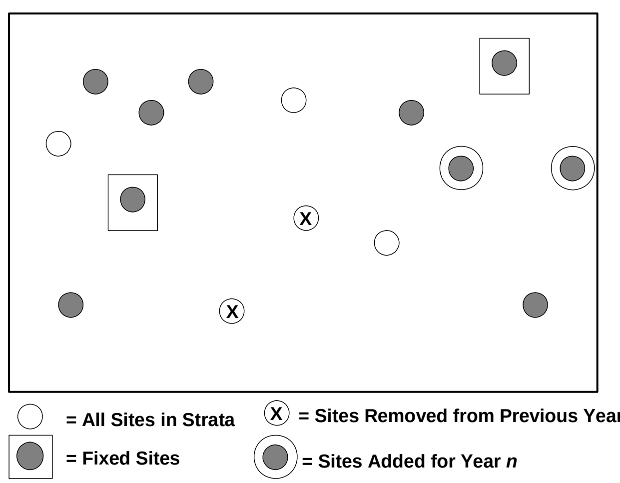


Figure 2.2. Example diagram of a rotational sampling design, utilizing fixed sites and rotational sites, with (a) showing year one, and (b) showing year two. In this example, 20% of the sites are fixed through all years and 20% are rotated out each year.

To select appropriate sites for fixed long-term sampling, the habitat classification system currently under development (See Appendix A) will be used in conjunction with the site list in Appendix B. For example, if the classification system identifies an oligohaline dendritic channel system of at least the fourth order as one complex, then sites with these features appearing on the list in Appendix B can be used as reference sites for that complex. The list in Appendix B represents areas that may be relatively undisturbed; however, it is a draft list that will be reviewed and updated as this project progresses.

We do not suggest that hypothesis testing be the focus of Phase I, as the extent of data collected may not allow inferences about habitats and specific communities to be drawn. In Phase I, the study area will be characterized by the estimation of features such as the following:

1) the percent swamp/marsh/shallows-flats/other/none;
2) variability in patchiness of vegetation and major vegetation type in each;
3) presence, absence, abundance, and variability in macroinvertebrate presence;
4) inventory of and variability in soil/sediment features (e.g., salt intrusion).

The selection of sampling points is further discussed in Statistical Population to Be Sampled in Section 2.4. Monitored attributes are detailed in Section 3.1, Monitored Attributes and Methods, and will include soil/sediment core samples, prey species, presence/absence of fish species, and vegetation type quadrats.

Phase II: Long-Term Monitoring will also use a stratified rotational sampling design incorporating both fixed and randomly-selected sites. Enhanced stratification (based upon the classification system devised for this project) is recommended because of the expected high variability within the Columbia River estuary, even within a given ecoregion. Appropriate strata will be selected based on the outcomes of Phase I, the habitat classification system, and known areas of interest (i.e., the concentration of restoration project sites). Strata may be differentially weighted with respect to sampling effort, should certain strata be found as predominant in the estuary. The spatial density and frequency of sampling in Phase II will be determined based on the variability of the system that is quantified in Phase I as well as other constraints (e.g., site access, cost, season, etc.).

Currently, a high-resolution dataset of the entire Columbia River estuary floodplain that is suitable for classifying vegetation cover does not exist. In the absence of this critical dataset, LandSat imagery for the entire estuary is being used for the purpose of developing the habitat classification "complex" layer (Burke pers. comm.). The monitored attributes included in this habitat monitoring plan include both point data on vegetation and transect data on vegetation from each sampling location. In the short term, this data can be used to analyze spatial variability within and between patches at the conclusion of Phase I, helping to scale the sampling design for Phase II. If high-resolution imagery is collected and/or further classified during Phase I, these data could also serve to ground-truth that imagery for the purpose of developing algorithms to process it for vegetation cover type. Such high-resolution imagery would also serve the monitoring of variables of hydraulic geometry, as discussed in the Estuary/Ocean Research Monitoring and Evaluation Plan (Johnson et al. 2004) and Rice et al. (In Prep.).

2.3.3 Hypotheses to Be Tested

The null hypotheses to be tested during *Phase II: Long-Term Monitoring* will depend on the variability of the system quantified during Phase I. Strata for the sampling design of Phase II will be selected based on the variability of the system, and the null hypotheses will be limited by the strata selected.

Under the Habitat Monitoring Project, null hypotheses related to the potential effects of restoration measures will not be developed or analyzed. However, a separate effort, the Corps-funded Cumulative Effects Study, is conducting this type of analysis. Some of the data generated in Habitat Monitoring *Phase I: Inventory* will be from swamp, marsh, and shallows/flats habitat types that are relatively undisturbed (i.e., not separated from the estuary by dikes or other barriers, although altered by the engineered nature of the Columbia River system). A list of potential sites is provided in Appendix B. These sites can serve as "reference sites" for comparative studies at restoration project sites. Thus, data gathered for the Habitat Monitoring Project can contribute to project implementation and effectiveness monitoring. Data will be made available for analyses evaluating changes at restoration project sites, where suitable pairing between restoration project habitats and reference site habitats exists. However, initial analyses using FragStats (Burke and Simenstad 2004) have shown considerable variability in species cover between even the same habitat type (e.g., marsh) in adjacent patches. On this basis, it is inadvisable to expect that the trajectories of development and mature conditions of project sites will conform even to nearby "reference sites."

In summary, the *Phase I: Inventory* sampling will serve to: a) characterize variability throughout the 243-km estuary; b) validate the designation of "complexes" and other strata in the habitat classification project; and c) ground-truth cover type analyses from remotely-sensed imagery. *Phase II: Long-Term Monitoring* sampling will: a) systematically collect baseline data about estuarine habitats at a discreet set of sites; b) track long-term changes in habitats, including geomorphology and cover type; c) evaluate an established set of null hypothesis (to be determined at the outset of Phase II, based upon data collected in Phase I); and d) provide information about the effects of restoration actions that can be used to evaluate and refine management measures in the estuary.

2.4 Sampling Design

2.4.1 Statistical Population to Be Sampled

Habitat Monitoring Phase I: Inventory

While the geographic scope of the habitat monitoring plan encompasses the entire estuary as bordered by the highest uncontrolled flood elevation, the scope of this sampling design for habitat monitoring is restricted to focus on shallow water aquatic habitats (e.g., marshes), riparian fringe, and adjacent small tidal channels in undiked areas of the estuary between the mouth and Bonneville Dam. The navigable waterway and mainstem channel will not be part of the statistical population to be sampled as part of this initial effort, but the classification system and umbrella monitoring plan would allow inclusion of these areas at a later date. A GIS platform with bathymetry and topography of the Columbia River estuary will be used to generate the statistical population. The estuary will be divided into eight strata following the hydrogeomorphic habitat classification (see Figure 2.3). For each stratum, 20 points will be sampled, providing a total population of 160. We will initiate a stratified rotational sampling design, which will utilize both fixed and randomly selected sites. Fixed sites will represent those areas closest to a pristine condition in each stratum and are intended to be carried through to Phase II of the project. These sites may already be recognized as having ecological value and should be included in the initial stage to maximize data for the long-term component of the plan.

Habitat Monitoring Phase II: Long-Term Monitoring

The population of sites to be sampled in Phase II will be determined based on Phase I estimates of the variance of key habitats throughout the estuary. The target statistical population for Phase II will be adjusted (ideally, reduced) from the population tested in Phase I as the analysis of data on variance permits. As in Phase I, the stratified rotational sampling design will incorporate both fixed and randomly selected sites. This approach allows the estuary to be sampled more broadly, while maintaining a suite of sites sampled the maximum number of times so that site-specific trends may be detected. The fixed sites may also serve as reference sites for action effectiveness research relative to habitat restoration in the estuary. Some potential reference sites for the upper portion of the study area are shown in Figure 2.3.

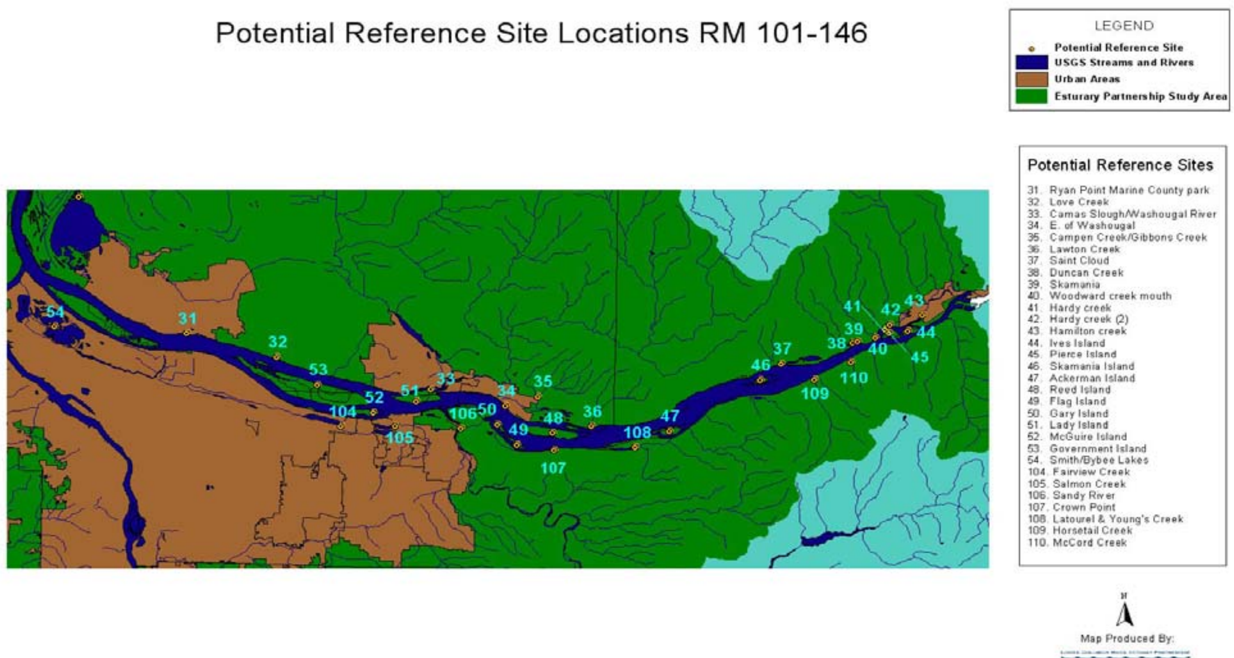


Figure 2.3. Upper portion of the Columbia River estuary, with potential reference sites.

2.4.2 Sampling Units

Habitat Monitoring Phase I: Inventory

Sampling units for Phase I will consist of randomly selected points in each stratum. All points will be monitored for landscape features, hydrology, sediments, conventional water quality, macroinvertebrates, and vegetation (see Section 3.1, Monitored Attributes).

Barriers to access at sampling sites will need to be assessed, including both private property restrictions and limitations imposed by water levels resulting from river flows and tides. The spatial distribution of private land ownership and frequency of inundation relative to the estimated population to be sampled will be critically reviewed. If a minority of the sites is privately owned, an attempt to secure access privileges will be made. If most sites are privately owned or access privileges cannot be secured, then alternative methods to develop a Phase I dataset will be evaluated. In particular, remote sensing with validation or ground-truthing at accessible sites will be considered.

Habitat Monitoring Phase II: Long-Term Monitoring

The sampling units for Phase II will be determined after analysis of Phase I results and development of strata are complete. Incorporating patch-based metrics (e.g., patch size, connectedness/fragmentation, core areas and edges) will help track landscape change. Additionally, techniques such as ranked set sampling (Mode et al. 1999) will be considered to maximize sampling efficiencies. The stratified rotational sampling design will incorporate both fixed and randomly selected sites. Fixed sites will be selected to achieve a variety of purposes, including a) to establish sites at which consistent measurements are made b) to represent a range of potential effects from project sites, based on proximity and other factors; and c) to provide "reference sites" that can be used for comparative studies of action effectiveness for the purpose of evaluating individual restoration projects and cumulative effects of restoration actions in the estuary. The protocols are expected to be the same in Phase II as in the initial phase, but will be revised should the initial sampling effort uncover unexpected problems or prove another method more informative for long-term study.

2.4.3 Sampling Frequency

Habitat Monitoring Phase I: Inventory

The sampling frequency for Phase I will be once for each sampling point. The duration of the study will be two years, and all field sampling will occur in year one, with analysis and planning for Phase II to occur in year two. The order of sampling will be randomly selected. The preferred season for sampling will be determined later.

Habitat Monitoring Phase II: Long-Term Monitoring

The sampling frequency for Phase II will be defined based on Phase I estimates of the variance for key features of habitats throughout the estuary, analyzed together with the habitat classification system. This effort is intended to incorporate fewer sites which will be sampled more intensively than in Phase I. As before, the stratified rotational sampling design will incorporate both fixed and randomly-selected sites. One or a small number of the fixed sites will be sampled on an annual basis. The remainder of the fixed sites and all of the randomly-selected sites will be sampled on a rotating basis; although sampling would occur every year, only a subset of these sites would be visited each year, on a 5-year rotation as described by Hillman (2004) in the *Monitoring Strategy for the Upper Columbia Basin*.

3.0 Implementation

3.1 Monitored Attributes and Methods

The sampling design described herein addresses status and trends in the physical and biological characteristics of estuarine habitats. Monitoring of other important attributes of the estuary, including habitat usage by salmon, water quality, and toxics, is underway or planned in related studies (see Section 1.3, Coordination). To the extent possible, existing sampling locations will be incorporated in this sampling design, while recognizing that project goals may not be concordant and therefore sampling regimes may necessarily differ. By incorporating existing efforts to the fullest extent possible, additional inferences about estuarine habitats and their functions may be drawn from a wider variety of monitored attributes, adding value to the habitat sampling effort in this design.

Several efforts are underway in the estuary to define appropriate metrics for assessment, including a project of the Estuary Partnership to assess ecosystem health, and a project of the Corps of Engineers to evaluate the cumulative effects of multiple restoration projects. The metrics defined here (Table 3.1) are drawn from a number of sources, including the *Puget Sound Estuarine Habitat Assessment Protocol (*Simenstad et al. 1991) and the *Plan for Research, Monitoring and Evaluation of Salmon in the Columbia River Estuary* (Johnson et al. 2004). As part of the Army Corps of Engineers' cumulative effects project, a standard protocol manual, similar to that used in Puget Sound (Simenstad et al. 1991), is being developed (Roegner et al. In Prep.). This protocol is expected to be complete in draft in November 2004, and we recommend that it be considered for habitat monitoring in the estuary.

A useful framework for classifying measurable attributes of salmon habitats and populations advanced by Simenstad and Cordell (2000) and adopted by Johnson et al. (2004) is "habitat opportunity," "habitat capacity," and "realized function." These are defined by Simenstad and Cordell (2000) as follows:

- *Habitat Capacity* –"habitat attributes that promote juvenile salmon production through conditions that promote foraging, growth, and growth efficiency, and/or decreased mortality"
- *Habitat Opportunity* – Attributes that "appraise the capability of juvenile salmon to access and benefit from the habitat's capacity"
- *Realized Function* – Attributes that "include any direct measures of physiological or behavioral responses that can be attributable to fish occupation of the habitat and that promote fitness and survival."

The sampling design herein monitors habitat capacity and opportunity attributes, such as prey availability, access to marsh habitats, and suitable water properties. Monitoring of the realized functions of the habitats as measured by attributes of salmon populations is not included at this time.

The potential attributes for estuarine habitat monitoring (Table 3.1) include those of high importance to salmon and those most useful for the evaluation of restoration project action effectiveness. In this way, the habitat monitoring design provides for status and trends monitoring of estuarine habitats in general, with particular emphasis on those attributes supporting salmon populations, and provides information from reference sites for comparison to restoration project monitoring results. The list of example attributes presented here will be refined for the second phase of the habitat monitoring project once hypotheses have been developed and variability of habitats has been assessed.

Table 3.1. Examples of monitoring attributes as applied to assessing the status and trends in juvenile salmon habitat in the Columbia River estuary.

Sampling Category	Characteristic	Monitored Attributes	Data Acquisition Method	Scale(s) of Application	Protocol Reference[5]/ ▲=Requires Protocol Development	Included in Phase I Sampling	Phase II Frequency (Fixed Sites)
Physical Features and Structure	Site features	Site classification (complex and cover type) and area	Remote sensing, aerial photo, LIDAR	Estuary-wide	▲	Yes	Every 5 Years
		Tidal channel area	Remote sensing, aerial photo, LIDAR	Limited to wetland sites with channels	Hood 2002	Yes	Every 5 Years
		Total edge tidal channels	Remote sensing, aerial photo, LIDAR	Limited to wetland sites with channels	Coats 1995; Williams and Orr 2002; Williams et al. 2002; Hood 2002; Desmond et al 2000; Finkbeiner et al. 2003	Yes	Every 5 Years
		Elevation, bathymetry, channel cross sectional profiles	Precision surveying (optical, GPS), acoustics, sonar	Site specific	▲	Yes	Every 5 Years
		Large woody debris	Presence, relative abundance, complexity, and position	Site specific	BURPTAC 1999	Yes	Annually
	Hydrology	Water elevation	Continuous pressure transducer (surveyed into appropriate datum)	Site specific	Sprecher 2000	No	Continuous every 15 minutes
		Lateral extent of flooding	Modeling, remote sensing (during events), compiled from other sources	Estuary-wide	▲	Yes	Annually

		Velocity	ADCP, other current meter deployment for local measurement, data acquisition from other sources (e.g., USGS, USACE) for estuary-wide	Site specific in channels, estuary-wide for river flow	Buchanan and Somers 1969; Callaway et al. 2001	Yes	Based upon river flow and tides
	Sediments	Grain size analysis	Sediment cores	Site specific	Standard EPA methods (EPA 1991); Simenstad et al. 1991	Yes	Annually
		Organic content analysis	Sediment cores	Site specific	Standard EPA methods (EPA 1991)	Yes	Annually
		Accretion/erosion rates	Marker horizon, rod surface elevation tables (RSET), precision surveying	Site specific	Callaway et al. 2001; Cahoon et al. 2002	Establish marker horizon	Seasonally
		Pore water salinity	Collected at PVC wells using hand held meter	Site specific, more descriptive in saline areas	Callaway et al. 2001	Yes	Seasonally (summer) based upon river flow and tides
	Landscape	Patch, Mosaic and Landscape metrics: e.g., shape, fragmentation, heterogeneity, connectivity, etc.	Remote sensing, aerial photograph, LIDAR, ground-truthing	Estuary-wide for remote sensing, site specific for on-the-ground measurement	▲	Yes	Annually
Water Quality	Parameters	Temperature Turbidity Salinity Dissolved oxygen	Continuous sensors and data logger or hand-held meter	Site specific	Callaway et al. 2001; OPSW 1999;	Yes	Continuous

		pH Nutrients			Schuette-Hames et al. 1999; NERR 2004		
Biological Features	Consumers and predators	Species and life history composition Abundance Size structure Temporal presence Diet	Sample with fyke nets, beach seines, or electroshockers; whole fish collection or gastric lavage for diet, systematic observation	Site specific	Simenstad et al. 1991; Murphy and Willis 1996; Skalski et al. 2001; Roegner et al. In Preparation	Sub-set of sites may be sampled for presence/ absence	Seasonally focused, multiple sampling events
	Macro-invertebrates	*Benthos* Species and life history composition Density Standing stock	Cores (500 µm)	Site specific	Simenstad et al. 1991; Gray et al. 2002	Yes	Weekly in spring
		Zooplankton Species and life history composition Density Standing stock	Ring net (250-500 µm)	Site specific	Peterson et al. 2002	Yes	Weekly in spring
		Insects Species and life history composition Density Standing stock	Neuston net (250-500 µm), fall-out traps, sweep nets	Site specific	Simenstad et al. 1991; Gray et al. 2002	Yes	Weekly in spring
	Vegetation	*Emergent* Species composition, frequency, and percent cover	Remote sensing, ground-truthing	Estuary-wide for remote sensing, site specific for on-the-ground measurement	Thom et al. 2002; Osprey Env. Services 1996; Williams 1989; Simenstad et al. 1991	Yes	Annually for ground-truthing, Every 5 years for remote sensing

		Scrub-shrub and Woody Species composition, frequency, stem density and percent cover	Remote sensing, ground-truthing	Estuary-wide for remote sensing, site specific for on-the-ground measurement	▲ Simenstad et al. 1991	Yes	Annually for ground-truthing, Every 5 years for remote sensing
		Submerged Aquatic Species composition, frequency, and percent cover	Hydroacoutstics, side-scan sonar, ground-truthing	Site specific	▲ Simenstad et al. 1991	Yes	Annually for ground-truthing, Every 5 years for mapping

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3.2 Data Management

3.2.1 Types of Data

The purpose of the habitat monitoring program is to assess status assessment (current habitat attributes) and monitor trends (detecting estuarine changes). The monitoring must also support action effectiveness monitoring, whereby specific restoration actions are compared to baseline data from established reference sites.

It is anticipated that Phase I of the monitoring plan outlined herein will be conducted under the direction of the Estuary Partnership. The intent of Phase I is to generate an inventory upon which future sampling efforts will be based. Generated data will consist of site location data, as well as data from each monitored attribute. Feedback to the GIS model under development concurrently will contribute to fully developing a classification system for Phase II sampling.

Phase II sampling will build upon data collected during the initial phase to generate a data set for long-term analysis. As such, the data collected from this program should be highly organized in a format that is adaptive to changing technology (i.e., on a 20+ year scale). Additionally, it is recognized that sampling strategies (such as protocols, equipment, etc.) may necessarily change during the course of study. All efforts should be made to transition to new data collection while maintaining continuity with past efforts (overlap of strategies, for example). Analyses, particularly laboratory processing, should be timely so that data can be analyzed, interpreted, and applied as soon as possible.

Data from monitoring of specific restoration actions is likely to be collected by numerous parties, since restoration actions are often piecemeal and sampling efforts are driven by project sponsors. Data from reference sites established as part of status and trends monitoring should be made available to restoration project managers in a format relevant for restoration project comparisons (both between reference and restoring sites and between similar types of restoring sites). As per Objective 3 in this monitoring plan, classification strata for both reference and restoring sites should be identified at the outset of restoration planning. This will enhance comparability and data sharing in the most appropriate manner. Restoration actions will often carry their own goals and objectives and as a result will use status and trends data to varying extents.

3.2.2 Metadata

The commencement of on-the-ground monitoring intended for long-term analysis requires that vast amounts of data be catalogued for future use. We recommend a data clearinghouse be established, whereby one organization (e.g., Estuary Partnership) is responsible for managing metadata, including a list of sites sampled, what type of data was collected and when, and what organizations (including points of contact) have the raw data files. Additionally, data could be posted by the data management group in a read-only or password protected format, allowing users to browse existing data sets.

Metadata management will be of increased importance for action effectiveness research, as it is likely that several parties will be collecting data at diverse restoration sites. However, all data collection efforts should, at a minimum, report what data was collected, so a catalog of existing information can be created.

3.2.3 Data Sharing and Dissemination

Among the parties working in the Columbia River estuary, the need for data coordination has been expressed as being of paramount importance. Because no standardized system for data management currently exists and projects are piecemeal based upon sponsor, results rarely get broadly disseminated. To facilitate better cooperation and increased value of collected data, we recommend annual meetings as a platform for sharing data and reporting on projects. Additionally, biennial reports would synthesize work from multiple years, while sharing results in a timely manner.

The Estuary Partnership is currently evaluating web-based data reporting systems to determine if a similar system could be used in the Columbia River. Additionally, several systems for data management and sharing are currently commercially available (e.g., Axiope, Cybozu Share360) and should be evaluated for use in this project, especially vis-à-vis action effectiveness research.

3.2.4 Quality Control and Assurance

Each phase of status and trends monitoring has been designed as a statistically based sampling plan. Standard protocols for collecting samples will be utilized, to maintain integrity in data collection between different organizations conducting the work. Quality assurance procedures associated with implementing standard protocols will be described in the field sampling plans for each sampling activity undertaken. A quality assurance field will be included in the metadata.

3.2.5 Data Archive

Data should be archived according to an established protocol, which will be determined by the Partnership or other agency handling the task. We recommend that voucher specimens be maintained (especially for fish, macroinvertebrates, and plants), but that sample retention be minimal. All fish specimens of value should be archived in a fish collection (e.g., UW or Oregon State University) so that future studies are possible. All computer data should be archived in a format which is widely compatible and should be evaluated on a five year basis to determine if more current methods need to be employed. Data sheets, raw computer files, processed and analyzed data, and reports should all be maintained to allow for re-evaluation of data at a later date should new information or new studies arise.

4.0 Management Implications

The purpose of this section is to explain the implications that data from this habitat monitoring program will have for decision-makers responsible for managing the Columbia River estuary and its resources. Management implications fall into five main topic areas: ecosystem health, habitat restoration, FCRPS operations, federal basin-wide RME, and recovery planning.

- *Ecosystem Health.* Status and trends in ecosystem health reveal whether the quality of the Columbia River estuary ecosystem is deteriorating or improving. The Habitat Monitoring Program is one of several that will provide data applicable to assessment of estuary ecosystem health; other efforts include the Water Quality and Toxics Monitoring by the Estuary Partnership, Contaminants and Fish Monitoring by NOAA Fisheries, and Juvenile Salmon Monitoring by the Corps of Engineers. Data from the Habitat Monitoring Program especially relevant to ecosystem health are the inventory of habitat classes and the measurements of habitat connectivity. For example, as more is learned from research by NOAA Fisheries and the UW on habitat classes most beneficial to the growth and survival of endangered juvenile salmon, it will be important to decision-makers to have data on the status and trends of these particular habitat classes as they assess ecosystem health. Also, assuming increased (restored) habitat connectivity leads to increased ecosystem health, then status and trends of this attribute will be indicative of ecosystem health. Results from the Habitat Monitoring Program will be incorporated into the Estuary Partnership's periodic assessments of ecosystem health mandated because the Columbia River estuary is in the National Estuary Program.
- *Habitat Restoration.* Research on the effectiveness of restoration actions in the Columbia River estuary will use monitoring data collected at reference sites as part of the Habitat Monitoring Program. Reference site monitoring data, e.g., vegetation cover, sediment grain size, and bathymetry, will be compared periodically with habitat restoration site data. The trend in similarity between the two sites will be one indication to managers of the effectiveness of the restoration action. In addition, the Habitat Monitoring Program's habitat classification system, coupled with the routine inventories of estuary habitats, and analysis of fish usage data from other programs, will provide key information to help managers prioritize habitat restoration actions. Results from the Habitat Monitoring Program will be used in action effectiveness research designed to aid decision-makers allocating the increasing level of resources being devoted to habitat restoration in the Columbia River estuary.
- *FCRPS Operations*. Monitoring data from the Habitat Monitoring Program would be applicable in evaluations of any future FCRPS operations designed to affect shallow water habitats in the Columbia River estuary. Hydrodynamic modeling showed that reductions in the magnitude of the spring freshet due to FCRPS operations could have contributed to the loss of shallow water habitats thought to be important for juvenile salmon survival (Kukulka and Jay 2003). Some entities, e.g., the Columbia Intertribal Fish Commission in Portland, Oregon, have called for increased flows in spring to closer resemble the historical hydrograph. Such an operation would

affect the Columbia River estuary habitats, and could be monitored at the sites in the Habitat Monitoring Program.

- *Federal Basin-Wide RME.* The Habitat Monitoring Program in the Columbia River estuary complements and is consistent with Federal RME for the entire Columbia basin as mandated in the Biological Opinion on FCRPS operations (NMFS 2000). The management implication of this is that the estuary is included along with tributary and mainstem habitats in deliberations on allocation of resources to implement RME basin-wide. That is, decision-makers will have information on the status and trends of estuary habitat conditions and the effectiveness of estuary habitat restoration actions to compare and contrast to similar data from areas above Bonneville Dam. The relative importance of management actions in these respective areas may be weighed and resources allocated accordingly.

- *Recovery Planning.* Recovery planning for salmonids listed under the Endangered Species Act will incorporate the best scientific data available on status and trends of habitats supporting listed populations, as will be produced by the Habitat Monitoring Program in the estuary. The NOAA Fisheries' Technical Recovery Team for the Willamette and Lower Columbia River, which covers the evolutionarily significant units for lower Columbia River Chinook and steelhead, among others, will be especially interested in the data from the Habitat Monitoring program as it formulates recovery plans for these listed species. In addition, as data from the Habitat Monitoring Program is used in research on the effectiveness of habitat restoration action (see above), recovery planners will be able to identify and prioritize habitat improvements designed to aid recovery of listed stocks.

In sum, the Habitat Monitoring Program will provide data to decision-makers in an adaptive management process to improve habitat conditions for listed salmonids, as well as the Columbia River estuary ecosystem as a whole.

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Appendix A: Habitat Classification

DRAFT

Lower Columbia River and Estuary Ecosystem Classification: Phase I

August 2004

Prepared for the
Lower Columbia River Estuary Partnership

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A.1 Introduction

A.1.1 Problem and Opportunity Addressed

Since the origin of the Lower Columbia River Comprehensive Conservation and Management Plan (LCR-CCMP) (Lower Columbia River Estuary Plan; LCREP 1999), organization of monitoring, management, and education has depended to a large degree on understanding the distribution and status of ecosystems and biota-specific habitat types in the lower Columbia River and estuary (LCRE). Included among 49 discrete actions, the LCR-CCMP recommended actions that would (a) "inventory and prioritize habitat types and attributes needing protection and conservation;" (b) "identify habitats and environmentally sensitive lands that should not be altered;" (c) "protect, conserve and enhance identified habitats, particularly wetlands, on the mainstem of the lower Columbia River;" and (d) "adopt and implement consistent wetland, riparian, and aquatic habitat protection standards that result in an increase in quality and quantity of habitat." Although considerable information was available for the lower ~75 km of estuary (Thomas 1983; see also dedicated issue of *Progress in Oceanography*, 1990, 24(1-4), L.F. Small, guest ed.), a critical constraint upon implementation of these actions recognized at that time was the lack of a clear accounting of the habitat types and spatial organization across the diverse ecosystems that composed the ~230 km of the lower River and estuary; this lack of data was cited as a critical constraint toward the implementation of the recommended actions. Commensurate with this information gap was the lack of an ecosystem classification system that would allow a scientifically-based delineation of habitats at the variety of scales required for different monitoring, planning, and management needs.

In 2004, the Lower Columbia River Estuary Partnership (LCREP) received funding from the Bonneville Power Administration (BPA) to develop and initiate a habitat-monitoring program for the lower Columbia River and estuary. Among the first tasks for this work is to develop draft protocols, including methods and indicator metrics, to assess the condition of LCRE habitats, and particularly those supporting juvenile salmonids. The result of these efforts will be a refined habitat monitoring program that LCREP and others can use to assess the quality of habitats and the progress toward goals established by the Partnership for the estuary.

During the initial stages of the development of the habitat-monitoring program, the need for an ecosystem classification was again recognized and identified as a tool necessary for the development and implementation of the monitoring program. Based upon such a classification system, a comprehensive geographical information system (GIS) platform would then serve as a template from which a statistically sound habitat-based ecosystem monitoring program can be formulated.

During 2004, the University of Washington (UW) and USGS developed a framework for the ecosystem classification scheme and initiated compilation of existing data and collection of additional information to provide the spatial dataset that would be used to identify and delineate different ecosystem scales in the LCRE.

A.1.2 Objective

The objective of this component of the LCRE Monitoring Plan development is to provide a hierarchical framework that will allow delineation across different scales of the diverse ecosystems and component habitats in the lower Columbia River and estuary. The primary purpose of this classification scheme is to enable systematic monitoring of diverse, scale-dependent and scale-independent ecosystem attributes.

A.1.3 Background

The complex and dynamic nature of ecosystems present challenges when attempting to characterize their structure and function at a manageable scale, even more so when the features and processes of interest occur at multiple scales. Further, that ecosystems tend to be self-organizing can present even more challenges. However, the concept of a hierarchy in ecosystems suggests that it may be tractable to delineate boundaries and that the transition in ecosystem processes across these boundaries many be meaningful to science and management (Gonzalez 1996).

While typical land cover classifications (e.g., C-CAP for LANDSAT imagery) are excellent tools for capturing status and change on a simple spatial basis, they do not necessarily capture larger, more landscape-scale features that form habitats of large, motile organisms such as fishes. Efforts to characterize dynamic, large-scale estuaries, where strong fluvial and tidal forces interact to structure complex landscapes and frequent natural disturbance continuously modifies and rearranges the landscape structure may benefit from this approach.

Large rivers are typically affected by two, semi-independent sources of disturbance: hydrologic and geomorphic stresses. Hydrographs of large rivers are frequently altered by reservoir regulation or water diversions and the restoration of the historical hydrograph has often been suggested as a primary action to restore ecosystem functions (National Academy of Sciences 1992; Poff *et al.* 1997), the assumption being that the natural hydrograph will return most, if not all, of the river's physical habitat template. However, large rivers are also characterized by extensive physical alterations of channel morphology by navigation and bank stabilization structures. These features control the distribution of water – and thereby exert a strong influence on physical habitat – and impede geomorphic adjustments of the river system. Hence, a natural hydrograph alone is unlikely to restore all the physical habitat of large rivers. Much of the practical management of large rivers involves informed tradeoffs between hydrology and geomorphology, a process that should be guided by the relative ecological benefits and societal costs of altering these characteristics.

The large size, high water velocities, and complex ecological interactions in large rivers present substantial challenges and opportunities for improved scientific understanding. Hydraulic models are the basic tool for quantifying the interplay between hydrology and geomorphology to describe the physical aquatic habitat template. Hydraulic models have been used in the analysis and modeling of large rivers (Tiffan *et al.* 2002, Garland 2004), but substantive differences in size, data requirements, and types of analyses dictate different approaches for using this tool on large rivers. For example, large rivers may stress computational resources for digital hydraulic models, and complex flow hydraulics around engineered structures will require investigation of fine-scale enhancements and the utility of 2+ and 3-

dimensional models. At the same time, large rivers also offer opportunities to employ high-resolution hydro-acoustic depth, velocity, and substrate-sensing instrumentation, new topographic data techniques such as LIDAR (Light Detection And Ranging), and extensive telemetry efforts that can provide datasets with high density and precision.

Both flow regulation and major alterations in channel configuration present constraints in habitat-sustaining processes in the lower Columbia River and estuary. Loss of access to the natural floodplain by construction of levees in the LCRE has been implicated in consequential habitat loss for juvenile salmon (*Oncorhynchus* spp., twelve populations of which are listed under the Endangered Species Act), both within the lower estuary (Thomas 1983) and in tidal freshwater regions (Kukulka and Jay 2003b). Although development of this classification will be based on ecosystem structure in order to encompass a wide range of habitats of diverse biotic resources in the LCRE, some emphasis will be placed on juvenile salmon habitat.

We will use the *Salmon at Rivers End* (Bottom *et al.* in press) approach and conceptual model as a template to classify habitat attributes that can be incorporated into the classification. In addition to adoption of the *Salmon at Rivers End* concepts of juvenile salmon habitat, in later phases of this ecosystem classification development we will also collaborate with the on-going NOAA-NWAFS research activities (supported by USACE and BPA) to define lower River and estuarine habitat requirements, including emerging results of their studies on juvenile salmon ecology in estuarine wetlands (Dan Bottom, NOAA, Charles Simenstad, UW), historic river reconstruction (Jennifer Burke, NOAA) and modeling of habitat change (Antonio Baptista and David Jay, OGI). We will also merge existing spatial datasets developed under LCREP (e.g., LANDSAT 7, CASI hyperspectral) with other spatial data (e.g., NOAA historic reconstruction, C-CAP) to provide quantitative, systematic data for analytical development of habitat classes and landscapes. Models of habitat requirements will be based on existing information and, more specifically, consultation with USFWS/USGS-BRD expertise in the region.

In developing a strategy for assembling a comprehensive ecosystem classification scheme appropriate to the tidally influenced region of the Columbia River and estuary, we will draw on the limited existing approaches to classifying and assessing functionality of large river, coastal floodplain and estuarine ecosystems in developing an appropriate protocol. Much of the lower Columbia (estuary) is essentially tidal freshwater. Probably at least 155 km of the study area was historically persistent tidal freshwater; limitation of natural low water events under flow regulation now results in considerably more persistent tidal freshwater (Sherwood *et al.* 1990; Simenstad *et al.* 1992). This is particularly relevant to the existing need for an ecosystem classification scheme because tidal freshwater regions, particularly of large tidal floodplain rivers such as the Columbia, are seldom included in the currently accepted classifications for either estuaries or rivers. While land cover classifications routinely include tidal freshwater vegetation and other unique surface features, hydrological, geomorphological, or landscape features are seldom included.

In the limited time available for Phase I development of the LCRE Ecosystem Classification, we surveyed the published literature, unpublished and other "gray" literature and the World Wide Web (WWW) for existing classification schemes that would be appropriate for applying *in toto* or in concept to the lower Columbia River and estuary. We found that, while many recent approaches (e.g., National Coastal/Marine Classification Standard for North America; Madden and Grossman 2004) were developed to resolve deficiencies and inconsistencies in earlier classifications of habitat units and local structures for the estuarine and nearshore marine systems (Wieland 1993; Allee *et. al.* 2000; Cowardin 1979; Dethier 1990; Brown 1993; Connor 1997; Madley *et al.* 2003), none of these extended into tidal fluvial ecosystems and few provided much insight into tidal floodplain ecosystems. However, Madden and Grossman (2004) make strong arguments for the need and mechanisms to link the National Coastal/Marine Classification Standard for North America to compatible freshwater classifications.

Examination of commonly utilized riverine and wetland classifications, and especially those including hydrological and geomorphological descriptors (e.g., Bovee 1982; Rosgen 1994; Leopold and Wolman 1957; Sear *et al.* 2003), indicated that they seldom approached tidal freshwater regions of watersheds, either literally or figuratively. Some classifications have been more explicitly developed for or to include tidal freshwater and tidal floodplain ecosystems, although these tend to originate from Europe, Australia, New Zealand, and Asia and to not yet have reached peer review publication. For instance, the Water Ecotope Classification (WEC) originated in The Netherlands (Van der Molen *et al.* 2003) and adopts a classification that comprehensively bridges watersheds and coastal waters with "transitional waters." It is based on morphodynamics, hydrodynamics and land use; floodplain ecotypes are particularly defined. However, the resolution of the ecotopes is not appropriate (high enough) for delineation of biotic habitats. Other applicable classifications (e.g., Simons *et al.* ND; Hume and Herdendorf 1988) also include tidal freshwater and tidal floodplain ecosystems.

Figure A.1. Basic physiographic setting and geographic extent of the lower Columbia River and estuary (LCRE) as applied to this ecosystem classification scheme. Historic flood plain based on Earth Design Consultants, Inc. (EDC) analyses for LCREP.

A.2 Approach

A.2.1 Scope

Commensurate with the spatial extent of the LCREP study area, the geographic scope of this classification scheme includes from the outer mouth (e.g., oceanic end of jetties) of the estuary to the upstream extent of tidal variability in water level, which is the downstream base of Bonneville Dam (~230 RKm) (Figure A.1). The lateral extent is defined as all elevations, from the deepest channel depths to the historic flood plain, with the upper limit at maximum flooding levels (based on USACE 1968; Kukulka and Jay 2003a&b) prior to historic development of the flood plain and regulation of the river. The rationale for this last criterion is that the classification scheme should not a) preclude comparison with historic ecosystem structure or b) prevent evaluation of restoration scenarios that may involve re-inundation of the tidal flood plain.

A.2.2 Criteria

We adopted the following primary and secondary selection criteria upon which the design of the classification, and selection of the data upon which it would depend, was to be based.

Primary

- data available from contemporary comprehensive and complete spatial datasets
- mapable at appropriate scale to delineate important ecosystem components (cover types and shapes)
- primary delineating factor at critical hierarchical level for monitoring plan is hydrogeomorphology, which is determined to be the forcing processes influence most other (e.g., ecological) attributes
- captures scale of ecosystem dynamics (e.g., development stage of ecosystems) that is anticipated to evidence change over likely monitoring scales
- relevant to habitat requirements of biota of concern (e.g., species at risk)
- incorporates features of relevance to landscape ecology of tidal floodplain systems

Secondary

- repeatable in part with historic spatial datasets
- applicable for future (change) analyses, such that spatial data would predictably be updated periodically and new technology would advance rather than preclude comparability.

The tool for this will be a geomorphic and habitat classification system that we will develop based on new bathymetry data and the existing LANDSAT 7 TM and hyperspectral information that was completed for LCREP in 2002 by University of Washington and Earth Design Consultants.

A.2.3 Components

Develop a geomorphic and habitat classification scheme for the lower Columbia River and estuary:

1. Incorporate existing spatial datasets developed under LCREP (e.g., LANDSAT 7, CASI hyperspectral) with other spatial data (e.g., NOAA historic reconstruction, C-CAP) to provide quantitative, systematic data for analytical development of habitat classes and landscapes (e.g., development of a geomorphic and habitat classification system).

- Compile existing information regarding the aquatic habitats in the lower Columbia River and Estuary to identify information gaps.
- Compile existing bathymetry data and associated meta-data.

  The Oregon Graduate Institute has done much work describing the hydraulic conditions of the lower Columbia River. The CORIE model that has been developed includes a pilot environmental observation and forecasting system for the Columbia River. It integrates a real-time sensor network, a data management system and advanced numerical models. Through this integration, they seek to characterize and predict complex circulation and mixing processes in a system encompassing the lower river, the estuary and the near-ocean. We will also collaborate with the on-going NOAA-NWAFS (Dan Bottom, NOAA, Charles Simenstad, UW), historic river reconstruction (Jennifer Burke, NOAA) and modeling of habitat change (Antonio Baptista and David Jay, OGI).

  Similarly, the USGS Columbia River Research Laboratory (CRRL) has compiled and collected additional bathymetry information in the lower Columbia River from Bonneville Dam to Skamania Island. Using this information, a two-dimensional hydrodynamic model has been developed for this river reach (Garland 2004).

  Obtaining habitat descriptors (e.g., bathymetry and substrate classifications) from both datasets and incorporating them into a comprehensive GIS will help to identify information gaps that need to be filled to more adequately describe the aquatic habitats in the lower Columbia River.

- Compile existing bathymetry not included in either the OGI or CRRL information databases.

  The Army Corps of Engineers has done selective bathymetry surveys in the lower Columbia River. Identifying the areal extent and meta-data associated with these surveys will further help to identify information gaps and strengthen the overall bathymetry database.

2. Collect additional bathymetry and substrate information to fill in data gaps identified in objective one and two as high-priority areas.

- Collect additional bathymetry, side-scan sonar, and substrate information in important areas where data gaps have been identified. The lower Columbia River is a large geographical area and gaps in existing information are likely to exist. Once the data gaps have been identified, additional information should be collected. However, filling in all the existing gaps is likely not possible during 2004/2005. Areas that are of particular interest should be identified so that data can be collected in these priority areas. Lower priority areas can be covered in future years.

A.3 Methods

The LCRE Ecosystem Classification is designed to aggregate conceptualized land and aquatic cover classes according to the ecosystem processes that structure landscape attributes, including biotic habitats, at different spatial scales. The classification methodology is entirely GIS-based using automated processes with minimal manual classification to generate an objective, repeatable, hydrogeomorphic class system. An explicit goal is to not involve any subjective delineation of classes at any level, but to either utilize scientifically based classification schemes that already exist for the area or to develop rational rules adaptable to GIS-based analyses. Many data sources are readily available as inexpensive GIS map layers that, if updated or improved in the future, can be incorporated into the classification methodology.

All GIS data in the classification methodology are readily available and offered free of charge from state and federal government agencies (Table A.1). The classification relies primarily on contemporary data sources. However, we will incorporate historical data sources to cross-validate the methods. We are requesting additional data, e.g. higher resolution bathymetric data from the U.S. Army Corps of Engineers, to improve the spatial extent and resolution of the classes in the next phase. Therefore, updated and improved data may replace existing data listed in Table A.1 in the early phases of this project.

A.3.1 Integration of Data Sources in GIS

GIS processing utilized an ESRI ArcGIS 9.0 ArcInfo version with the Spatial Analyst extension. All data layers were imported to a geodatabase and projected to the State of Oregon standard (Lambert Conformal Conic, NAD 1983 datum, meter map units) for consistency in processing with existing GIS layers available from LCREP. A majority of the data were freely available on the World Wide Web. All processes will be documented in metadata provided in the final report.

5.1 Base Data - Historical Flood Plain and Tidal Extent

The spatial extent of this classification scheme is defined by the historical flood plain and extent of tidal influence in the main river and tributaries. A map layer generated by Earth Design Consultants, Inc., (EDC, Inc.) (Figure A. 1) closely correlates with this but will be refined by this project using tidal elevation data, USGS 10-m DEMs, and historical T-sheets. EDC, Inc. delineated the floodplain map layer using 5.5-m (18-ft) contours from 10-m DEMs in addition to manual editing where the head of tide has been determined in tributaries. Because the applied elevation data were consistent across the entire estuary, but tidal extent is not consistent as it reaches up the estuary, there is a strong need to generate a higher resolution floodplain for the entire estuary.

The historical floodplain and tidal extent GIS data layer will be freely available to resources managers. The historical main river floodplain will be generated from the Mean High Water (MHW) delineation on the historical T-sheets. To determine the maximum lateral (flood plain) extent of tidal flooding in tributaries, 10-m DEMs for the estuary and tributaries will be stratified at major tidal elevation breaks (USACE 1968; Kukulka and Jay 2003) and geospatially processed using elevation criteria unique to each strata to extract the maximum extent of flooding within each strata. The historical floodplain map layer and spatial extent of tidal flooding map layers will be merged into a single polygon and lines between strata will be smoothed.

Table A.1. Sources and attributes of spatial data used to develop present version of LCRE Ecosystem Classification; RKm 75 = RM 46, Rkm 214 = RM 133, RKm 230 = RM 145)

Data Type	Year	Spatial Extent	Resolution	Data Sources
Ecoregions	1984 to 2003	RKm 0 to 230	Varies	U.S. Environmental Protection Agency (EPA)
Bathymetry	2001 -2002 survey	RKm 0 to 75	To be determined	U.S. Army Corps of Engineers
	1938 to 1958	RKm 75 to RKm 230	30m	NOAA National Ocean Service
Hydrology	varies	RKm 0 to 230	1:24,000	USGS topographic surveys as digital raster graphics (DRG)
	varies	RKm 0 to 230	30m	Floodplain extent from Earth Design Consultants, Inc.
Land cover	2000	RKm 0 to 230	30m	LANDSAT 7 TM imagery from LCREP and Earth Design Consultants, Inc.
	1974	RKm 0 to 230	1:24,000	National Wetland Inventory (NWI)
Elevation	varies	RKm 0 to 230	10m	USGS Digital Elevation Models (DEMs)
	2004 (avail. 2005)	RKm 0 to 230	unknown	USGS LIDAR Survey
Aerial Imagery	2001	RKm 0 to 230	1m	Digital Ortho Quads from Oregon Spatial Data Clearinghouse
Historical Bathymetry (H-sheets)	1866 to 1901	RKm 0 to 214	1:10,000 to 1:20,000	U.S. Coast and Geodetic Surveys, provided by NOAA Coastal Services Center
Historical Topography and Land Cover (T-sheets)			1:10,000	

A.3.3 Data Sources

A.3.3.1 Eco-Regions

We selected the EPA-adopted Ecoregion Level III to provide the broad regional context at the highest level of the hierarchy. As initially developed by Bailey (1983, 1987, 1995), Bailey et al. (1994), Omernik (1987, 1995), and Omernik and Bailey (1997), the ecoregion concept provides a broad-scale framework in which ecological regions are identified by patterns and the composition of abiotic and biotic phenomena, such as climate, geology, physiography, hydrology, vegetation, soils, land use, and wildlife. Although there may be similarities among some of these characteristics, the relative importance of each, and the interrelationship among them vary across regions.

Our rationale for utilizing this system for Level 1 (and Level 2) of this scheme is that watersheds are going to play a strong peripheral, if not cumulative, effect on the structure of LCRE ecosystems. No GIS processes were applied to the Level II, III, or IV Ecoregions.

A.3.3.2 Hydrogeomorphic Reaches

Historical floodplain and tidal extent Level IV Ecoregions, and major hydrologic features served as the basis for the delineation of hydrogeomorphic reaches within the third level of this ecosystem classification hierarchy. The historical floodplain and tidal extent map layer were manually split using heads-up, i.e. on screen, editing tools in ArcMap. Level IV Ecoregion breaks and major hydrologic features from the USGS topographic maps coincided well with the boundaries and transition points of the other hydrogeomorphic features used for this level of the classification. These strata may be further refined following review.

A.3.3.3 Ecosystem Complexes

We integrated numerous data sources and GIS processes to derive the Ecosystem Complex level structure of the classification. Each hydrogeomorphic reach will be processed individually for complexes. At this time, a segment of one hydrogeomorphic reach was processed as a pilot project. Therefore, the methods are still in draft format and further refinements to the methods will occur in the next phase.

The foundation of the Ecosystem Complex level was the isolation of major hydrologic features of the estuary represented by the bathymetric data. For example, in the pilot illustration (see below), a deep water channel was defined for depths greater than 8 m and extracted from the map layer to create a separate single map layer in polygon format. Distributary channel bathymetry, defined as depths greater than 1 m, was extracted and processed in Spatial Analyst to create polygon boundaries for the complexes in a single map layer. Minimal manual editing will be enforced in the generation of these map layers. However, unique and anthropogenic features will be delineated within their own complexes, e.g., islands created from dredge materials.

A complex boundary map layer was overlaid on land cover data, bathymetric data, aerial imagery, and elevation data. A rules-based approach will be used in an automated manner to classify the complexes based on the percentages of the map layer classes that appear within each individual complex. To generate a set of tables listing the percentages of each class within each complex, each map layer will be processed in GIS with ESRI ArcTools, Spatial Analyst, and Summarize Zones where the complex boundary layers define the zones.

A.3.3.4 Primary Land Cover

Existing data sources will be used for the land cover classes within the LCRE Ecosystem Classification. No processing will occur unless the data sets need to be refined or corrected. For the present, we are using the classified 2000 LANDSAT 7 TM processed by Earth Design Consultants, Inc., for LCREP.

A.4 Results: DRAFT Classification

Based on the structure of other classification schemes developed for estuarine ecosystems described in the literature, and common concepts of ecosystem geography (Bailey 1996), we defined a classification scheme for the lower Columbia River and estuary that is structured in five hierarchical levels:

1. Ecosystem Province
2. Ecoregion
3. Hydrogeomorphic Reach
4. Ecosystem Complex
5. Primary Cover Class.

Each level encompasses different scales of influence on ecosystem structure, where the highest levels in the scheme describe regional-scale structure and the lowest levels compose the finer scale components of the strata in the levels higher in the hierarchy. For example, each of the Ecosystem Complexes in level 4 is composed of sets of the Primary Cover Classes in Level 5. These sets or aggregations of cover classes are not necessarily unique, other than their association with larger-scale features (described below). Similarly, each Hydrogeomorphic Reach in Level 3 is composed of various compositions and arrangements of Ecosystem Complexes, which are somewhat unique within each reach.

A.4.1 Level 1: Ecosystem Province

Level 1 of the LCRE Ecosystem Classification is defined as the Ecosystem Province encompassing the Marine West Coast Forest of Ecoregion Level II that occupies the coastal terminus of the Columbia River watershed (Figure A.2). This is immediately adjacent to the Western Cordillera Province which occupies much of the remainder of the Columbia River basin.

A.4.2 Level 2: Ecoregion

The Ecoregion level of the LCRE Ecosystem Classification adopts in principle and basic delineation the EPA Ecoregion Level III structure (Figure A.3). Only the boundaries joining the ecoregion on either side of the Columbia River were added in our processing. Four Ecoregion strata are delineated within the LCREP study area.

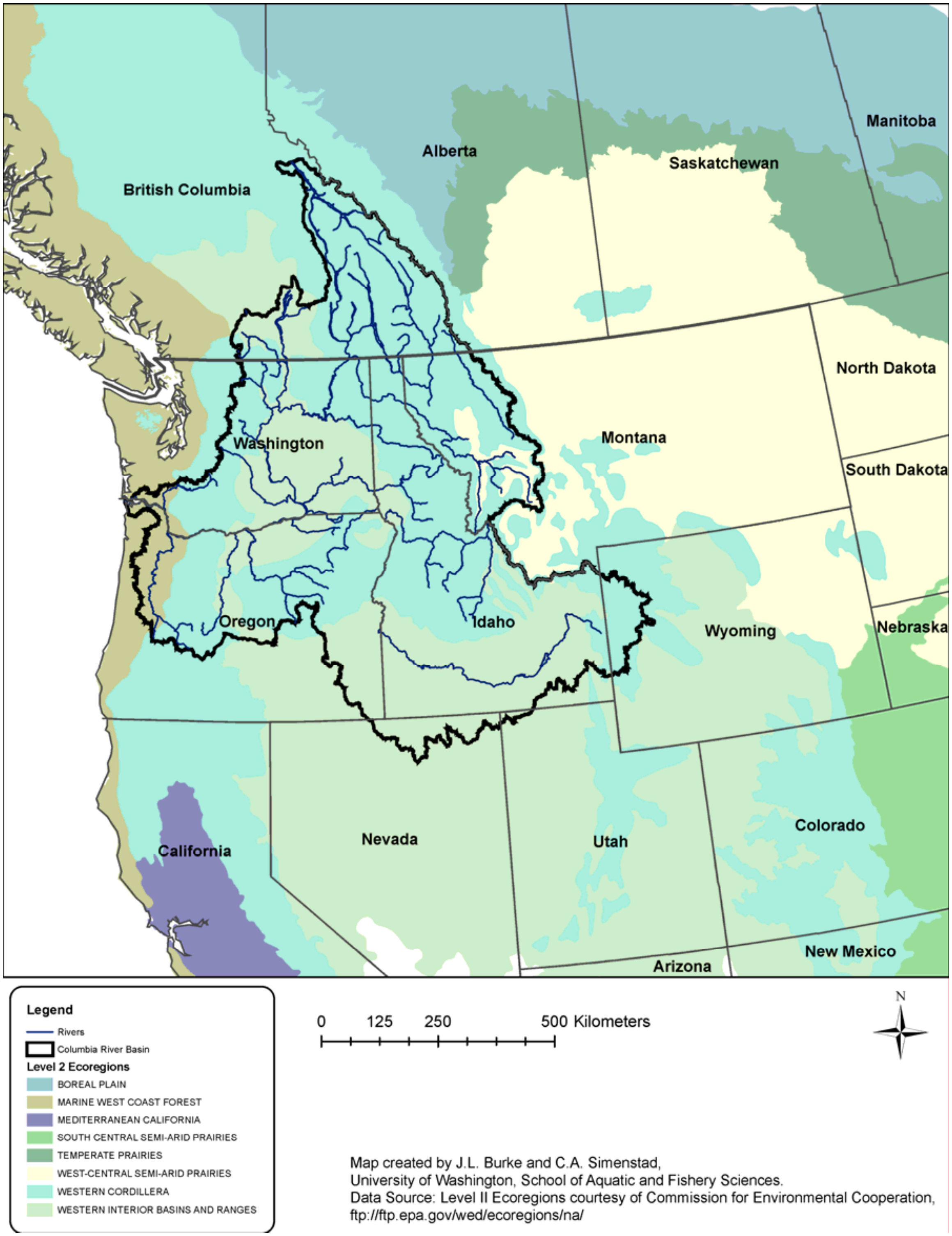

Figure A.2. Ecoregion Province of hierarchical LCRE classification, adopting the Ecoregion Level II framework.

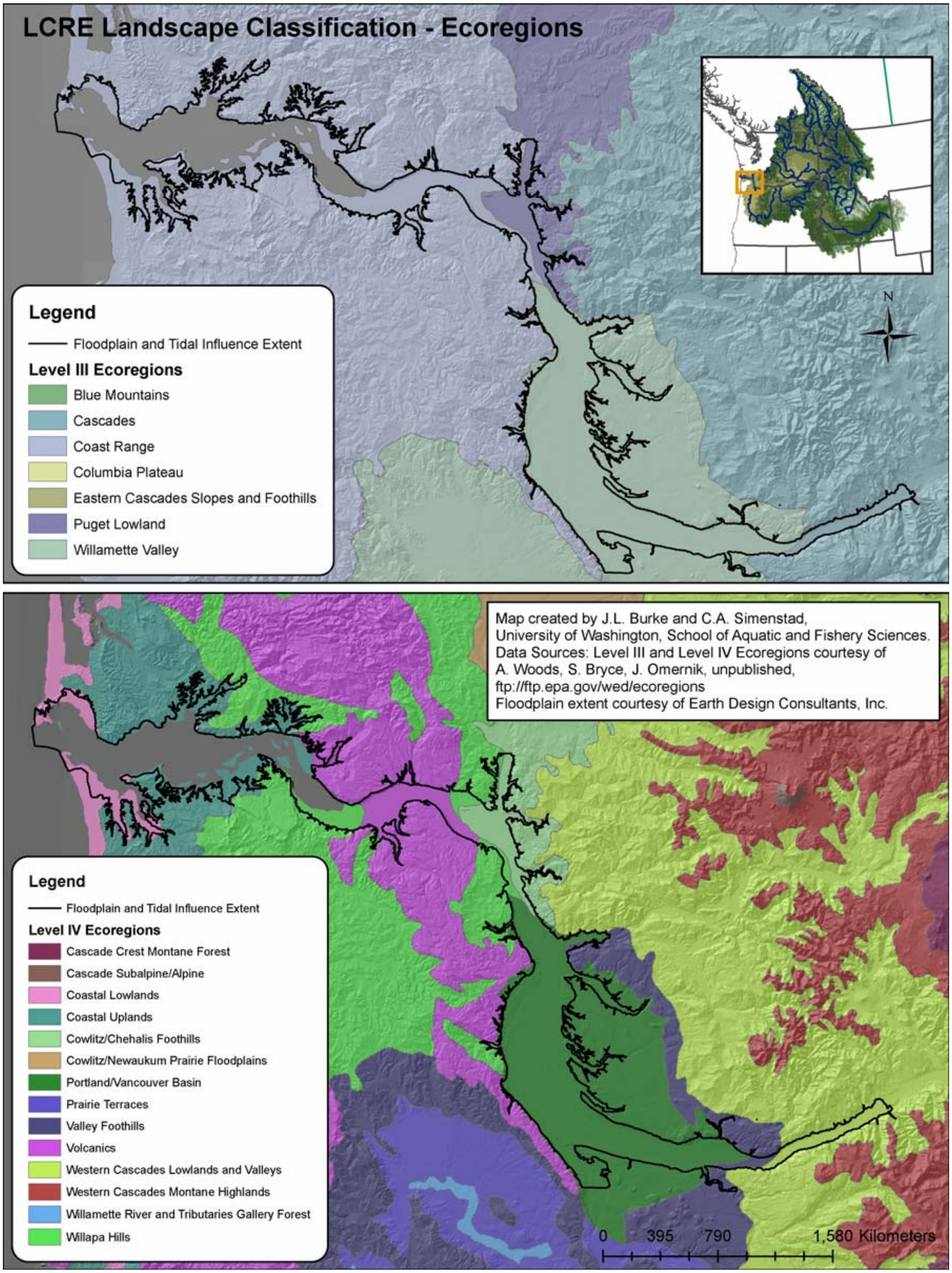

Figure A.3. Level III and Level IV Ecoregions with the LCRE Ecosystem Classification area (historic floodplain) superimposed.

A.4.3 Level 3: Hydrogeomorphic Reach

The structure of the Hydrogeomorphic Reach level of the LCRE Ecosystem Classification is based initially upon the EPA Level III Ecoregions (Figure A.3). These strata were then modified, either by further division or by adjusting their upstream or downstream boundaries using spatial data that demarked transitions in strong, large-scale hydrogeomorphic and tidal-fluvial forcing. As described in more detail in Methods, these included (a) maximum (historic) salinity intrusion, based on Sherwood *et al.* (1990); (b) transitions in maximum flood (pre-regulation) tide level (USACE 1968; Kukulka and Jay 2003); (c) the upstream extent of current reversal (estimated from predicted currents using Tides & Currents Ver. 2.5, Nautical Software, Inc.); and (d) convergences with major tributaries and slough systems. These extensions or modifications of the Level III Ecoregions resulted in eight Hydrogeomorphic Reaches (Figure A.4).

A.4.4 Level 4: Ecosystem Complex

The forth level in the LCRE Ecosystem Classification is intended to capture similar abiotic and biotic (Primary Cover Class, Level 5) characteristics in distinct geomorphic settings within each hydrogeomorphic regime (Level 3). These complexes are also distinguished by their landscape setting. These complexes are likely the most appropriate level of the classification to use for designing and implementing monitoring and assessment of biotic habitats.

Until all datasets are available, we can only provide a focal area example (e.g., Cathlamet Bay region of lower estuary), where polygon classification, georeferencing, bathymetry, etc. are available and complete (Figures A.4 and A.5). After initial testing, we found that complexes in this pilot area could be delineated by selective bathymetric divisions that could distinguish the deeper mainstem (principally navigation) channel and the distributary channels. In some cases, there were apparent mismatches between these boundaries and the Level 5, Primary Cover Class dataset, most likely because of a significant difference between the dates of acquisition of the two datasets. However, these were relatively minor occurrences (Figure A.6).

Complexes are classified by their geomorphic and bathymetric characteristics and the composition and arrangement of the cover classes composing them. In the pilot example, we have identified six Ecosystem Complexes: Deep Channel; Shallow Subtidal Slope; Mud/Sand Flat, Unvegetated Sand; Emergent Marsh, and Scrub-Shrub Forested. Where anthropogenic factors are known to or can be reliably interpreted to modify the Primary Cover Class elements or structure, it is additionally distinguished by a Modifier (M in parentheses), which might for example distinguish the dredged channel or disposed dredged (sand) material. Although the Ecosystem Complexes delineated and classified in this example were derived primarily from expert knowledge, in the operational LCRE Ecosystem Classification, we will develop systematic rules (e.g., GIS queries) that will be used to analytically delineate and classify the complexes.

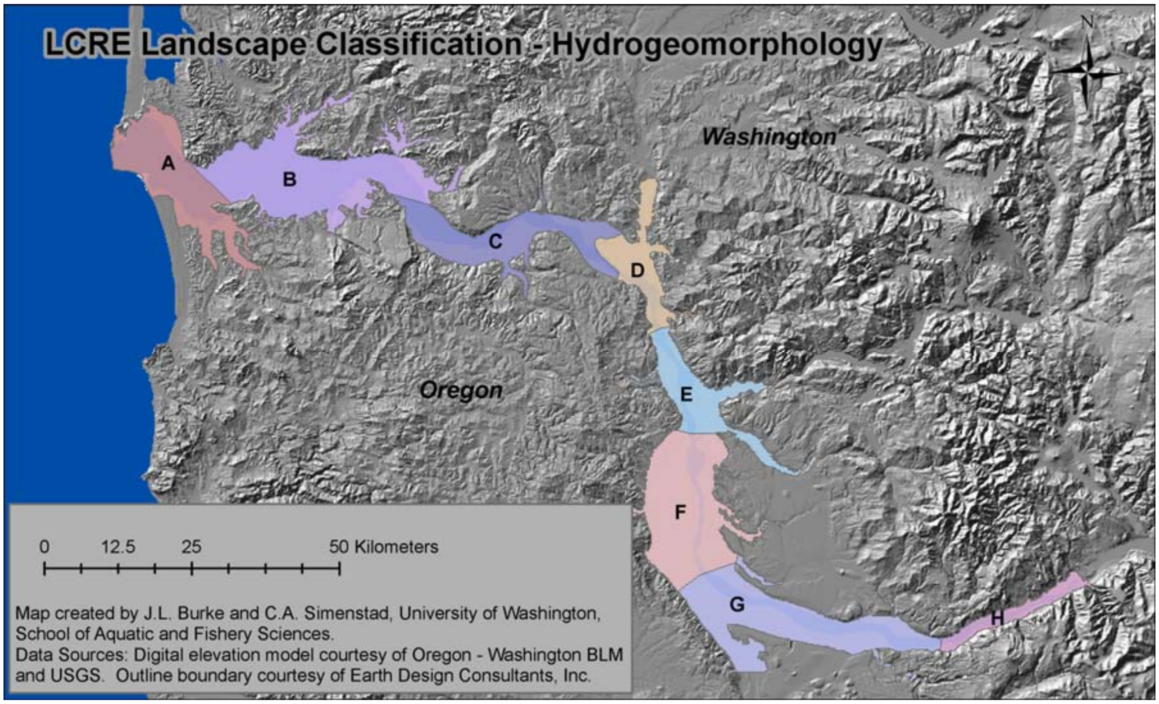

Figure A.4. Hydrogeomorphic Reach level (Level III) of LCRE Ecosystem Classification.

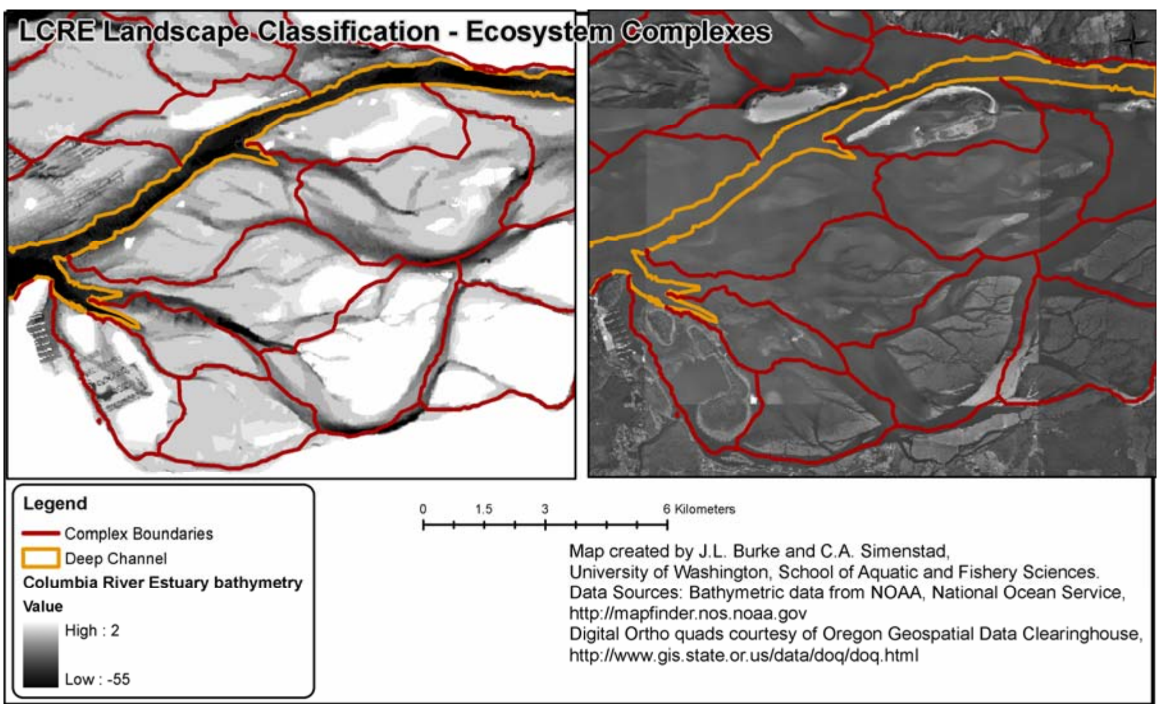

Figure A.5. Illustration of ecosystem complexes in Cathlamet Bay (central Hydrogeomorphic Regime B, Fig. 4) based on delineating mainstem and distributary channels using current bathymetry data (see Methods). Further classification of the different complexes is based on a combination of geomorphic structure and cover class composition.

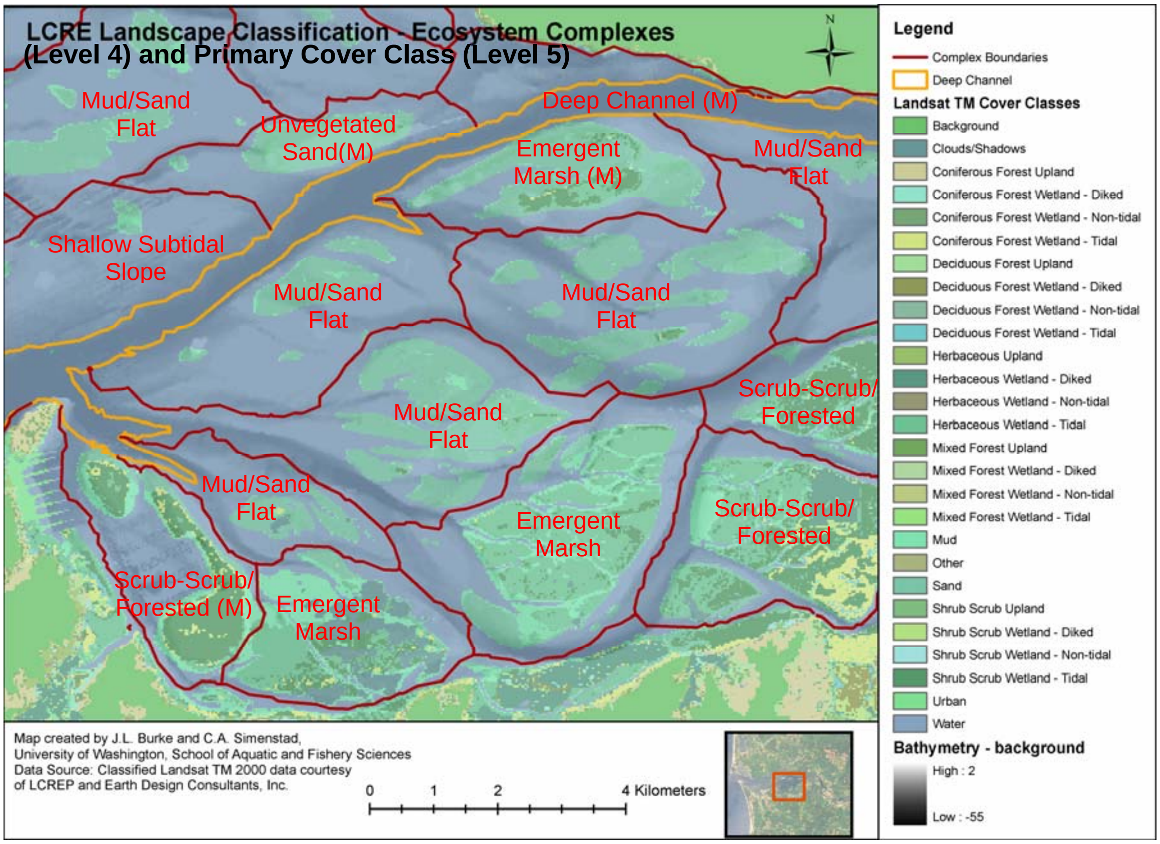

Figure A.5. Illustration of Ecosystem Complex and Primary Cover Class levels (4 and 5) of LCRE Ecosystem Classification.

A.4.5 Level 5: Primary Cover Class

The Primary Cover class is the elemental level of the hierarchical scheme. It includes the elements that compose spatial coverage of the Ecosystem Complexes in Level 4. From a number of available classified cover class data sources we are presently using LCREP 2000 LANDSAT 7 TM because it provides the most recent information and is supported by extensive training data in some regions of the system. However, it does require further validation and groundtruthing (see Phase II, below). Any artificial or otherwise modified Primary Cover Class is additionally distinguished by a Modifier. In the pilot example, 27 Primary Cover Classes are represented.

A.5 Phase II

Phase I has permitted development of a draft LCRE Ecosystem Classification and evaluation of spatial datasets that can be used to delineate ecosystem components at the different hierarchical levels. In Phase II, we propose to continue to revise the structure of the classification, evaluate and refine datasets based on further review and groundtruthing, and propose additional steps, studies, and approaches to applying the scheme. Once data gaps are identified, additional information can be collected to both refine and validate the classification. Additionally, the classification can be used to develop predictive models that will help identify aquatic habitats or other environmental conditions that are affecting the distribution of aquatic organisms or promoting the establishment and proliferation of invasive species in the lower Columbia River. All work will be completed with consultation of the LCREP technical advisory group to assure that the classification system will meet current and future needs of all sampling and monitoring efforts of habitat, water quality, contaminants and biological efforts.

A.5.1 Peer Review

In Phase II, we will initiate peer review of the classification scheme by distributing this draft version to qualified estuarine/large river floodplain hydrologists and geomorphologists for their review and comment. We will choose both regional experts as well as several of the individuals involved with the classifications that explicitly included the tidal freshwater (especially from The Netherlands, New Zealand, etc.). We will also seek feedback from scientists and managers (e.g., Dr. C. Levings, DFO) who are familiar with the lower Fraser River because that system may be the most comparable to the lower Columbia River and British Columbia and Canadian agencies and managers have explored a number of existing classifications (C. Levings, pers. comm.). Results of these peer reviews will be reported in the next (Phase II) report.

A.5.2 Assessment and Validation of Classification Structure and Datasets

We will continue to evaluate the level of completeness and identify data gaps in the spatial datasets we have adopted for use in the development of this classification.

A.5.3 Refinement and Expansion

There are at least two critical data needs for the LCRE Ecosystem Classification, updated bathymetric data and refined LANDSAT 7 TM cover classes above RKm 75.

A.5.3.1 Bathymetry

Initial assessment of the available data sources for the classification of the estuarine complexes revealed a number of data gaps and the need for data refinement. The current bathymetric coverage of the entire estuary from RKm 0 to RKm 230 is based on 1938 to 1958 surveys. Thus, the existing bathymetry is outdated and inconsistent with the contemporary structure of the estuary (Figure A.4). The complexes presented in Figures A.4 and A.5 had to be manually edited to circumvent islands that developed following the bathymetric survey.

As part of the Channels and Harbors Project, and in particular, the Columbia River Channel Improvement Project, the Army Corps of Engineers, Portland District, Hydrographic Survey has conducted an extensive bank-to-bank bathymetric survey of the Columbia River Estuary from RKmn 0 to RKm 75. The ACOE has recently made the data available and we will incorporate into GIS platform during Phase 2. Further, the Hydrographic Survey conducts channel-line surveys (Survey-lines that run parallel to the channel; 7 lines across, spaced 150 feet apart) of the Columbia River from Rkm 75 to Rkm 230 on a monthly basis and cross-line surveys (Survey-lines that run perpendicular to the channel; bank-to-bank and are generally spaced 500 feet apart) annually. Additional bathymetric data collected at a higher resolution for the Columbia River from Bonneville Dam to Skamania Island has been identified (e.g., Garland 2004). During Phase II we will continue to investigate whether additional sources of bathymetric data exist and incorporate the most up-to-date information available into the GIS platform. All meta-data associated with the data used will be compiled and documented.

A.5.3.2 Land Cover

EDC, Inc., and UW recently determined that the LANDSAT 7 TM cover classes overestimated wetland habitats above RKm 75 in the estuary. The habitats from RKm 0 to 75 have been mapped for numerous projects in the last 20 years providing ancillary data sources for the LANDSAT 7 TM classification. However, the region above RKm 75 remains largely undocumented, which contributed to a lack of supporting data available for the LANDSAT 7 TM classification. Our project proposes to work with EDC, Inc. to refine the classification of the LANDSAT 7 TM data by ground-truthing the LANSAT 7 TM classification above RKm 75.

A.5.3.3 Velocity

Velocity is the primary underlying factor behind the hydrogeomorphic structure that we have incorporated into the classification. However, at this point we can only incorporate relatively static patterns rather than more integrative measures of the actual velocity distributions. We propose to investigate the utility of using the CORIE (Dr. A. Baptista, OHSI) model for estimates of velocity ranges and extremes if it becomes available for the entire 230 km study area.

A.6 Recommendations

As described above, perhaps one of the factors most limiting our ability to populate the classification through the entire study system is the availability of current bathymetry. Rather than continuously filling in data gaps, our highest recommendation is for acquisition of comprehensive shallow-water bathymetry. This is particularly needed in the upper half of the study region, but generally applies across the entire region. During the fall/winter of 2004/2005 the USGS has provided funds to conduct an LIDAR survey of the floodplain of the lower Columbia River floodplain from the mouth to Bonneville Dam. These data will be subsequently subjected to post-processing during 2005. As new data become available we will update the GIS platform and refine the classification system accordingly. We expect that as technological advancements occur and as time passes, similar opportunities to refine our understanding of the LCRE will arise. Thus we recommend that the GIS platform be a living document that is periodically updated as new information becomes available.

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Appendix B

Potential Reference Sites in the Columbia River Estuary

The table and maps in this appendix, prepared by the Lower Columbia River Estuary Partnership, contain a preliminary set of potential reference sites in the lower Columbia River and estuary that have been identified by the Estuary Partnership and associates. This list is currently undergoing review by the Science Work Group and others with specialized knowledge of sites in the estuary. Reference sites are characterized by pristine or nearly pristine character.

In Table B-1, which lists potential reference sites, "ACOE map #" refers to the U.S. Army Corps of Engineers channel deepening study maps, which include National Wetland Inventory (NWI) wetland areas, current dredge spoil locations, proposed dredge spoil locations, proposed mitigation sites, and levee areas. Site numbers can be used to cross-reference Table B-1 to Figures B-1, B-2, and B-3. The three figures represent the potential reference sites for the estuary, which has been divided into three sections for the purpose of presentation in this format.

Table B-1. List of potential reference sites for Columbia River estuary, as compiled by the Lower Columbia River Estuary Partnership. Site number corresponds to numbers on maps in Figures B1-B3. ACOE Map # refers to US Army Corps of Engineers channel deepening maps. Notes were compiled by various scientists working in the estuary,

Site #	Potential Site Name	ACOE Map #	River Mile	Coordinates (Lat./Long.)	County	Notes
Washington Side (from mouth to dam)						
1	Wallacut River	7	3	46° 18' 5' N/ -124° 1' 9" W	Pacific	1 mile upstream, a large wetland complex on either side of the river
2	Sand Island	7	3		Clatsop	West side of island is old dredge spoils
3	Just S. of Chinook R. mouth	7	4	46° 17' 49"N/ -123° 58' 3" W	Pacific	Dark tract of land just S of mouth
4	S. of Cliff point (S. of Knappton, N. of Hungry Harbor)	7	15-16	46° 15' 42" N/ -123° 50' 56" W	Pacific	Tiny NWI strip
5	Frank Born Creek	7	19-20	46° 17' 33" N/ -123° 44' 51" W	Pacific	Small drainages, dark tracts, difficult to make out
6	Sisson Creek	7	21	46° 18' 11" N/ -123° 43' 33" W	Wahkiakum	Diking upstream but not at mouth, dark tracts of land
7	Deep River 2nd elbow	7	22	46° 19' 5" N/ -123° 42' 24" W	Wahkiakum	Landsat shows decent vegetation, no dikes
	Secret River Reference site	7	?		Wahkiakum	See Ian Sinks (between Gray's and Deep rivers)
8	Devil's elbow (TNC property)	7	24	46° 18' 37" N/ -123° 40' 9" W	Wahkiakum	Dark tract of land
9	Crooked Creek first mile	7	23	46° 17' 46" N/ -123° 40' 31" W	Wahkiakum	No levees/dikes at the mouth, good looking habitat near the mouth on both sides
10	Jim Crow Creek	7	29	46° 16' 5" N/ -123° 33' 6"W	Wahkiakum	Good Landsat cover type, no dike or levee, good looking habitat on the first few bends of the river
11	Skamokawa/Sleepy Hollow area	6	33-34	46° 16' 30" N/ -123° 27' 31" W	Wahkiakum	Patchy leveed area, good looking habitat on the first few bends of the river

12	Brooks slough, south side of road	6	33-34	46° 16' 3" N/ -123° 27' 11" W	Wahkiakum	Leveed on south side, small NWI patch on north side, some decent looking tracts on edge of slough
13	Prince Island/ Steamboat slough	6	34	46° 15' 56" N/ -123° 26' 47" W	Wahkiakum	Dredge spoils on west side of island, P. Isl. looks decent, some patches on east side of Steamboat Slough as well
14	Columbia White-tailed deer refuge	6	35	46° 14' 59" N/ -123° 25' 49" W	Wahkiakum	Heavily diked and leveed, some good tracts, mostly on the edge of sloughs
15	Oak Point/ just south of deer refuge	6	37	46° 13' 49" N/ -123° 23' 22" W	Wahkiakum	NWI patch open to tidal flow, southern end of Elochoman slough
16	Abernathy Creek	5	54-55	46° 11' 28" N/ -123° 9' 57" W	Cowlitz	NWI at the mouth Joe Hymer has contact info for fish monitoring
17	Germany Creek	5	55	46° 11' 22" N/ -123° 7' 25" W	Cowlitz	Wetland tracts at the mouth of the river
18	Coal Creek slough	4	56-57	46° 10' 54" N/ -123° 4' 25" W	Cowlitz	West of Longview, NWI on south, north and terminus of slough
19	Fisher Island	4	59	46° 10' 3" N/ -123° 3' 11" W	Cowlitz	Any history?
20	Cowlitz river	4	68	46° 5' 57" N/ -122° 54' 36" W	Cowlitz	????
21	within Carrolls channel, south of Collins estate	4	69	46° 5' 33: N/ -122° 53' 26" W	Cowlitz	Influenced NWI from both the Cowlitz and Columbia
22	Cottonwood island	4	70	46° 5' 3" N/ -122° 52' 58" W	Cowlitz	Looks heavily impacted by dredge spoils, possible some wetlands?
23	Kalama River	3	73	46° 2' 17" N/ -122° 52' 10" W	Cowlitz	Several wetland complexes id on subbasin browser
24	Martin and Burke Islands	3	80	45° 56' 35" N/ -122° 47' 25" W	Cowlitz	Possible wetland mitigation sites, see ACE
25	Lewis River	2	87	45° 51' 15" N/ -122° 46' 36" W	Cowlitz/Clark	Wetlands at mouth on both north and south sides, borders Ridgefield reserve
26	North point of Bachelor Island	2	89	45° 50' 29" N/ -122° 46' 49" W	clark	Unleveed
27	Campbell lake on Bachelor island	2	93-94	45° 49' 41" N/ -122° 46' 29" W	clark	Receives flow from Columbia, unrestricted?
28	Lake River	2	95	45° 45' 34" N/ -122° 44' 50" W	Clark	Small NWI patch just north of Green Lake, unnamed tributary

29	Lake River to Salmon Creek	2	96	45° 43' 58" N/ -122° 43' 54" W	Clark	Patchy NWI wetlands at mouth and up Salmon Creek
30	Vancouver lake??	1	100	45 41' 49" N/ -122 43' 5" W	Clark	NE and NW edge are NWI wetlands, unrestricted flow from Lake River?
31	Ryan Point Marine County park	1	109	45° 36' N / -122° 37' W	Clark	Just east of park
32	Love Creek			45° 35' 57" N/ -122° 32' 37 W	Clark	Just east of I - 205
33	Camas Slough/ Washougal River			45° 34' 44"N/ -122° 23' 52" W	Clark	South of the city of Camas several different patches of wetlands just north of Lady Island (other sites on Washougal?)
34	East of Washougal			45° 34' 8"N/ -120° 20' 29"	Clark	Just Northwest of Reed Island
35	Campen Creek/Gibbons Creek			45° 34' 9"N/ -122° 18' 58" W	Clark	Don't even know if the browser is accurate at this spot, checked against the Gazetteer, it looks like these two creeks drain into a much smaller water body
36	Lawton Creek			45° 33 22 N/ -122° 16 1 W	Clark	???
37	Saint Cloud			45° 36' N/ -122° 4' W	Skamania	Indian Mary Creek drainage to a small lake several wetland types adjacent to Columbia River
38	Duncan Creek			45° 36' N/ -122° 3' W	Skamania	See Joe Hymer chum channel construction project
39	Skamania			45° 36'N/ -122° 1' W	Skamania	Just SE of the town a couple of wetland types
40	Woodward creek mouth			45° 37' N/ -122° 1' W	Skamania	Small wetland at the bottom of Woodward Creek
41	Hardy creek			45° 37' 12" N/ -122° 1' 11" W	Skamania	Where Hardy meets Little Creek
42	Hardy creek			45° 37' 46" N/ -122 0' 18" W	Skamania	2/3 upstream is a decent wetland complex, BPA project site?
43	Hamilton Creek			45° 38' 0" N/ -121° 58' 52" W	Skamania	Several wetland complexex at the mouth and upstream on both sides of Hamilton Creek
Islands/Sloughs (from the dam to the mouth)						
44	Ives Island			45° 37' 24" N/ -121° 59' 40" W	Skamania	Entire island is a wetland complex

45	Pierce Island			45° 37' 19" N/ 122° 0' 36" W	Skamania	Eastern side of island has several wetland tracts
46	Skamania Island			45° 35' 24" N/ -122° 7' 5" W	Skamania	Wetland covers the island
47	Ackerman Island			45° 33' 10" N/ -122° 12' 9" W	Multnomah	Wetland tracts on S. side of island
48	Reed Island			45° 33' 9" N/ -122° 17' 58" W	Clark	Wetland tracts both internal and on edges of island
49	Flag Island			45° 32' 50" N/ -122° 20' 13" W	Multnomah	Eastern edge of Col. Slough, several wetlands cover most of the island
50	Gary Island			45° 33' 23" N/ -122° 20' 52" W	Multnomah	Entire island is a wetland complex
51	Lady Island			45° 34' 36" N/ -122° 25' 6" W	Clark	Several small wetlands, mostly on N. side of island
52	McGuire Island			45° 33 51" N/ -122° 27' 40" W	Multnomah	SE of Gov't island, some small wetland tracts on the eastern side of the island
53	Government Island			45° 35' 5" N/ -122° 32' 22" W	Multnomah	Several types of wetlands throughout the island, most of them associated with the
54	Smith/Bybee lakes	1	105	45° 36' 55" N/ -122° 44' 15" W	multnomah	Lots of wetlands location of 1 project, water control structure at Bybee?
55	Sauvie Island	1,2	98	45° 45' 18"N/ -122° 48' 23" W	multnomah	Sturgeon Lake and associated backwaters influenced by Multnomah Channel
56	Sauvie Island	2	87-90	45° 50' 5" N/ -122° 47' 52" W	Columbia	Northern tip between first bend in Mult. Channel and island
57	West of Multnomah Channel, Scappoose Bay	2	87-90	45° 49' 15 N/ -122° 49' 57" W	Columbia	Project site, see SBWC for possible reference sites… (Teal Slough?)
58	Goat Island	3	80-82	45° 56' 43" N/ -122° 49' 3" W	Columbia	A few wetland areas, on northern and eastern side of island
59	Northern tip of Deer Island	3	76-77	45° 58' 52" N/ -122° 50' 59" W	Columbia	No levee or dike, NWI, unnamed channel
60	Sandy Island	3	75	46° 0' 37" N/ -122° 51' 43" W	Columbia	Most of island is has wetland habitat, condition?
61	Small peninsular NWI north of Prescott	3	71	46° 3' 38" N/ -122° 53' 28" W	Columbia	No levee or dike, adjacent to dredge spoils site
62	Lord Island	4	62-63	46° 8' 3" N/ -123° 1' 21" W	Columbia	All NWI besides dredge spoils on southeast tip of island

63	Walker Island	4	61	46° 8' 59" N/ -123° 3' 0" W	Columbia	All NWI besides dredge spoils on northeastern edge of island
64	Crims Island	5	55-56	46° 10' 48" N/ -123° 8' 42" W	Columbia	ACE project site (Ken Tiffan), no levees
65	Wallace Island	5	48-50	46° 8' 26" N/ -123° 15' 2" W	Columbia	No levees or dikes, dredge fill on western tip
66	Whites Island	5	45	46° 9' 24" N/ -123° 19' 55" W	Wahkiakum	Many types of wetlands, condition?
67	Puget Island	5	39-45	46° 10' 47" N/ -123° 22' 58" W	Wahkiakum	South central portion of the island
68	Little Island	5	40-42	46° 11' 13" N/ -123° 22' 40" W	Wahkiakum	Several wetland tracts
69	Tenasillahe Island	5	38	46° 12' 35" N/ -123° 26' 1" W	Clatsop	Southern tip of refuge undiked
70	Tenasillahe Island	6	35-37	46° 14' 17" N/ -123° 26' 43" W	Clatsop	Eastern edge undiked, northern edge undiked
71	Welch Island	6	33-35	46° 15' 8" N/ -123° 28' 20" W	Clatsop	Undiked refuge
72	Transon Island	6	30-32	missing data from browser	Clatsop	Undiked
73	Grassy Island	6	30-32	missing data from browser	Clatsop	Undiked
74	Quinns Island	6	30-32	46° 14' 58" N/ -123° 29' 49" W	Clatsop	Undiked
75	Woody Island	6	29	missing data from browser	Clatsop	Undiked
76	Horseshoe Island	6	28	missing data from browser	Clatsop	Undiked
77	Marsh Island	6	27	missing data from browser	Clatsop	Undiked
78	Karlson Island	6	26	missing data from browser	Clatsop	Undiked, see Joe Hymer notes
79	Minaker Island	6	26	missing data from browser	Clatsop	Undiked
80	Russian Island/Seal Island	7	23-25	missing data from browser	Clatsop	Undiked (Si Simenstad)
81	Green Island	7	23-25	missing data from browser	Clatsop	Undiked
Oregon Side (from mouth to dam)						
82	Clatsop spit	7	5	46° 13' 33" N/ -123° 59' 45" W	Clatsop	NWI on Eastern side of Clatsop spit peninsula, no dike or levee
83	Trestle Bay/Point adams	7	7	46° 12' 22" N/ -123° 58' 41" W	Clatsop	Undiked, no levee, small wetland tracts
84	Tanay Point/Bay	7	11	46° 11' 16" N/ -123° 55' 22" W	Clatsop	No dikes or levees
85	Young's Bay	7	12	46° 9' 49" N/ -123° 52' 43" W	Clatsop	Small NWI tracts north of Hwy
86	Lewis and Clark river	7	13	46° 8' 25" N/ -123 51' 52" W	Clatsop	Heavily leveed at the mouth, talk with Todd Cullison of CREST
87	Dagget point	7	15	46° 10' 4" N/ -123° 49' 24" W	Clatsop	Mouth of Young's river?
88	Walluski River	7	16-17	46° 8' 54" N/ -123° 48' 21" W	Clatsop	Some NWI tracts, project site, talk with Ian Sinks

89	John Day river mouth	7	19	46° 10' 34" N/ -123° 44' 59" W	Clatsop	Southeast side has no dikes or levees, further upstream on an East - West stretch, no dike/levee on south side of river
90	South Channel	7	22	46 10' 23" N/ -123 42' 25" W	Clatsop	Just SE of Lois Island NWI islands and some NWI wetlands north of Hwy 30 just before Settler Point
91	Settler Point	7	24	46° 10' 34 N/ -123° 40' 12" W	Clatsop	South and Southwest of Svenson Island some intact wetlands, and small creeks?
92	Mary's Creek/ Bear Creek/ Hillcrest Creek	7	25	46° 10' 21" N/ -123° 39' 34" W	Clatsop	Same as above, no dikes or levees
93	Calendar slough	7	26-27	46° 11' 18" N/ -123° 37' 10" W	Clatsop	East of Svenson Island, just north of Hwy 30 no levee or dikes
94	Knappa slough	7	27	46° 11' 35" N/ -123° 32' 20" W	Clatsop	A couple of drainages into Knappa Slough
95	Blind Slough	7	28	46° 12' 12" N/ -123° 33' 53" W	Clatsop	No dikes or levees NWI between Prairie Channel and Blind slough, see Allan for Blind Slough/Brownsmead project
96	Bug Hole	6	29	46° 13' 45" N/ -123° 32' 41" W	Clatsop	No dike/levee NWI, peninsular
97	Clifton channel	6	31-32	46° 13' 57" N/ -123° 29' 26" W	Clatsop	At the mouth, south of Quinns Island
98	James River/ Driscoll Slough	6	43	46° 8' 52" N/ -123° 23' 56" W	Clatsop	Just S of Wauna, no levee or dike
99	Westport Slough	6	44	46° 8' 21" N/ -123° 22' 57" W	Clatsop	Borders James River site, proposed wetland mitigation site, follow up with ACE contacts.
100	Westport Slough	5	45-46	46° 7' 29" N/ -123° 21' 22" W	Columbia	More proposed mitigation, worth pursuing?
101	Clatskanie River	5	50	46° 8' 0" N/ -123° 13' 29" W	Columbia	No levee or dike, 2nd island in from the mouth of the river.
102	Carr Slough	4	71	46° 3' 25" N/ -122° 53' 38" W	Columbia	Small drainage, north of Prescott, adjacent to dredge spoils site
103	S. Multnomah Channel	1	102	45° 38' 40" N/ -122° 49' 31" W	Multnomah	Some tracts of NWI wetlands just upstream of where the Multnomah channel dumps into the Willamette
104	Fairview creek			45° 33' 26" N/ -122° 28' 57" W	Multnomah	East end of Columbia Slough, some wetland tracts
105	Salmon Creek			45° 33 28 N/ -122° 25' 53" W	Multnomah	Several disconnected wetland habitats

106	Sandy River			45° 33' 18" N/ -122° 22' 50" W	Multnomah	Several disconnected wetland habitats that are associated with the Sandy's floodlplain.
107	Crown Point			45° 32' 22" N/ -122° 19' 14" W	Multnomah	Thin stretch of wetlands west of Crown Point state park
108	Rooster Rock State Park/Latourel and Youngs creek			45° 32' 45" N/ -122° 14' 11" W	Multnomah	Project site, check with Jack Wiles of ODR
109	Horsetail Creek/Falls			45° 35' 40" N/ -122° 4' 10" W	Multnomah	Thin stretch of wetlands west of Horsetail Falls on shoreline of Col.
110	McCord Creek			45° 36' 56" N/ -121° 59' 53" W	Multnomah	Wetland sites at the mouth of creek

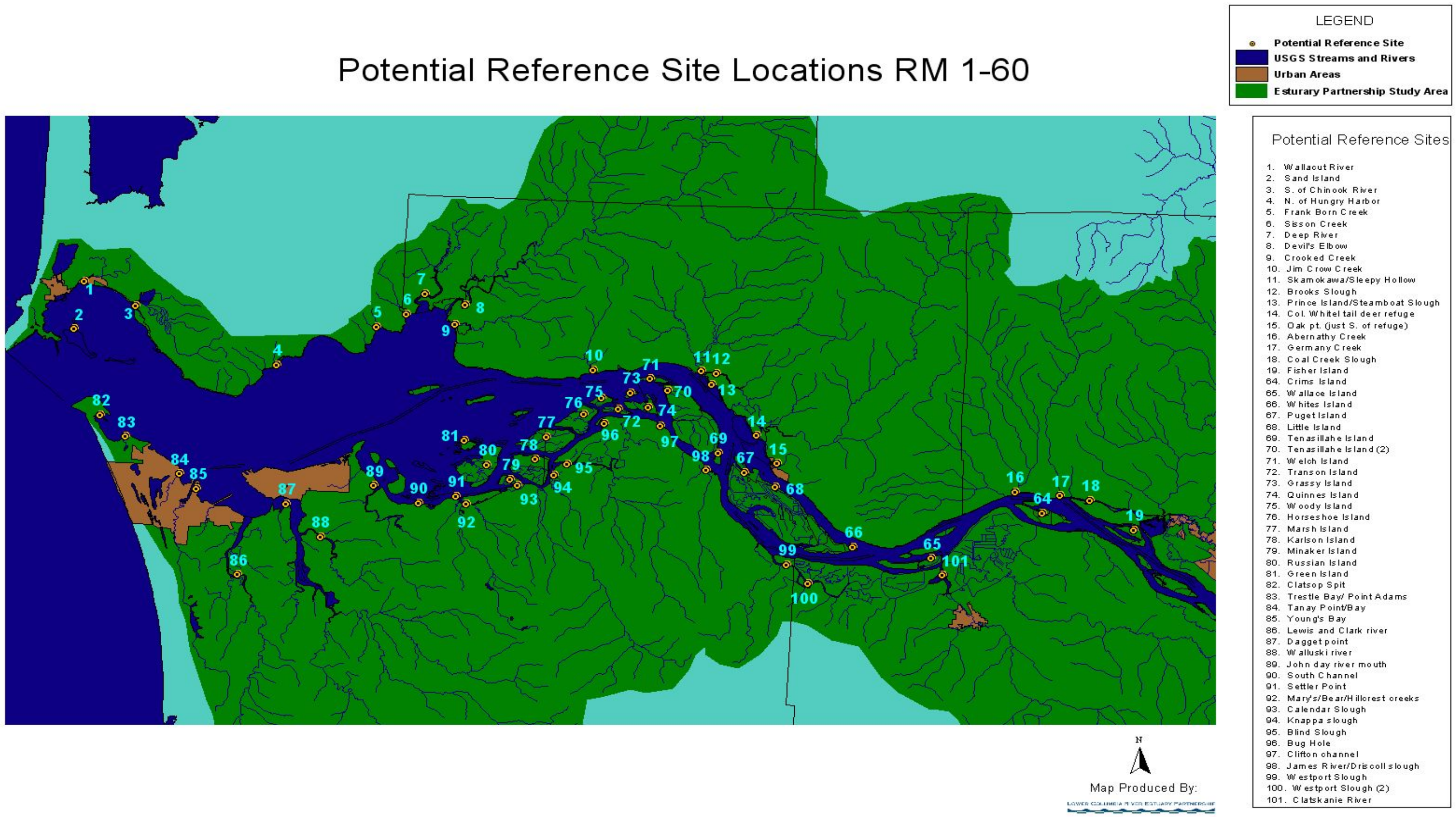

Figure B-1. Lower portion of the Columbia River estuary, with potential reference sites.

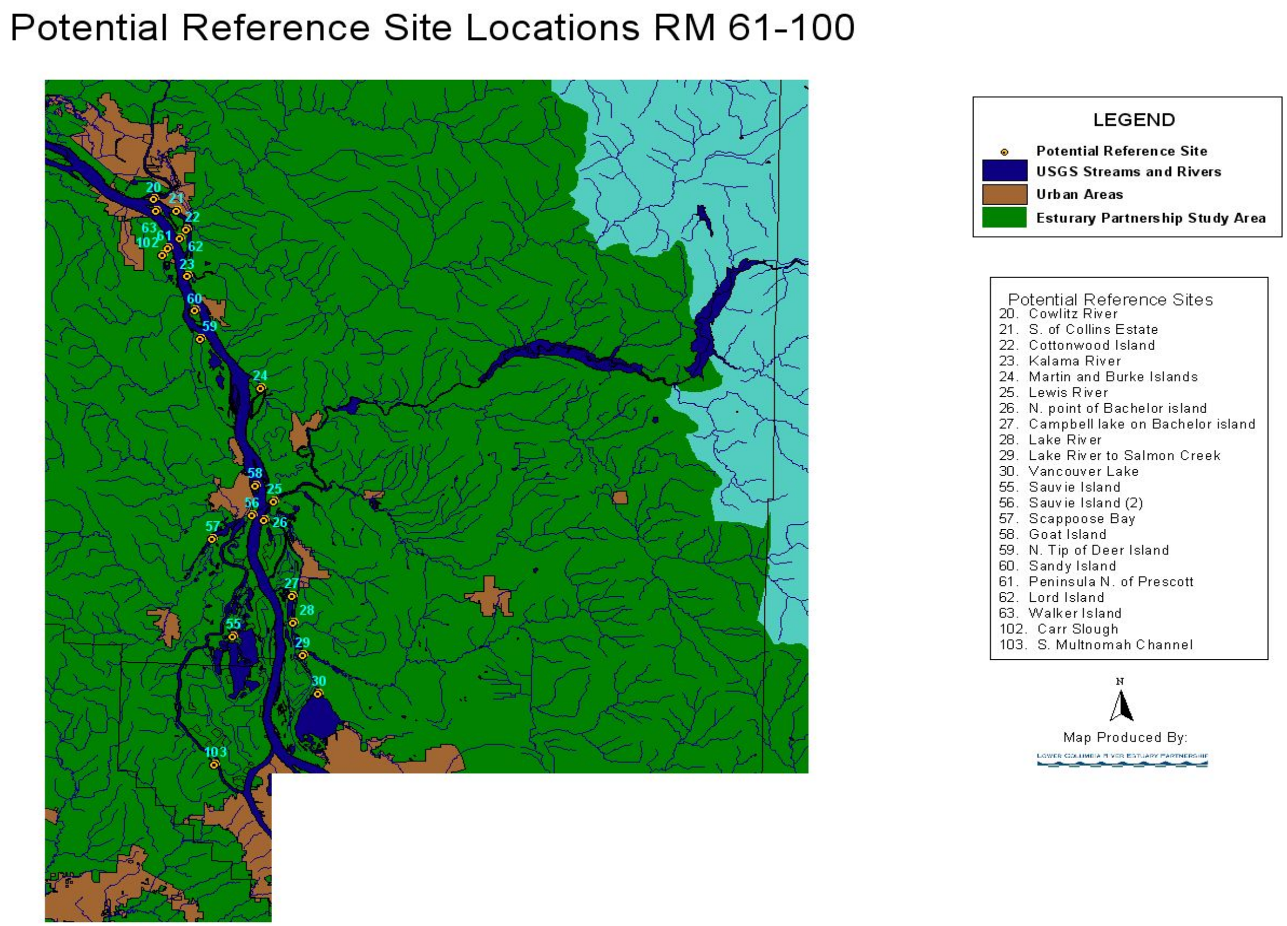

Figure B-2. Middle portion of the Columbia River estuary, with potential reference sites.

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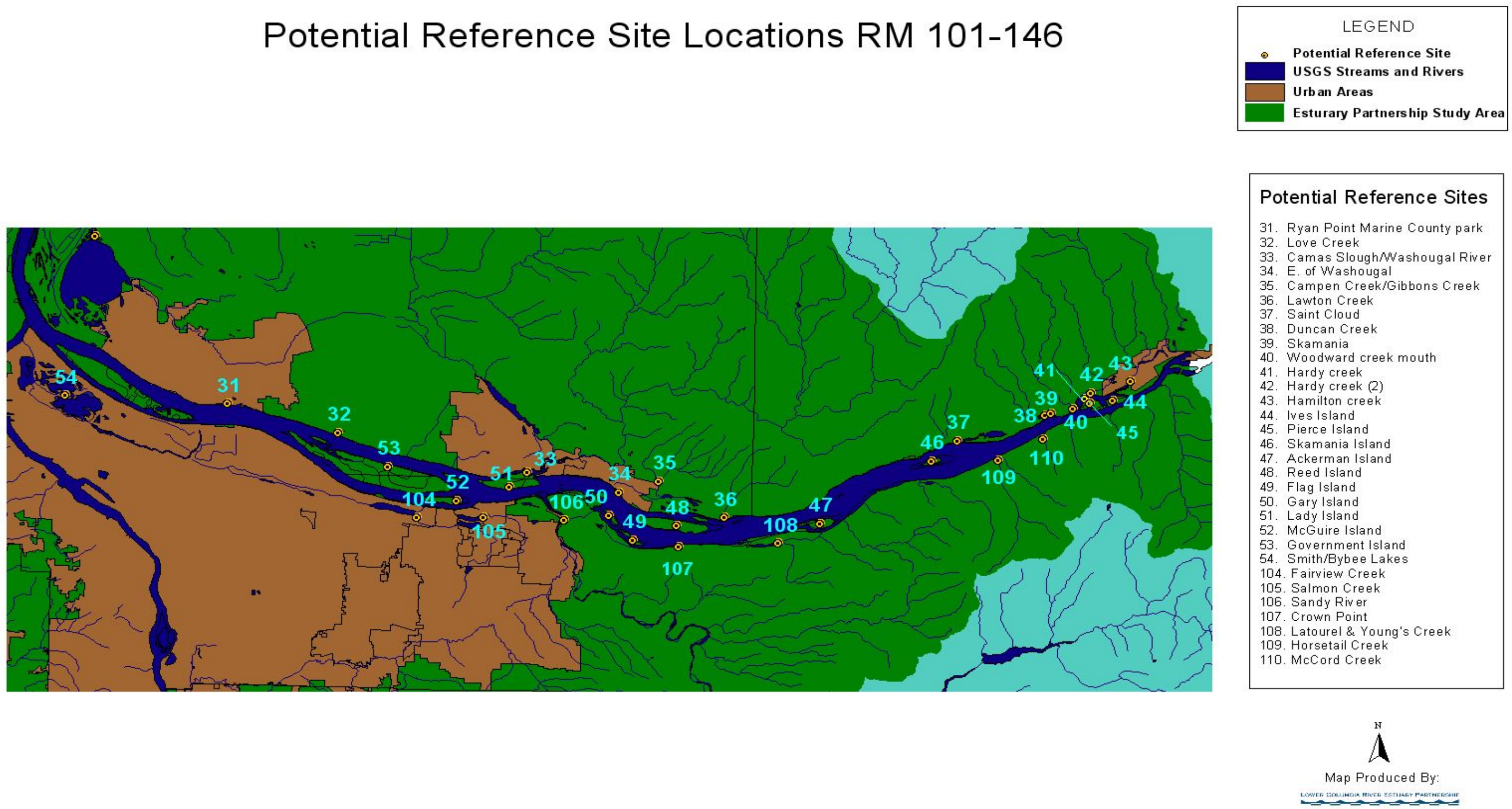

Figure B-3. Upper portion of the Columbia River estuary, with potential reference sites.