Lower Columbia River Ecosystem Monitoring Project

Annual Report

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Lower Columbia River Ecosystem Monitoring Project
Annual Report for Year 2 (September 2004 to August 2005)

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Project Goals and Purpose

Our ability to understand the relationship of sensitive organisms such as salmonids to the lower Columbia River and Columbia River estuary ecosystem is greatly hindered by major data gaps and poor access to existing data. The Estuary Partnership proposes to continue to implement elements of its Aquatic Ecosystem Monitoring Strategy to address habitat and toxics monitoring needs and data management. This project has two components: Habitat Monitoring and Toxics Monitoring and addresses RPAs 161, 163, and 198.

The Habitat Monitoring component focused on creating the tools necessary for planning and conducting comprehensive habitat monitoring for measuring the status and trends of habitat types in the Lower Columbia River and Estuary. The work elements listed under Habitat Monitoring for Year 2 (September 2004 to August 2005) of this contract are directed at creating a scientifically sound sampling plan and creating a hydrogeomorphic classification for the Lower Columbia River and Estuary.

The Toxics monitoring component continued to address issues such as the accumulation of toxics in sensitive habitat areas, contaminant trends over time, and contaminant impacts on salmonids. NOAA Fisheries and USGS Water Resources Discipline (USGS WRD) were subcontracted to monitor toxics in salmonids and in the water column respectively.

Project Background and Introduction

Bonneville Power Administration (BPA) originally awarded a three year contract in September 2003 to the Lower Columbia River Estuary Partnership (Estuary Partnership) for its Aquatic Ecosystem Monitoring and Data Management Strategy. Prior to this date, the Estuary Partnership's Science Work Group had been working on designing the elements of this project involving toxics monitoring and habitat monitoring. Once funding was secured, BPA project managers conferred with the Science Work Group to finalize the project. Plans were developed during fall 2003 to proceed with a toxics monitoring plan that took a multi-species approach, including salmon, eagles, and osprey, monitored conventional and toxic pollutants, including fecal coliform, and mercury, and investigated a data management strategy.

With plans to move forward with on the ground work in late 2003, BPA notified the Estuary Partnership of the need for ISRP review after the project was further defined. Specifically, the toxics monitoring program focus should be on salmonids and the effects of toxic and conventional pollutants in the lower Columbia River on salmonid species. Further, it was requested that fecal coliform, mercury, and data management be removed from the proposal. It was also indicated that the habitat monitoring portion of the project was in relatively good condition; however, no work could proceed until the toxics monitoring portion of the project was resolved. USGS, NOAA Fisheries, and Estuary Partnership staff re-submitted the toxics portion of the project and both components, habitat and toxics monitoring, were reviewed by the ISRP in April. ISRP yielded a favorable review of the toxics monitoring portion of the project and given minor additions, the water quality monitoring could move forward. The habitat monitoring portion did not receive favorable reviews and the habitat monitoring plan was drafted to define clearly the goals and methods of the habitat monitoring program.

Once the habitat monitoring plan was reviewed by the ISRP, Estuary Partnership staff, Pacific Northwest National Laboratories, USGS, and the University of Washington focused on creating a scientifically sound sampling plan for the Lower Columbia. The habitat monitoring program is utilizing the sampling plan to measure the status and trends of habitat types in the Lower Columbia River and Estuary. The sampling plan was informed by the creation and refinement of an ecosystem classification system for the Lower Columbia River Estuary (LCRE). This classification was derived from LANDSAT TM imagery and bathymetry data and was used to identify specific reaches of the LCRE to sample during summer 2005. Field surveys were conducted in reaches D & F to collect biological and physical data on habitat conditions, including salinity, depth, and temperature as well as vegetative cover and water elevation estimates.

During Year 2, toxics monitoring was also implemented by NOAA Fisheries and USGS WRD to address issues such as the accumulation of toxics in sensitive habitat areas, contaminant trends over time, and contaminant impacts on salmonids. NOAA Fisheries organized a workshop to coordinate fish, habitat, and water quality monitoring projects being undertaken in the Lower Columbia (RM 0-146) as a means of creating a conceptual model to track toxic sources, pathways, and effects on salmonid populations. This conceptual model was developed and is being incorporated into a contaminant flux model that shows the transport and uptake of conventional and toxic pollutants in the LCRE. Moreover, an ecological risk model was created to link contaminant body burdens in salmonids to health risks such as impaired immune systems, growth inhibition, and reduced survival rates. The ecological risk model also shows the impacts of these health risks on the survival and productivity of listed salmonids. Fish sampling will occur from March 2005 through August 2005 and the sampling results will be incorporated into the models after analysis is completed during Year 3 (September 2005 to August 2006) of this contract. Finally, USGS WRD conducted fixed station water quality monitoring and installed semipermeable membrane devices (SPMDs) to provide data on conventional pollutants and toxics near NOAA salmonid sampling sites. Water chemistry data will be incorporated into the model as well and the findings of each study will be synthesized in a report during Year 3 (September 2005 to August 2006).

Project Area Description

The Ecosystem Monitoring Project's study area is the Lower Columbia River Estuary, defined by the Clean Water Act as those waters that are tidally influenced. The Columbia River Estuary extends from the plume of the Columbia River to the Bonneville Dam. The habitat monitoring program is focused on habitats that support juvenile salmonids, including shallow emergent wetlands, undiked tidally influenced sloughs adjacent to the Columbia River, scrub/shrub forested wetlands, mud/sand flats, and others. The toxics monitoring program is collecting data in

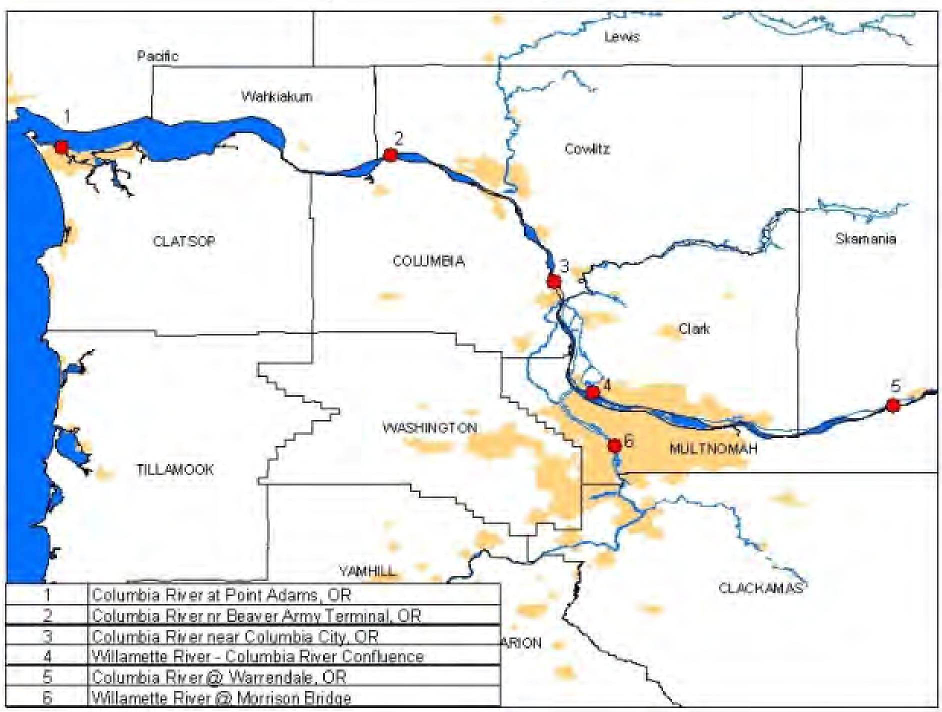


Figure 1: Water Quality and Fish Sampling Locations

the main channel of the lower Columbia River (Figure 1). Water quality and fish sampling took place at the sites in Figure 1 and the completion of this sampling will occur at the end of September 2005.

The habitat monitoring program relied on a multi-scaled stratification of the lower Columbia River Estuary. As proposed in the draft habitat monitoring draft, the river was stratified based on major hydrogeomorphic transitions. These transitions are based on salinity intrusion, maximum tide level, upstream extent of current reversal, geology and convergences with major tributaries (Figure 2).

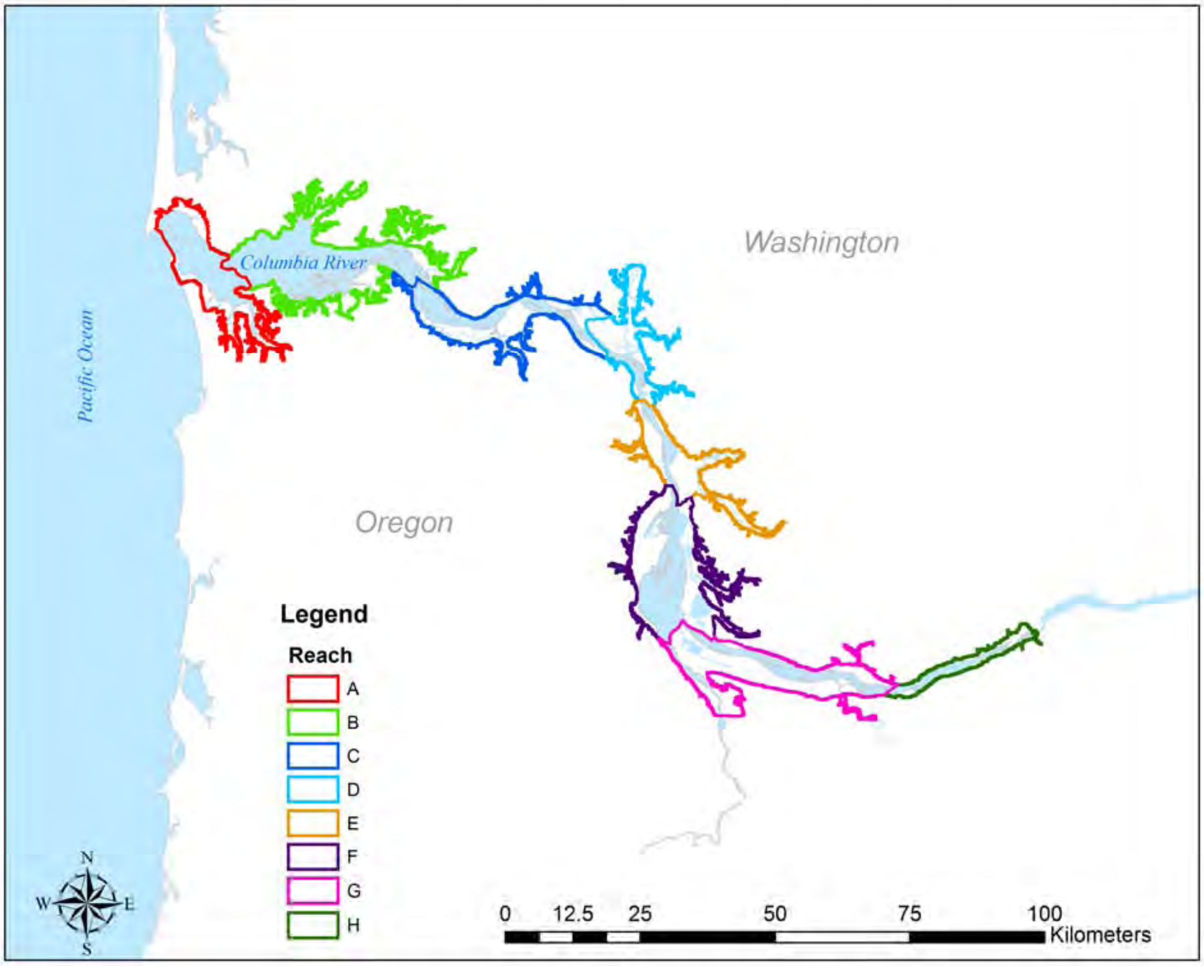


Figure 2: Columbia River estuary with hydrogeomorphic reaches outlined. The focus reaches for the Year 2 pilot field study were D and F.

Summary of Toxics Monitoring Activities in Year 2

Water Quality Monitoring

USGS WRD Fixed Station and Semipermeable Membrane Device Water Quality Monitoring

USGS WRD conducted fixed station water quality monitoring and installed semipermeable membrane devices (SPMDs) to provide water quality data on conventional pollutants and toxics near NOAA salmonid sampling sites. Appendix A shows the parameters USGS WRD monitored for in each of the groups of compounds, the method reporting limits, and the units reported. Appendix B provides a summary of the sites sampled and how many times each of these groups of compounds were sampled for during Year 1 and Year 2.

Monthly water-quality monitoring

USGS WRD collected monthly water-quality samples at the Columbia River at Warrendale (Point 5 in Figure 1), the Willamette River at Portland (Point 4 in Figure 1), and the Columbia River at Beaver Army Terminal (Point 2 in Figure 1) from May 2004 through April 2005 (Figure 1). These were water-column samples for nutrients, alkalinity, carbon species, trace elements, a select listing of pesticides, chlorophyll a, and biomass. In addition, field parameters such as pH, dissolved oxygen, temperature, and specific conductance were measured and samples were collected for the determination of suspended-sediment concentration. USGS WRD also collected bacteria samples that Oregon Department of Environmental Quality (ODEQ) analyzed for E. coli and total coliforms. Four times the number of pesticides and degradates analyzed was expanded. USGS WRD also collected large volumes of water to analyze the trace elements on the suspended sediment. The Columbia River at Beaver Army Terminal (Point 2 in Figure 1) site was sampled every month for organochlorine compounds on the suspended sediment.

Expanded water-quality monitoring to characterize high and low-flow conditions

The expanded water-quality samplings to characterize low-flow conditions occurred in August 2004, while the high-flow samplings occurred in April 2005. The Columbia River is a snow-melt driven system, so during normal weather conditions peak flows are during May and June, whereas lower flows occur during August and September. The Willamette River, however, is a storm-driven system, with peak flows normally occurring during December and January and low flows during summer months. Water year 2005, however, was an exception. USGS WRD had originally scheduled the high-flow work for the Willamette in January 2005, but delayed the work due to near drought conditions. The Willamette River high-flow sampling ended up being combined with the Columbia high-flow work in April. In August, the efforts included the 3 monthly monitored sites (Columbia River at Warrendale, Willamette River at Portland, Columbia River at Beaver Army Terminal, Columbia River at Columbia City and Columbia River near Point Adams. In April, however, additional USGS WRD funding (aside from the Ecosystem Monitoring Program’s grant) was discontinued and sampling at the Columbia City site ended. However, the Point Adams site was added on to the 3 monthly sites. This work included the same constituent groupings as analyzed for the monthly samples, but also included waste-water compounds, pharmaceuticals, and antibiotics.

Sampling with SPMDs to characterize high and low-flow conditions

Semipermeable membrane devices (SPMDs) (Figure 3) were deployed during April 2005 sampling and again during a sampling in August 2005 at all 4 sites (Columbia River at Warrendale, Willamette River at Portland, the Columbia River at Beaver Army Terminal and Columbia River near Point Adams). SPMDs are sometimes referred to as "virtual fish." They are fat bags that are suspended in the river in a protective cage for roughly a month. The fat absorbs hydrophobic compounds much like a fish would bioaccumulate compounds from the water column, therefore, providing a way to estimate a fish's exposure to toxics. The dialysate from these SPMDs is being analyzed for four different groups of compounds: organochlorines (DDT, endosulfan, etc), polyaromatic hydrocarbons (PAHs), polychlorinated biphenyl ethers (PCBs, all 209 congeners), and polybrominated diphenyl ethers (PBDEs, which are flame retardants). At the time of deployment, suspended-sediment samples were collected and submitted for analysis of these same 4 groups of compounds.

NOAA Toxics Model Development and Salmonid Sampling

Introduction

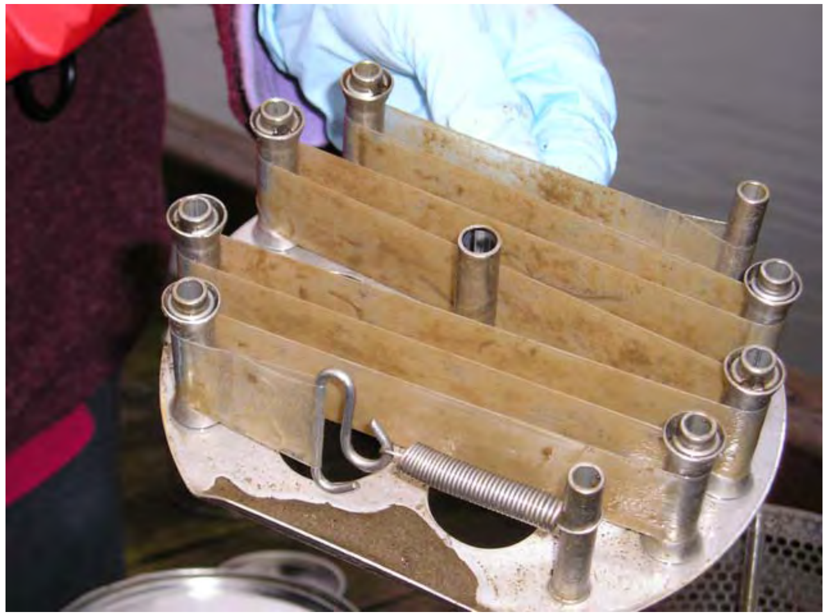


Figure 3: Photograph of Semipermeable Membrane Device (SPMD)

In addition to water quality monitoring, the toxics monitoring component of the Ecosystem Monitoring Project also encompasses the development of three models by NOAA and UC Davis. The overall goal of their work is to explore the risks associated with exposure to major classes of chemical contaminants to listed Columbia River salmon. Components of this project include the development of (i) a conceptual model; (ii) a contaminant transport and uptake model; and (iii) an ecological risk model. In addition, contaminant exposure is being be assessed through a focused set of field sampling efforts that will collect data on contaminant concentrations in salmon and their prey in the habitats they utilize as they migrate through the Columbia River and Estuary. This document provides a preliminary discussion of the three models that will be finalized at the end of FY06, and a summary of field sampling efforts conducted in FY05.

Conceptual Model of Contaminant and Endangered Salmonid Species Interactions within the Lower Columbia River and Estuary

The Columbia River is the second largest river in the United States and drains an area exceeding 668,200 km^2 (258,000 mi^2). A diverse array of biota inhabit the Columbia River and Estuary including 13 salmon runs (ESUs) listed as either threatened or endangered under the Endangered Species Act. The species listed include Chinook (*Oncorhynchus tschawytscha*), chum (*O. keta*), coho (*O. kisutch*), sockeye (*O. nerka*), and steelhead (*O. mykiss*). For at least some period of time, all of these stocks use the Columbia River Estuary for a migration corridor, and some stocks, such as the Lower Columbia River, Upper Columbia River, and Snake River fall chinook, and Columbia River chum, use it for a more extended period of rearing.

Numerous factors influence the recovery of these listed stocks, including ocean and climatic conditions, access to and quality of habitats, predators, hydropower operations, and hatchery and harvest practices (NRC 1996; Fresh et al. 2005). This study is focused primarily on characterizing and quantifying the effects of chemical contaminants, one particular aspect of habitat quality, on listed Columbia River salmon.

The general conceptual model framework for the analysis of the risks of contaminants on Columbia River salmonids, adapted from the EPA ecological risk assessment process (USEPA 1998; Scholz et al. in prep), is shown in Figure 4. The first major component of the framework is exposure analysis, in which contaminant distribution patterns are combined with the abundance and distributions of listed salmonids to generate an exposure profile for both salmonids and their habitat. The second component is ecological response analysis; where empirical, monitoring, and modeled data are used to generate a response profile that predicts the effects of contaminants on individual salmonids and their habitat, including the species with which they interact (i.e. predators, pathogens, and prey). The exposure and response profiles are then combined to characterize how contaminants may contribute to the risk of extinction of ESA-listed salmonid ESUs. This analysis can then be used to guide potential management actions that could mitigate this risk.

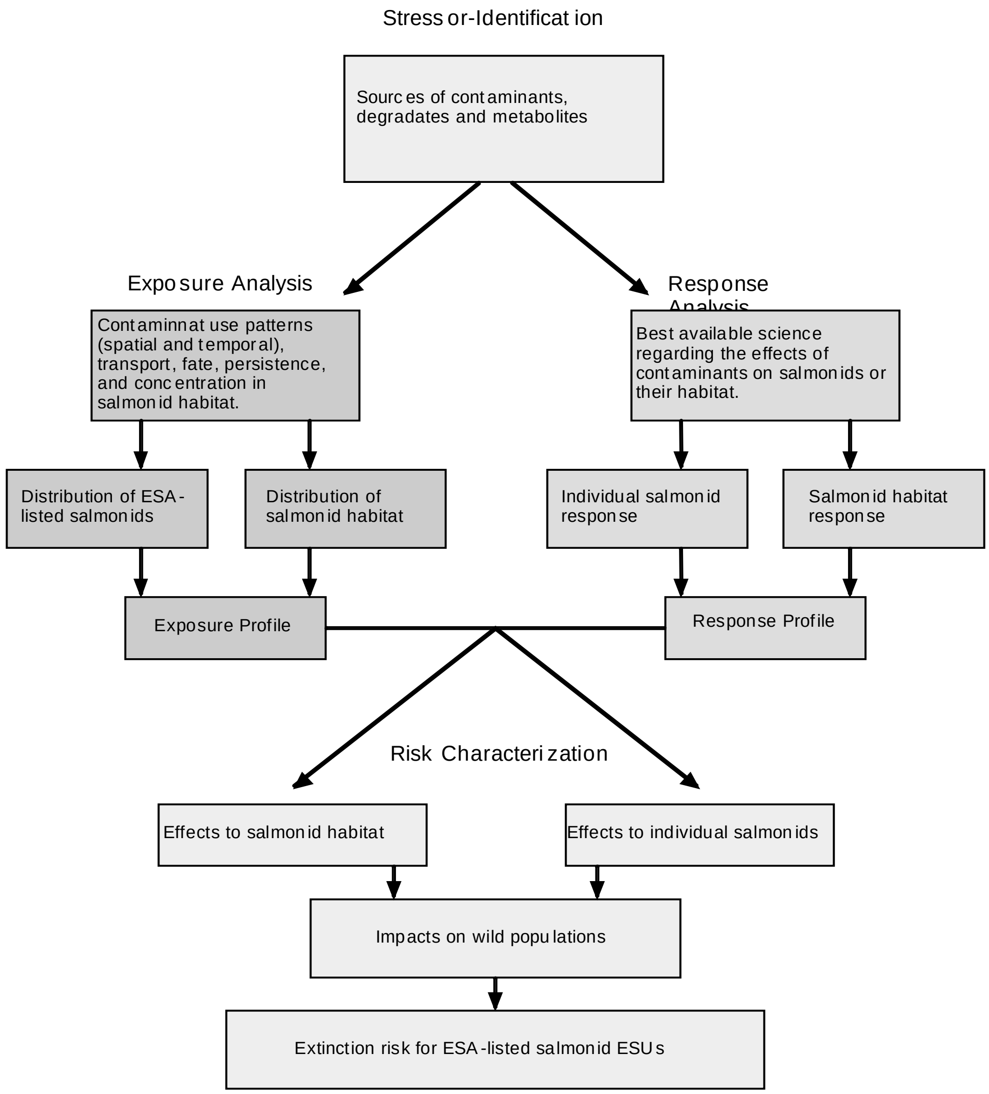
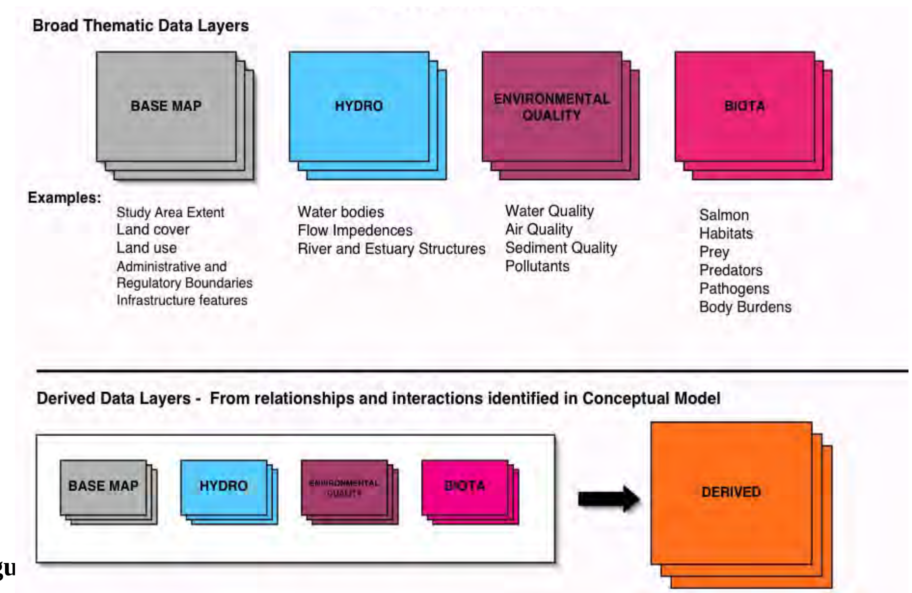


Figure 4: Conceptual model of risk assessment process for effects of contaminants on listed Columbia River salmon. Adapted from USEPA 1998 and Scholz et al. (in prep).

In conjunction with this general model framework, NOAA developed a series of descriptive and graphical sub-models to support the exposure and response analyses. These sub-models depict biotic and abiotic processes that influence contaminant transport and uptake, and the resulting sub-lethal and lethal effects that may influence salmon mortality and reproductive rates, both directly and through interactions with their pathogens, predators, and prey. The model is further supported by a geographic information (GIS) (Figure 5) that contains data on influential variables within the conceptual model based on spatial location. GIS layers provide visualization of spatial relationships and interactions between factors such as contaminant distributions, distributions of salmonids, habitat attributes, and distributions of predators, pathogens and prey.

Conceptual Sub-Models and Data: Exposure Analysis

Contaminants enter into and are transported within the Lower Columbia River and Estuary (LCRE) 1) though the air; 2) through surface and subsurface waters, either in solution or in association with suspended particulates and sediments from upland areas or from within the river and estuary; and 3) from biological sources, through the food web (Figure 6).



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layers depicting system variables system

Air Compartment Airborne contaminants discharged either as gases or as particulates, may enter the river and estuary directly or indirectly through atmospheric deposition. Sources of atmospheric contaminants include point source emissions from industry, and more diffuse emissions from municipal, agricultural, and natural sources (e.g., gasoline and diesel exhaust, pesticide and fertilizer applications, home fireplaces and barbecues, volcanic eruptions, and forest fires). PAHs are a major class of airborne contaminants, but many other contaminants may enter the estuary through this pathway. Once airborne, the fate and transport of the chemical contaminants are dependent on atmospheric weather conditions (e.g., prevailing wind patterns, precipitation events, storm-driven mass loadings of non-point source runoff from land surfaces into the estuary and river). UV radiation produced by the sun may contribute to chemical transformations of contaminants in the atmosphere, in some cases to more harmful forms (e.g. dieldrin to photodieldrin as per Wolfe and Seiber, 1993).

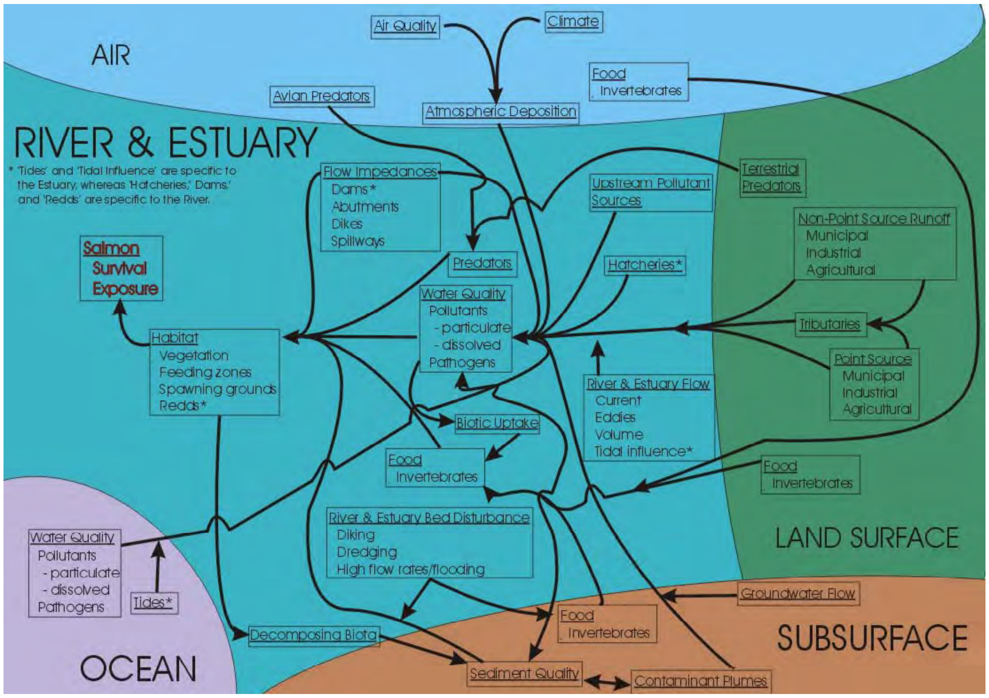

Figure 6: Conceptual sub-model of contaminant sources, fate, and transport in the river and estuary.

Surface and Subsurface Compartment The types and concentrations of pollutants released into surface and subsurface waters are closely associated with land use. In agricultural areas, the predominant contaminants are various classes of herbicides and pesticides. Common industrial and municipal contaminants include metals, organic solvents and other organic compounds, and municipal sanitary wastewater effluents. Transport mechanisms for contaminants include mass fluxes associated with point and non-point source discharges into receiving waters; and migration of contaminants into groundwater from landfills, waste lagoons, or similar sources, and from there into the river and estuary (e.g., see DOE 1999 for studies on the of transport of radionuclides into the Columbia via contaminated groundwater).

Contaminants in surface and ground water may be either in solution, or in association with suspended sediments or other particulate matter. Surface and subsurface transport are both heavily influenced by rainfall (Proctor et al. 1980). Land use and land cover also affect contaminant transport. For example, bank erosion and the type and extent of vegetation will influence the extent of runoff and the transport of contaminated soil.

Once contaminants have entered the river and estuary, their fate depends in part on their chemical characteristics, especially their partitioning between solid and liquid phases. The octanol-water (K_{ow}) and octanol-carbon (K_{oc}) partitioning coefficients are indicative these tendencies. Compounds with low K_{ow} and K_{oc}, such as many current use pesticides, are easily water soluble, and tend to remain in solution in the river and estuary, while compounds with high K_{ow} and K_{oc}, such as PCBs and DDTs, are typically associated with suspended sediments and particulate matter in water column, or deposited in bed sediments. The extent to which sediment will adsorb contaminants is dependent on its composition, that is, its organic carbon content, grain size, cation-exchange capacity, pH, particle surface area, and dissolved organic matter (Barron 1995). The interaction of metals with sediments is additionally influenced by the availability of metal-binding sites which are increased by the presence of iron oxides, acid volatile sulfides, and humic acid, as well as metal speciation, transformation (methylation), and redox potential. Transport mechanisms of contaminants in the water column are driven by advection and diffusion processes associated with tidal action and river flow that are further influenced by dikes and obstructions. Similar processes are responsible for the deposition and resuspension of bed sediments. Physical and chemical breakdown processes such as photolysis and weathering contribute to the removal of some compounds from the river and estuary.

Estuarine and River Biotic Compartment In addition to entering and being transported within the LCRE through surface and groundwater and atmospheric deposition, contaminants can be incorporated into this environment by trophic transfer through the food web. Like their partitioning into water or sediment, the extent to which compounds are available to organisms and their persistence within the food chain are influenced by their hydrophobicity (i.e., K_{ow} and K_{oc}). Hydrophilic, water soluble contaminants with low K_{ow} are easily taken up by organisms, but tend to be less persistent in tissues. Hydrophobic contaminants (e.g., PCBs and DDTs) that tend to associate with organic carbon may be tightly adsorbed to sediments and less bioavailable than water soluble contaminants. However, once taken up by organisms, these compounds are likely to be concentrated in lipid-rich tissues and may biomagnify through the food web as contaminated organisms are eaten by their predators. Contaminants may be removed from the food web through chemical transformation (metabolism) within the organisms that have absorbed them, and/or excretion back to the water column. Unless physically removed from the environmental compartment, chemicals that are incorporated in living biomass will continue to cycle through organisms or return to the sediment and water column during decomposition.

Contaminants may be cycled through the pelagic web, which involves organisms that reside primarily in the water column, or the benthic food web, which involves organisms associated with bed sediments, or both. The benthic food web is often considered an important pathway for contaminant cycling for persistent pollutants and tends to adsorb to sediments. However, in an environment such as the Columbia River, where there is considerable resuspension and transport of sediments and organic matter in the water column, the cycling of these contaminants through pelagic food web may also be a significant.

Land Use and Contaminant Distribution Within the LCRE

Within the LCR&E drainage specifically, land use can be categorized as 74% forest, 17% agriculture, and 5% industrial or municipal (Tetra Tech 1996). While the urban area constitutes a small percentage of overall acreage, it is an important factor in governing river water use and water quality (Tetra Tech 1996). Point source dischargers into the lower Columbia River include municipal wastewater treatment plants, fish hatcheries, and industries such as aluminum smelters, chemical plants, pulp and paper mills and related wood product plants, and seafood processors (Tetra Tech 1996). Conventional pollutants whose release is permitted under NPDES include suspended solids, fecal coliform, ammonia, nitrogen, phosphorus, and oil and grease, while regulated toxic pollutants of include metals and synthetic organic compounds. Non-point sources of contamination in the LCR&E include surface water runoff, recharge of groundwaters contaminated from hazardous waste sites and landfills, combined sewer overflows, septic systems, marinas, and moorage, and accidental spills, as well as transport from tributaries and upriver sources. Surface water runoff transports contaminants such as polycyclic aromatic hydrocarbons (PAHs), metals, pesticides, and nutrients from streets, homes, industries, and farms into the river and its tributaries; combined sewage outfalls and septic systems may be a source of contaminants derived from personal care products and pharmaceuticals. Contaminants associated with soils that enter the river and estuary through erosion may also be major contributors to loadings of persistent agricultural contaminants such as DDTs.

Previous studies (e.g., Tetra Tech 1996; Fuhrer et al. 1996; US Army Corps of Engineers 1998; Brown et al. 1998) have documented many types of contaminants present in the water, suspended and bed sediments of the LCR&E as a result of human activities. Major classes present in the LCR&E include PAHs, PCBs, dioxins, polybrominated diphenyl ethers (PBDEs), and various semi-volatile industrial organic compounds; DDTs and and other organochlorine pesticides; current use pesticides and herbicides; metals; and wastewater contaminants such as pharmaceuticals, personal care products, and surfactants. PCBs, PAHs, dioxins and OC pesticides have been detected primarily in bed and suspended sediments; current use pesticides and herbicides and wastewater contaminants have been detected primarily in surface waters, and metals have been detected in both compartments. These contaminants are heterogeneously distributed in the LCR&E, with highest concentrations of most compounds in the Portland and Longview area. Contaminants in freshwater tributaries of the Columbia River Basin outside of the LCR&E may also contribute to exposure in ESUs originating in these watersheds. The USGS has surveyed contaminants in the water column, sediments, and fish tissue in several basins in Washington and Oregon that drain into the Columbia River, including the Willamette Basin, the Upper Snake River Basin, and the Columbia Plateau (Wentz et al. 1998; Clark et al. 1998; Williamson et al. 1998). Major contaminants identified in all of these areas include DDTs and other organochlorine pesticides and current use pesticides and herbicides associated with agricultural activities. Industrial contaminants such as PCBs, PAHs, and trace metals were also detected downstream or urban areas in the Willamette and Upper Snake River Basins.

Conceptual Sub-Model of Exposure Routes for Salmon

Salmon in the Columbia River and Estuary generally come into contact with contaminants in solution, within the water, through their diet, and from interaction with contaminated bed and suspended solids. There are four primary mechanisms of salmonid contaminant uptake (Figure 8); (1) gill uptake, (2) ingestion, (3) dermal sorption, and (4) maternal transfer, when the female mobilizes lipids and proteins for egg production. Water soluble contaminants are taken up primarily through the gills, and to a lesser extent through dermal sorption.

The dietary pathway and maternal transfer pathways are especially important for contaminants that bioaccumulate or bioconcentrate in either the food web or sediments (i.e., compounds with a high K_{ow} or K_{oc}), such as chlorinated pesticides, PCBs, dioxins, DDT, and PBDEs. Dietary exposure can greatly increase the tissue concentrations from one trophic level to the next, a process commonly referred to as biomagnification. Once contaminants enter the fish, they can be cleared from salmonids through chemical transformation and excretion with varying efficiencies that depend on the chemical and fish.

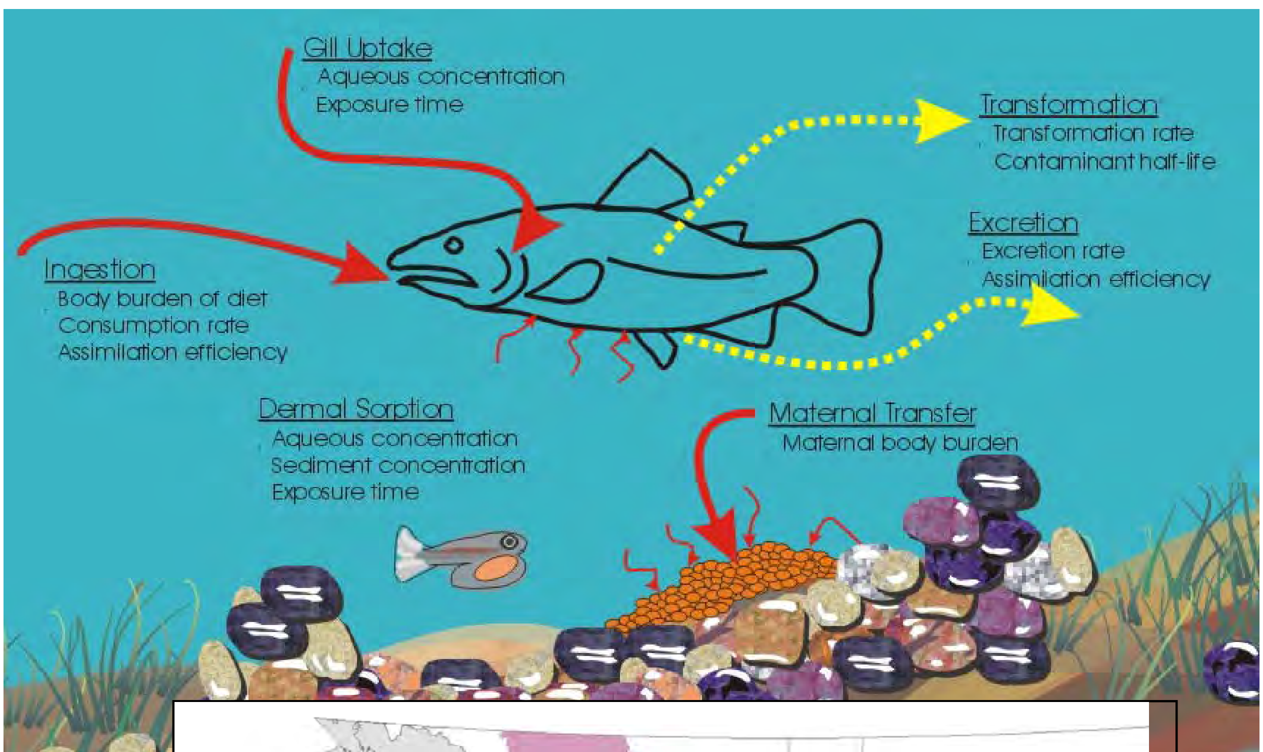

Figure 7: Sa

Figure 8: Geographic distribution of ESUs that migrate through the Columbia River and Estuary.

The benthic and pelagic invertebrates, which are important components of juvenile salmon diets in both estuarine and freshwater habitats (i.e., chironomids, ephemeroptera, calanoid copepods, cladocera, and gammarid amphipod), accumulate contaminants from sediments, their diet (detritus, phytoplankton, macroalgae), and water (Klosterhaus et al. 2003, Hecht et al. 2004). These contaminants are then transferred to the juvenile salmon through ingestion. However, the types and sources of prey consumed by juvenile salmonids, and their contaminant exposure profiles, can be quite variable. Movement of prey items through LCR&E could allow dietary exposure to contaminants that are not present in the local water column or sediment. In addition, juvenile salmon change their diet as they migrate through the LCR&E depending on the season, prey availability, their size, and their habitat. Fry in freshwater systems and the mainstem of the Columbia River feed primarily on aquatic insects and zooplankton including chironomids, ephemeroptera, calanoid copepods, cladocera, and gammarid amphipods (Dauble et al 1980, Higgs et al 1995, Craddock et al 1976). Upon entering the estuary, their diet expand to include gammarid amphipods; aquatic and terrestrial insects; calanoid copepods; and larval fish such as osmerids, anchovy, and euphausiids (Higgs et al 1995; Craddock et al 1976; Higgs et al 1995). The amount of time spent rearing in the estuary vs. the river, and size at migration to the estuary, will affect salmonid diet, and so influence the types and amount of contaminants that are absorbed. Terrestrial insects that contain or carry surface-derived contaminants may also be an exposure route for juvenile salmon. At present, the significance of uptake of surface derived contaminants through terrestrial insects is unknown, but they can be a major component of the diet, and we are not aware of evidence that would preclude insects as being depicted as a possible contaminant source. Indeed, monitoring studies of juvenile salmon at restoration sites in Commencement Bay, Washington (Olson et al. 2005) suggest that at certain life stages and estuarine environments, terrestrial insects in the diets of juvenile salmon could be influencing contaminant exposure patterns.

In addition to prey items occurring naturally in the Columbia River and Estuary, hatchery fish may be exposed to contaminated feed. Although contaminant body burdens in hatchery fish have not been investigated in the Columbia River specifically, studies in other areas in the Pacific Northwest have shown accumulations of contaminants in hatchery feed and fish, particularly PCBs (Meador 2002; Johnson et al. 2005). Salmon have been shown to absorb approximately 50% of the available PCBs in their diet (Meador 2002).

Salmon Distribution and Habitat Use

Geographic Distribution of Listed and Threatened Salmonid Stocks. Currently 13 salmon ESUs inhabiting the Columbia River Basin are listed as threatened or endangered under the Endangered Species Act (Table 1). In addition to naturally spawning populations, the Lower Columbia River and Upper Columbia River ESUs includes hatchery salmon from selected artificial propagation programs within the regions. Because they have a great diversity of life history and are widespread throughout the Columbia Basin, this study is focused primarily on Chinook salmon, but other stocks are also of concern.

Salmon Life-History Strategies Salmon behaviors such as migration patterns and habitat preferences are associated with their life-history strategy. The majority of Pacific salmon species are anadromous and semelparous. The general life-history consists of hatching and rearing in freshwater, smoltification, migration to the ocean, maturation at sea, and returning to the natal freshwater system for spawning followed shortly by death. The exception is iteroparous steelhead, which may migrate and spawn multiple times (Groot and Margolis 1991). The stocks can generally be classified into one of two major life history types, steam type or ocean type, based on their migration patterns during the first year of life. Stream-type fish rear and overwinter in freshwater and migrate as yearlings, spending minimal time in the Lower Columbia Estuary. As adults, these stocks are typically spring and summer runs that enter freshwater before fully maturing. They develop secondary sexual characteristics during the long freshwater portion of their migration and spawn in the fall (Brannon 2004). Ocean-type fish begin their seaward migration in the subyearling fry or fingerling stages, and may spend up to several months rearing in the Estuary before entering the ocean. Adults are typically fall runs; they enter freshwater in late summer to early fall showing their secondary sexual characteristics after having matured at sea, and spawn within days or weeks of returning (Dauble and Watson 1997). Stream-type and ocean-type Columbia River salmon ESUs are shown in Table 1.

Habitat Use Habitat types in the Columbia River Estuary include tidal swamps characterized by shrubs and woody vegetation, tidal marshes characterized by emergent vegetation, and tidal flats with no vegetation, as well as deeper mainstream channels (Fresh et al 2005). Juvenile size determines habitat use (Fresh et al 2005, Bottom et al 2005). Larger juveniles, generally stream-type migrants or hatchery fish, utilize deeper main-stem channels and spend less than a month in the estuary (Fresh et al 2005). Smaller ocean-type outmigrants, likely naturally produced, use peripheral tidal marsh, shallow side channels, and forested marsh habitats for rearing. Fry and early fingerling outmigrants are believed to spend less than two months in the estuary while late fingerlings, entering the estuary June to October, over-winter in the estuary (Fresh et al 2005). Coupling life-history strategies with dietary patterns (discussed previously), ocean-type juveniles, which spend an extended time rearing in the estuary, will consume a higher proportion of zooplankton and species associated with the estuary such as gammarid amphipods, aquatic and terrestrial insects, and calanoid copepods (Craddock et al 1976, Higgs et al 1995). Stream-type salmonids, conversely, will consume organisms associated with freshwater for most their juvenile period, and upon entering the estuary will move primarily to marine species, such as juvenile fish, amphipods, and copepods (Higgs et al 1995).

Table 1: Summary of ocean and stream type life-history strategies expressed by ESUs in the Columbia River (Adapted from Fresh et al 2005, Healey 1991). Year listed as threatened or endangered indicated in parentheses.

Ocean Type	Stream Type
ESU	
Lower Columbia Chinook (1999)	Upper Columbia River Spring Chinook (1999)
Snake River Fall Chinook (1992)	Snake River Spring/Summer Chinook (1992)
Deschutes River Summer Fall Chinook	Upper Columbia Summer/Fall Chinook
Lower Columbia River Coho (2005)	Mid Columbia Spring Chinook
Lower Columbia River Chum (1999)	Snake River Sockeye (1991)

Upper Willamette River Chinook (1999)	Upper Columbia River Steelhead (1997) Middle Columbia River Steelhead (1999) Lower Columbia River Steelhead (1998) Snake River Steelhead (1997) Upper Willamette Steelhead (1999)
Characteristics	
Short freshwater rearing period Longer period of estuarine residence Smaller size at time of estuarine entry Primarily utilize shallow water estuarine habitats, especially vegetated Longer ocean residence Uses area of ocean south of stream type Adults run in Summer and Fall, spawn soon after entering freshwater	Long freshwater rearing period (overwinter) Short period of estuarine residence Larger size at time of estuarine entry Primarily utilize deeper, main channel estuarine habitats Shorter ocean residence Uses area of ocean north of ocean type Adults run in Spring and Summer, spend months in freshwater before spawning

Exposure Profiles: Integration of Sub-Models and Data

Exposure profiles of listed salmon stocks will be influenced by their geographical distribution and their life history type. For example, salmon from the Lower Columbia River and Upper Willamette ESUs are likely exposed to industrial contaminants present in the Portland and Longview areas. Snake River and Upper Columbia ESUs, originating in heavily agricultural watersheds, such as the Yakima and Snake River Basin and parts of the Upper Columbia Plateau, may be especially at risk for exposure to current use herbicides and pesticides, as well as legacy pesticides such as DDT. For ESUs that include hatchery fish (e.g., the Lower Columbia River and Upper Columbia River ESUs) uptake of contaminants during hatchery rearing could significantly contribute to exposure profiles.

Differences in diet and habitat use between stream-type and ocean-type salmonid stocks will also contribute to differences in contaminant exposure and uptake. Contaminant exposure profiles in stream-type salmonids will likely reflect their freshwater habitat, as this is where they spend most of their rearing-time. Dietary exposures would be closely related to contaminant concentrations in freshwater organisms, or possibly marine organisms for older yearling outmigrants. Their exposure to contaminants in the LCR&E would be relatively short-term, and primarily to contaminants in the water column and in deeper channel habitats. Exposure to contaminants in the sediments would probably be minimal, in part because of the movement patterns of the fish, but also because sediments in the main channel of the Estuary tend to be coarse-grained, sandy material where contaminants are unlikely to accumulate. In contrast, contaminant exposure profiles in ocean-type salmonids will likely reflect LCR&E habitat, as this is where they spend most of their rearing-time. Dietary exposures would be closely related to contaminant concentrations in prey species typically associated with the estuary. In addition, they would be exposed to contaminants in both the water column and in sediments because they tend to rear in shallow near-shore habitats with fine-grained sediments where contaminants tend to accumulate. For both ocean- and stream-type life-history strategies, the potential for dietary uptake of contaminants from prey organisms will be affected not only by the contaminant profiles of the environments they occupy, but by their trophic levels. Shifts in diet to organisms higher in the food chain, which typically occur as outmigrants increase in size, will tend to increase the possibility of bioaccumulation of persistent contaminants.

GIS layers as a tool for generating exposure profiles

Derived GIS layers can be used to explore relationships between contaminant sources, fate, transport, and biogeochemical cycling within the LCR&E. Extensive GIS data is available regarding the location of NPDES permitted point source discharges; municipal storm and sanitary sewer outfalls; tributaries and associated water quality; groundwater contaminant plumes; regional elevation models; land cover; land use; current and historical habitat; hatchery type and location; dredging locations and disposal sites; and sediment quality. As an example of the use of GIS databases (Figure 9), a derived layer was generated to elucidate possible impacts associated with point-source discharges. The derived GIS layer can provide information to inform and guide the collection of either in-river fish or data from existing water quality field stations, or the installation of new sites, as well as the selection of chemical constituents specific to point-source discharges (e.g., endocrine disruptors and other hormonally active agents commonly found in municipal wastewater), to quantify the significance contaminant fluxes into the LCRE.

<u>Conceptual Sub-Models and Data: Response Analysis</u>

Effects of Contaminants on Salmon

Exposure of salmonids to anthropogenic contaminants can result in rapid mortality, delayed mortality, reduced reproductive output, or suppression of the ability of the individual and population to thrive through a variety of mechanisms (Fig. 10). Salmonid functions influenced by contaminants that directly or indirectly affect individual and population survival include: (1) body mass or growth, (2) reproductive function, (3) smoltification, (4) immune function, (5) endocrine function, (6) migration/homing, and (7) behavior. Contaminants in the LCRE that have been shown or are suspected to affect these functions include current use herbicides and pesticides (Waring and Moore 1997; Scholz et al. 2000; Sandahl et al. 2004); PCBs (Meador et al. 2002; Chen et al. 1986; Folmar et al. 1982; Arkoosh et al. 2001); PAHs (Folmar et al. 1982; Arkoosh et al. 2001; Incardona et al 2004; Johnson et al. 2002; Rice et al. 2001; DDTs and other organichlorine pesticides (Donohoe and Curtis 1996; Dunier and Siwicki 1994; Milston et al. 2003); copper, lead, and other metals (Baldwin et al. 2003; Sandahl et al. 2004; Hansen et al. 1999; Davies et al. 1976; Detloff and Bailey 1998; Clements et al. 1990; Moore and Ramamoorthy 1984; Woodward et al. 1994); PBDEs (Eriksson et al. 2001); and wastewater compounds that may have endocrine-disrupting effects (Halling-Sörensen et al. 1998; Balk and Ford 1999; Daughton and Terns 1999; Schlumpf et al. 2004).. High concentrations of chemicals can cause outright mortality, whereas lower contaminant levels may have sublethal effects that increase the likelihood of mortality from other causes, such as infectious disease or predation. For example, PCBs and PAHs weaken the immune

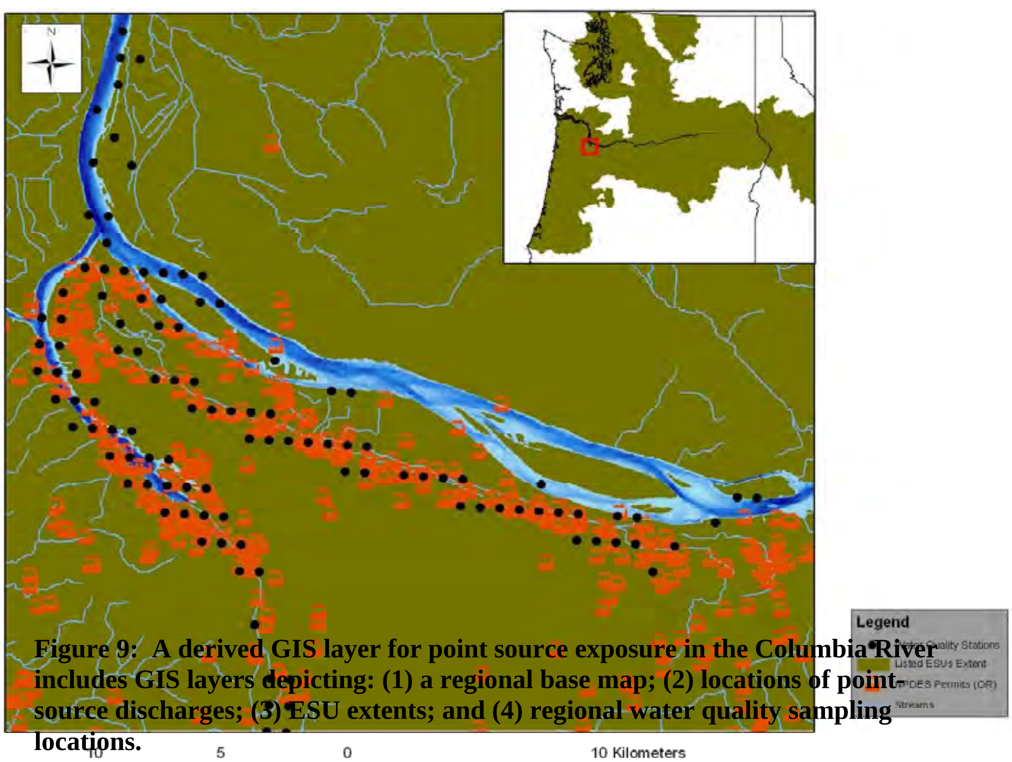

Figure 9: A derived GIS layer for point source exposure in the Columbia River includes GIS layers depicting: (1) a regional base map; (2) locations of point-source discharges; (3) ESU extents; and (4) regional water quality sampling locations.

system in juvenile salmon, but a pathogen stressor is required to induce mortality, a process commonly referred to as delayed disease-induced mortality (Arkoosh et al. 1998). Some toxic effects may trigger delayed harm to the population on year or generational scales. For example, fish size has been correlated to reproductive success, fecundity, and egg size (Healey and Heard 1983; Beacham and Murray 1987). Hence, contaminants that attenuate growth rate may reduce population numbers over generations through gradual impairments to reproductive success on a yearly basis. Life-history models of chinook salmon have concluded that survival through the first year of life most most directly impacts the population growth rate (Zabel 2003; Spromberg and Meador 2005). Therefore, contaminant impacts on these early life stages may be the most critical for the health of listed stocks.

Effects of Contaminants on Salmon Habitat

Chemical contaminants can affect salmon habitat in a variety of ways. There may be physical changes to habitat, such as loss of riparian vegetation, due to applications of herbicides. Herbicides may also important primary producers in streams and estuaries, such as benthic algae (Minshall 1978, Vannote et al. 1980), at concentrations in the low parts per billion (Carder and Hoagland 1998), comparable to those observed in the environment (DeLorenzo et al. 2001). Severe atmospheric pollution may limit the growth of terrestrial and aquatic vegetation. Changes in biological community composition are also possible, such as a shift to more tolerant invasive species in polluted systems. Contaminants are especially likely to affect salmon habitat by adversely impacting the salmon prey base. The majority of contaminants present in the LCR&E show some toxicity to insects and other aquatic invertebrates that comprise the juvenile salmon diet, and some classes of contaminants (e.g., pesticides) are designed specifically to kill or impair the growth and reproduction of these organisms. Data on the toxicity of both sediment-associated and waterborne contaminants to several of these classes of prey are available from short-term bioassays where mortality is the primary endpoint. However, the sublethal or chronic impacts of many contaminants on salmonid prey taxa have not been widely investigated. Aquatic plants and invertebrates are more sensitive to the acute and chronic toxic effects of some contaminants than fish, so these chemicals may reduce the productivity of aquatic or estuarine systems at concentrations that are below a threshold for direct effects on salmon health.

Impacts of toxicants on the salmonid prey base can have important consequences to salmon survival and productivity, as the growth of salmonids is largely determined by the availability of prey (Mundie 1974), and juvenile growth in turn is a critical determinant of freshwater and marine survival (Higgs et al. 1995). For example, a recent study on size-selective mortality in chinook salmon from the Snake River (Zabel and Williams 2002) found that naturally reared wild fish did not return to spawn if they were below a certain size threshold when they migrated to the ocean. Mortality is higher among smaller and slower growing salmonids because they are more susceptible to predation during their first year in the marine environment (Parker 1971, Healy 1982, Holtby et al. 1990), and because they may be more vulnerable to starvation or exhaustion (Sogard 1997). Moreover, even if slower growing and smaller salmon survive to adulthood, their productivity may be affected, because growth rate and size are important determinants of fecundity, especially for female fish. The smaller the fish, the smaller the number of eggs it can produce. Because the onset of sexual maturation is also influenced by size, slow growth will increase the age at reproduction.

Salmonid Interactions with Predators and Pathogens

In addition to affecting the salmonid prey base, contaminants may also influence interactions of salmonids with predators and pathogens, often by making them more susceptible to their impacts. For example, exposure of juvenile salmon to chemical contaminants such as copper and current use pesticides (e.g., diazanon, carbaryl) affect the olfactory system, and hence, reduce the ability of salmon to detect and avoid predators (Scholz et al. 2000; Baldwin et al. 2003; Sandahl et al. 2004). Such effects could be quite significant, as predation is a important source of mortality for outmigrant salmonids. For example, predation by Caspian terms (*Sterna caspia*) in the mouth of the estuary is thought to be one of the factors limiting salmonid stock recovery, specially for stream-type stocks (Roby et al. 1998, 2003; Independent Multidisciplinary Science Team 1998). Northern pikeminnow may also consume large number of outmigrant salmon, especially as they pass through the hydropower system in the region around Bonneville (Vigg et al. 1991; Zimmerman 1999; Friesen and Ward 1999; Zimmerman and Ward 1999;). Recognizing that salmon are part of a much larger food-web, they may in turn influence the health of their predators through trophic transfer of contaminants. For example, reported whole body concentrations in smolts from some sites in the LCR&E are within the range associated with reduced survival of the embryos and chicks of eagles and cormorants (Buck et al. 2004, 2005).

Exposure of salmonids to pathogens can cause immediate mortality, delayed mortality, or altered physiological functions that lead to impaired growth and reproduction. A number of contaminants found in the LCR&E modulate the immune system of juvenile salmon, thereby making them more susceptible to infectious disease (Arkoosh et al. 1994, 1998, 2001). Thus, pathogens in the LCR&E can interact with contaminant exposure profiles to affect the population dynamics of endangered ESUs. The type of disease that is contracted, as well as the likelihood of infection, is dependent on the types and prevalences of pathogens present in the environment. In a preliminary survey of pathogen prevalence in salmonids in the Pacific Northwest, Chinook collected from the Columbia River Estuary were found to be infected with the bacteria *Renibacterium salmoninarum*, *Listonella anguillarm*, *Flavobacterium columnare, and Aeromonas salmonicida;* an erythrocytic cytoplasmic virus; the trematode *Nanopyhetus salmincola;* and the protozoa *Myxobolus cerebralis and Ceratomyxa shasta*. Based on the prevalence of pathogens observed in salmon from the Columbia River Basin, disease appears to be a potentially significant factor governing population numbers.

Conclusions

Currently 13 salmon ESUs listed threatened or endangered under the Endangered Species Act inhabit the Columbia River Basin. Their general life-histories consist of hatching and rearing in freshwater, smoltification, migration through the LCR&E to the ocean, maturation at sea, and returning to their natal freshwater system for spawning followed shortly by death. The conceptual model has identified the chemical stressors that salmon encounter throughout their life-histories, and the physical and biological factors that influence their exposure and response profiles. There is considerable evidence that chemical contaminants can contribute to salmon mortality, reduce the prey base, and cause sublethal health effects that may reduce reproductive capacity and growth. Hence, salmonid exposure to anthropogenic contaminants will likely impair population recovery strategies for listed threatened or endangered ESUs within the Lower Columbia River and Estuary.

The interactions between contaminant sources, transport processes, and exposure routes, and salmon habitat identified in the conceptual model result in a distribution of exposures among the listed stocks that is dependent on their geographic range, habitat use and movement within the LCR&E. The differential residence times of ocean- and stream-type salmonids in the LCR&E influence the duration, type, and location of contaminant exposure. For example, stream-type life-histories are characterized by growth in the river and only a short period of aquatic contaminant exposure in the estuary during ocean emigration, whereas ocean-type life-history strategies are typified by longer periods of estuary rearing, hence the possibility for significant dietary exposures. However the comparative risks and adverse health outcomes associated with these divergent strategies and dietary versus aquatic exposures in the LCR&E are currently unknown.

The development of a conceptual model is one of the first steps in evaluating the cumulative risks associated with exposure to chemical contaminants for listed Columbia River salmon. As we proceed to evaluate the ecological risk posed by contaminants on listed salmon stocks, the conceptual model will serve as a resource to identify relevant physical, chemical, and biological system variables, processes, and contaminant-ESU interactions. These interactions, processes, and variables will serve as the basis in the future for the development of semi-quantitative and quantitative models of contaminant transport, uptake, and effects on salmon. These models will require significant data for development, calibration, and validation. The size of the LCR&E study area coupled with the mobility of contaminants and salmon preclude realistic physical monitoring of every area of interest. However, the conceptual model, in conjunction with derived GIS layers, can be used as a basis for informed decisions regarding efficient environmental monitoring. The monitoring efforts (both locations and analytes) should be designed not only to fulfill the data requirements of future models, but also to evaluate the success or failure of restoration efforts.

Contaminant Transport Model

Introduction

The goal of the Salmon Toxics study is to explore the potential impacts of chemical contaminants on listed Columbia River salmon. The contaminant transport and uptake models are being developed to assist in determining the potential sources of contaminant uptake by juvenile salmon in the Lower Columbia River and Estuary (LCRE). The models will be applied in conjunction with the collected water, sediment, body burden, and genetic data to assess the potential impacts and to develop exposure profiles for the different salmon stocks that utilize the LCRE. Water and sediment contaminant data will help address source questions. Genetic analysis of sampled fish will classify the individuals by ESU or hatchery. This plus sampling location may identify the general habitats utilized by the fish, which will in turn influence their contaminant exposure profiles. The following report discusses key factors in developing the contaminant uptake models including site description, selected model contaminants and uptake mechanisms and models scenarios.

LCRE Description and Segments

For the purpose of the contaminant uptake models the potential exposure and uptake for subyearling migrants along LCRE will be assessed by river segments as defined below and as outlined by the BiState Study (Tetra Tech 1992). Using river segments for defining the models will assist in defining exposure time and ESU specific scenarios. It will also allow flow, sediment, habitat, and contaminant measurements to be modeled in slightly more uniform segments since segment borders are often defined by system changing elements such as salinity or confluence with a major tributary. Segment one extends from the mouth to Tensillahe Island (RM 0 – RM37). This includes the estuary and transition reach. There is a large discharge as well as strong tidal currents. The salt wedge can extend to RM27 during low flow, but RM 14 during high flows. River segment two includes the riverine system from RM37 to RM72. Tributaries that enter the Columbia in this stretch include the Cowlitz and Clatskanie River. There is tidal influence on the flood stages and river velocities in the lower end of this reach. The average flow rate is 6ft/s at low tide and 2ft/s at high tide. Segment three extends from RM72 to the confluence with the Willamette River at RM 102. Other tributaries that enter here include the Lewis, East Fork Lewis and the Kalama Rivers. River segment four extends from RM102 to the Bonneville Dam at RM 146. Tributaries include the Washougal and Sandy Rivers.

Model Contaminants

There are many ubiquitous contaminants that have been historically found in the LCRE (Tetra Tech 1996, Fuhrer et al 1996). We selected PCBs and copper as our model contaminants since they are known to be historically present, accumulate in biotic tissues through water column, sediment and dietary exposures, and produce effects in salmonids that are well-characterized. Additional contaminants will be addressed as the models are developed.

PCBs Polychlorinated biphenyls (PCBs) are persistent, water insoluble compounds that tend to accumulate in aquatic sediments and biota. Salmon have been shown to absorb approximately 50% of the available PCBs in their diet (Meador 2002). A variety of effects have been identified resulting from exposure to various PCB congeners, including direct mortality, impaired growth and reproduction, immune dysfunction, hormonal alterations, neurotoxicity, behavioral alterations, enzyme induction, and mutagenicity (Meador et al 2002). Planar congeners exhibit "dioxin-like" toxicity mechanisms and are known to bind to the aryl hydrocarbon (Ah) receptor resulting in various enzyme systems, including P450s, producing effects at low tissue concentrations (Meador et al 2002). Some effects measured in chinook salmon include suppression of immunological memory due to PCB exposure as measured by primary and secondary plaque-forming cell (PFC) responses (Arkoosh *et al.*, 1994). Compromised immune function was investigated in juvenile Chinook collected from hatcheries and urban and nonurban estuaries in Puget Sound that were exposed to *Listonella anguillarum* (*Vibrio anguillarum*) (Arkoosh *et al.*, 1998). It is not known whether juvenile immune suppression leads to effects at later ages or if open ocean chemical exposures may reach high enough levels to trigger immune suppression (Arkoosh, pers comm). Chen *et al.*, (1986) fed rainbow trout PCB contaminated diets at 0.2 !g/g body weight for six months and observed a significant suppression of vitellogenin production. Ankley *et al.,* (1991) observed an inverse relationship between maternally transferred PCBs in eggs and hatching success in Chinook salmon at approximately 100 pg TCDD-EQ/g egg. Tissue concentrations of 0.1 ppm Aroclor 1254 in coho salmon resulted in altered concentrations of thyroid hormones, which can interfere with the smoltification process and osmoregulation (Folmar et al 1982). A review of salmonid PCB toxicity data determined a residue effect threshold for juvenile salmon of approximately 24 to 48 ng/g wet weight whole body tissue concentration and for adult salmon of 240 ng/g (Meador et al 2002). Tissue concentrations below these levels are considered protective.

Copper - Copper toxicity is influenced by chemical speciation, hardness, pH, alkalinity, total and dissolved organic content in the water, previous exposure and acclimation, fish species and life stage, water temperature, and presence of other metals and organic compounds that may interfere with or increase copper toxicity. Biological copper toxicity has a diversity of systemic effects including reduced growth and survival rates and altered hematology, respiratory, and cardiac physiology. Reproductive effects, including reduced frequency of spawning, reduced egg production, reduced survival of young, and increased deformity of fry, have been reported (Sorensen 1991; Eisler 1998). Elevated copper levels also influence the immune system and vulnerability to disease. Baldwin et al. (2003) and Sandahl et al. (2004) found that exposure to copper at concentrations in the 3-6 µg/L range for as little as 30 min affected olfactory function in coho salmon so they could no longer respond normally to test odorants. This could impair the ability of juveniles to find prey and avoid predators, or interfere with homing and reproductive behavior in adults. Dissolved copper concentrations at the estuary sites sampled in the USGS NAQWA survey were within this range (Fuhrer et al. 1996), and copper in suspended sediments was substantially higher (45-120 µg/L). Copper is highly toxic to most freshwater invertebrates (Moore and Ramamoorthy 1984). Aquatic macroinvertebrates are sensitive to both dissolved and particulate copper and some taxa can be more sensitive than salmonids. Invertebrate communities in rivers appear to respond to elevated copper levels in the sediments by changing composition to pollution-tolerant taxa, rather than by reducing overall biomass (Clements et al 1990). Copper contained in bed sediments has been found to be elevated in benthic invertebrates in field studies conducted in metals-contaminated streams (Woodward et al. 1994). Copper is more strongly bioconcentrated in invertebrates than in fish, and is more commonly found in tissues of herbivorous fish than in carnivorous fish from the same location. In salmonids, copper has been determined to accumulate in liver, gill, muscle, kidney, pyloric caecae, and spleen tissues and the concentrations of copper in fish tissues reflect the amount of bioavailable copper in the environment (Sorensen 1991).

Modeled Biotic Uptake Mechanisms

Contaminants can be transported in an aquatic system as a dissolved fraction in the water column, bound to suspended sediments, or bound to bed sediments. River flow rate, bathymetry, river currents, suspended sediment load, bed sediment load, channelization, tidal flows, and obstructions all can contribute to transporting these media to sites where organisms are present and exposure can occur. Bioavailable contaminants can be accumulated in biotic organisms passively through direct contact with dissolved phases that can transport across gills or epidermis. Active accumulation of contaminants occurs through ingestion of water, sediment, or prey items. Contaminant effects depend on their ability to move to a site of action and produce an effect. Some basic properties will help determine a contaminants potential for biotic uptake and/or environmental persistence. Two factors primarily determine the persistence of organic chemicals, hydrophobicity and the ability of the compound to be metabolized. Hydrophobicity is the tendency of a compound to partition into non-polar phases, such as lipid and organic carbon. The partitioning coefficients for octanol-water (Kow) and octanol-carbon (Koc) help determine where a compound will partition. Highly lipophillic compounds, high Kow, are more likely to concentrate in lipid-rich tissues and be sequestered away from excretory and detoxification processes. PCBs have high log Kow coefficients, ranging from 4.5 to 9. High Koc values predict partitioning to organic carbon, such as in many sediment types. Environmental breakdown processes such as photolysis, weathering, and microbial metabolism contribute to the removal of some compounds from availability to biota. Metabolism by the organism is another route of reducing bioavailability and will be discussed below.

Uptake of waterborne contaminants (bioconcentration) involves competing rates of dissolved contaminant uptake and elimination by the organism. Uptake of dissolved compounds occurs across the epidermis, the skin, gills, and gut. The primary site for uptake in is the gills due to the large surface area, blood counter current, large volume of water exposed, and short diffusion distance between water and blood. Hydrophobic compounds, such as low molecular weight polyaromatic hydrocarbons diffuse directly through the cells, while metals pass between cells or through intracellular channels. Chemical distribution and elimination are controlled by blood flow, hepatic biotransformation enzymes, molecular size, lipid solubility, cardiac output, and renal filtration and active secretion (Barron 1995). Factors that contribute to bioavailability of waterborne contaminants include the exposure concentration, the amount of particulate or dissolved organic matter, and steric hindrance of the molecule to passive or facilitated diffusion. Metals depend on chemical speciation which is driven by pH, hardness, and water chemistry. Organometals that do not carry a charge will diffuse more easily than charged particles. The bioconcentration of organic compounds depends on the organism lipid content, molecular size, hydrophobicity, temperature, pH, salinity, and dissolved oxygen. Many of these items also affect the metabolism of the organism and can reduce bioconcentration by increasing elimination.

Bioaccumulation is the uptake of contaminants from sediments and depends on sediment composition and species behaviors (Barron 1995). Organisms increase their potential for exposure to sediment bound contaminants by ingesting sediments and organic matter, having direct contact between body surface and sediments, or by being exposed to the sediment/water boundary layer. Metals bound in sediments depend on the availability of metal-binding sites on the sediment which are influenced by iron oxides, acid volatile sulfides, humic acid, metal speciation, transformation (methylation), pH, redox potential, and dissolved organic matter (Barron 1995). Bioaccumulation potential of organics can be augmented by the availability of reversible binding sites in the sediments. Driving factors include organic carbon content, clay type and content, cation-exchange capacity, pH and particle surface area.

Biomagnification is the uptake of contaminants above levels acquired from bioconcentration and bioaccumulation caused by the trophic transfer of contaminants when tissue residues are passed from lower to higher trophic levels, and is a significant exposure pathway for chlorinated pesticides, PCBs, dioxins, and other compounds (Barron 1995). Dietary absorption occurs by passive diffusion for unionized chemicals that are water soluble or moderately lipid soluble. Metals absorption occurs through carrier mediated or facilitated diffusion. Extremely hydrophobic contaminants cannot diffuse through the aqueous lumen and depend on lipid absorption for uptake (Barron 1995). Dietary exposure can greatly increase the tissue concentrations from one trophic level to the next. Movement of prey items from through a system could allow dietary exposure to contaminants that are not present in the local water column or sediment. In addition, hatchery diets have been shown to be a source of contaminants for young fish and the food web, particularly PCBs (Meador 2002). Salmon have been shown to absorb approximately 50% of the available PCBs in their diet (Meador 2002). Juvenile salmon change their diet as they migrate through the LCR&E depending on the season, prey availability, their size, and their habitat. Their migratory behavior within the estuary could reduce their direct exposure to contaminant hot spots, but feeding on localized prey will provide snapshots of contaminant doses representing the bioavailable compounds present.

Model Systems and Scenarios

The modeling system selected for this project *TrophicTrace* is a stand alone tool used by the U.S. Army Corps of Engineers for calculating the potential human health and ecological risks associated with bioaccumulation of contaminants (von Stackelberg et al 2005). The program incorporates the concepts discussed above and estimates expected fish body burdens using a sediment-based food web, via trophic transfer factors from invertebrates to fish for certain metals, and via bioconcentration factors from water to fish for the remaining metals and hydrophilic organic compounds. Calculations of uptake and trophic transfer use equilibrium partitioning from sediment to invertebrates and the Gobas steady state model (Gobas 1993) to estimate fish concentrations for organic contaminants and a BCF approach to estimate fish concentrations for inorganic and hydrophilic organic contaminants. Chemical input data required include chemical name, CAS number, Kow for organics, and bioconcentration factor for metals. Environmental factors needed include sediment concentration, sediment total organic carbon content, whole or dissolved water concentration, temperature, hardness, and dissolved organic carbon. Biotic data needed include fish weight and lipid content, and juvenile salmon dietary composition. This data is available and varies with river segment, time, and juvenile migrant ESU and will be applied as appropriate to the exposure scenarios selected. *TrophicTrace* allows users to characterize and propagate uncertainty using trapezoidal fuzzy numbers (e.g., a minimum, a range of likeliest values or probable values, and a maximum) for each input parameter. Concern has been raised regarding the appropriateness of using the steady-state Gobas model for short term exposures to transient species in a heterogeneous system and comparing model output to body burden data will address the appropriateness of this approach.

As discussed above, juvenile salmon from different ESUs will move through and utilize the LCRE in different ways depending on their life history, size, and location. The time spent in each river segment and the habitat used will determine the exposure. For example, fish that migrate down the Willamette River to the estuary would be expected to have a greater contaminant body burden from hazardous waste sites and wastewater treatment sources than a fish from the Kalama River that may not be exposed to similar sources or concentrations of contaminants. In addition, hatchery fish would be expected to carry an initial body burden from their hatchery diet and will be modeled separately. Naturally spawned fry migrants from the

Lower Columbia ESU would experience their entire contaminant uptake within the estuary. In contrast, fingerling migrants from the same region may accumulate contaminants while rearing for several months within their natal stream. For this reason the trophic models will assess a number of scenarios to look at the length of time a migrant spends in each river segment and where they enter the LCR&E and whether they encounter all the segments. Some example scenarios are listed in Table 2. These times are rough estimates and the genetic analysis may guide more appropriate assignment. The scenarios can be applied separately to naturally produced and hatchery fish to account for possible hatchery diet contaminants, and will be calibrated based upon the body burden data that were collected for prerelease hatchery fish.

Table 2. Possible exposure scenarios for time spent in each river segment based upon location that migrant enters the LCRE for an estimated 50 day residence.

	Upriver	Willamette	Cowlitz	Youngs Bay
Segment 1	20	20	30	50

Segment 2	10	20	15
Segment 3	10	10	5
Segment 4	10		

The next steps will be to complete collection of physical and contaminant data for each segment and construct the Trophic Trace models. The models will be run for scenarios selected based upon size and genetic data collected this sampling season. Once run, the output will be compared to collected body burden data for confirmation of appropriateness of the model system. If the modeling system provides acceptable estimates of body burdens, future monitoring would require collecting fewer fish to gain the same information. Model output can also be used to estimate potential for adverse effects due to contaminant body burden (Meador et al. 2002) If the models appropriately estimate biotic uptake of the selected compounds they could be expanded to include other emerging contaminants, such as synthetic musks and pharmaceuticals.

Ecological Risk Model

Introduction

The intent of the ecological risk model is to provide a quantitative measure of the impact of contaminant exposure on population numbers of salmonids in the Columbia River Basin. The ecological risk model is being developed within an integrated experimental-modeling approach to risk assessment. The framework for the LCRE ecological risk assessment model (Figure 1) was adapted from the US EPA human and environmental risk assessment paradigms (EPA, 1998). The experimental-modeling approach to risk assessment involves: (1) laboratory studies to collect the data necessary to explicitly link the dose of contaminant to specific health outcomes (or assessment endpoints); (2) field studies to assess the level of exposure of members of a population to the contaminants of interest; and (3) integration of field and laboratory studies into an explicitly dose-structured population dynamic model to infer population-level impacts over both short- and long-term time periods. The ecological risk model integrates the breadth of the project scope as the final "risk characterization" step (Figure 10).

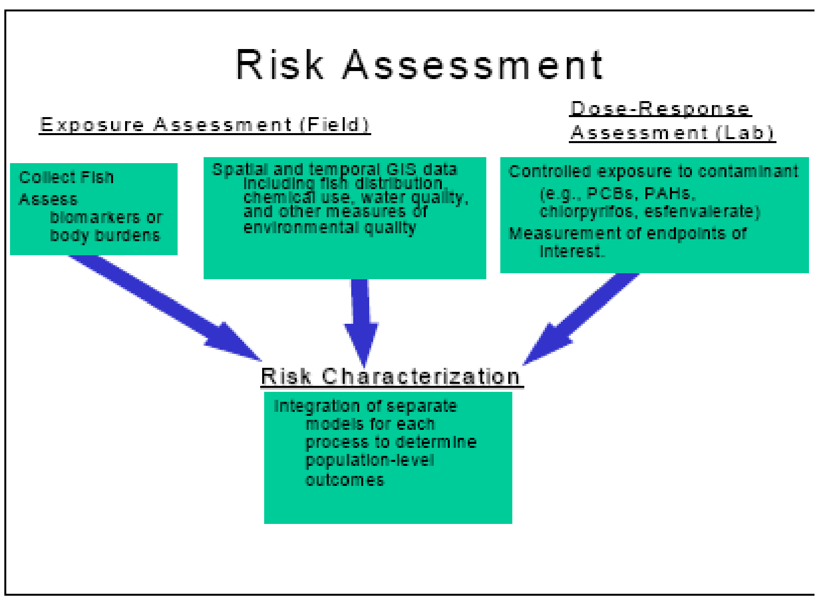

Figure 10: The conceptual framework for the ecological risk assessment integrates field-scale exposure assessment; laboratory dose response assessment; and risk characterization within a dose-structured population dynamic model.

Field exposures can be estimated either through the collection and subsequent analyses of fish samples at spatial and temporal scales of interest, or through analysis of geographic information system (GIS) layers of existing water quality and land-use data overlayed with GIS fish distribution data. Chemical analyses of field collected salmon are being carried out as part of this project. However, for the scale of the LCRE study area, collection of sufficient in-river fish tissue data to characterize exposure for all stocks and life stages of interest is neither technically nor economically feasible. Hence, in addition to fish tissue data, NOAA will rely on the overlay of fish distribution data with landuse and water quality data in a GIS format to infer spatial and temporal levels of exposure.

Currently available laboratory data that link contaminant exposure to assessment endpoints (growth, immunocompetence, reproduction, and predator detection) are integrated in the ecological risk model. These assessment endpoints provide the biological context for evaluating the impacts of contaminants on the salmon population. The current project funding and scope preclude conducting additional laboratory studies, but NOAA is pursuing such studies using other sources of funding and suggests their inclusion in future proposals. NOAA anticipates the ecological risk assessment model will continually evolve as additional field and laboratory data become available.

Model Structure

Presently, there is an operating skeleton of the ecological model. This model is an individual-based population model that retains the 'traits' (e.g., sex, age, weight, growth rate, fecundity, and mortality) for yearly cohorts of 100,000 juvenile Columbia River salmon. Each salmon migrates from the river spawning grounds, to the estuary, then the ocean, and when mature, returns to the river to spawn. At the conclusion of each model cycle (a calendar year), a subset of the fish are removed from the population due to fishing, spawning, or natural mortality, and a new cohort of juveniles is introduced in the river. The model uses established quantitative relationships that describe growth and maturity (Quinn and Deriso, 1999) along with existing data on Columbia River Fall Chinook survival, maturity, growth rate, and river passage (Howell *et al.*, 1985; Beaty, 1996; www.fpc.org; VanHyning, 1968). At anytime throughout the model run, salmon can be 'sampled' in order to identify the effect of certain stressors on the population.

The individual-based program structure is modular, such that additional assessment endpoints can be added into each life-history phase of the program. The full ecological model will employ additional constitutive relations proposed by Quinn and Deriso (1999) and others that quantitatively map selected assessment measures with associated endpoints (examples are provided in Table 3). The constitutive relations will then be integrated into a dose-structured (Ginn, 1999) population dynamic models using a hybrid approach that combines elements of both individual-based and continuum population dynamics for detailed ecological risk characterization at the population-level. Selected parameters in each constitutive relation will be structured on contaminant dose with specific functional values estimated from the laboratory studies discussed previously.

The selection of assessment and model endpoints depends on the scope of the risk assessment. We are specifically interested on the impact of contaminants with respect to annual and decadal changes in population abundance. Consequently, the assessment endpoints are focused on growth, mortality (from direct exposure and indirect effects associated with predation, impacts on the salmon prey base, and disease), and fecundity (Table 3). Growth alone does not influence long-term population numbers, but will rather be used to infer (1) mortality during the first year of ocean residence associated with reductions in outmigrant size (Beamish and Mahnken 2001), and (2) reduced fecundity associated with egg production.

Example of Model Implementation

Although dose-structured population dynamics modeling is a departure from steady-state matrix modeling (e.g., Kareiva et al., 2000; Caswell 2001), this approach was recently used to assess the impacts of both chemical and non-chemical stressors on delayed disease-induced salmon mortality (Loge *et al.*, 2005). This study was completed by members of the research team and a similar strategy for modeling delayed disease induced mortality will be integrated within our ecological risk model. A brief discussion of this study follows; see Loge *et al*. (2005) for specific details.

The researchers used a dose-structured “SIR” (Susceptible – Infected –Recovered) model of population disease transfer that included immunosuppression from chemical stressors (variables and parameters defined in Table 3). The dose-structured population dynamic model defined salmon health states as susceptible (S), infected (I), and deceased (M). The model also included dose of stressor (ω) as a structural variable (Ginn, 1999) and a density-dependent pathogen growth rate (*r*) (Anderson, 1994; Anderson and May, 1996) within individual fish. The dose ω was defined as the cumulative exposure to ambient chemical stressors integrated along the fish’s migration trajectory from its point of origin in the river to its collection in the estuary. Exposure within a population varies due to the heterogeneous distribution of contaminants in the environment, the mobility of contaminants, and the mobility of fish. Hence, values for ω were distributed over the population.

Table 3. Examples of assessment endpoints, associated measures, and constitutive relations for evaluating the potential impacts of contaminants on salmon health within the ecological risk model.

Assessment Endpoints	Assessment Measures	Example of Constitutive Relations[a]
Direct mortality	Fish number	$\frac{dN}{dt} = -\xi N$ [T1]
Juvenile growth	Growth rate	$\frac{dL}{dt} = k^*(L_\infty - L)$ [T2]
	Swimming activity or foraging hits	$\frac{dL}{dt} = k^*\left(\frac{\psi_e}{\psi_c}\right)(L_\infty - L)$ [T3]
Reproduction	Number of eggs produced	$f = \alpha L^B e^\varepsilon$ [T4]
Disease-induced mortality	Immunocompetence	$\frac{\partial S}{\partial t} = -\beta(\omega)bS$ [T5] $\frac{\partial I}{\partial t} = \beta(\omega)bS$ [t] $\frac{\partial M}{\partial t} = \mu I$ [t]
Predation-induced mortality	Predator detection	$\frac{dN}{dt} = -\varpi N$ [T6]
Mortality during first year of ocean residence	Length	$\frac{dN}{dt} = -\kappa\left(\frac{L - L_c}{L_\infty - \overline{L}}\right)N$ [T7]

[a] Taken from Quinn and Deriso (1999). Other relations will be explored as necessary.
[T1] N=fish number density; ξ=model parameter structured on pesticide dose.
[T2] L=length; k^*=model parameter that will be structured on dose; and L_∞=maximum attainable size. Weight and length are related based on other constitutive relations.
[T3] L=length; k^*=model parameter that will be structured on dose and estimated with laboratory data; ψ_e=instantaneous rate of either movement or foraging hits of fish exposed to contaminant; ψ_c=instantaneous rate of either movement or foraging hits of unexposed fish; and L_∞=maximum attainable size.
[T4] f=number of eggs produced per female; L=length; e=lognormal error; α, B, ε=model parameters.
[T5] b=aqueous pathogen concentration; $\beta(\omega)$ is the initial rate of infection structured on pesticide dose ω; μ=rate of mortality; S, I, M= number of susceptible, infected, and morbid fish, respectively.
[T6] N=number of fish; ϖ=rate of mortality, structured on pesticide dose, associated with predation.
[T7] N=number of fish; κ=rate of natural mortality during ocean residence; L_∞=maximum attainable size; $\overline{L}$ =average size of fish in all year-classes in the ocean; L_c=length of fish at the end of the first year of ocean residence.

Prior to this study the incidence of delayed mortality due to chemically altered disease susceptibility in the Columbia River was unknown. However, laboratory evidence had demonstrated a correlation between increased disease susceptibility and chemical exposure (Arkoosh *et al.*, 1998, 2001). Data collected in disease challenge studies performed by Arkoosh *et al.* (1998, 2001) were used to calibrate the model by estimating the dose-structured rate of infection ($\beta(\omega)$; Table 3). When the calibrated model was applied to body-burdens typical of outmigrant salmon in the Columbia River Basin, , it demonstrated that a 1.5 to 9% cumulative incidence of delayed disease-induced mortality could be attributed to chemical exposure. These results not only indicated that chemical exposure is a potentially significant stressor inhibiting salmon population recovery efforts, but also revealed dose-structured population dynamic modeling as a functional approach for characterizing risk in study areas with heterogeneously distributed stressors, such as the Lower Columbia River and Estuary.

Juvenile Salmon Contaminant Monitoring

Contaminant uptake by junvenile outmigrant salmon was directly assessed by collecting juvenile salmon (primarily fall chinook), salmon stomach contents, and sediments samples from 6 sites in the Lower Columbia and Estuary. Sampling sites included Warrendale, near the Bonneville Dam; the Columbia Willamette confluence; the Willamette River at Morrison Street Bridge; Columbia City; Beaver Army Terminal; West Sand Island; and Point Adams; see Figure 1). The sites were chosen to provide geographical coverage of the river and estuary from Bonneville Dam to the mouth, and for their proximity to USGS water sampling stations. Sampling was carried out monthly from April through September. Samples collected included sediments and salmon stomach contents for measurement of chlorinated and aromatic hydrocarbons (e.g., PAHs, PCBs, PBDEs, DDTs, and other organochlorine pesticides); salmon whole bodies for measurement of chlorinated hydrocarbons (listed above); bile for measurement of PAH metabolites; and blood for measurement of vitellogenin. Fin clips were collected for genetic analysis to identify the ESU of origin of each fish. Juvenile chinook salmon and feed samples were also collected for chemical analysis from several hatcheries (Elochoman, Cowlitz, Lewis River, Washougal, Little White Salmon, Spring Creek, Klickatat, and Priest Rapids) that release fall Chinook juveniles into the LCR&E. Sample analyses are currently in progress, and results will be available in FY06.

Summary of Year 2 Habitat Monitoring Activities

Habitat Monitoring

In August 2004, USGS and UW prepared a draft Lower Columbia River and Estuary Ecosystem Classification that was designed to provide guidance to the Estuary Partnership in developing and refining their Lower Columbia River and Estuary (LCRE) Habitat Monitoring Plan. The Classification provided a first order landscape hierarchy for implementation of the initial LCRE Habitat Monitoring Plan design and pilot sampling.

In October 2004, a habitat monitoring planning meeting was convened by the Estuary Partnership staff, Battelle-Pacific Northwest National Laboratories (PNNL), USGS, and the University of Washington. During that meeting, preliminary and intermediary steps for classifying reaches of the Columbia River estuary were suggested (Figure 1). It was agreed that landscape scale analysis using LANDSAT TM imagery would be completed by the University of Washington and USGS prior to undertaking field sampling. This step was deemed necessary in order for Battelle to select the most appropriate reaches for the pilot field study as well as to put the selected field sites in geomorphologic and ecological context. The results of the landscape scale analysis were presented as part of a March Habitat Monitoring workshop and guided the selection of sites for the field study.

Habitat Monitoring Workshop

In March 2005, the habitat monitoring team convened a workshop to present the classification system, bathymetry data assessment, and preliminary field plan to a wider audience for peer review. Battelle received suggestions regarding the field plan ranged from emphasizing the nature of the work as a pilot study (and thus a chance to refine and test protocols) to specific suggestions for field collected data, such as collecting water quality data from tidal wetlands to tie in with the mainstem river water quality monitoring project. Emphasis was placed on using the field study as an opportunity to focus on ecosystem function. USGS and UW also presented the initial draft of the classification system for review at the workshop. USGS and UW obtained important feedback on the objectives, design and information sources to revise the Classification. This feedback is reflected in an updated draft of the Classification for Year 2.

University of Washington (UW) and USGS Lower Columbia River and Estuary Ecosystem Classification System: Phase II Objectives and Methods

Lower Columbia River and Estuary Ecosystem Classification System Objective

The objective of this component to 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. It is, however, designed to provide a more utilitarian framework for understanding the underlying ecosystem processes that create the dynamic structure of the LCRE. As such, it is intended to assist the broader community of scientists and managers who seek a larger scale of understanding required to study, manage and restore LCRE ecosystems.

Lower Columbia River and Estuary Ecosystem Classification System Methods

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

1. **Ecosystem Province**
2. **Ecoregion**
3. **Hydrogeomorphic Reach**
4. **Ecosystem Complex**
5. **Geomorphic Catena**
6. **Primary Cover Class**

The 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 all readily available and 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 4). The classification relies primarily on contemporary data sources. However, UW and USGS will incorporate historical data sources to cross-validate the methods. UW and USGS 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 4 in the early phases of this project. After further development and refinement of the datasets to either improve the delineation of existing Classification levels or to develop analytical techniques for a new level, a final version of the Classification system will be published in Year 3. For more detail on the background, approach and recommendations for future research please see Appendix C.

Table 4. 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 Estuary Partnership 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	

Data Sources

Ecoregions

USGS and UW 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, varies across regions. The rational 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.

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 was 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.

Ecosystem Complexes

USGS and UW 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 during Year 3. 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 Results section), 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 and 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.

Geomorphic Catena

Each complex will be further refined and partitioned in detail using a multi-step approach with elevation, bathymetry, hydrology, and vegetation stage datasets to discern geomorphic structures and processes. Hydrologic features were extracted from a dataset delineating mean high water as the feature boundaries. Simple algorithms were used to analyze bathymetry and the combination of elevation with vegetation stage. This approach resulted in a rules-based methodology that can be reapplied as new data becomes available. The methodology is currently in draft format and will be completed as part of Phase III which will happen in Year 3 of the contract. If significant data gaps are present, heads-up digitizing will replace the automated processes. All processing of the data will occur in ArcGIS 9.1 using the Spatial Analyst extension and ModelBuilder.

Primary Cover Class

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 refined or corrected. For the present, UW and USGS are using the classified 2000 LANDSAT 7 TM processed by Earth Design Consultants, Inc. for the Estuary Partnership.

USGS-CRRL Bathymetry Assessment, Collection and Database Creation

Bathymetry data is a key component of the ecosystem classification system. In 2005, the USGS Columbia River Research Lab (USGS-CRRL) completed a bathymetric gap assessment of the Lower Columbia River, collected bathymetry data in several locations, and created a GIS bathymetry database. USGS visually assessed gaps in the bathymetry data by overlaying bathymetry layers and water sources identified off of a Thematic Mapper (30-m resolution) image (Fig. 11). This is an on-going effort because USGS continues to get additional data from the Army Corps of Engineers Hydrographic Survey and other sources, such as NOAA. There are additional bathymetry sources available from private survey companies that could be used to fill in many of the gaps, and USGS-CRRL is currently trying to secure them. Once the initial bathymetry gap assessment was completed, USGS-CRRL prioritized where to conduct summer field surveys to collect more bathymetry data. In consultation with UW staff, USGS-CRRL collected bathymetric data during August of 2005 at Carroll's Channel and the mouth of the Cowlitz River (Figure 12), near Saint Helens, OR, and near Ridgefield National Wildlife Refuge. The data were collected with an echosounder and an RTK GPS system to insure maximum accuracy. USGS-CRRL also created a GIS database of existing bathymetry data from various sources including the Army Corps of Engineers Hydrographic Survey and NOAA. All of this data is combined in Figure 13 and shows areas where no bathymetry data is available in purple.

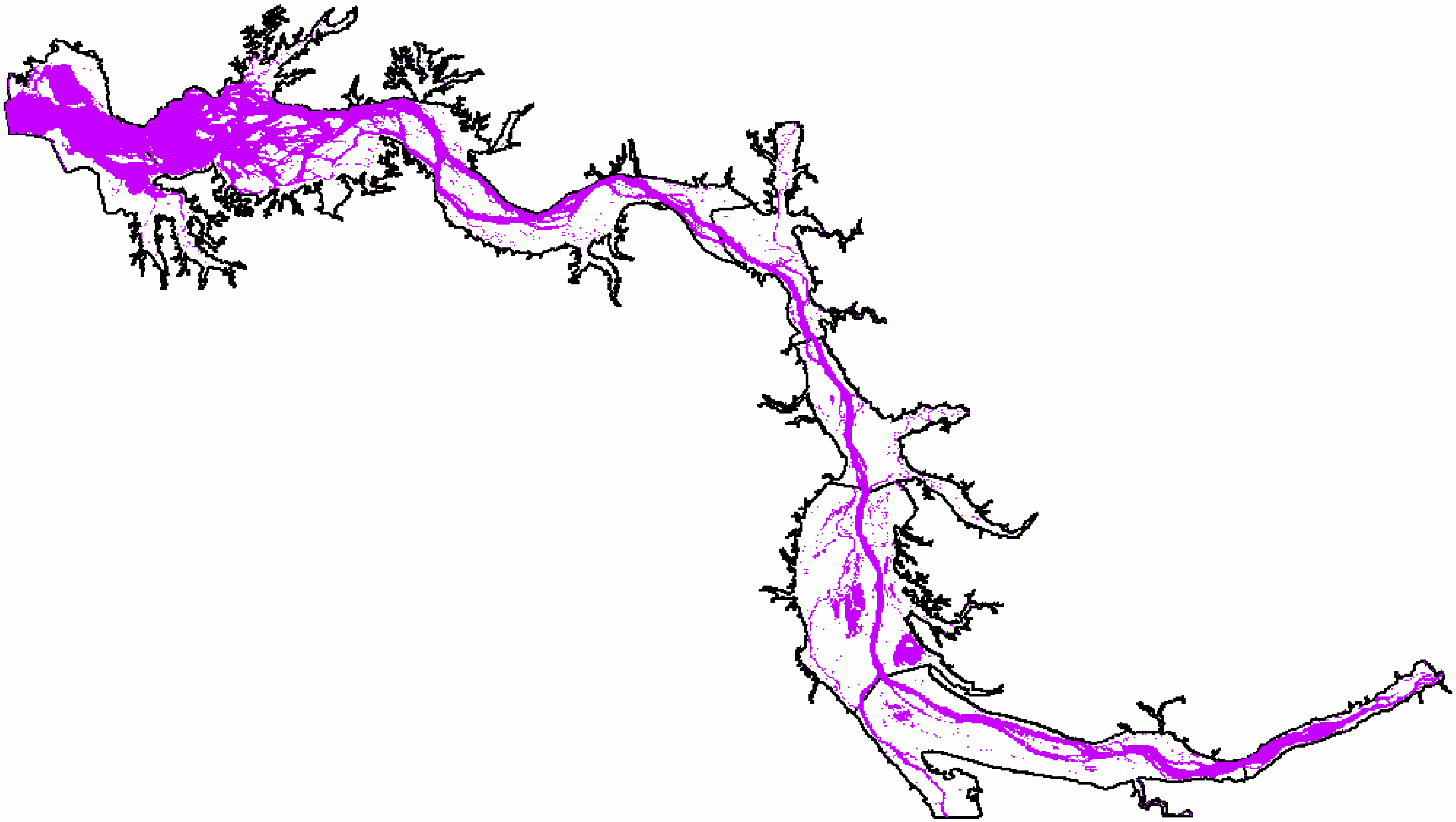

Figure 11: Water - identified from a classified TM image - overlaid on the floodplain boundary.

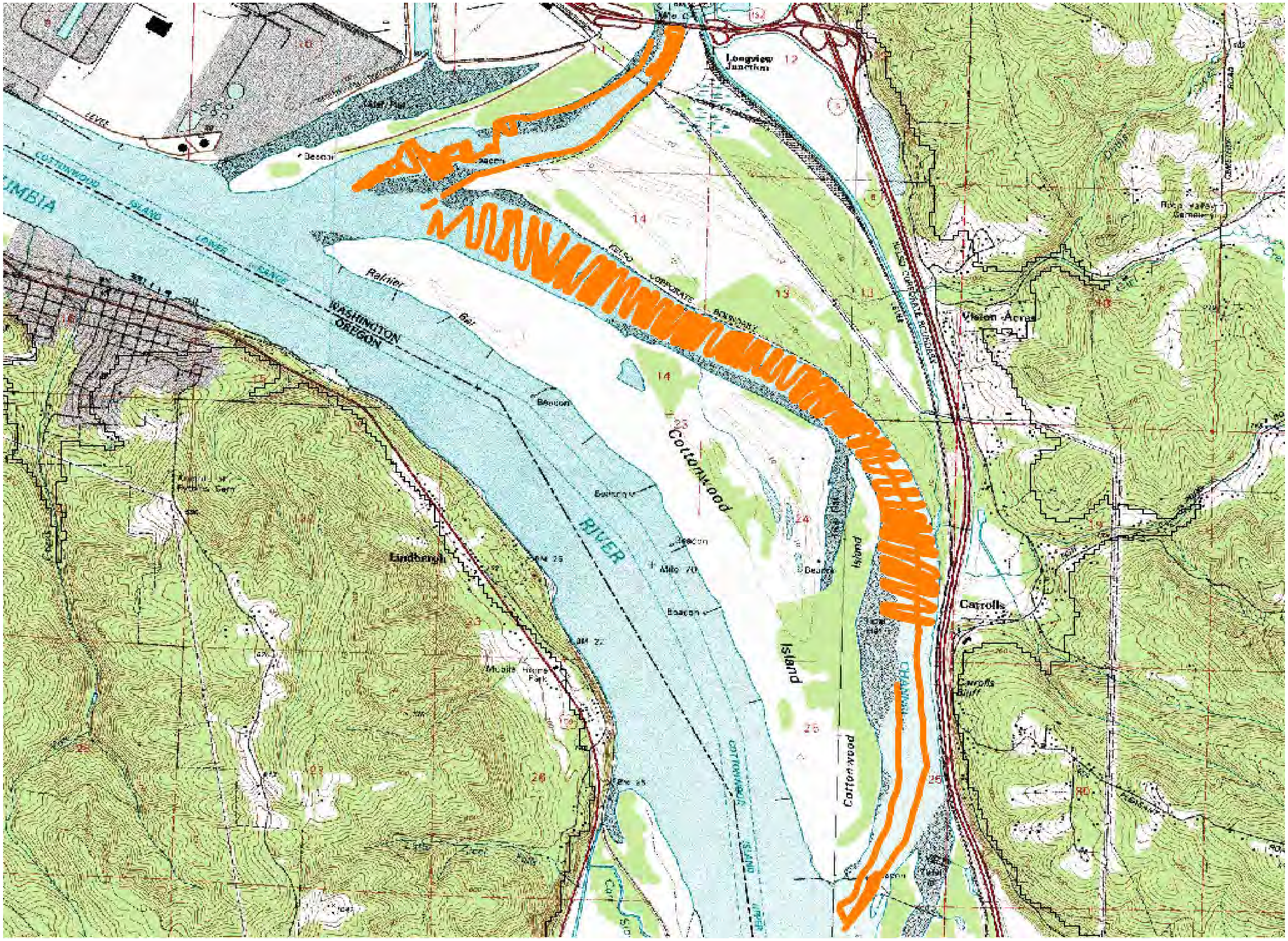

Figure 12: USGS-CRRL collected new bathymetry data at Carrolls Channel and the mouth of the Cowlitz River in August, 2005.

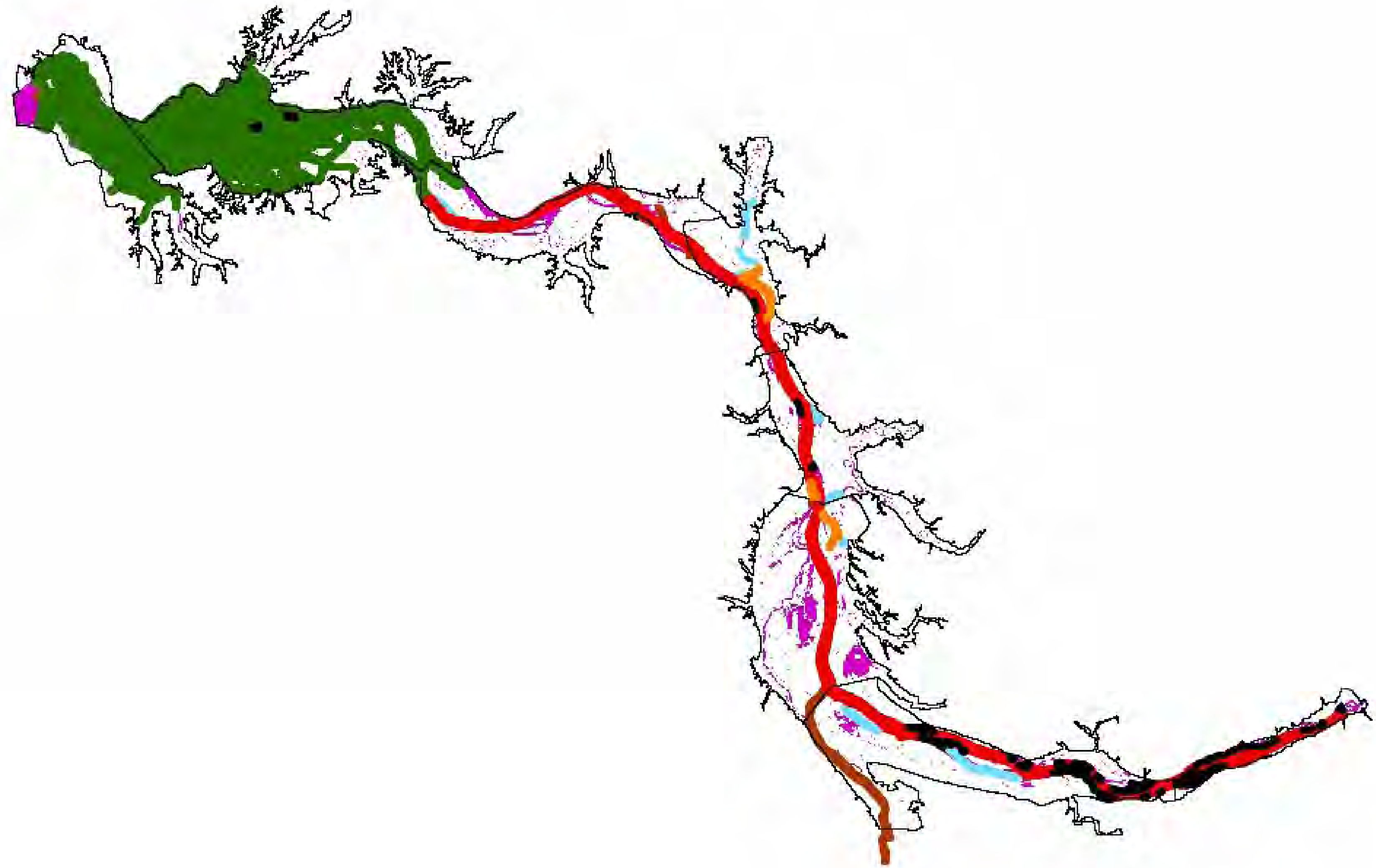

Figure 13: All bathymetry – that were referenced in proceeding images - overlaid on water (in purple) that was identified from a classified TM image (Fig. 1). Gaps in bathymetry are represented in purple.

<u>Battelle-Pacific Northwest National Laboratories Field Sampling Summer 2005</u>

Site Selection/Project Planning Trip, June 2005

As a result of the ecosystem classification analysis undertaken by the University of Washington and USGS, two reaches of the estuary were recommended for the pilot field study to be completed by Battelle. Analysis of complex and cover class types suggested that reaches D and F (according to the classification system) have similar complex types, but vary in the degree of development and intact wetland habitat. These reaches were selected as the focus of Battelle's field study because of the strong contrast and the understanding that the freshwater tidal reach of the river has been poorly studied.

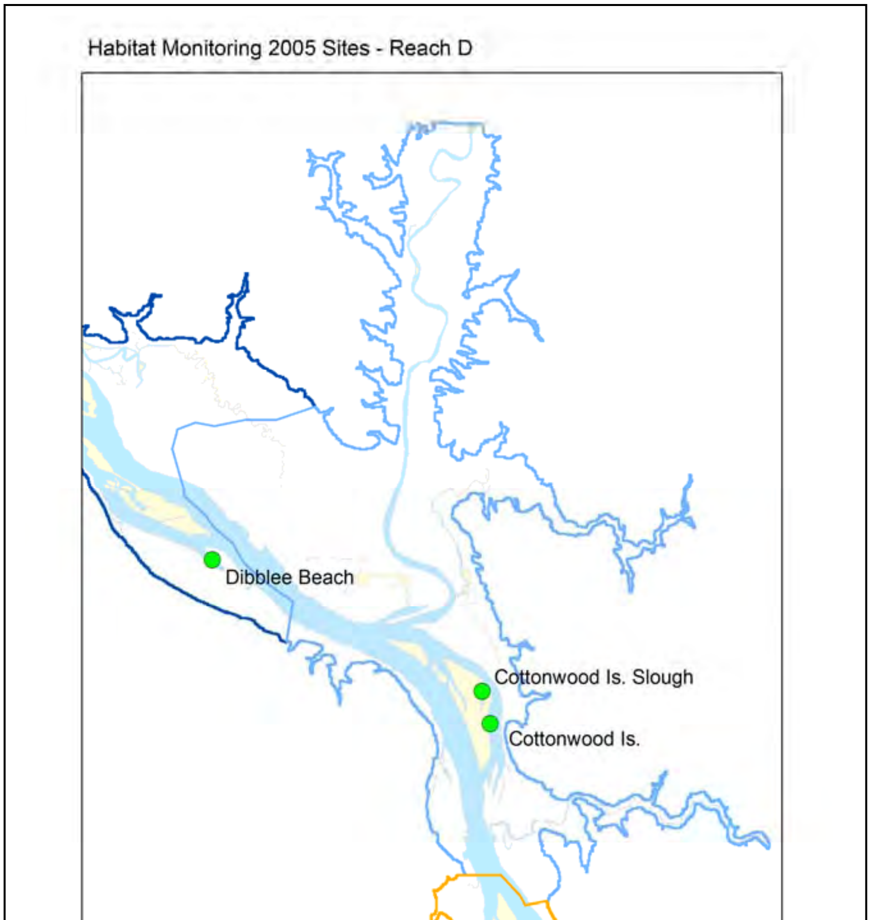

Figure 14: Reach D with sampling sites. The water quality instrument is installed at Dibblee Point. Note: A preliminary delineation of the downstream boundary of Reach D was used during the site selection phase; Dibblee Point fell within the preliminary boundary.

Descriptions of the two reaches are as follows: Reach D (Fig. 15) is from approximately RKm 98 to 118 (approximately 1,377 ha) and encompasses the area around Longview, WA, including the confluence of the Cowlitz River. While Reach D is heavily urbanized, patches of tidal wetland remain, with herbaceous wetlands being the most prominent. Reach F (approximately 3488 ha) is located upstream from Reach D, encompasses Scappoose Bay, Sauvie Island, and Vancouver Lake, and extends from approximately RKm 140 to 170 (Fig. 16). Similar cover classes are found in Reach F, again with herbaceous wetland being most common, both in number of patches and in core area.

Due to the lack of potential sampling sites in the estuary as a whole, and particularly reach D, Battelle-Pacific Northwest National Laboratories took a site selection field trip to further evaluate potential field sites. These sites were chosen by using a combination of aerial photographs, LANDSAT imagery and conversations with local partners to identify locations where tidal wetlands would occur (i.e. wetlands where daily tidal inundation occurred). The selected sites encompassed meandering blind sloughs feeding lakes (Cunningham Lake, Campbell Slough, Hogan Ranch), finger sloughs off of the mainstem of the Columbia river (Sauvie Cove and Dibblee Point), and island wetland complexes (Cottonwood Island). Notable characteristics included the presence of wapato (*Sagittaria latifolia*) and distinct vegetation banding (driven by hydrology), with different species of spikerush (*Eleocharis* spp.) near the water's edge, reed canary grass (*Phalaris arundinacea*) in the middle elevations and willow (*Salix* spp.) and ash (*Fraxinus latifolia*) approaching the upland. Additionally, sites with the potential to incorporate fish sampling (or other faunal sampling) in future years were selected.

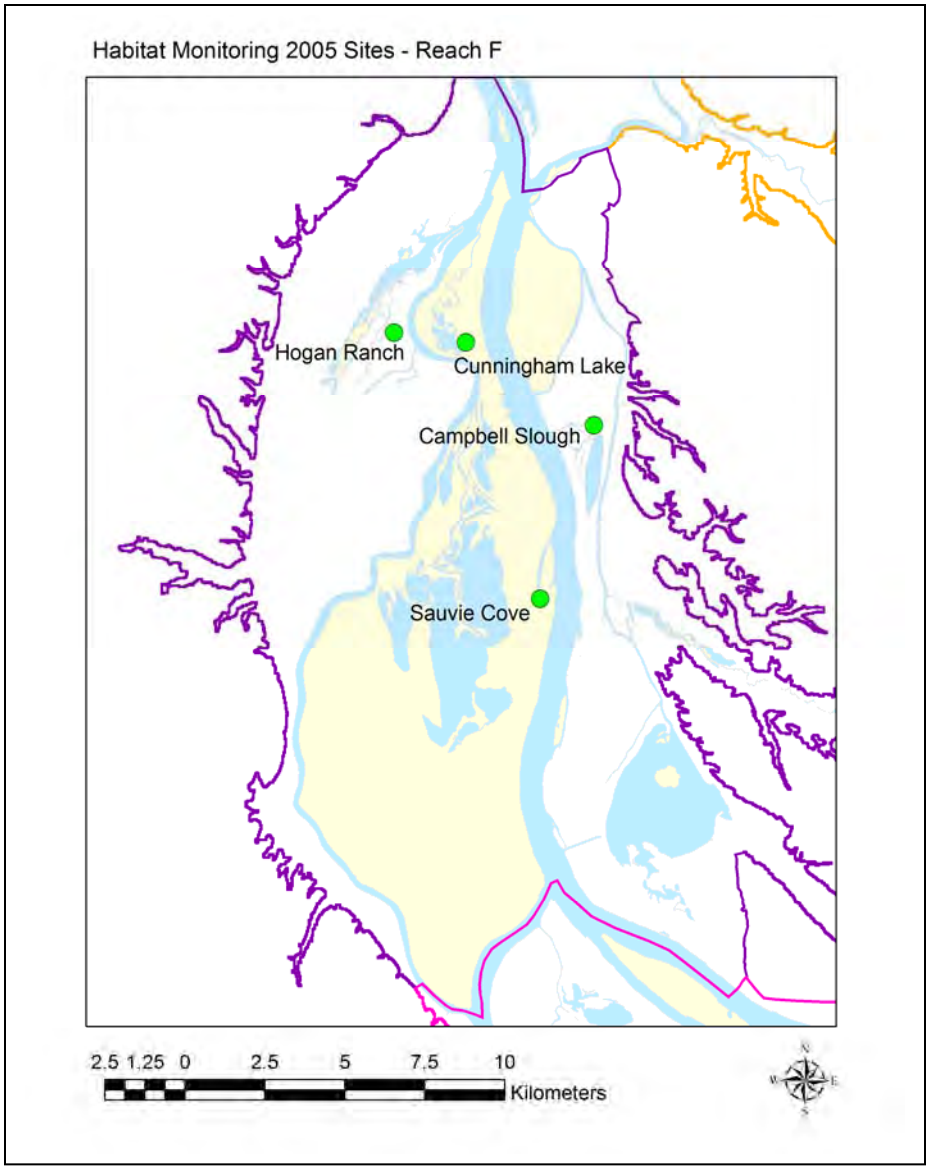

Figure 15: Reach F with sampling sites. The water quality instrument is installed at Campbell Slough.

Field Sampling, July/August 2005

Extensive field sampling took place during July and August 2005. Using the sites selected during the investigative field trip and two additional sites, Battelle was able to sample a total of seven sites (four in reach F and three in reach D). At each site the following occurred:

- A benchmark was temporarily established
- Vegetation was mapped using dGPS (this included defining bands of vegetation and any patches within the bands) (Figure 17)

- Vegetation species cover was sampled using transects and 1-m^2 quadrat surveying methods
- A species list for plants found at the site was compiled (both along transects and elsewhere)
- Elevations of sampling points were surveyed from the temporary benchmark
- densities of wapato were assessed

Figure 16. Vegetation mapping in Scappoose Bay, OR.

Within reaches D and F, YSI multi-parameter water quality instruments with depth sensors were installed (Dibblee Point in D and Campbell Slough in F). The YSI instruments monitored temperature, dissolved oxygen, and salinity. Depth measurements are also being used to explain how hydrology at these sites (away from the mainstem of the river) differs from the predicted tides along the river. These instruments will be deployed for up to six months and will be downloaded monthly by Battelle and the Estuary Partnership.

Battelle conducted a separate field trip in late August to survey the temporary benchmarks. Using a Trimble real time kinematic (RTK) GPS unit and known benchmarks, Battelle was able to survey in the temporary benchmarks with high precision. These data will be used to correlate vegetation distribution to elevation.

As part of the vegetation mapping effort, polygons of known species distribution were recorded. These polygons can be used independently to map vegetation change over time, but will be used in the short-term as ground-truthing for remotely sensed imagery collected concurrently with summer field work. While a separate effort, the imagery will be used in coordination with the field collected data to determine the extent to which imagery can be used for detecting habitat types and cover classes and ultimately detecting change within those habitats over time.

Results

This is the second annual report for a three-year program designed to account for the variability of certain habitat types in the lower Columbia River Estuary. Data has been collected by NOAA, USGS WRD, and Battelle and will be analyzed as part of Year 3 of this project. Findings from this analysis will be detailed in reports for Year 3, including a report synthesizing the findings of the salmonid sampling conducted by NOAA and fixed water quality station and SPMD data collected by USGS WRD as well as an updated version of the Habitat Monitoring Plan incorporating the findings of Year 2 field sampling by Battelle and the revised classification system developed by UW and USGS. Results that were obtained during Year 2 are summarized below including the revisions to the ecosystem classification system and preliminary observations from Battelle's field sampling.

UW and USGS Results: Revised DRAFT Classification

Classification Hierarchy

Each level of the ecosystem classification encompasses different scales of influence on ecosystem structure, where the highest levels in the scheme describe regional-scale structure and the lowest levels composing the finer scale components of the strata in the levels higher in the hierarchy. For example, each of the Geomorphic Catena in level 5 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.

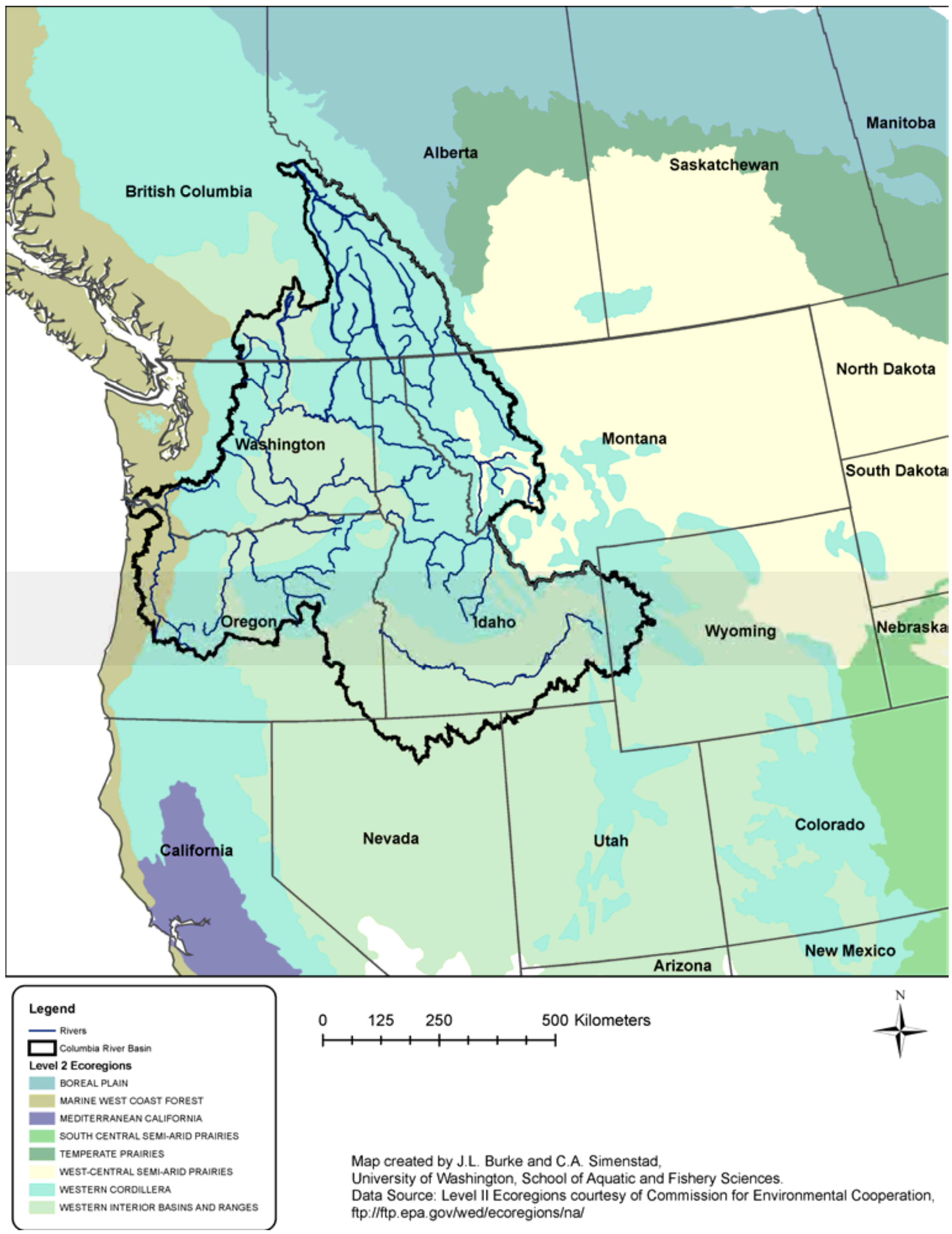

Figure 17. Ecoregion Province of hierarchical LCRE classification, adopting the Ecoregion Level II framework.

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 18). This is immediately adjacent to the Western Cordillera Province that occupies much of the remainder of the Columbia River basin.

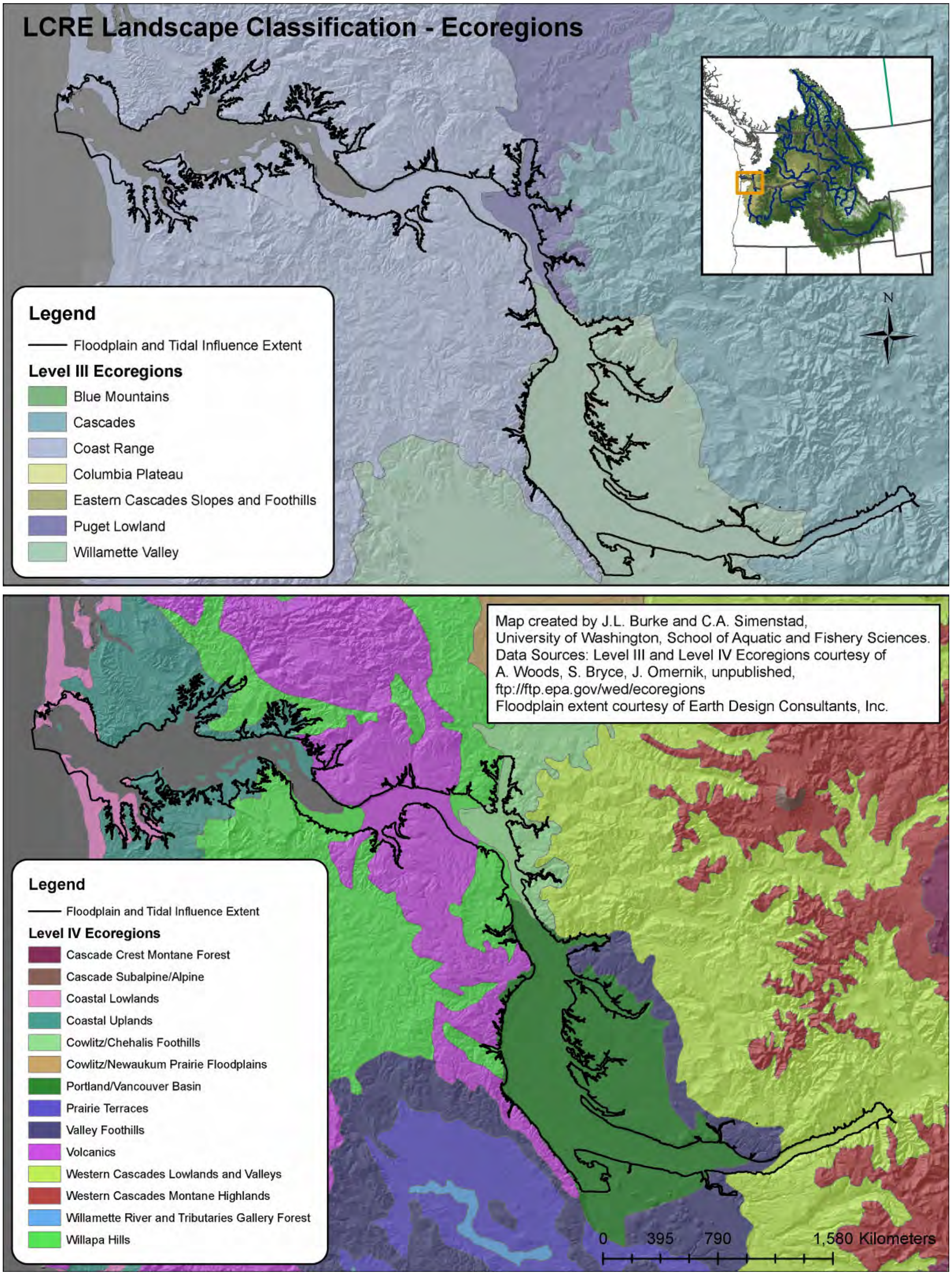

Figure 18. Level III and Level IV Ecoregions with the LCRE Ecosystem Classification area (historic floodplain) superimposed.

Level 2: Ecoregion

The Ecoregion level of the LCRE Ecosystem Classification adopts in principle and basic delineation the EPA Ecoregion Level III structure (Figure 19). Only the boundaries joining the ecoregion on either side of the Columbia River were added in processing. Four Ecoregion strata are delineated within the Estuary Partnership's study area.

Table 5: Preliminary list of geomorphic catena that constitute Level 5 in the Lower Columbia River and Estuary Ecosystem Classification.

- Active mainstem channel(s)
- Secondary (distributary) channels
- Shallow subtidal slopes (adjacent to channels)
- Floodplain-terrace transition zone
- Floodplain ponds and relict channels
  - o Connected
  - o Unconnected
- Floodplain distributary channel
  - o Paratidal (inundated during high water events)
  - o Orthotidal (inundated only during rare and extreme floods)
- Natural levees; stable vegetation
- Forested tidal floodplain
- Scrub-shrub tidal floodplain
- Emergent tidal marsh
  - o Mature (stable, high)
  - o Mid-successional (low)
  - o Immature (low)
- Dendritic tidal channel and sloughs
  - o Low order (always drains except during extreme tides)
  - o High order (always retains water at lower extremes)
- Flats (mud and/ or sand)
  - o Fringe(transition between marsh and channel)
  - o Mid-channel
  - o Bay (e.g. Youngs Bay or Grays Bay)

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 20). 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 above, these included: (a) maximum (historic) salinity intrusion, based on Sherwood et al. (1990); (b) transitions in maximum flood (pre-regulation) tide level (USACE 1968; Kujulka 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 21).

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, UW and USGS 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 21 & 22). After initial testing, UW and USGS 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.

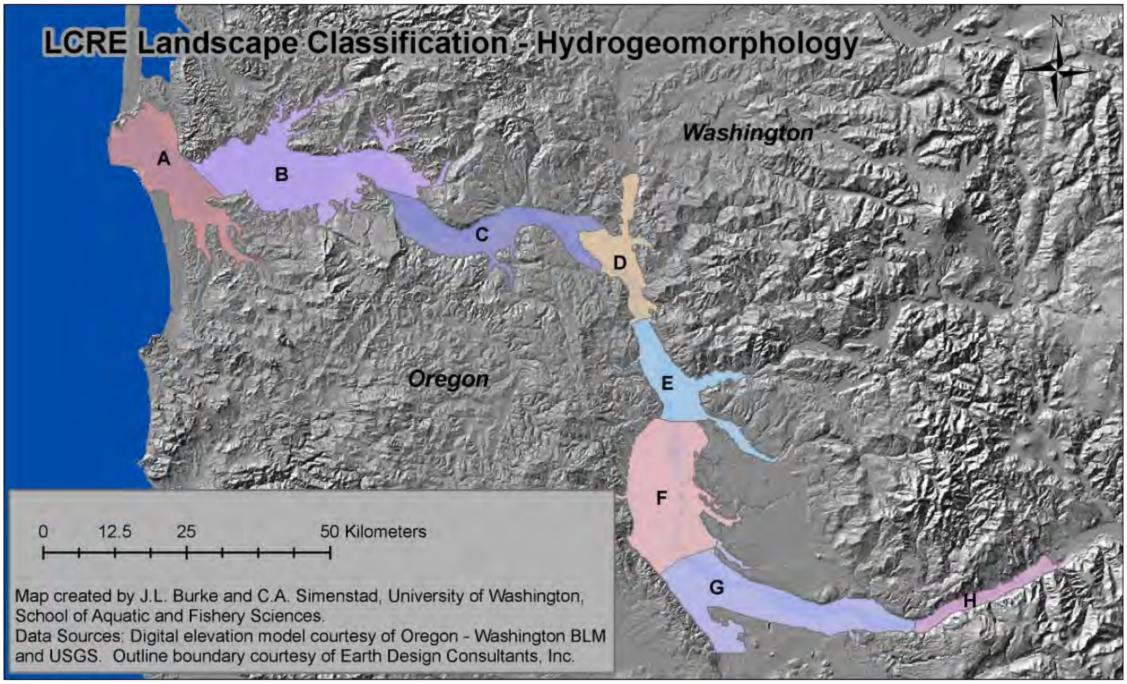

Figure 19. Hydrogeomorphic Reach level (Level III) of LCRE Ecosystem Classification.

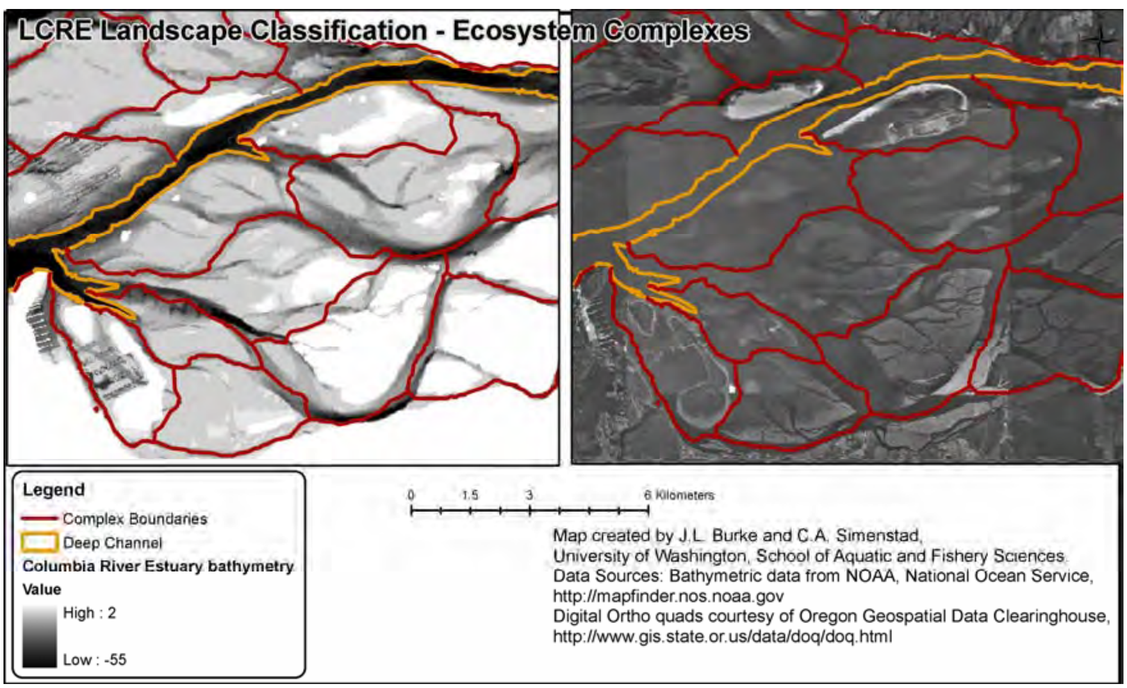

Figure 20. Illustration of ecosystem complexes in Cathlamet Bay (central Hydrogeomorphic Regime B, Fig. 4) based on delineating mainstem and distributary channels using current bathymetry data. Further classification of the different complexes is based on a combination of geomorphic structure and cover class composition.

Complexes are classified by their geomorphic and bathymetric characteristics and the composition and arrangement of the cover classes composing them. In the pilot example, UW and USGS 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, UW and USGS will develop systematic rules (e.g., GIS queries) that will be used to delineate and classify the Complexes analytically.

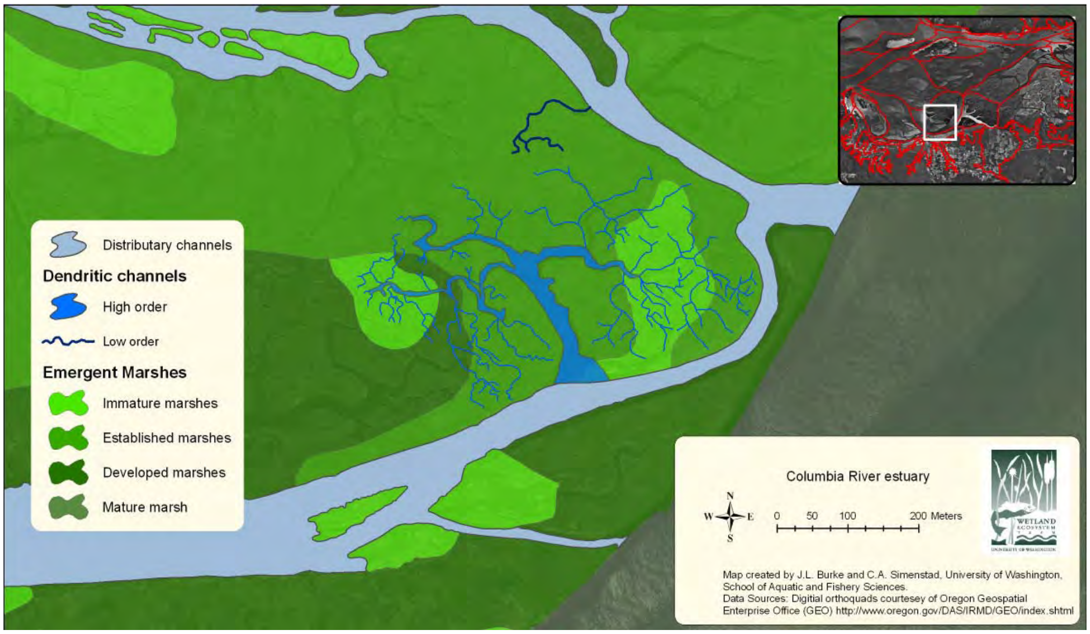

Figure 21. Illustrated example of several geomorphic catena (Russian Island, Fig. 5) based on hydrology, elevation, and vegetation stage datasets. This is just a partial illustration of geomorphic catena.

Level 5: Geomorphic Catena

While Level 4 encompasses discrete organizations of landscape elements into units delineated primarily by distributary channel bathymetry, these units are composed of elements described by structure that represents a suite of geomorphic processes UW and USGS theorize to correlate with the different complexes. UW and USGS have adopted the concept of geomorphic catena as described by Standford *et al.* (in press) for floodplain rivers. Because they describe connectivity along the river-estuary corridor and characterize floodplain mosaics, they capture metrics of both ecologically important landscapes and their dynamic nature. Because they are based principally on geomorphic surface and form, USGS and UW anticipate that a combination of bathymetry, topography and remote sensing classification of surface substrates can be applied with a set of spatial analysis rules to map discrete catena (e.g., Poole *et al.* 2002). The preliminary list of geomorphic catena are listed in Table 5 and illustrated as an example for Hydrogeomorphic Reach B in Figure 22.

Level 6: Primary Cover Class

The Primary Cover class is the elemental level of the hierarchical scheme (Fig. 23). 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 UW and USGS are presently using the Estuary Partnership's 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, which will be completed during Year 3 of this project. Any artificial or otherwise modified Primary Cover Class is additionally distinguished by a Modifier. In the pilot example, 27 Primary Cover Classes are represented.

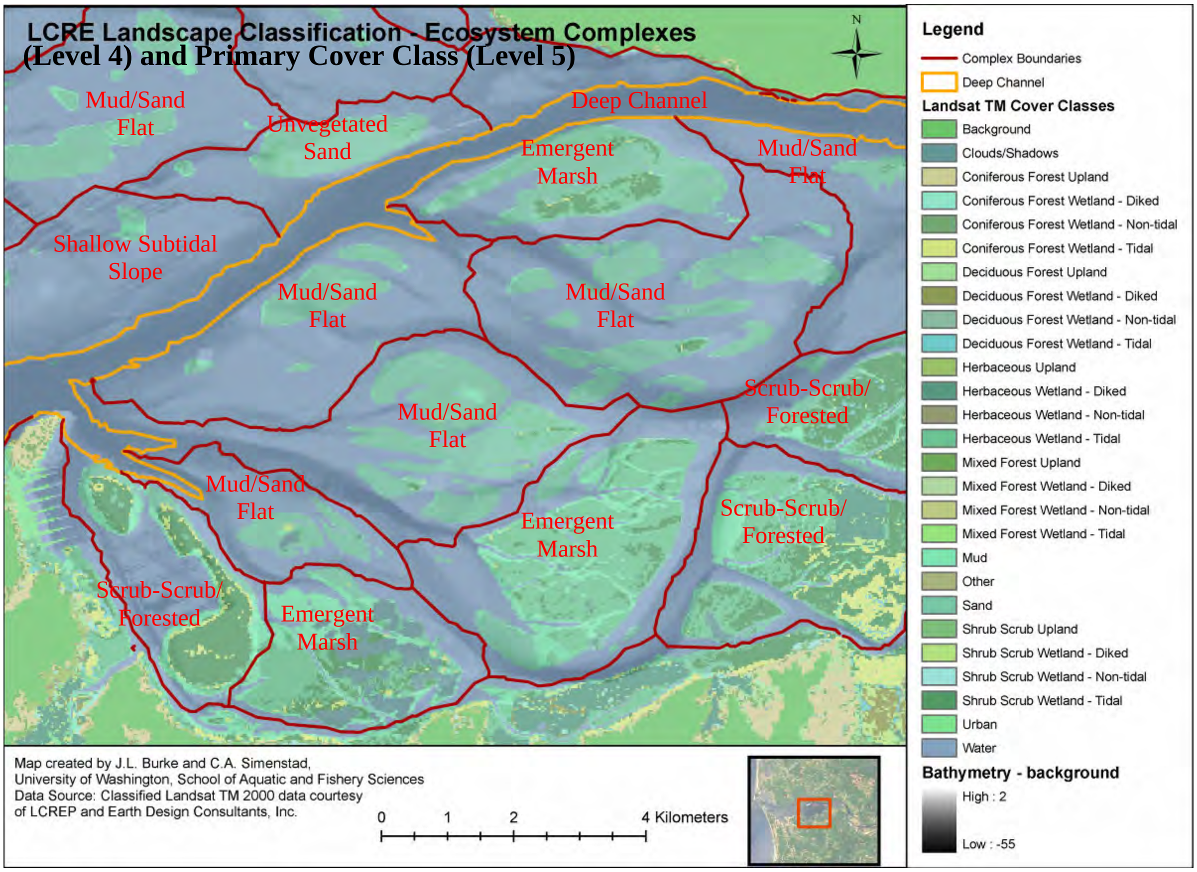

Figure 22. Illustration of Ecosystem Complex and Primary Cover Class levels (4 and 5) of LCRE Ecosystem Classification.

<u>Battelle Preliminary Field Investigation Observations</u>

While analysis of data collected during July and August is just beginning, Battelle has made several observations that will be useful in planning the next stages of the Habitat Monitoring field work for Year 3:

- Viable sampling sites in the estuary are limited
- Few previous studies on tidal freshwater habitat exist
- Hydrology at sites off of the mainstem Columbia River is substantially different than along the mainstem of the river
- Invasive species (such as purple loosestrife, reed canary grass, Himalayan blackberry, and yellow flag) are pervasive
- Species occurrence and distribution are highly variable between sites
- Sediment type may be an important variable in determining wetland plant distribution

- Strong gradients occur along the river (between reaches) and from the river to off-channel sites (between sites) hindering the ability to draw inferences from site to site or reach to reach

During Year 3, Battelle will organize and analyze data from the pilot field study. Expected outcomes include: species lists, species area curves, site maps with borders and unique features delineated, vegetation-elevation tables, and a synopsis of water quality and hydrology (see Figure 24 for example of site map). Additionally, as part of other on-going work, Battelle anticipates analyzing remotely sensed imagery for its ability to detect patterns in species distribution over a test area. The results of the pilot field data analysis will complement this work so that recommendations regarding these techniques for future work can be made.

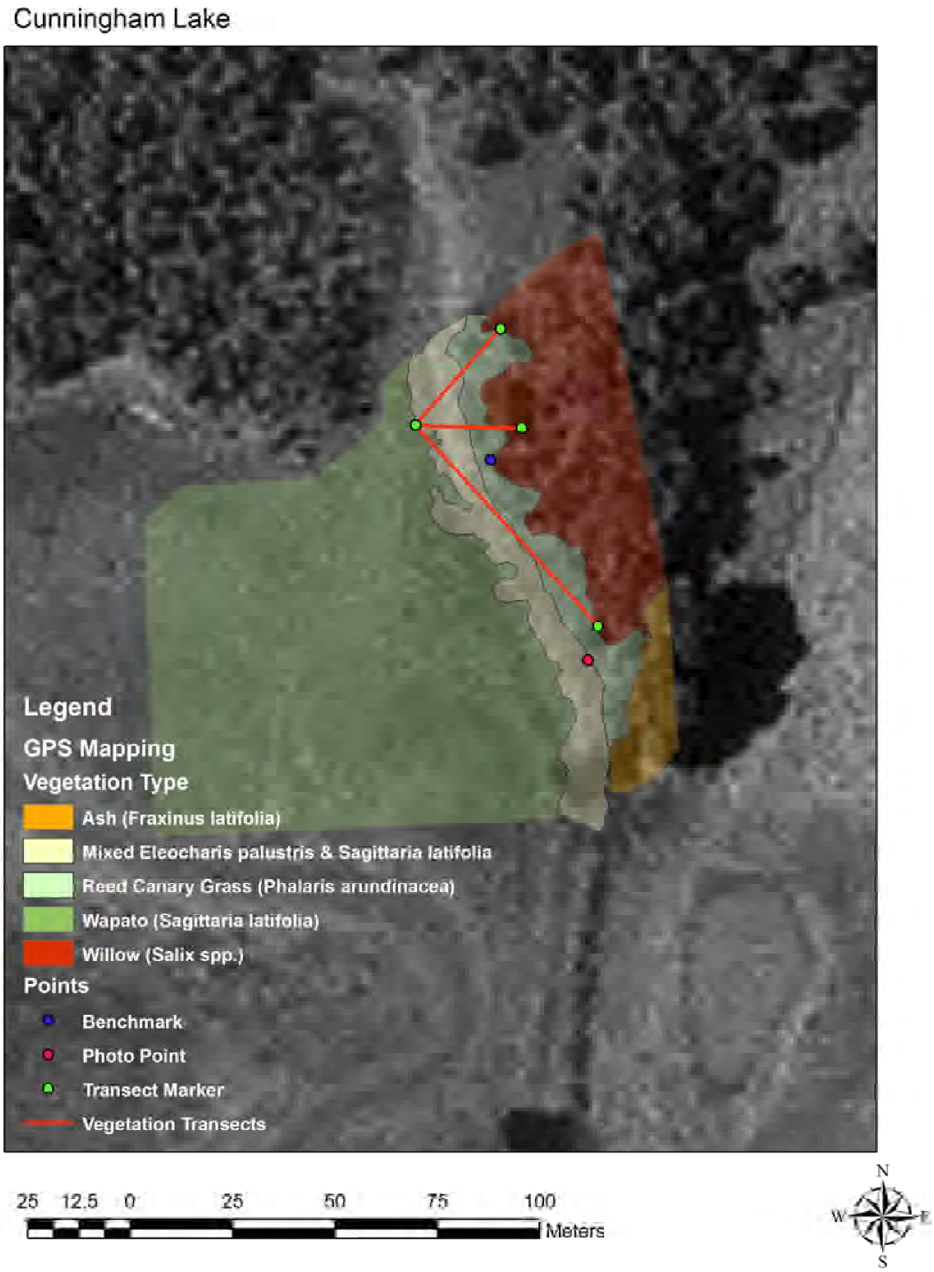

Figure 23. Mapping and transect layout at Cunningham Lake site.

Summary

A great deal of work has been completed in both the toxics and habitat monitoring portions of the Ecosystem Monitoring project. Toxics information will continue through September 2005 and the integrated results of Year 2 and Year 3 salmonid sampling and fixed water quality station and SPMD analysis will be available at the end of Year. In terms of habitat monitoring, field work will continue in an additional Reach of the LCRE and the results coupled with the analysis completed on the data collected in Reaches D and F during Year 2. Moreover, additional bathymetry data will be collected and the ecosystem classification system revised and finalized so that future sampling efforts can be informed by ecosystem processes. Both the habitat and toxics monitoring teams will continue to work closely to make sure efforts are not duplicated and resources can be shared to maximize the efficiency of the Ecosystem Monitoring project.

Summary of Expenditures

September 1, 2004 - August 31, 2005(1)

Budget Items	Original Contract	Final Contract	Funds Expended	Contract Balance
I. Direct Costs				
Personnel	$35,855	$35,855	$29,778	$6,077
Travel	$779	$779	$301	$478
Vehicles	$2,900	$2,900	$173	$2,727
Supplies / Equipment	$4,368	$4,368	$4,368	$0
Rent Utilities	$2,808	$2,808	$2,808	$0
Sub Total	*$42,342*	*$46,710*	*$37,429*	*$9,282*
Overhead *(20% on above)*	$8,468	$9,342	$7,486	$1,856
Capital Equipment	$0	$0	$0	$0
Sub Total Direct Costs	*$50,810*	*$56,052*	*$44,914*	*$11,138*
II. Sub Contracts				
Pt 1: Habitat Mon	$58,836	$223,167	$224,198	-$1,031
Pt. 2: Toxics Mon.	$451,523	$451,523	$451,160	$363
Technical Consultants	$0	$0	$0	$0
Sub Contracts Sub Total	*$510,359*	*$674,690*	*$675,358*	*-$668*
Project Management	$74,500	$69,258	$69,258	$0
Totals	**$635,669**	**$800,000**	**$789,530**	**$10,470**

(1) Funds Expensed include Invoices submitted to BPA prior to 9/26/05 and FY05 Subcontractor Accruals to be billed to BPA after 9/26/05.

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