DESIGN GUIDELINES FOR THE ENHANCEMENT AND CREATION OF ESTUARINE HABITATS IN THE MIDDLE REACHES OF THE LOWER COLUMBIA RIVER

Phase 2 Report

Prepared for
INCA Engineers

September 2011

Prepared by
ESA PWA, Ltd. and
PC Trask

DESIGN GUIDELINES FOR THE ENHANCEMENT AND CREATION OF ESTUARINE HABITATS IN THE MIDDLE REACHES OF THE LOWER COLUMBIA RIVER

Phase 2 Report

Prepared for

INCA Engineers

Prepared by

ESA PWA, Ltd.

and

PC Trask

September 21, 2011

PWA REF. # 2023.00

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1. INTRODUCTION

Over the last 150 years the natural landscape of the estuarine Lower Columbia River has been transformed by human activities through diking, dredging and river training works. In addition the hydrologic and geomorphic processes that sustained the river ecosystem have been altered by hydropower dam operation, upriver diversions and channel deepening. Conversion of wetlands and floodplains to agriculture and development and changes in river stages has resulted in the loss of 77% of these habitats (Fresh *et al*. 2005). Recent research has documented the importance of the remaining intertidal wetlands and floodplains along the Lower River in supporting juvenile wild salmon (Bottom *et al* 2011) and the paucity of these habitats along the river corridor is now identified as a major limiting factor in salmon population recovery (NOAA 2011).

There are significant opportunities to expand and enhance floodplain, intertidal wetland and marsh slough habitat on a number of existing dredged material placement sites through grading and filling to intertidal elevations and reducing wind wave fetch. In addition, there are opportunities for using future maintenance dredging to create new islands with similar morphology to the wetlands and floodplains that existed prior to human intervention, and to place material in a way that optimizes the rate of wetland evolution.

The U.S. Army Corps of Engineers (USACE), Portland District (CENWP) therefore retained INCA Engineers and its consultants ESA PWA and PC Trask to develop restoration planning and engineering design guidelines to support its effort for wetland and floodplain habitat creation utilizing dredged material in the middle reaches of the Columbia River estuary to support juvenile salmon. These design criteria described in this report are based on the observed evolution of wetland habitats on natural and dredged material placement sites within the freshwater tidal reaches C, D and E (River Mile 38 to 85) which includes the majority of the sites with a high restoration potential (PCT 2009).

These guidelines are intended to facilitate restoration site selection, enable cost effective design of new habitat restoration and creation projects, and inform an adaptive management program for continued design refinement. Specifically, development of these criteria will enable the Government to identify locations that optimize opportunities for rapid wetland development, appropriate site configuration, and specific grading and/or dredged material placement designs.
The engineering design criteria can be used to expedite implementation of habitat enhancement on existing dredged material islands and inform engineering design for creation of new habitat on future dredged material disposal locations.

This report documents the second phase of this effort and incorporates in its appendix the data and analysis previously presented in our 2010 Phase 1 report.

2. EVOLUTION OF WETLAND HABITATS IN THE LOWER COLUMBIA RIVER ESTUARY

The estuarine habitats in the Columbia River estuary (from Bonneville Dam at River Mile 146 to the mouth of the river) are the result of natural forces dating back millions of years as well as more recent anthropogenic forces. The estuary is a former river valley approximately 110 meters below current sea level (Petersen et al. 2003). Sea level rise submerged the valley, and sediments, including sand originating from the Missoula Floods, filled the drowned valley. Peripheral bays and sheltered areas accreted as a result of fine sediment loads originating from marine and upstream tributary sources. Over time, swamps and tidal marshes, and other shallow water habitats formed as a result of hydrology, sediment supply, and other controlling factors.

Over the past 150 years physical alterations have occurred, both upstream and within the estuary, that have significantly changed the estuary and the controlling factors which shape salmonid habitat evolution. Major alterations include flow modification, sediment availability, construction of dikes and levees, shoreline hardening, construction of two major jetties at the estuary mouth, development of a navigation channel, and construction of pile dikes. These alterations have had profound effects on salmonid habitat distribution, size, and evolution throughout the estuary.

2.1 GEOMORPHIC SETTING

Prior to human interventions, the river was bordered by extensive floodplain wetlands intersected by active secondary channels that created discrete floodplain islands. The channels collectively were wider, shallower and more depositional than the present day. These channels migrated laterally across the entire width of the floodplain. Typically floodplain islands would be lens shaped, eroding on their concave side along the main flow channels and accreting on their convex side. Accretion took place during each major flood creating parallel accretionary ridges of sand deposits of varying elevations aligned with the flow. During major flood events avulsions might occur; the main flow paths would switch, closing off secondary channels. These relict cut-off channels became backwater areas that subsequently would silt in with fine estuarine sediments creating freshwater tidal marshes. These geomorphic processes created a dynamic complex wetland and floodplain habitat structure along the entire river corridor.

Topographic and ecological patches (main channel, side channel, accretionary island, floodplain, eroding overhanging edges, etc.) were created, maturing to different ages and successional states, and were either eroded or buried in a continuous cycle. Since many of the valuable ecological niches for aquatic life such as emergent wetlands do not represent steady state but rather dynamic equilibrium conditions, the processes of channel migration prevented the landscape from ‘fossilizing’ in to a static condition. Such a condition would likely consist largely of deepwater channel and terrestrial floodplain, with relatively little shallow or emergent topography in between.

2.2 PHYSICAL CHANGES

Historically, flow conditions in the estuary were determined by seasonal climate effects (such as precipitation) and hydrology. The most significant alterations to hydrology in the Columbia River Estuary came in the form of dam construction for hydropower. The development of the federal Columbia River hydrosystem has affected the magnitude, duration and timing of discharge patterns. Today the mean flow to the estuary is about 16 percent less than it was in the latter part of the 19th century, and spring freshet peak flows have declined about 44 percent in that same time period (Jay and Kukulka 2003). In addition, the timing of peak flows occurs about 14 to 30 days earlier than it did historically.

Together with irrigation, flow regulation has increased fall and winter flows (winter flows have increased because of pre-release before the freshet season), and much of the seasonal timing of modern flows in the estuary can be attributed to flood control and hydroelectric operations. Historically, the force of spring freshets moved sand down the river and into the estuary, where it formed shallow-water habitats that are vital for salmonids, particularly subyearlings. Historical spring freshets influenced the distribution of coarse and fine sediments in the estuary thereby providing the dynamism that influences the size and distribution of habitat patches within the estuary. Today, alterations to spring freshet flows have reduced sand discharge in the Columbia River estuary to 70 percent of nineteenth-century levels (Jay and Kukulka 2003).

Reduction in water velocity as a result of upstream reservoirs has altered the transport of organic matter associated with fine sediments such as silt and clay. Historically, fine sediments entering the estuary predominately originated in the upper watersheds of the Snake River (Northwest Power and Conservation Council 2004). Reduced velocities behind upstream reservoirs cause reservoirs to act as a sink to fine sediments and likely reduce amounts delivered to the estuary (Northwest Power and Conservation Council 2004). Currently, organic matter associated with fine sediments supplies the majority of estuarine secondary productivity in the food web (Simenstad et al. 1984 as cited in Northwest Power and Conservation Council 2004). Additionally, reductions in the quantity of fine sediments can increase water clarity and thus contribute to increased predation by piscivorous fish and birds.

Dredging and the disposal of sand have been a major cause of estuarine habitat loss over the last century (Northwest Power and Conservation Council 2004). Currently, three times more sand is dredged from the estuary than is replenished by upstream sources (Northwest Power and Conservation Council 2004). Additional losses of vegetated wetlands in the Columbia River estuary are attributable to filling activities, with deposition of dredged materials accounting for most of the filling activities in the estuary (Fresh et al. 2005).

Most dredged materials result from maintenance of the shipping channel. Dredged materials are disposed of in-water, along shorelines, or on upland sites. Annual maintenance dredging since 1976 has averaged 3.5 million cubic yards per year (Northwest Power and Conservation Council 2004). Dredge fill and diking activities have significantly reduced the availability of wetlands to the river. Deepening of the shipping channel may reduce inundation patterns in floodplain tidal wetlands.

2.3 HOW DREDGED MATERIAL ISLANDS EVOLVED

Over the last century navigational channel deepening and maintenance dredging on the estuary of the Lower Columbia River has pumped sand into the shallows adjacent to the main river channel, creating artificial islands up to 40 feet high in areas that were formerly subtidal. The way in which this dredged material was placed, in a series of long linear features parallel to the navigation channel, has sometimes inadvertently mimicked the accretionary ridges and cut-off channels of natural floodplain islands. In many instances, the successive dredged material sand ridges created sheltered embayments that have subsequently filled with estuarine muds and silts to create intertidal mudflats over a period of decades. Eventually, as sedimentation has continued, mudflats have been colonized by wetland vegetation, creating a succession of low immature, to high mature marshplains. Tidal channel systems have formed within these emergent tidal marshes. At the margin of emergent marshes scrub-shrub and forested tidal habitats have developed, grading upwards at supratidal elevations into floodplain forest.

The combination of both tidal and fluvial flood influences on the evolution of the islands habitats creates a characteristic morphology as shown in Figure 2.1. Tidal processes control the evolution of the emergent marsh and the channels which connect it to the main stem. Flood events associated with the spring freshets control the floodplain and also channel avulsions. This bimodal system is very dependent upon elevation, both of tides and annual flood stages. Changes in the water surface elevation will affects the frequency, depth and duration of inundation which in turn will impact access to, and processes that connect, the floodplain, the marsh and the River.

Pile dikes are common hydraulic control structures used by the USACE in the Columbia River, working in tandem with dredging and dredged material disposal to help maintain the navigation channel. The main purposes of pile dikes are to reduce the need for dredging, to control alignment in the navigation channel by focusing flow and to provide bank protection by reducing erosion. In the 20th century they were also used to provide protected areas for dredged material placement. Dredge material was often placed on top of the pile dike to reduce the mobility of the dredged material and which stabilized the islands.

Although many of these islands provide rearing habitat for juvenile salmonids, some dredge islands have not developed suitable habitat, for example because fill has been placed too high or too low to develop tidal wetland, because tidal prisms are too small to support tidal channel development, or because the islands are too exposed to fluvial scour processes or wind waves.

2.4 HOW MARSHES, CHANNELS AND SUBTIDAL AREAS EVOLVED – WHAT WE HAVE LEARNED FROM OUR MONITORING

The physical characteristics of marsh systems, including the elevations of emergent marshes and floodplains, channel geometries, vegetation types and colonization elevations, are influenced by tidal variations in water levels and riverine flood events. Five islands were monitored by conducting transect surveys, for which elevations and channel geometries were measured and vegetation types were recorded. Water level data from NOAA tide gages was analyzed to understand the monitoring results relative to local tidal datums and ranges, and to investigate the roles of tidal and flood water levels on the emergent tidal marsh and floodplain geomorphology. The following sections include a description of the monitoring site visits and methods, an analysis of tidal and flood water level data, a description of the marshplain elevations and vegetation colonization elevations, and a discussion of the shape and size of tidal channels in the context of marsh development and evolution.

2.4.1 Field Data Collection

Monitoring efforts on five islands in Reaches C and D were conducted during the week of August 9 to 13, 2010, to collect information including transect surveys of emergent marsh and floodplain elevations, vegetation types and colonization elevations, and channel geometries. The summer season was chosen as the time period for field data collection to facilitate surveying during low tide conditions with low river flows. Average weather conditions for August generally exhibit temperatures ranging from 60-80°F and low to moderate winds blowing predominantly from the northwest.

Field data sites were located on several islands in Reaches C and D (see Figure 2.2); Wallace, Hump-Fisher, Lord-Walker, Sandy, and Goat Islands. The locations of the sites within the estuary range from River Mile 49 to 81, and were chosen as being representative in form, having easy access and covering the range of salinity and inundation considered suitable for salmonid habitat.

Vertical and horizontal control was established at each site using a temporary global positioning system (GPS) base station. The survey control was spatially referenced to State Plane Coordinate System of the Washington South Zone and North American Vertical Datum of 1988 (NAVD) in feet. Transects were surveyed perpendicular to the main channel at several locations from the mouth of the channel up into the higher reaches of the marsh systems using a total station and RTK units, or "rovers." The surveyed transects were used to establish elevation-colonization relationships, soil-elevation relationships, channel cross-section form, and to provide groundtruthing for LiDAR data[1]. Vegetation types were recorded at each spot elevation to develop the vegetation colonization relationships. The results of the field data collection for each island are reported in Appendices A to E.

---

[1] USACE 2010 LiDAR survey of the Lower Columbia River basin.

2.4.2 Water Levels

Water level characteristics of Reaches C and D were determined through analysis of approximately eight years (2002 to 2011) of hourly water level measurements at three NOAA tide gages: Skamokawa (NOS #9440569), Longview (NOS #9440422), and St Helens (NOS #9439099). The locations of the tide gages and their positions relative to the five monitoring sites are shown in Figure 2.3. The five islands are located within the range of the three tide gages facilitated the estimation of local water levels at each island by linear interpolation.

The recorded time series of water level at each tide gage shows variations in the water surface elevation due to tidal influences and seasonal flood conditions. Hourly water level measurements at the Longview gage are presented in Figure 2.4. High frequency fluctuations of the water level are associated with the mixed semidiurnal tides, whereas the low frequency fluctuations occurring on seasonal time scales are due to flood events resulting from rain and snow storms and from dam operations upstream. Tidal range is greatest during periods of low river discharge, and decreases in the winter and spring months when large river flows are present (see Figuure 2.1).

Removal of the tidal fluctuations from the water level time series yields the residual water levels, for which two strong flood peaks are observed (Figure 2.5). The first flood peak is associated with winter runoff events that typically occur between November and January, and the second flood peak is the spring freshet event that typically occurs between March and July. The spring freshet events are generated by dam operations and are intended to mimic the natural, or historic, spring freshet, for which the peak flow has greatly decreased since as late as the 1960's (Jay and Kukulka 2003; Volkman 1997). The river flows during flood periods are thought to be responsible for influencing large-scale channel avulsions through the marsh systems and activation of the forested floodplains, whereas the tidal fluctuations control emergent marsh geomorphology and channel networks.

Published tidal datums for the three tide gages were linearly interpolated along the river to establish local tidal datums at the five islands (Table 2.1). Here, mean higher high water (MHHW), mean tide level (MTL), and mean lower low water (MLLW) are reported. The annual maximum water elevations for the period 2002 to 2011 were tabulated for each tide gage and interpolated similar to the tidal datums to establish the minimum and maximum local annual flood elevations for each study island (see Table 2.1). It should be noted that the flood elevations that are reported are not representative of statistical events, or recurrence intervals such as the 100-year water level, but rather are intended to present site elevations that will be flooded approximately annually. All the gages show a maximum water elevation in the dataset in January and February 2006 (Skamokawa, 13.2 ft NAVD; Longview, 15.9 ft NAVD; and St Helens, 18.4 ft NAVD).

Table 2.1. Observed flood elevations and published tidal datums at NOAA tide gages were interpolated to estimate local water levels at restoration sites.

Gage / Island	Skamokawa Tide Gage	Wallace Island	Hump-Fisher Island	Lord-Walker Island	Longview Tide Gage	Sandy Island	Goat Island	St. Helens Tide Gage
River Mile	33.3	49.0	60.0	62.5	66.4	75.0	81.0	85.6
Maximum Flood[1] Level (ft NAVD)	13.2	14.5	15.4	15.6	15.9	17.0	17.8	18.4
Mean Flood Level[1] (ft NAVD)	11.7	12.9	13.7	13.9	14.2	15.1	15.6	16.1
Annual Flood Level[1] (ft NAVD)	10.6	11.6	12.2	12.4	12.6	13.1	13.4	13.7
MHHW (ft NAVD)	8.9	9.2	9.4	9.5	9.6	9.5	9.5	9.4
MTL (ft NAVD)	5.2	6.1	6.8	7.0	7.2	7.4	7.5	7.6
MLLW (ft NAVD)	1.3	3.1	4.3	4.6	5.0	5.5	5.9	6.1

[1] Flood levels were determined from water level records from 2002 to 2011.

Profiles of the various flood water levels and tidal datums along the river are presented in Figure 2.6. Several characteristics of the tides and floods along the river are evident from this figure, including the decrease in tide range moving upstream from the mouth of the estuary and the increase in the flood elevations and range between an annual and maximum observed flood level during the period 2002 to 2011. The decrease in tidal range can be mainly attributed to the 4.8 foot increase in the elevation of MLLW from Skamokawa to St. Helens tide gage, whereas the elevation of MHHW varies by less than 1 foot. In other words, low tides are damped moving upstream in the system. Similarly, but to a lesser degree, the MTL elevation increases by 2.4 feet from the Skamokawa to St. Helens tide gage. This figure is considered a preliminary analysis of flood and tidal water levels in the Lower Columbia River Estuary, and should be updated as more data is available and tidal datums are revised.

2.4.3 Marshplain Elevations and Vegetation Colonization

Multiple transects were taken at each of the island sites to record elevations and vegetation types colonized in the vicinity of the point measurement. Figure 2.7 shows the elevation ranges for different types of vegetation observed on Wallace Island. The emergent marsh was defined by the vertical extent of native marsh species – namely, Wapato, Spike Rush, Baltic Rush, Common Forget Me Not and Water Stalwort for low marsh, and Common Monkey Flower and Tufted Hairgrass for high marsh. Vegetation types included in the low and high marsh vegetation classes are presented in Table 2.2, which were used to identify the upper and lower elevation bounds of the emergent marsh for each site.

Table 2.2. Wetland classes and associated vegetation types.

Wetland Class	Native Species	Mixed Species	Non-Native Species	Non-Native Invasive Species
Supratidal Activated Floodplain	Cottonwood Horsetail	-	-	Scotsbroom Himalayan Blackberry
Forested Tidal Floodplain	Treeline Willow Red Alder	-	-	-
High Emergent Tidal Marsh	Common Monkey Flower Tufted Hairgrass	Bentgrass	Mixed Prairie Grasses Noddings Beggarstick	Reed Canary Grass Purple Loosestrife
Low Emergent Tidal Marsh	Wapato Spike Rush Baltic Rush Common Forget Me Not Water Stalwort Slough Sedge Tule Three Square Bullrush	Swamp Smartweed	-	-

A separate check on the vertical extent of the emergent marsh was made using a hypsometry analysis of the wetland areas derived from LiDAR data. The hypsometry analysis involved generation of a relationship of wetland area as a function of elevation, and estimating the marshplain elevation bounds through identification of inflections on the area-elevation curve. Breaks in slope and changes in gradient between the channel and marsh (top of bank) and between the marsh and floodplains were noted in the field during transect surveys. These breaks invariably coincided with the observed vegetation transitions described above, as well as the inflections identified in the analysis of the hypsometry curves for each site. The upper and lower bounds of the emergent marsh are summarized in Table 2.3.

Table 2.3. Elevation bounds for emergent tidal marsh as derived from transect surveys, wetland class, and hypsometry analysis.

Island	Minimum Marshplain Elevation (ft NAVD)	Average Marshplain Elevation (ft NAVD)	Maximum Marshplain Elevation (ft NAVD)
Wallace	4.5	5.5	6.5
Hump-Fisher	5.0	6.3	7.5
Lord-Walker	6.0	7.0	8.0
Sandy	6.5	7.0	7.5
Goat	6.0	7.0	8.0

The range in elevations of the emergent marsh observed at the five island sites have been plotted on the profiles of flood and tidal water levels for Reaches C and D (see Figure 2.6). The average marshplain elevation consistently falls around MTL. This differs from the observed elevations of marshplain in mature San Francisco Bay tidal marshes, which consistently establish near MHHW (Williams et al. 2002). The elevations of the marshplain increase upstream according to the location of the island in the estuary similar to the distribution of tidal datums in the estuary described in Section 2.4.2.

2.4.4 Tidal Channels

Williams et al. (2002) describes an approach to determine empirical hydraulic geometry relationships to aid in the design of marsh restoration projects being initiated in San Francisco Bay and other meso-tidal estuaries on the Pacific Coast. Building on earlier coastal inlet research (O'Brien 1931), this empirical method uses tidal prism as a surrogate for discharge (Williams & Harvey 1983; Williams 1986; Haltiner & Williams 1987) and uses measures of channel dimensions based on geomorphic criteria rather than flow stage. Empirical correlations between channel cross-section morphology and tidal prism for a San Francisco Bay data set were used to predict equilibrium cross-section morphology for a given tidal prism.

It should be noted that there can be a significant range of uncertainty in these predictions and where possible they should be calibrated with data on similar marshes in the vicinity of the restoration site. The consequences of overestimating or underestimating equilibrium or transient channel dimensions need to be considered in the design. Post-restoration or short-term channel dimensions are calculated using the tidal prism of a flooded site upon breaching. Long-term equilibrium channel dimensions can be inferred from estimations of the predicted marsh drainage area; assuming that a mature vegetated marsh with established channel networks will eventually evolve.

Field data collected during the present study at the five island sites was used to calibrate empirical hydraulic geometry relationships for Reaches C and D. Width, depth and cross-sectional area were derived from the survey transects at each site. In all cases, depth was measured at the thalweg relative to MHHW and the width was measured as the distance between the tops of the two banks. Cross-sectional area of the channels was calculated as the area below MHHW for the part of the channel within the designated channel width, where the tops of bank were projected vertically upward to MHHW. Potential diurnal tidal prism (defined as the volume of water upstream of a cross-section between MLLW and MHHW) and marsh area were derived from the hypsometry analysis of LiDAR data and water gage data.

Figure 2.8 shows a log-log linear regression plot of channel cross-sectional area versus tidal prism (San Francisco marshes are shown for comparison). As expected, the Lower Columbia data shows a strong positive correlation between cross-sectional area and tidal prism, and follows a similar relationship to the San Francisco marshes (Williams et al. 2002). The regression curve for the Lower Columbia is:

$$A_c = 25.535\ T_p^{0.6465},\ r = 0.85 \tag{2.1}$$

where A_c is channel area (ft^2) and T_p is tidal prism (ac-ft).

Comparison of the channel widths and depths observed in the Lower Columbia to San Francisco Bay marsh channels shows that the cross-sectional shape of the channels differ between the two locations. The Lower Columbia channels are shallower and wider than those in San Francisco, while the area is approximately the same. This probably reflects the sandier material in the Columbia and the lower marshplain elevations that allow more over-marsh flow. This may also reflect the relative immaturity of the sites monitored in the Lower Columbia River.

Use of hydraulic regime relationships to design a marsh can be simplified by transforming tidal prism into equivalent marsh drainage area. Figure 2.9 shows this relationship for both San Francisco Bay and the Lower Columbia. The Lower Columbia sites follow a parallel curve but the tidal prism is larger for a given drainage area. This is a consequence of marsh elevation generally being at MTL rather than MHHW (see section 2.4.3).

Two design curves can then be constructed for the Lower Columbia: cross-sectional area versus drainage area and maximum channel depth below MHHW versus drainage area. Figure 2.10 presents a log-log linear regression of the channel depth below MHHW versus drainage area for the sites in this study and for those of San Francisco Bay. The regression curve for drainage area versus maximum channel depth is:

$$D_c = 3.2922\ A_d^{0.215},\ r = 0.90 \tag{2.2}$$

where D_c is channel depth (ft) and A_d is drainage (ac).

Equations 2.1 and 2.2 can be used to size a channel for a given marsh area and, conversely, size a restoration site to sustain a channel of given dimensions.

2.5 RESTORATION LOCATION

The University of Washington (UW) and US Geological Survey (USGS) have created an ecosystem classification (CREEC) of the 146 miles of the estuary. Using CREEC, the estuary is divided up into eight distinct hydrogeomorphic reaches. The delineation of river sections is based primarily along tidal-fluvial gradients throughout the Lower Columbia system. This includes distinctions between tidal fresh water and extent of salinity intrusion, sharp transitions in tidal and flooding levels, and currents. These also reflect inputs from contributing tributaries and confluences. Figure 2.2 illustrates the eight hydrogeomorphic reaches in the estuary. Reach C, D and E (River Miles 38 to 85) are the focus of the present study.

2.5.1 Reach C

This area, which includes deep channels and steep shorelines on both sides of the river, ends just downriver of the city of Longview. This is a fluvially dominated reach, the primary disturbance is due to flooding, which is also the upriver extent of current reversal due to tidal action. The narrow channel structure produces an area dominated more by tidal swamp habitat than by edge habitat. It contains large mid-channel islands, distributary channels and sloughs and floodplains. Dike construction and clearing of vegetation have resulted in a substantial loss of tidal marsh habitat on Puget Island and within the Skamokawa and Elochoman floodplains. Wallace Island and Crims Island are located within Reach C.

2.5.2 Reach D

This area begins just downriver of Longview and ends near the city of Kalama. Tidal current reversals seldom occur although tidal fluctuations are measureable. It includes flows from the Cowlitz and Kalama rivers. The confluence of the rivers created a broad floodplain dissected by back channels and tidal channels. Lateral channel migration formed bar-and-swale morphology on islands and floodplains. Extensive diking and filling around Longview and the mouth of the Kalama River have significantly reduced access to the floodplain, and islands created through the disposal of dredged material are prevalent.

2.5.3 Reach E

Reach E include the confluence with the Lewis River. The estuary is again confined by rocky margins and terraced gravels. Tidal fluctuations are very small and no current reversals are recorded. Flood flows have produced bar-and-swale morphology on the islands and floodplains.

2.6 HOW FUTURE CHANGES IN PROCESSES WILL AFFECT HABITATS

2.6.1 Climate Effects on Flow

Climatic fluctuations have a significant effect on the amount and timing of water flowing to the estuary (Fresh et al. 2005). Since 1878, climatic changes have reduced Columbia River flows by about 9 percent (Jay and Kukulka 2003).

Natural variations in Columbia River flow as a result of long- and short-term climate fluctuations have occurred throughout history. The Pacific Decadal Oscillation (PDO) alternates between cold and warm phases approximately every 30 years. The cold, rainy phase is typical of the Northwest and increases flows, while the warm phase is drier and decreases flows (Fresh et al. 2005). The El Niño/Southern Oscillation (ENSO) is a shorter, 3- to 7-year phenomenon that similarly has cold and warm phases that may magnify or reduce the effects of the PDO. NOAA/NMFS’s Northwest Fisheries Science Center has observed changes in PDO and ENSO indicators that suggest that changes in ecosystem structure which are unfavorable for salmon and steelhead can be expected (Varanasi 2005). These changes may continue over the next several years.

Some evidence suggests that salmonid response to climate change varies among populations (Crozier and Zabel 2006 as cited in Independent Scientific Advisory Board 2007). Other potential impacts of global warming in the estuary may include continued rises in sea level and associated effects on intertidal habitat formation and maintenance.

2.6.2 Climatic Effects on Temperature

The Independent Scientific Advisory Board for the Northwest Power and Conservation Council (2007) reports that the Pacific Northwest has warmed about 1° C since 1900 (this is about 50 percent more than the global average for the same time period) and is projected to warm at a rate of 0.1 to 0.6° C per decade during the next century.

Over the long term, winter precipitation is expected to increase, and summer precipitation is expected to decrease. Within the Columbia River basin, expected effects of rising temperatures include more precipitation falling as rain rather than snow, diminished snow pack, associated reductions in late-summer/early-fall flow, altered timing of flows, increased peak flows, and continued rises in water temperatures.

In the estuary, these factors could lead to changes in flooding and ecosystem processes and conditions that already are considered limiting factors for salmon and steelhead—namely, flow-related habitat changes, sediment transport, food web dynamics, populations of non-native species, and water temperature (Independent Scientific Advisory Board 2007).

Increasingly, water temperatures in the estuary are approaching the upper thermal limit for salmonids (National Research Council 2004). Further increases in water temperature could render some current estuarine habitat unsuitable for salmonids, enhance conditions for warm-water fish that prey on or compete with juvenile salmonids, and alter physiological processes such as growth and metabolism among juveniles (Independent Scientific Advisory Board 2007).

3. DEVELOPING PLANNING AND DESIGN CRITERIA

3.1 ADAPTIVE MANAGEMENT CONTEXT

These design guidelines are a key component for implementing a long term adaptive management program intended to restore healthy wetland ecosystems that support ESA-listed salmon on the lower Columbia River. In this context ‘adaptive management’ is defined specifically as a rigorous decision making process that learns from successive iterations of performance monitoring of restored sites, illustrated generically in Figure 3.1. The adaptive management framework of the Columbia Estuary Ecosystem Restoration Program (CEERP) is shown in Figure 3.2.

Within the adaptive management planning framework the key management problem for this system has been defined as the precipitous decline of ESA-listed salmon – a keystone species for the Columbia River system (NOAA 2011). Consequently, the primary goals are the enhancement and expansion of wetland and floodplain habitats to support juvenile salmonids. This goal statement is informed by existing ecologic conceptual models that link desired habitat attributes to benefits to salmon (NOAA 2011). These conceptual models can be ‘operationalized’ to the restoration project scale to provide simple explanations of the linkages between restoration actions, physical processes, landscape structure and desired habitat attributes. These operational conceptual models make explicit why we believe specific restoration design elements will result in enhanced habitat structure and function consistent with our understanding of the ecologic response. Physical conceptual models are informed by analysis and data collected to develop specific design criteria.

3.2 USING LIMITING FACTORS TO ESTABLISH RESTORATION GOALS

Both ocean- and stream-type salmonids suffer significant mortality in the estuary. By tracking individual juvenile fish, Ferguson (2006) was able to estimate mortality rates between 25 and 35% for subyearlings and yearlings, however this may be a low estimate as only fish over a certain size were tagged. There are a number of factors responsible for these mortality rates and which limit the population of salmonids. For ocean-types, significant limiting factors are believed to be lack of habitat, food availability and contaminants. For stream-types the same factors may have less of an impact due to their shorter stay in the estuary but other factors, such as predation may be more important as they prefer deeper, less turbid channels (Fresh *et al* 2005). In most cases it is very difficult to point to a specific limiting factor and then estimate mortality due to the complex interaction of physical, chemical, and biological factors that limit the productivity (NOAA 2011).

The Columbia River Estuary ESA Recovery Plan Module for Salmon and Steelhead (NOAA 2011) identifies a number of limiting factors that will impact salmonid populations (Table 3.1). These are grouped into habitat-related factors; food web-related factors and toxic contaminants factors.

Habitat-related factors are divided by location in the estuary: in-channel habitat on the main stem channel; off-channel habitat in wetlands and floodplains associated with islands and the river banks; and the estuary plume. These habitat related factors mainly speak to the lack of habitat opportunity due to changes in the timing and volume of Columbia River flows, combined with higher bankfull elevations, which have reduced the amount and accessibility to suitable salmonid habitat. Overbank flooding frequency and habitat structure have been significantly altered, reducing access to off-channel refugia and food resources.

The food-web related factors together with water temperature and toxic contaminants speak mainly to habitat quality. Water temperatures in the estuary are relatively high for salmon and steelhead and are expected to increase. A variety of toxic contaminants are present in the water, sediments, and salmon tissue in the estuary. With changes in vegetation and flow, macrodetrital food sources have become scarcer and the food base has switched to a microdetritus-based source, thus altering the productivity of the estuary. Predation by northern pikeminnow, pinnipeds, Caspian terns, and cormorants has increased. It is likely that the presence of exotic fish, introduced invertebrates, and invasive plant species is further altering food web dynamics.

Table 3.1 goes further by prioritizing the limiting factors by ocean- and stream-type salmon and steelhead, at the estuary scale, using a scale of 1 to 5 based on:

- how the source documents evaluated limiting factors;
- the magnitude or severity of limiting factors as described in the source documents;
- estimates of mortality caused by predation; and
- the frequency with which a limiting factor was identified in the source documents.

For the purposes of this study, a subset of these limiting factors has been identified based upon those factors that might be addressed by restoration measures on individual islands and which scored highly in the prioritization. This subset consists of four limiting factors. For each of the limiting factors we have identified restoration goals:

1. **Limiting factor:** food source changes due to reduced macrodetrital inputs. Macrodetrital plant production has declined as a result of the construction of revetments along the estuary shorelines; the disposal of dredged material in what formerly were shallow or wetland areas where plant materials or insects could drop into the water; simplification of habitat through the removal of large wood; and reductions in flow. Flow reductions affect detrital sources by limiting the amount and availability of wetlands - areas that normally would be contributing macrodetritus to the food web - and cutting the number of overbank flows. Historically, much of the detrital inputs occurred during overbank events, which provided additional shallow-water habitat for juvenile salmonids and resulted in significant detrital inputs to the estuary. However, overbank events occur much less frequently today than they did historically.

   Restoration goal: to reconnect the forested floodplain to the emergent tidal marsh.

2. **Limiting factor:** reduced off-channel habitat opportunity due to flow related changes in access to off-channel habitat. Typically, overbank flows which gave access to emergent marshes were driven by spring freshets, which occurred at the time of year when there was the greatest variety of juvenile salmon and steelhead using the estuary (Fresh *et al.* 2005). Peak freshet flows have been reduced as a result of flow regulation for electricity generation, storage for irrigation and municipal use, and flood control. Reduced access to off-channel habitats is a limiting factor for salmon and steelhead because of impacts on food webs and the reduced availability of habitats preferred by fry and fingerlings. The evolution of emergent tidal wetland habitat will depend upon the achievement of an appropriate elevation with respect to the tide.

   Restoration goal: to increase access to off-channel habitat.

3. **Limiting factor:** reduced off-channel habitat opportunity due to changes in the bankfull elevation. Increases in the bankfull level of the Columbia River have occurred as a result of the construction of dikes and levees. The reduction in overbank events is a limiting factor because it reduces the availability of food and refugia for juveniles rearing in the estuary. This goes hand in hand with the preceding limiting factor of flow related changes in access to off-channel habitat where the cumulative effect of impacts is greater than the sum of the individual factors. To compensate for the loss of access to off-channel habitat due to dikes and levees will require the creation of more emergent tidal marsh.

   Restoration goal: same as for the previous factor, to increase access to off-channel habitat.

4. **Limiting factor:** water temperature. Higher water temperatures (above 20°C) reduce the habitat quality for salmonids that use the estuary during summer months (National Research Council 2004). Adverse physiological and behavioral effects increase as a result of persistent, intermittent, or cumulative exposure to high and variable water temperatures (McCullough 1999). Temperatures above 18°C can impair the metabolism, growth, and disease resistance of salmonids, as well as alter the timing of adult migrations, fry emergence, and smoltification (McCullough et al. 2001, Sauter et al. 2001).

   Restoration goal: to provide deeper subtidal channels close to the emergent marsh and ‘overtiding’ areas to allow the fish to remain close to the marsh edge during low water. However reservoir management will be the primary control on water temperatures in the Lower Columbia; individual site design will only ameliorate some of the temperature related effects.

The restoration goals described above are guides for defining the “operational” objectives as defined in Section 3.3. We can summarize the measures to ameliorate the limiting factors described above as:

1. providing productive feeding areas which in turn will be dependent upon increasing inputs of macro detritus and providing a habitat mosaic with structural complexity by restoring forested floodplain and emergent tidal marsh; and

2. providing access by fish to feeding and rearing areas by restoring channel networks and creating overtiding areas.

3.3 TRANSLATING GOALS INTO OPERATIONAL OBJECTIVES

It is important to be able to articulate the restoration goals in terms of “operational” objectives. Operational objectives are ones that are measurable and whose metrics can be used in an adaptive management program. Each operational objective will raise specific design questions for which guidance can be given (see section 4):

1. **Restoration goal:** providing productive feeding areas by reconnecting the forested floodplain to the emergent tidal marsh

   Operational objective: to expand the area of functional floodplain by grading a sufficient area of floodplain to an elevation that is regularly inundated and allows macrodetritus to enter the wetlands. This will result in expansion of the area of functional floodplain. The metric is the area of woodland topography between frequent typical or ‘activation’ flood stage elevation (e.g. annual flood level) and high tide elevation connected to the river system.

2. **Restoration goal**: providing access to off-channel habitat.

   Operational objective: to expand the area of emergent wetland within the designated planning horizon. The metric is the area of intertidal vegetated marsh between initial colonization elevations and the upper elevation of the tidal frame, as typically characterized by mean higher high water (MHHW).

   Operational objective: to expand the tidal channel system within the marsh. The metric is linear extent of different orders of marsh channels within a channel system hierarchy.

In designing a wetland restoration project at a particular location in the estuary, it is important to recognize that the physical and ecological processes affecting a particular site are operating at a continuum of different spatial and temporal scales. The main focuses of these design guidelines are restoration actions on sites in the freshwater middle reaches of the Lower Columbia River

(Reaches C, D and E, River Mile 38 to 85) in the range of 10 -100 acres, with expected ecologic benefits that realized within 10 years.

Over the last two decades monitoring and research has shown that the availability of freshwater emergent wetland habitat is a key limiting factor for wild salmon populations; the tidal prism has been reduced by about 20% due to infilling and diking (NOAA, 2011). This work also indicates that not only is the total areal extent of wetlands important, but also that a mosaic of different wetland habitat types needs to be available to juvenile fish as they migrate from Bonneville to the river mouth. (see member/vagrant discussion p2-5 NOAA, 2011).

At the reach scale (approximately 10 to 25 river miles) it is now possible to articulate wetland restoration objectives that would restore the mosaic of habitats; and it is likely that these objectives will be informed by the extent and type of pre-colonization wetland habitats. These reach scale objectives can be translated to an aggregation of a set of smaller geomorphic unit or ‘island’ scale restorations based on land use constraints and opportunities. Planning at this scale establishes the desired mix of habitat types that guides the design of a specific site.

The site design also needs to anticipate long-term changes at the island and reach scale to ensure the habitats restored are sustainable and resilient to the anticipated long term and episodic anthropogenic and natural geomorphic changes in the estuary that are likely to occur within a particular planning horizon. This means that a site design needs to take into account geomorphic and hydrologic processes which occur over longer scales, including:

- Potential change in tidal frame due to sea level rise
- Potential change in tidal frame due to anticipated changes in river bathymetry
- Changes in flood elevation due to changing reservoir operation in response to climate change
- Wind wave erosion of exposed shorelines
- Flood erosion of banks of the main river channel and major secondary channels
- Potential for major channel migration
- Potential for overflow channel avulsions during floods.

3.4 CONCEPTUAL MODELS LINKING RESTORATION ACTIONS TO OBJECTIVES

Within the Lower Columbia estuary a large number of habitats or ecosystem structures has been identified (Table 3.2). For the purposes of this study, a subset of these structures needs to be identified which in particular serve the needs of juvenile salmonids discussed in section 3.2, and which can be enhanced or recreated on the dredged islands. Identifying the linkage between ecosystem structures and the processes and functions they support results in a complex pattern of relationships. The Pacific Northwest National Laboratory (PNNL) has developed a conceptual model of the Columbia River Estuary for the Portland District of the USACE (Figure 3.3). This model attempts to describe the complexity of the system. For reference, the limiting factors described in section 3.2 are equivalent to stressors in the conceptual model: macrodetrital inputs =

nutrients; flow related change = hydrodynamics, bankfull elevation = elevation/bathymetry, and temperature = temperature.

Subsets of the PNNL conceptual model were used in the present study to identify processes and subsequently structures which support particular functions of salmonid production. By identifying the structures that support salmonid production, the range of possible restoration actions can be determined and a list of design questions drawn up which describe those actions.

Figures 3.4 shows the conceptual model for the goal of providing productive feeding areas by reconnecting the forested floodplain to the emergent tidal marsh and increasing macrodetrital input. The model shows the linkages between function, process and structure. The actions that can then be applied to the ecosystem structures of emergent marsh and floodplain are identified in the left hand column. These actions are essentially related to grading marshplains to appropriate elevations to restore and enhance both tidal and flood inundation frequency and depth. This relation will be discussed further in section 4.

Figure 3.5 shows a similar conceptual model for the goal of providing access to off-channel habitat by promoting the growth of emergent tidal marsh and expanding the channel system within the marsh. The actions that can be applied to emergent marsh are more extensive. These actions include grading, channel enhancements and the wind wave blocks (see Section 4).

3.5 THE PLANNING PROCESS

The planning and design process can be summarized in the following 8 steps:

1. <u>Selection of planning horizons.</u> Suitably designed and cost effective wetland enhancement or creation projects will excavate or place dredged material sediments to create an initial grading template. This template is designed to allow habitat evolution to take advantage of estuarine erosion and sedimentation processes that take place over many years and in response to infrequent extreme events. To allow for the comparison of different restoration approaches, specific planning horizons need to be selected in order to project anticipated ecologic benefits. In other restoration initiatives these planning horizons have ranged from 30 to 200 years after project implementation, with 50 years being the most common.

2. <u>Defining Spatial Extent of Anticipated changes</u>. Ecologic benefits are likely to occur both within the project site and at a larger spatial scale. Physical impacts need to be assessed both within the site, at the site boundaries and in adjacent areas. In documenting anticipated benefits, costs and impacts of a restoration project, both the project boundary and the relevant spatial scale for assessing project impacts need to be defined.

3 Articulate “operational” objectives. Operational objectives must be clearly articulated. These objectives must be measurable and have metrics that can be used in an adaptive management program.

4 Evaluation of no action alternative. Assessing the anticipated net benefit of a proposed restoration action requires a comparison with how the no action scenario would meet the operational objectives described above within the planning horizon and project boundaries. For typical restoration sites on the lower Columbia this requires a geomorphic prediction of habitat evolution that takes into account processes such as bank erosion, sedimentation, wind wave action and major floods.

5 Identification of opportunities and constraints. The no-action assessment will assist in identifying physical constraints and opportunities for achieving the desired wetland habitats on site. Constraints can be major determinants of restoration design. Typical constraints include: property boundaries, utility easements, public access, impacts on offsite flooding and drainage, the presence of toxic contaminants, impacts on existing populations of endangered species, and potential for colonization by exotic species.

6 Development of restoration action design. This is the subject of sections 4 of this report.

7 Projection of outcome of restoration action. As with the no action alternative, a prediction needs to be made for how habitats are expected to evolve within the planning horizon and project boundaries following restoration actions. In the planning process, alternatives can be developed that provide for an evolving mix of habitats: floodplain, transitional marsh, marsh plain, mudflats and subtidal open water. Typically, these projections will examine and compare the evolution of desired wetland functions, as defined by the operational objectives, from different site templates at Year 0, to a mature state, taking into account future changes in physical and ecologic processes.

8 Monitoring and management plan. A monitoring and maintenance plan is an integral part of the restoration design. A monitoring plan specifies how the metrics for achievement of operational objectives are to be measured. The management plan component identifies how managers will learn from monitoring and what management actions will be taken in response to monitoring information.

3.6 DESIGN APPROACH

In general, for estuarine habitats in the Lower Columbia River physical processes are the major influence on habitat form and function. The biota is responding to, rather than interacting with, the hydrologic and geomorphic processes that form the physical landscape of the lower River. Important species of plants, fish, and birds have evolved to exploit the diverse physical habitats and the functioning and variability of the physical processes that occur in these estuarine wetlands. This means that restoring the *physical integrity* of the wetlands offers the best opportunity of restoring ecologic integrity. Ecosystem integrity or health is defined as the:

> *condition in which a system realizes its inherent potential, maintains a stable condition, preserves its capacity for self-repair when perturbed, and needs minimal external support for management (Karr 1993).*

A functioning estuarine wetland is physically defined, at any given time, as both a landscape structure and the set of physical processes that govern the evolution and sustenance of that structure's morphology. In designing tidal marsh or floodplain restoration projects, we are restoring physical processes that create and sustain the particular forms or structures that support desired wetland functions. Through the appropriate grading of a site we can restore estuarine and fluvial sedimentary processes which will create marsh plains, flood plains and tidal drainage channels that will, in turn, support juvenile Anadromous fish.

This design approach does not attempt to precisely "engineer" a predetermined replicate of a wetland, but instead creates a 'template' landscape with suitable initial conditions for the natural evolution of wetland functions and interplay of ecologic processes. An appropriately designed template will guide the evolution of the wetland towards the desired mature state. This approach means that the initial grading of the site is not done to instantly replicate wetland topography, but instead to create the conditions that allow the wetland landscape to evolve through hydrodynamic and sedimentary processes. If the appropriate initial design template is selected, the need for further management interventions is minimized. The initial site template can also be designed to achieve a mix of interim habitat types that provide a mix of transitional wetland functions as the site evolves.

4. DESIGN GUIDELINES

Each operational objective will raise specific design questions for which guidance can be given:

1. **Operational objective 1:** to reconnect the floodplain to the emergent marsh by grading a sufficient area of floodplain to an elevation that permits macrodetritus to enter the wetlands, hence ***Design Question 1: What elevation should the floodplain be?***

2. **Operational objective 2:** to increase access to off-channel habitat by grading a sufficient area to an elevation that emergent marsh habitat to be created, hence ***Design Question 2: What elevation should the emergent marsh be?***

3. **Operational objective 3:** to create self-sustaining channels of certain size, depth and complexity, hence ***Design Question 3: How should tidal channels be sized?*** A given tidal channel network will require sufficient tidal prism to be sustainable and, since the emergent marsh plain elevation and tidal range are set, the minimum area of wetland will need to specified, hence ***Design Question 4: How large and what shape should the wetland be?*** In addition, the location of the inlet where the marsh connects to the main stem needs to be considered, hence ***Design Question 5: How can residence time for fish using the marsh be increased?***

One other general design question can be raised which relates to the general evolution of restored wetlands. Wind wave action may retard the evolution of a restoration site by suppressing sedimentation rates and limiting overall site elevation, hence ***Design Question 6: Should wave breaks be constructed?***

The design guidelines are based on an assessment of sites within reaches C, D and E (see Section 2), which includes the majority of the sites with a high restoration potential (PCT 2009). Goat Island, which has been identified as a good prototype for the design criteria, is located in Reach D. The design criteria will therefore be applicable to freshwater tidally influenced sites. Reaches A and B are in the brackish zone of the Lower Columbia and are also exposed to more wave activity. Reach F is similar to reaches C, D and E, and will benefit from the design criteria established through C, D and E. Reaches F and G, while freshwater tidal, are further away from the majority of dredge material sources and so present fewer opportunities. These other reaches could be added, if desired, but are not included in the present study.

4.1 QUESTION 1: WHAT ELEVATION SHOULD THE FLOODPLAIN BE GRADED TO?

RATIONALE

Floodplains that are low enough in elevation to be inundated by the annual spring freshet will provide a source of macrodetritus from the riparian woodland to the estuarine food web, as well as temporary access to an expanded area of off channel habitat for juvenile salmonids. Historically much of the macro detrital input into the estuary has occurred during these overbank events (NOAA 2011).

Since the flows in the Lower Columbia have been modified and seasonal stages lowered, it is necessary to define an elevation zone for the forested floodplain that will be inundated on an annual basis. The annually activated floodplain is defined as the area between the annual flood stage and regular tidal inundation. Grading upland areas to within this elevation range will therefore expand annual source areas for macrodetritus. Graded slopes between these two elevations would support the establishment of scrub, shrub, and riparian woodland habitat.

Floodplain areas higher than the annually activated floodplain also supply occasional macrodetrital inputs in years when the spring freshet is high enough to inundate such higher elevations. Grading upland areas surrounding restoration sites to elevations between the annual activation elevation, which is inundated every year, and the elevation which is inundated in half of all years will also provide food web support benefits.

The floodplain activation elevations, defined relative to NAVD, increase upriver according to the location of the island in the estuary as shown in Figure 2.6 and tabulated in Table 2.1 and Table 2.3. Elevation bounds for the island sites that lie between NOS gages are interpolated based upon their River Mile.

DESIGN GUIDEINES

1. An annually activated floodplain, inundated every year or in 100% of years, should be graded between the upper edge of emergent marsh at MHHW and the annual flood stage, as defined from the recent water surface record. Figure 2.6 can be used to define this zone in Reaches C, D and E.

2. The width of the annually activated floodplain should be wide enough to accommodate fallen trees and provide benefits of shading from standing trees; a minimum width of the order of the height of a tree could be used as a guide.

3. Grading upland areas between the annual flood stage and the elevation inundated in 50% of years, in areas surrounding restoration sites, would also provide food web support benefits.

4. The graded floodplain should be gently sloped to allow easy mobilization of detritus and prevent fish stranding. Any impediments, such as pile dikes or cross levees, should be removed from the floodplain to allow for unimpeded movement of water and macro detritus.

5. Close attention should be taken to the correct specification and use of vertical datums.

4.2 QUESTION 2: WHAT ELEVATION SHOULD THE EMERGENT MARSH BE GRADED TO?

RATIONALE

A vegetated intertidal emergent marsh provides important feeding habitat for salmonids. Specifically, small subyearling Chinook salmon enter emergent marshes and consume chironmids, which themselves feed on decaying marsh macrodetritus (Bottom et al, 2011 p109).

The design criterion is to specify a range of elevations for the emergent marsh that will maximize fish access. Water surface elevations vary considerably between spring freshets and late summer tidally dominated flows. To ensure that there is access year round, emergent marsh elevations need to be set to a tidal datum rather than freshet elevation. The marsh elevation needs to be high enough to allow vegetation colonization, but low enough to reduce variability in habitat opportunity, and low enough to provide sufficent tidal prism to stabilize deep channels. It was decided to use the observed emergent marsh elevation at the five islands sites as a guide to set the lower limit of the emergent marsh; the upper limit will be MHHW where the marsh transitions to forested floodplain.

Different species of freshwater tidal wetland vegetation will colonize intertidal mudflats and sandflats at different elevations relative to the tidal frame (see Table 2.2 and Table 2.3). Our surveys of marshplain vegetation at the 'accidently' created marshes on the dredged material islands show that at most locations there is initial colonization at 1 to 2 feet below MTL. Once plants are established vegetation will expand laterally and raise the marshplain surface vertically. Fully vegetated marshplains have now developed to about MTL at the 40-year old (approximately) vegetated sites we examined, as shown in Figure 2.6. These 40-year old emergent marshplain elevations are lower than those observed in freshwater tidal systems elsewhere and could be considered immature. Over succeeding decades, with continued estuarine sedimentation and organic accretion, we expect marshplains to gradually rise higher within the tidal frame.

There are three different techniques that can be applied to create extensive areas of naturally colonizing emergent marsh. The first and most economical technique is to take advantage of natural estuarine sedimentation in sheltered shallows to build up mudflat elevations to where plants can colonize. The second technique is to fill and grade shallow subtidal areas with dredged sediments to raise elevations. The third technique is to lower existing filled areas to intertidal elevations – as was done at the Crims Island restoration site.

Accretion of estuarine sediments depends on the amount of sediment carried into the site and deposited on flood tides, the amount of sediment eroded and carried out of the site on ebb tides, and the consolidation of deposited sediments. The amount of sediment carried into the site depends on the suspended sediment concentration at the source of sediment supply, the distance of the site from the sediment source, and the degree to which tidal exchange to the site is restricted. The expected rate of natural estuarine sedimentation at a restored site should be estimated from an analysis of measured suspended sediment concentrations, observed rates of sedimentation at similar restoration sites or nearby dredged sites, and simple models of tidal sedimentation calibrated to measurements and observations (e.g. Krone, 1987).

The rate of sedimentation in a restored site due to flood tide deposition will decrease with the period of tidal inundation as the mudflats build in elevation. Estimates of sedimentation rates should also account for the relative decrease in mudflat elevation due to the consolidation of deposited sediments over time. As the mudflats increase in elevation within the tidal frame, consolidation occurs due to the self-weight of the material and increased dewatering at low tides.

For sites that are more than several feet below mean tide level, it may take several decades or more for the site to reach vegetation colonization elevations through natural estuarine sedimentation. Wind-wave conditions may retard net sedimentation and vegetation colonization rates, potentially causing the site to remain as intertidal mudflat in the long-term.

If the estimated rate of natural estuarine sedimentation is found to be too slow to achieve target habitat conditions and restoration within the planning horizon, the alternative strategy is to fill shallow areas with dredged material to raise site elevations and shorten the time required for site evolution.

Dredged material islands were formed mainly by hydraulically pumped sand which provides a poor substrate for plant colonization as opposed to areas where estuarine sediments have deposited. Ideally the root zone of pioneer vegetation (approximately 1 foot below the surface of the mudflat) should be in estuarine muds.

Another consideration in designing extensive marshplains is providing habitat heterogeneity. In natural marshes disturbance due to flood events and deposition of large wood would create variations in elevation within the marshplain. In addition natural marshes gradually transition in elevation from intertidal to supra tidal habitats.

Finally, in calculating the final elevation of the created surface, consideration should be given to assessing the amount of elevation loss that will take place with time if the fill material settles and consolidates.

DESIGN GUIDELINES

1. For shallow subtidal or intertidal sites estimate the potential rate of natural estuarine sedimentation accounting for proximity to sediment supply, assuming sheltered conditions prevent wind-wave re-suspension. Sedimentation rates can be estimated using cores from adjacent reference sites.

2. If the area is shallow enough to allow for the development of intertidal mudflats within colonization elevations within the planning horizon no action is required except for assessing the need for wave breaks to enhance sedimentation (see question 6 below). If shallow areas require filling to reach colonization within the planning horizon determine the design initial emergent marshplain elevations based on local tidal characteristics and adjacent reference marshes.

3. Design fill placement or removal to grade between about 1 foot below MTL, to allow for the deposition of a substrate suitable for plant colonization, and MHHW at the inland edge.

4. Design the grading so that approximately 50% of the area between these intertidal elevations is greater than MTL based on hypsometric analysis. This will ensure a large part of the site will vegetate quickly.

5. The marshplain should be sloped between the upper and lower bounds towards the nearest tidal channels.

6. For dredged fill sites, allow for compaction between time of placement and breaching.

7. For hydraulically placed fill, identify discharge pipe disposal location so that deposition cone fill slopes will drain towards the anticipated main tidal drainage channels.

8. In specifying particular elevations for grading, in general it should be noted that grading tolerances of +/-0.15 m (0.5 ft) can be expected on most sites. The placing of dredged material is particularly problematical and the slope of the dredge spoil should be anticipated as well as hydraulic sorting of the sediment.

9. Close attention should be taken to the correct specification and use of vertical datums.

4.3 QUESTION 3: HOW SHOULD TIDAL CHANNELS BE FORMED?

RATIONALE

Subyearling salmon use tidal channels to access the marsh for feeding and refuge (Bottom, 2011 p.46 also USGS 2011 p.26). Therefore the size, drainage density and consequent extent of edge habitat provided by tidal channels are important design criteria.

A tidal channel system can form naturally in emergent marsh systems. As vegetation colonizes higher mudflat elevations, tidal flows are concentrated in lower elevation mudflat channels. Over time, as marshplains build up and vegetation expands laterally, more confined channels scour deeper. Eventually as the marsh matures channels evolve from broad shallow mudflat channels to deeper steep banked channels with overhanging vegetation.

The size of channels and the drainage density of the tidal channel system formed in this way are dependent on the tidal prism. As an emergent marsh develops through estuarine sedimentation the tidal prism gradually is reduced until the marshplain surface equilibrates to the tidal range. This mature system can then sustain channels of particular dimensions and drainage density. Therefore if natural sedimentation is the technique used to create areas of emergent marshes tidal channels can be allowed to develop naturally.

If the site is filled the tidal prism of the diurnal tides flooding the site is smaller. This means that the higher the fill, the weaker the tidal scouring, and the longer it may take for tidal channels to form in placed material. Therefore, there is sometimes a compromise between filling the site high for rapid vegetation establishment and keeping it low enough for a tidal channel system to form. However, implementing the grading guidelines described in question 2 provides a large diurnal tidal prism. In addition, placed or reworked material is likely to be very erodible by tidal scouring. Therefore, provided there are no obstructions that would mute tidal access, a tidal drainage system would be expected to form quickly.

In sites that have been graded down from higher elevations compacted soils and root masses can impede tidal scouring. In this case tidal channels may need to be excavated, as was done on the Crims island restoration.

Empirical hydraulic geometry relationships, developed from our measurements on dredged material islands and described in section 2, can be used to size tidal channel excavations in marshes, predict channel sedimentation or erosion responses to changes in upstream tidal prism, and estimate the minimum tidal prism and corresponding marsh size necessary to provide sustainable subtidal channel habitat for resident fish.

Earthwork is usually the largest part of construction costs for a restoration project and channel excavation can add disproportionately to the costs for fill removal and disposal. If the fill or underlying material is mud, the limited bearing capacity makes the use of heavy equipment difficult and may require placement of temporary load bearing pads or mattresses for construction equipment to work from. In addition, slumping of the banks of cut channels is difficult to predict or control. It is particularly difficult to excavate small first and second order channels within a reasonable tolerance using standard construction equipment, and sinuous or curved channels can be difficult to survey and stake out for construction crews.

DESIGN GUIDELINES

1. Channel excavation need only be considered on graded down, high elevation sites.

2. The channel system should be designed in planform to replicate drainage densities typical of these observed in monitored sites as described in Section 2.

3. Channel cross sections should be designed based on hydraulic geometry of channels in monitored sites as described in Section 2.

4. If the site is being graded down then it will be necessary to cut through any upland root mass (e.g. reed canary grass) and disk any compacted material to allow first order channels to form.

5. Cutting small pilot channels to the required depth will help locate channel position in relation to marshplain.

6. Any erosion resistant material, such as compacted sediments, should be removed to 1 foot below the bottom of the channel.

7. Cost savings can be achieved by specifying depth and bottom width of channels and allowing channel banks to stabilize as they are cut, rather than requiring a design side slope or top width.

8. Adjacent marsh plains should be gently sloped to the channel edge to encourage drainage and ensure channels do not evolve in undesired locations.

9. Wherever possible excavation should be done in the dry.

4.4 QUESTION 4: HOW LARGE AND WHAT SHAPE SHOULD THE WETLAND BE?

RATIONALE

There is a correlation between the scale of the emergent marsh, the habitat opportunity and the number and size of fish (Bottom et al 2011, p103). This appears to be related to both the extent of connected channel edge, which is greater given a larger channel network, and the availability of deep subtidal channels within the marsh. The plan form will also be important as a sinuous channel will have more heterogeneous edge than simple linear creeks (Hood 2002; Ramirez 2008). Fish stay for longer periods if channels are subtidal or if they have access to quiet subtidal areas nearby (Bottom 2011, p102). Access to subtidal areas allows ‘overtiding’ within, or close by, the marsh.

A minimum size of emergent marsh area that will support given channel depths can be calculated from the hydraulic regime relationships calibrated in Section 2. The target channel depth of 1.5 feet below MLLW is shown relative to MHHW for Reaches C, D and E in Figure 4.1 and presented in Table 4.1. The relation found in Figure 4.1 allows for the calculation of drainage area for a given depth:

$$A_d = 3.2922^{-1} D_c^{1/0.215} \tag{4.1}$$

where D_c is channel depth below MHHW in feet and A_d is drainage area in acres. The resultant minimum drainage area for reaches C, D and E is shown in Figure 4.2 and these are tabulated in Table 4.1.

Table 4.1. Target channel depths and minimum drainage area required to support subtidal channel networks along Reaches C, D, and E.

Gage/Island	**River Mile**	**Target Channel Depth below MHHW (ft)**	**Minimum Drainage Area to sustain Target Channel Depth (ac)**
Skamokawa	33.3	9.2	119.7
Longview	66.4	6.2	19.3
St Helens	85.6	4.9	6.6
Wallace	49.0	7.8	54.9
Hump-Fisher	60.0	6.8	29.1
Lord-Walker	62.5	6.6	24.8
Sandy	75.0	5.6	12.3
Goat	81.0	5.2	8.7

DESIGN GUIDELINES

1. The minimum size of drainage area to support a channel suitable for overtiding (i.e. 1.5 feet below MLLW) can be calculated using Equation 4.1 and is shown in Figure 4.2 for Reaches C and D.

2. Emergent marsh areas should ideally be larger than the minimum size to support the required channel size.

3. The shape of the marsh area and the channel network may be governed by the desire to maximize the edge to area ratio of the channel, the marsh and the floodplain.

4. The orientation of the marsh should take into account the wind fetch (see question 6 below).

4.5 QUESTION 5: HOW CAN RESIDENCE TIME FOR FISH USING THE MARSH BE INCREASED?

RATIONALE

There is a correlation between juvenile salmon growth and residence time in or adjacent to emergent marshes where there are feeding opportunities. There are three ways of providing for increased residence time:

- by creating emergent marshes large enough to develop and sustain deep subtidal channels within the marsh;
- by designing emergent marshes to drain into shallow backwater areas rather than directly into the deep navigation channel; and,
- by providing a chain of accessible emergent marsh habitats along the river corridor.

With these measures, during low tide the fish are able to stay in, or close to, emergent marsh habitat and reenter to feed on the subsequent flood tide. Bottom et al (2011, p102), suggest that water depths in large marsh channels should be greater than 1.5 feet at low water, which was the minimum depth that juvenile salmon were observed to enter and exit wetland channels.

DESIGN GUIDELINES

1. Where possible emergent marshes should be created large enough to sustain subtidal channels deeper than 1.5ft at low tide. Typically for elevations specified in question 2 this mean sites should be configured to be at least 20 acres.

2. Main tidal channels feeding emergent marshes should be located to discharge into quiet shallow back channels, and away from possible avulsion pathways.

4.6 QUESTION 6: SHOULD WAVE BREAKS BE CONSTRUCTED?

RATIONALE

The evolution of the five island sites studied follow the same general pattern of pile dike construction followed by shoaling as more dredged was placed. As shoaling continued a barrier beach developed enclosing a shallow lagoon. This protection allows estuarine sedimentation to occur in the lagoon until the elevation is high enough for marsh plants to become established. However there are examples where shallow embayments have not sedimented in and marsh evolution has been prevented or retarded due to wind wave activity.

For the windy environment of the Lower Columbia estuary the potential for wind wave-induced resuspension of deposited estuarine sediments is largely a function of orientation, fetch length, and water depth. Wave erosion rates generally increases as mudflat elevations increase and water depths decrease, causing even small waves to break. This means that vulnerability to sediment disturbance and re-working from wave action increases as site (or rather fetch) size increase, as mudflats build in elevation, and water depths decrease. For a particular wave climate there is an inherent equilibrium mudflat elevation where net erosion and deposition is zero. If this elevation is above the typical colonization elevation, vegetation will eventually become established. The presence of vegetation then promotes further marsh plain elevation building through increased sedimentation, protection from scour, and accumulation of organic material. Once an extensive vegetated marsh plain develops, it will dissipate wave energy and prevent the scouring of accumulated sediment on the marsh plain (French and Stoddart 1992).

However, if a given wind wave climate dictates an equilibrium mudflat elevation below the colonization elevation, the site will remain bare mudflats. To create emergent tidal marshes, wind wave energy will need to be reduced. This can be done in two ways: by filling the site to above the colonization elevation or grading wind wave breaks.

Wind wave breaks created from dredge material can be graded as high elevation areas, berms, or peninsulas. These can be designed to replicate the form of a barrier beach at the mouth of an embayment or within the site used to define tidal watersheds and guide the shape and location of the evolving tidal channel network. High elevation areas or berms that are planted with or colonized by marsh vegetation can provide an alternate means of reducing wind wave action. Wave break design will be a trade-off between height, width, slope, vegetation, cost, and design objectives. For example, vegetated wave breaks that are lower within the tidal frame would need to be broader and have gentler slopes than a higher wave break. Wave breaks are essentially sacrificial structures; they are only needed until vegetation is established along the edges of wave breaks and marsh elevations have accreted.

DESIGN GUIDELINES

1. Wind wave action needs to be evaluated to determine whether it needs to be considered in the design. In general, if fetch lengths are smaller than about 3,000 feet and elevations are above MTL, wave effects are usually minor. If fetch lengths are greater than about 3,000 feet and the site is below MTL, wave erosion needs to be considered during the period until the marsh plain is fully vegetated. If fetch lengths are greater than about 3,000 ft and the site is more deeply subsided, filling or grading to create wave breaks needs to be considered.

2. The strategy is to minimize the effects of wave action on net sedimentation and therefore maximize rate of evolution to a vegetated marsh.

3. Wave breaks should be designed to dissipate most of the wave energy during the period before the site becomes fully vegetated. This can be done by grading a broad shallow berm and encouraging the establishment of marsh vegetation on berm slopes to provide additional wave dissipation. A minimum width of vegetated marsh of 30 feet on berm slopes of 1:15 will provide adequate wave dissipation (Knutson 1990 p.95).

4. The wave break crest should be constructed as low as possible within the tidal frame but high enough to trip and break waves passing over during high tides. Barrier beach elevations at adjacent reference sites will provide information on an effective elevation. The objective is to limit wave entering the lagoon and so only a spit at the mouth is required.

5. Because locally generated waves have a short period and wavelength is small, wave energy dissipation due to refraction is negligible. Therefore, wave breaks need to be either continuous features, or if discontinuous "islands" they need to completely block waves from the dominant fetch directions because there would be minimal dissipation of wave energy due to refraction through the gaps.

6. Because the dominant fetch directions are not usually well defined, it is preferable to configure wave breaks as curved features that offer protection from a variety of wave directions.

7. Allowance must be made for the initial subsidence of the wave break.

8. Wave breaks are essentially sacrificial structures; they are only needed until vegetation is established along the edges of wave breaks and marsh plain elevations have accreted. There is no need to armor the slope unless the wave breaks perform some other function, such as guiding where channels are forming.

5. RECOMMENDATIONS

Adaptive management for restoring wetlands on the Lower Columbia can be accomplished by implementing and monitoring successive restoration projects rather than successive manipulations of the same site. The first step in this learning process is to monitor accidently created wetland sites of different ages within the estuary as described in this study. This enables articulation of an initial or ‘version 1.0’ of design guidance.

There is a significant opportunity to continue to improve design decisions by incorporating explicit adaptive management experiments within future restoration projects. These experiments can address uncertainties in project design that significantly affect cost, feasibility, and ecologic performance. For example, these uncertainties include:

- The rate of evolution of a subsided site to a mature emergent marsh.
- The importance of the size and depth of tidal channels within the marsh to support estuarine fish.
- The degree to which locally generated wind waves hinder sedimentation and establishment of emergent marsh.
- The rate of natural establishment for a full range of emergent marsh plant species.
- The impact of invasive species on emergent marsh habitat for a range of species.

Useful adaptive management experiments that should be incorporated in future restoration projects include:

- Examine the tradeoff between the amounts of dredged fill required in a subsided site and the rate of evolution of desired wetland functions.
- Predict more accurately the rate of evolution of wetland form and function for different erosional and sedimentary environments that take into account consolidation, organic accretion, future sea level rise, changes in sediment budget, and changes in estuarine sediment dynamics.
- Design improvements such as the size and spacing of wave breaks and cost effective ways to create channel systems in dredged materials.
- Understand the benefits of grading more heterogeneous habitat within the site—particularly integrating emergent marsh and floodplain in the site design.

- Develop techniques for controlling aggressive invasive plants that limit or replace native species.

Restoration practice is an applied science that is now maturing. We now understand tidal wetlands as vital components in a larger estuarine ecosystem that is continually evolving in response to human and natural physical processes and that this context has to be taken into account if we are to achieve sustainable long-term benefits from restoration. We also now perceive that restoration projects are best planned and designed with a rigorous, explicit, planning methodology. This report is intended to be a snapshot of our evolving knowledge on best design guidance. If new restoration sites are designed and implemented using this report, monitoring analysis of their performance can be used to develop successive generations of design improvements; versions 2.0, 3.0, etc.

6. REFERENCES

Bottom, D. L., C. A. Simenstad, A. M. Baptista, D. A. Jay, J. Burke, K. K. Jones, E. Casillas, and M. H. Schiewe, 2005. *Salmon at river's end: The role of the estuary in the decline and recovery of Columbia River salmon*. NOAA, Northwest Fish. Sci. Center, Seattle, Wash.

Bottom, D.L., A. Baptista, J. Burke, L. Campbell, E. Casillas, S. Hinton, D.A. Jay, M.A. Lott, G. McCabe, R. McNatt, M. Ramirez, G.C. Roegner, C.A. Simenstad, S. Spilseth, L. Stamatiou, D. Teel, and J.E. Zamon, 2011. *Estuarine Habitat and Juvenile Salmon: Current and Historical Linkages in the Lower Columbia River and Estuary*. *Final Report 2002-2008*. Prepared for USACE.

Ferguson, J.W. 2006. *Role of the Columbia River Estuary—Recent Findings Describing Use and Benefits to Salmon*. NOAA memorandum, Northwest Fisheries Science Center. July 31, 2006.

Fresh, K.L., E. Casillas, L.L. Johnson, and D.L. Bottom, 2005. *Role of the estuary in the recovery of Columbia River basin salmon and steelhead: an evaluation of the effects of selected factors on salmonid population viability*. U.S. Dept. Commer., NOAA Tech. Memo. NMFS-NWFSC-69, 105 p.

Haltiner, J.H., and P.B. Williams, 1987, Slough channel design for salt marsh restoration, Proceedings of the Eighth Annual Meeting of the Society of Wetland Scientists, May 6, 1987, Seattle, Washington.

Independent Scientific Advisory Board, 2007. *Final Review of Proposals Submitted for Fiscal Years 2007–2009*. Northwest Power and Conservation Council, Portland, Oregon.

Jay, D.A. and T. Kukula, 2003. Columbia River discharge on salmonid habitat. A non-stationary fluvial tide model. *J. Geophys. Res.,* vol. 108, no. C9.

Kukula T. and Jay, D.A., 2003. Impacts of Columbia River discharge on salmonid habitat: 2. Changes in shallow-water habitat. *J. Geophys. Res.*, vol. 108, no. C9, 3294.

McCullough, D. A. 1999. A review and synthesis of effects of alterations to the water temperature regime on freshwater life stages of salmonids, with special reference to Chinook salmon.

McMichael, G., J. Vucelick, B. Ryan, L. Gillbreath, R. McComas, S. Smith, M. Carper, D. Elliott, T. Murray, L. Applegate, and C. McKibben. 2006. *Alternative Barging Strategies to Improve Survival of Transported Juvenile Salmonids—2005 Draft Report.* Prepared for the U.S. Army Corps of Engineers Walla Walla District, Walla Walla, WA.

National Research Council. 2004. *Managing the Columbia River: Instream Flows, Water Withdrawals, and Salmon Survival*. The National Academies Press. Washington D.C.

NOAA, 2011. *Columbia River Estuary ESA Recovery Plan Module for Salmon and Steelhead*. Prepared for NOAA Fisheries by the Lower Columbia River Estuary Partnership and PC Trask & Associates.

Northwest Power and Conservation Council. 2004. ―Mainstem Lower Columbia River and Columbia River Estuary Subbasin Plan‖ In *Columbia River Basin Fish and Wildlife Program*. Portland, OR.

O'Brien, M. P., 1931, Estuary tidal prisms related to entrance areas, *J. Civil Engr.*, Vol. 1, pp. 738-739.

Petersen, J.H., R. Reisenbichler, G.R. Gelfenbaum, C. Peterson, 2003. *Historical Changes in the Columbia River Estuary Based on Sediment Cores: Feasibility Studies*. US Geological Survey.

Varanasi, U., 2005. *Biological Implications of Recent Ocean Conditions*. Memorandum to Regional Administrator.

Volkman, J. M., 1997. *A River in Common: The Columbia River, the Salmon Ecosystem, and Water Policy*. A Report to the Wester Water Policy Review Advisory Commission. Springfield, VA: National Technical Information Service.

Williams, P. B., 1986, Hydrology in coastal wetland restoration design, Proceedings of the National Wetland Symposium-Mitigation of Impacts and Losses, Association of State Wetland Managers, New Orleans, Louisiana, October 8-10, 1986.

Williams, P. B., and H. T. Harvey, 1983, California coastal salt marsh restoration design, O.T. Magoon and H. Converse, eds., Proceedings: Coastal Zone '83 Conference, American Society of Civil Engineers, New York, June 1983.

Williams, P.B., M.K. Orr, and N.J. Garrity, 2002, Hydraulic geometry: A geomorphic design tool for tidal marsh channel evolution in wetland restoration projects, *Restoration Ecology*, Vol. 10, No. 3, pp. 557-590.

FIGURES

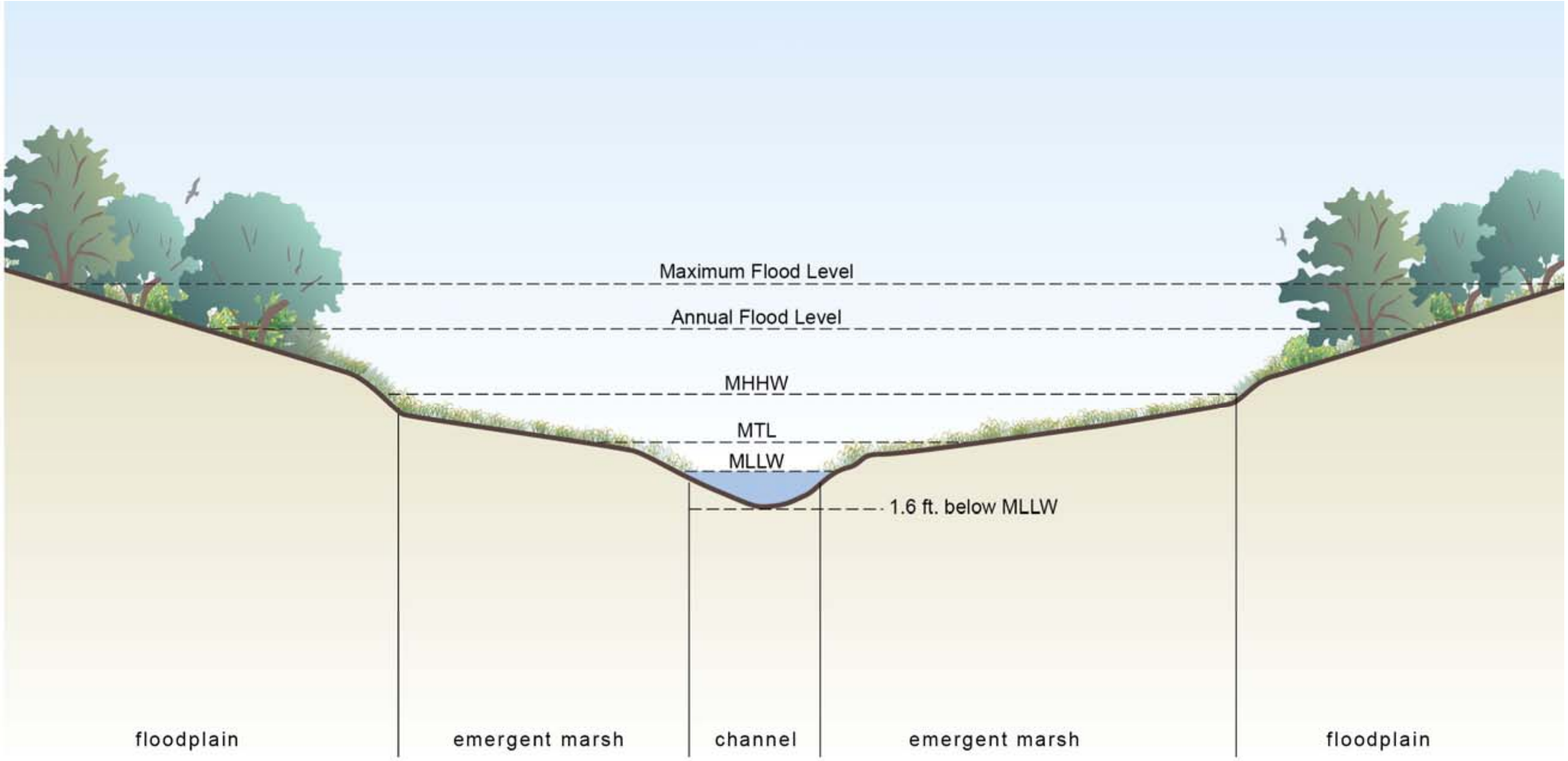


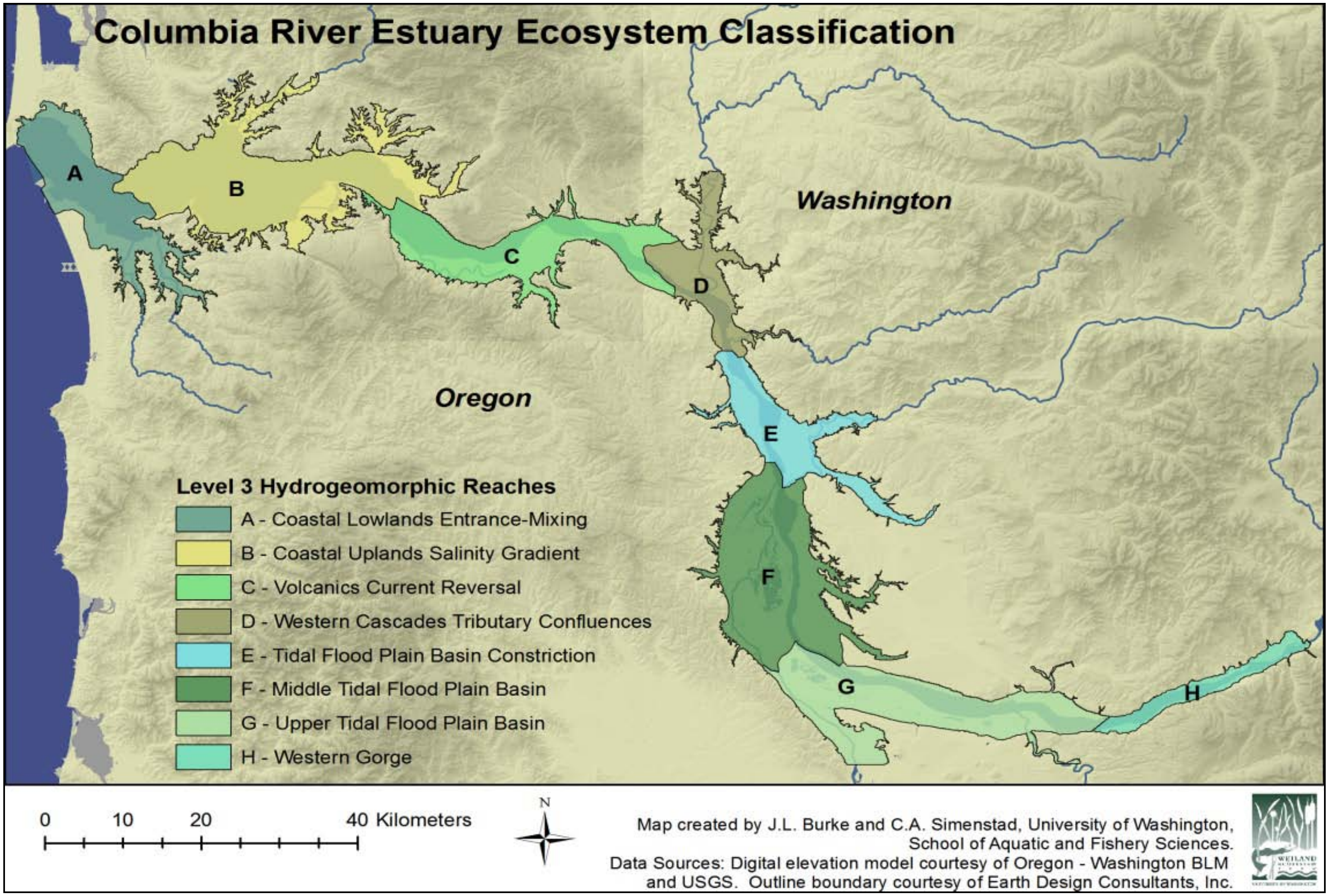
figure **2.1**

Lower Columbia Design Guidelines

Representative Cross Section Showing Water Surface Profiles

PWA Ref# 2023

ESA PWA



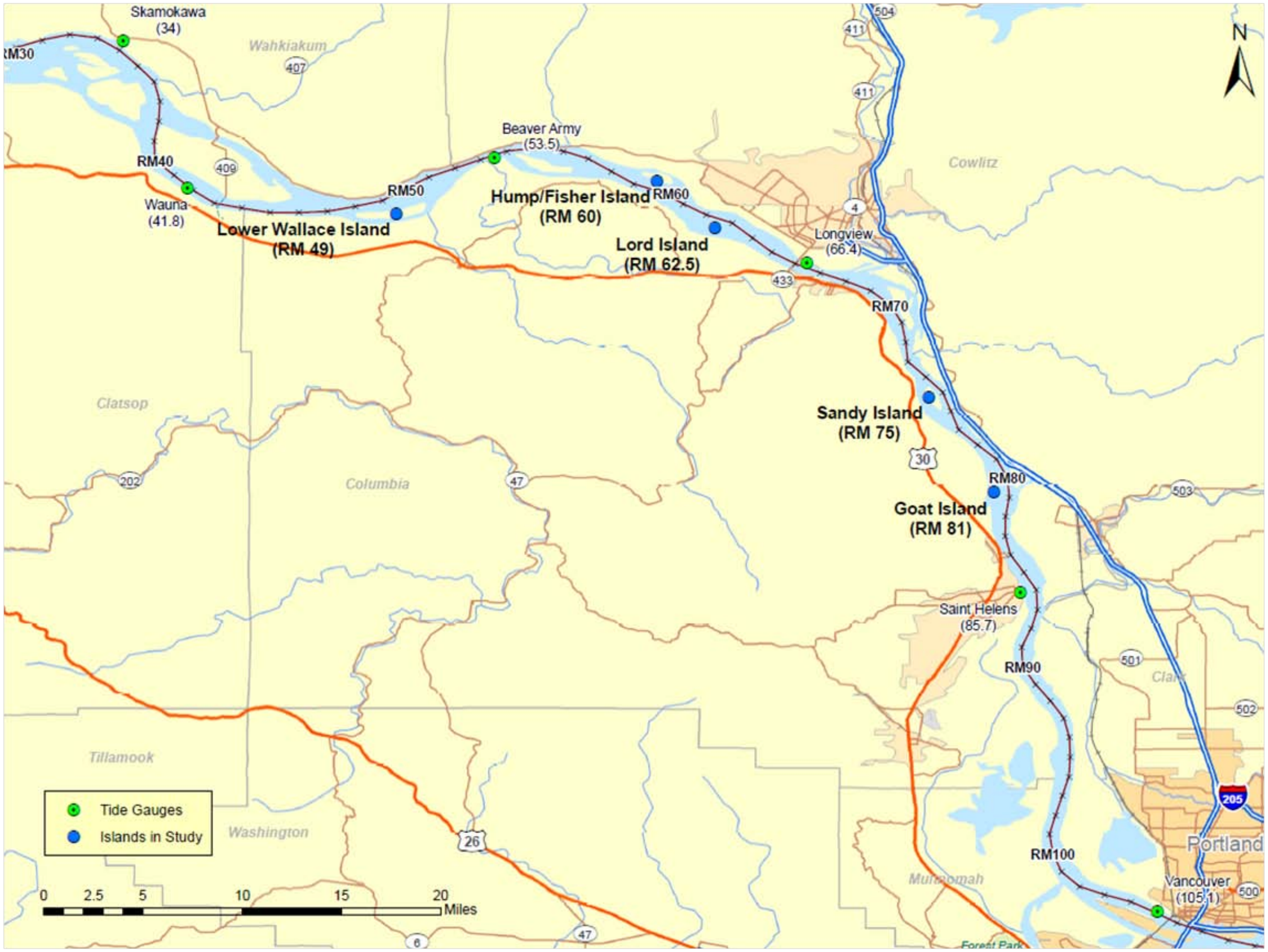
Map created by J.L. Burke and C.A. Simenstad, University of Washington, School of Aquatic and Fishery Sciences.
Data Sources: Digital elevation model courtesy of Oregon - Washington BLM and USGS. Outline boundary courtesy of Earth Design Consultants, Inc.

Source: Burke and Simenstad, School of Aquatic and Fishery Sciences, University of Washington

figure **2.2**
Lower Columbia Design Guidelines

Eight Hydrogeomorphic Reaches of the Lower Columbia Estuary

PWA Ref# 2023.00



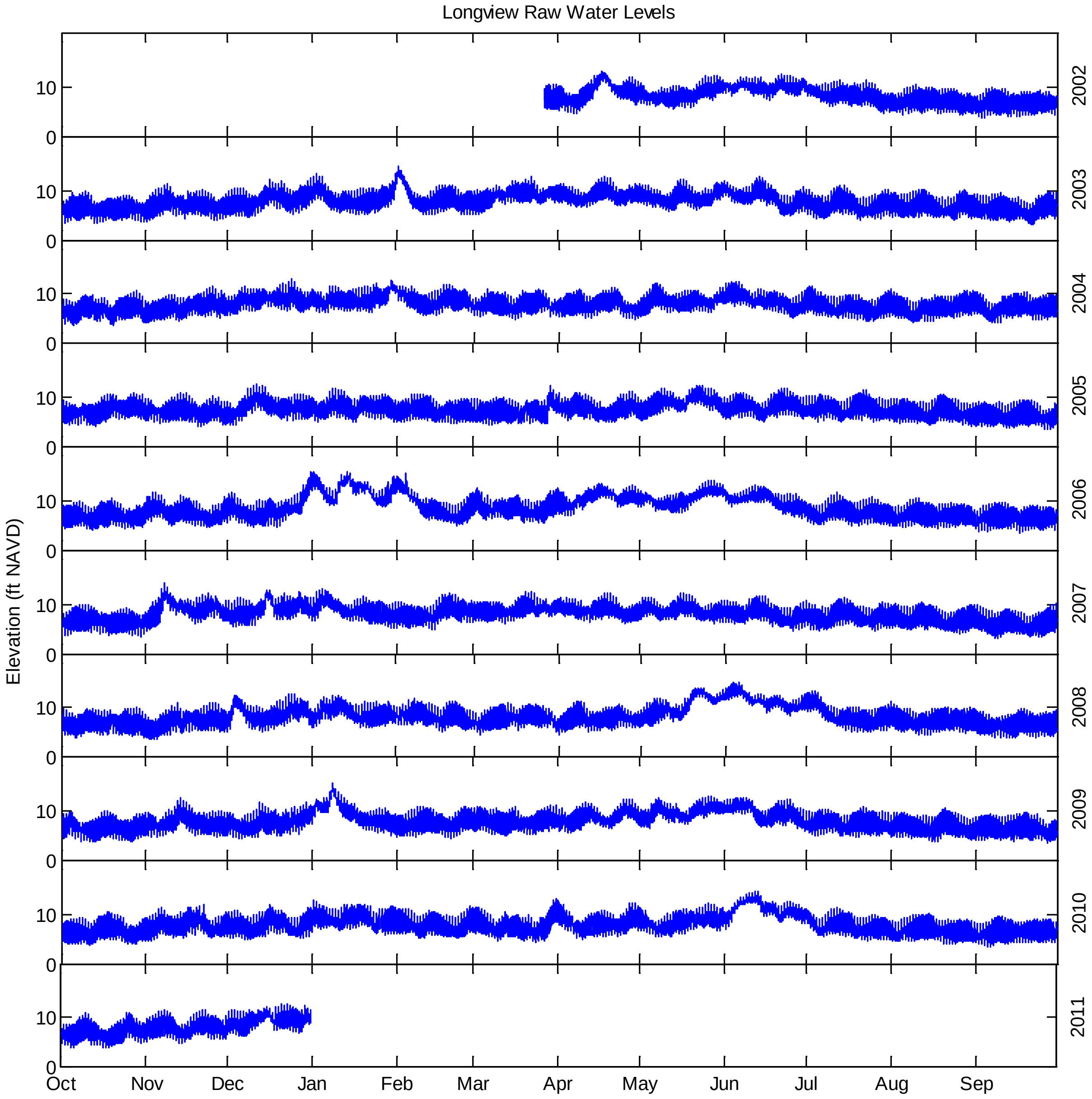
Source:
River Miles (USACE)
Map (ESRI 2011)

figure **2.3**
Lower Columbia Design Guidelines

Tide Gage Locations

PWA Ref# 2023

\\sfo-file01\esapwa\Data\projects\2023_Lower_Columbia_Design_Guidelines\Report\Phase 2\Figures\6.1 Figures\TideGageMap.png.doc

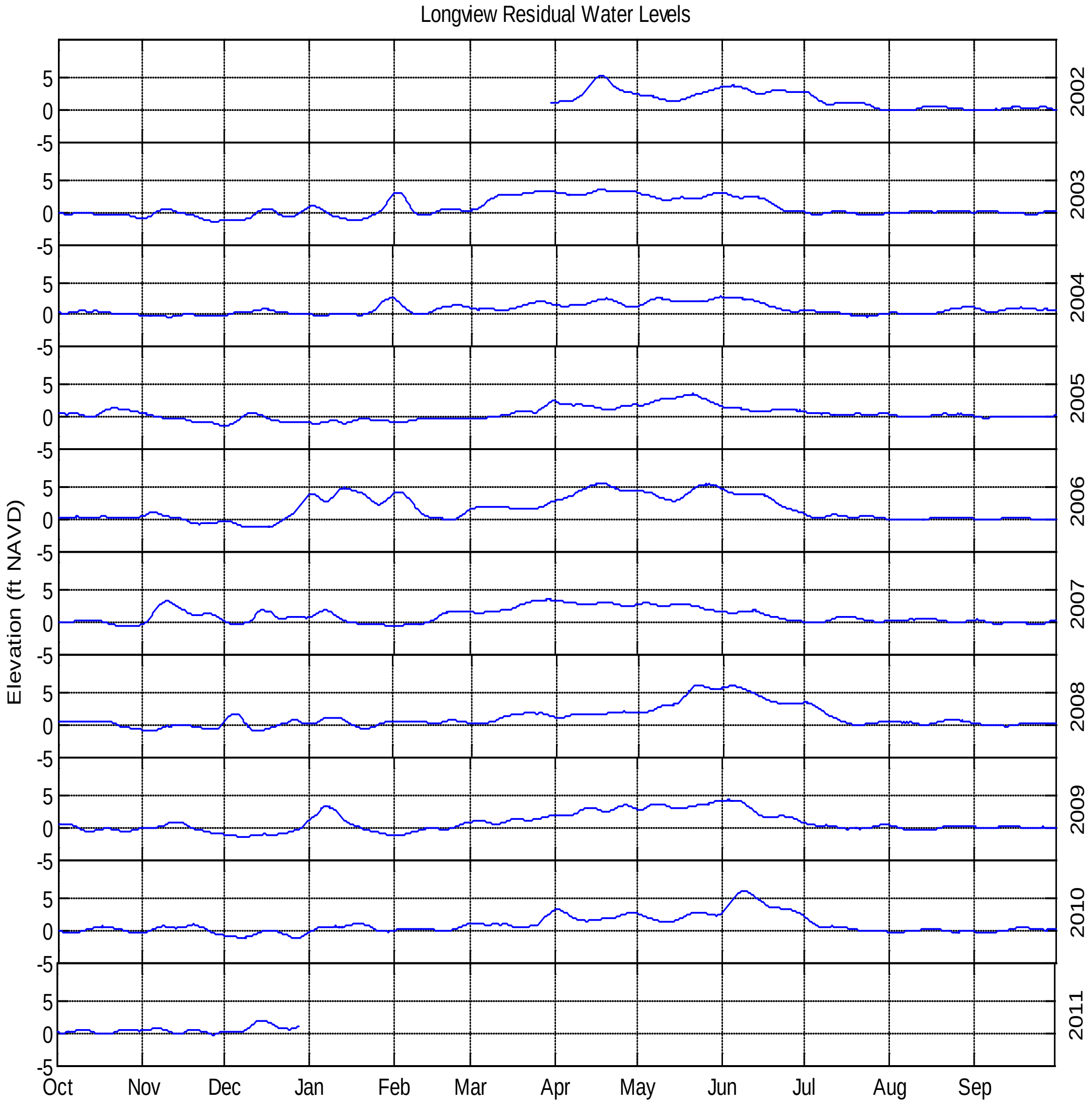


Source:
NOAA Longview Tide Gage (NOS #9440422)
Hourly Water Level 3/27/2002 to 12/31/2010

figure **2.4**
Lower Columbia Design Guidelines

Hourly Water Levels at Longview

PWA Ref# 2023



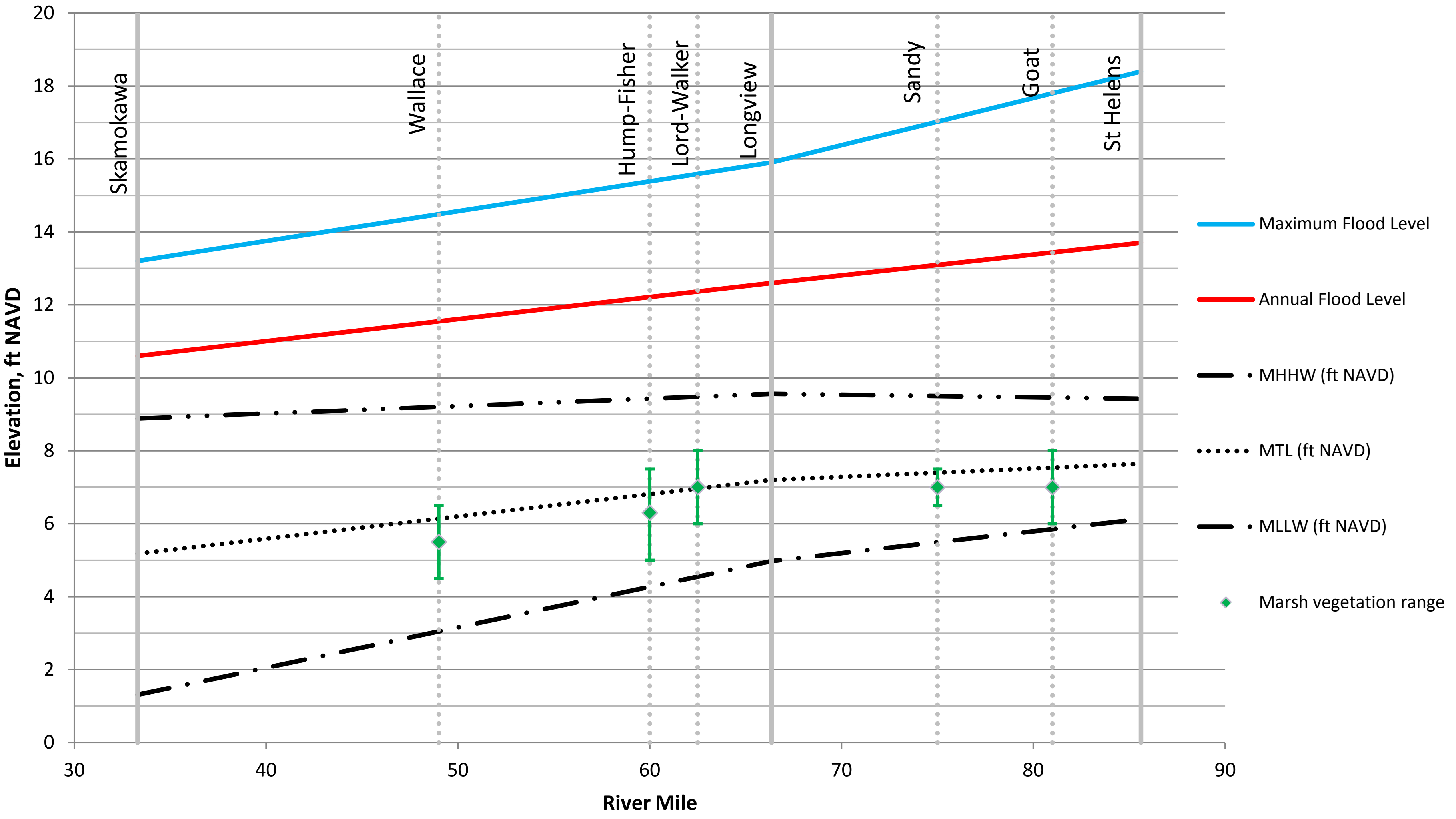
Source:
NOAA Longview Tide Gage (NOS #9440422)
Hourly Water Level 3/27/2002 to 12/31/2010

figure **2.5**
Lower Columbia Design Guidelines

Residual Water Levels at Longview

PWA Ref# 2023

ESA PWA



Notes: Marsh plain vegetation colonization ranges determined from field data and LIDAR
Source: River Miles from USACE
Tidal datums and hourly water level data from NOAA tide gages
St. Helens Gage (NOS #9439099) 3/27/2002 to 12/31/2010
Longview Gage (NOS #9440422) 3/27/2002 to 12/31/2010
Skamokawa Gage (NOS #9440569) 3/27/2002 to 12/31/2010

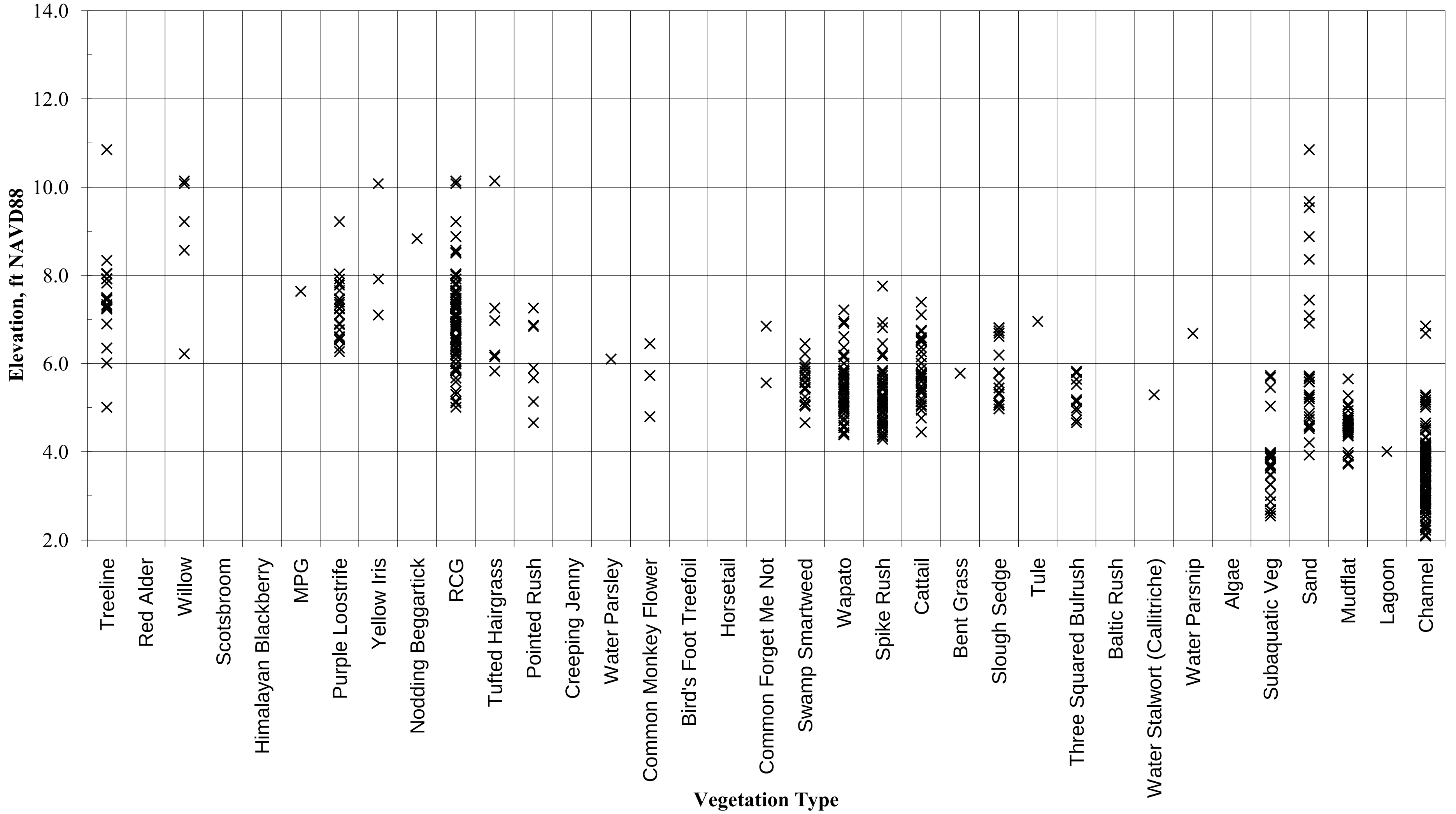
figure **2.6**

Lower Columbia Design Guidelines

Water Surface Profiles and Marsh Vegetation Colonization Ranges

PWA Ref #: 2023.00

ESA PWA



Notes: Field work August 12, 2010
Source: Vertical control was established by Statewide Land Surveyors. Vertical datum is NAVD88 in feet.

figure **2.7**

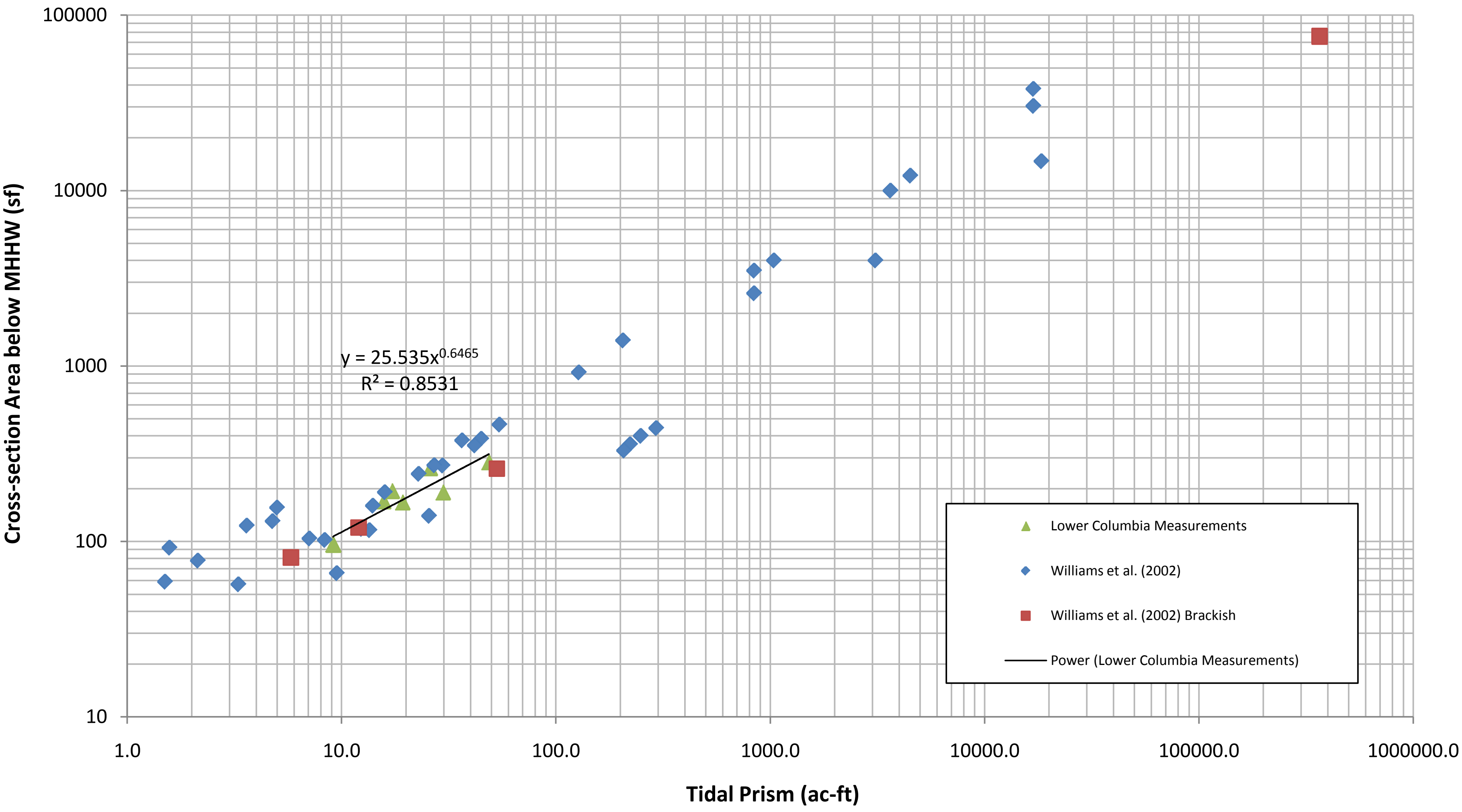
Lower Columbia Design Guidelines

Wallace Island: Vegetation-Elevation Ranges

PWA Ref #: 2023.00

PWA

\\sfo-file01\esapwa\Data\projects\2023_Lower_Columbia_Design_Guidelines\Fieldwork\Test Veg Colonization Elevation\Final_Workup\2023_Wallace_All_Field_Data-REV01



Source:
SF Bay Data from Williams et al.(2002)

figure **2.8**

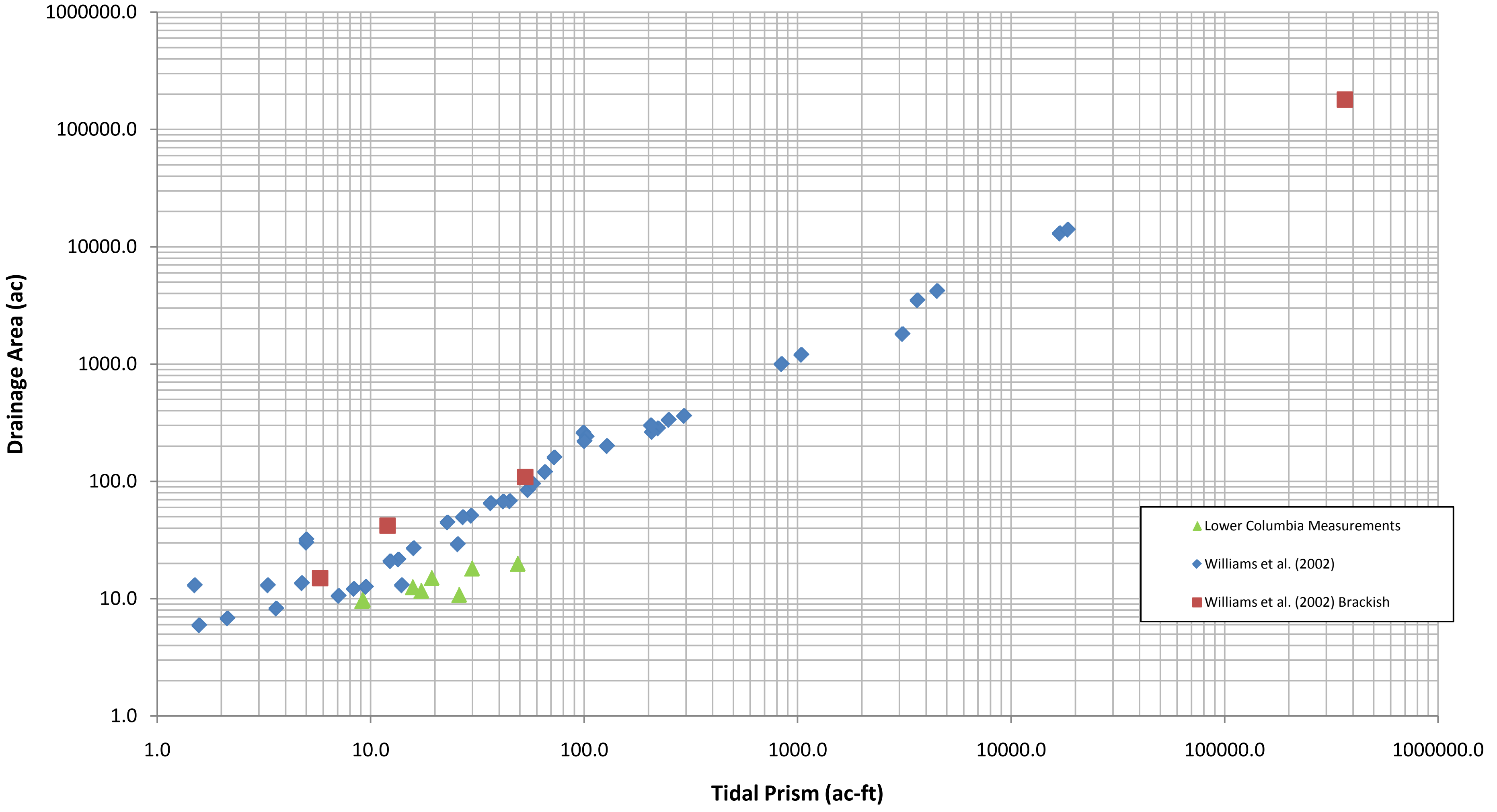
Lower Columbia Design Guidelines

Cross Section Area vs. Tidal Prism

PWA Ref #: 2023

\\sfo-file01\esapwa\Data\projects\2023_Lower_Columbia_Design_Guidelines\Topo Analysis\Hypsometry\HypCurves_v3

7/26/2011



Source:
SF Bay Data from Williams et al.(2002)

figure **2.9**

Lower Columbia Design Guidelines

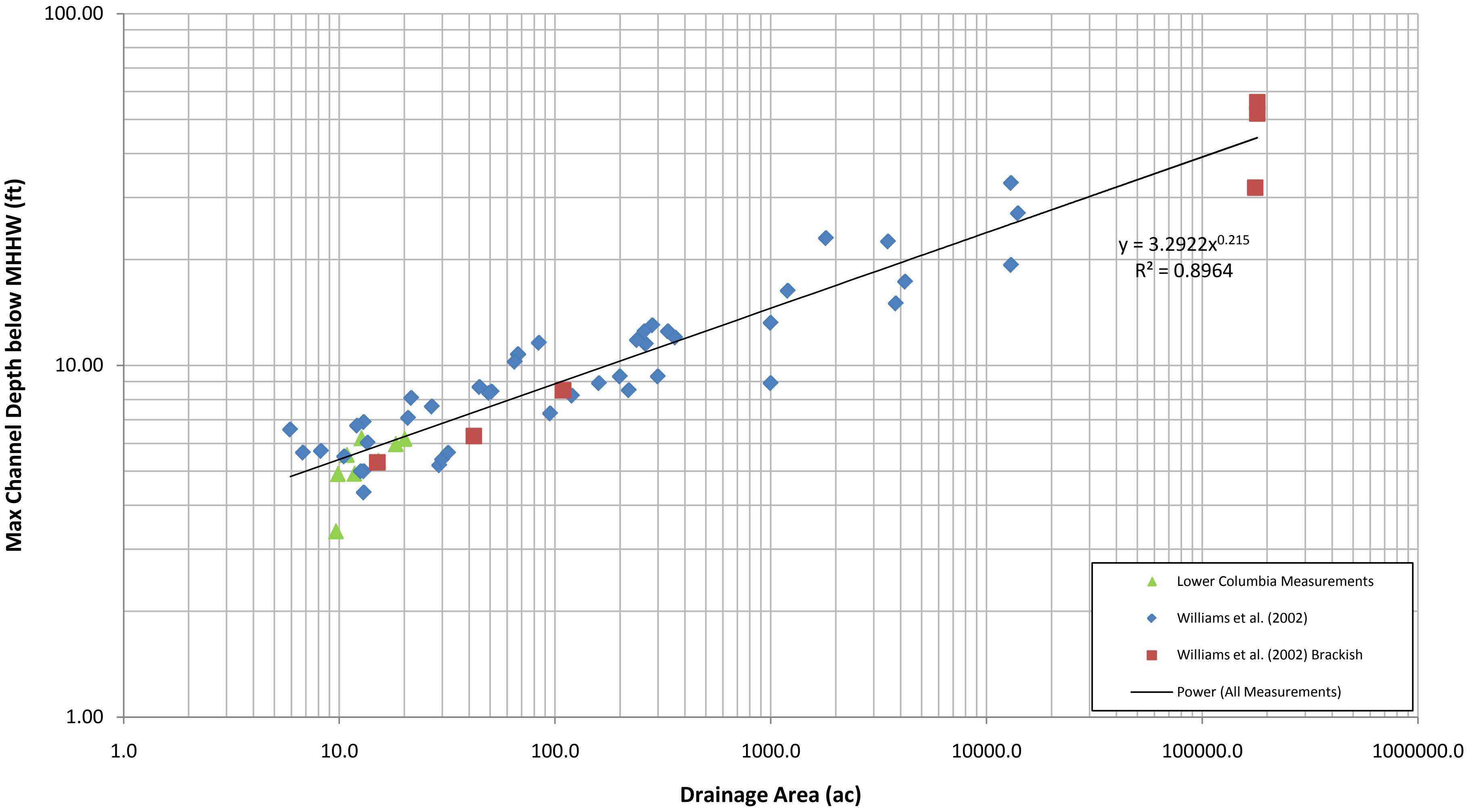
Drainage Area vs. Tidal Prism

PWA Ref #: 2023

ESA PWA

\\sfo-file01\esapwa\Data\projects\2023_Lower_Columbia_Design_Guidelines\Topo Analysis\Hypsometry\HypCurves_v3

7/26/2011



Source:
SF Bay data from Williams et al. (2002)

figure ***2.10***

Lower Columbia Design Guidelines

Maximum Channel Depth vs. Drainage Area

PWA Ref #: 2023

ESA PWA

\\sfo-file01\esapwa\Data\projects\2023_Lower_Columbia_Design_Guidelines\Topo Analysis\Hypsometry\HypCurves_v3

7/26/2011

	Limiting Factors		Ocean Type Impact	Stream Type Impact	Priority
Habitat-Related	Reduced in-channel habitat opportunity	Flow-related estuary habitat changes	5	3	Top
		Sediment/nutrient-related estuary habitat changes	4	3	High
	Reduced off-channel habitat opportunity	Flow-related changes in access to off-channel habitat	5	3	Top
		Bankfull elevation changes	5	2	High
	Reduced plume habitat opportunity	Flow-related plume changes	3	5	Top
		Sediment/nutrient-related plume changes	2	3	Low
		Water temperature	5	3	Top
		Stranding	3	2	Low
Food Web-Related	Food Source Changes	Reduced macrodetrital inputs	5	3	Top
		Increased microdetrital inputs	3	2	Low
	Competition and Predation	Native fish	3	2	Low
		Native birds	2	5	High
		Native pinnipeds	2	5	High
		Exotic fish	2	2	Lowest
		Introduced invertebrates	2	2	Lowest
		Exotic plants	2	2	Lowest
Toxic Contaminants		Bioaccumulation toxicity	4	2	Medium
		Short-term toxicity	4	3	High

*Significance of limiting factor to life history strategy:
1 = No likely effects; 2 = Minor effects on populations; 3 = Moderate effects on populations; 4 = Significant effects on populations; 5 = Major effects on populations.

Table **3.1**
Lower Columbia Design Guidelines

Limiting Factors Affecting Columbia River Salmonids

PWA Ref# 2023-00

ESA PWA

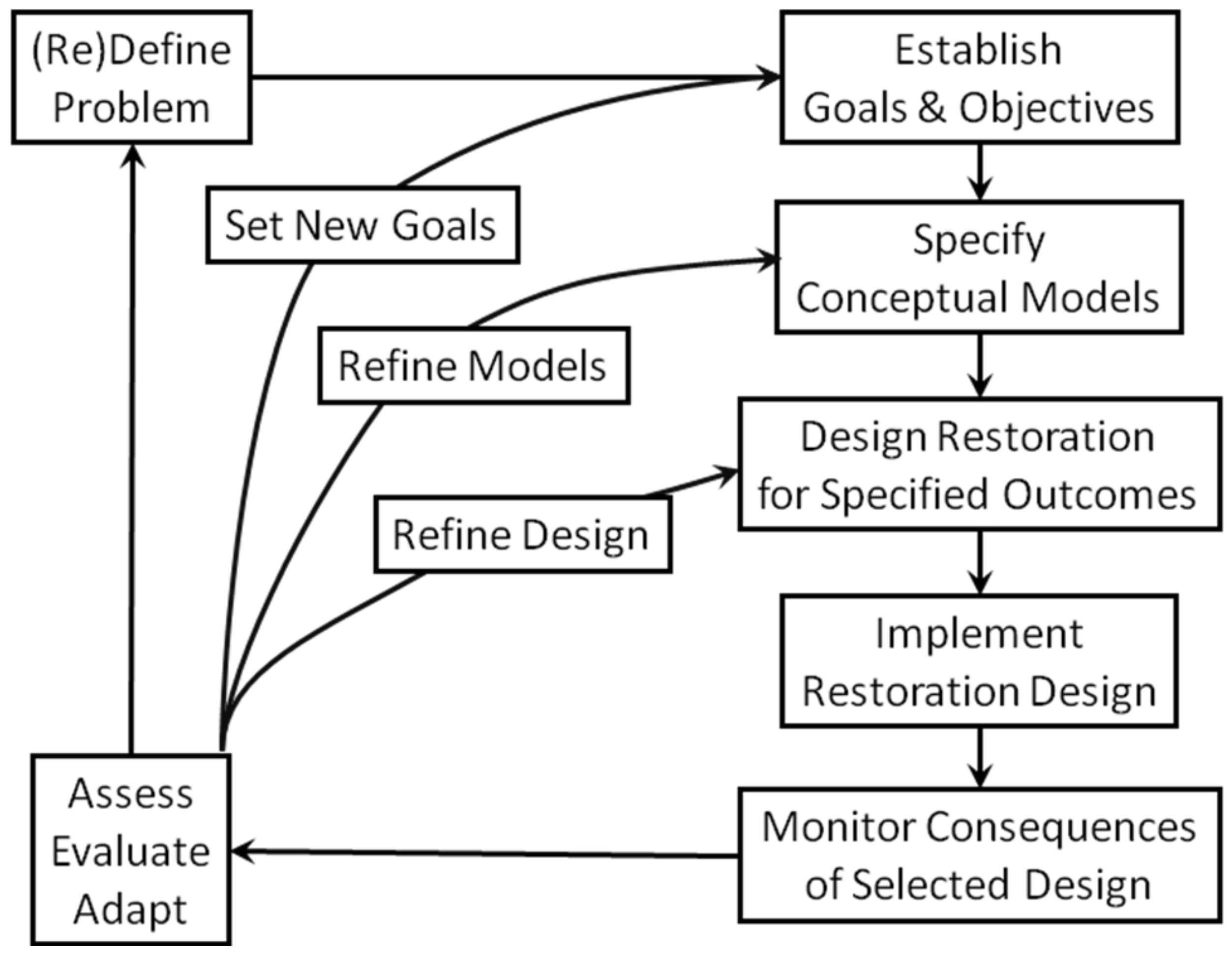


figure **3.1**

Lower Columbia Design Guidelines

Adaptive Management Cycle

PWA Ref# 2023

ESA PWA

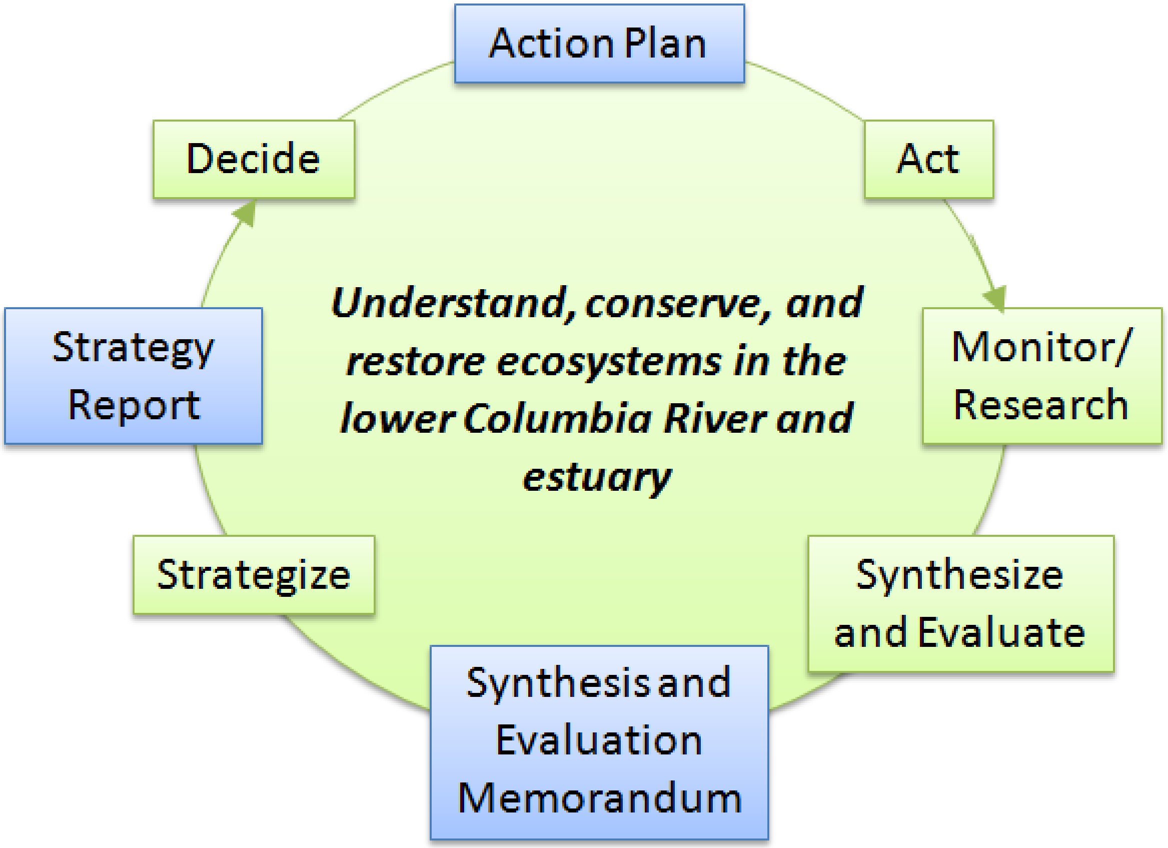


figure **3.2**

Lower Columbia Design Guidelines

CEERP Adaptive Management Framework

PWA Ref# 2023-00

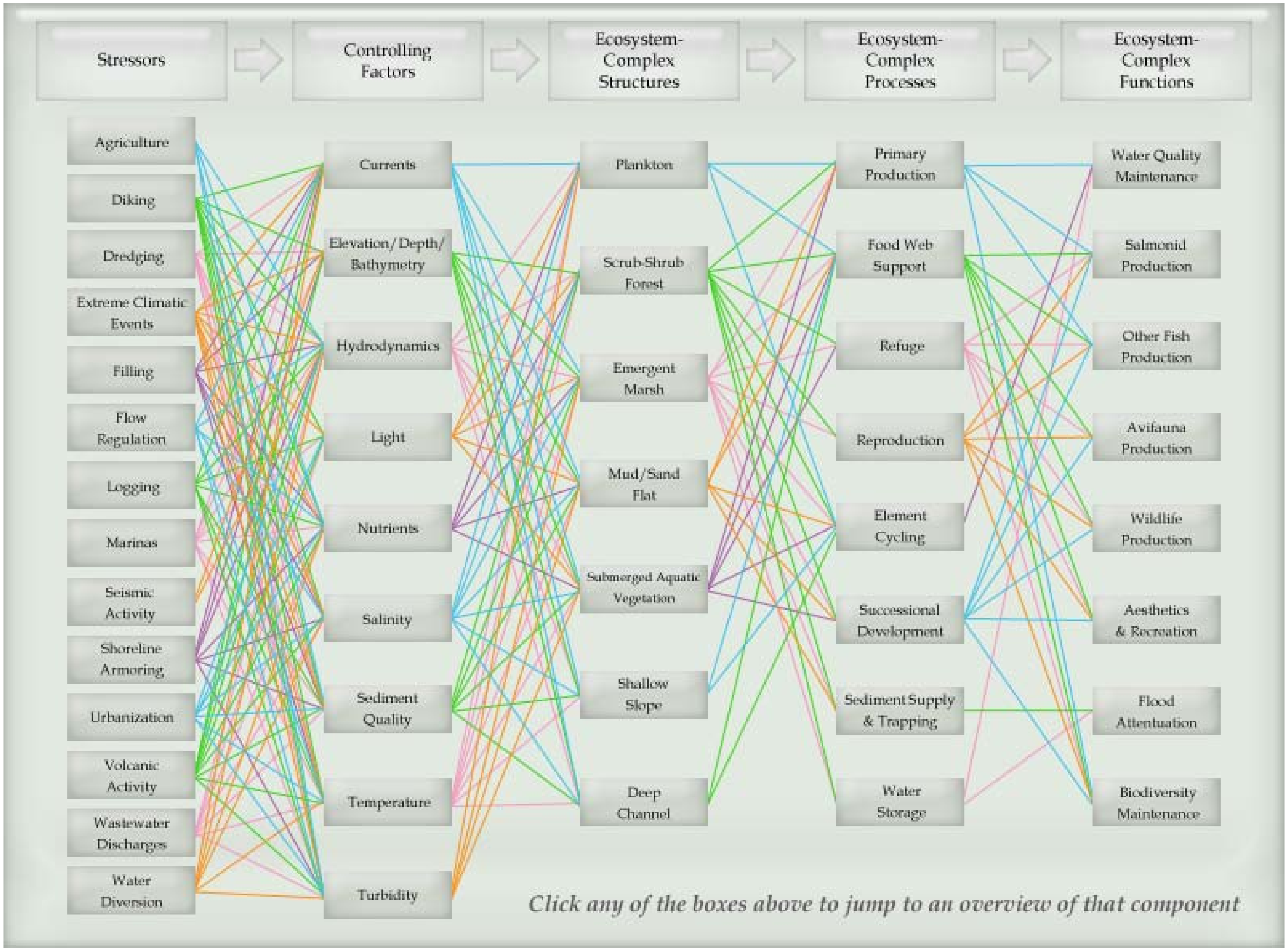
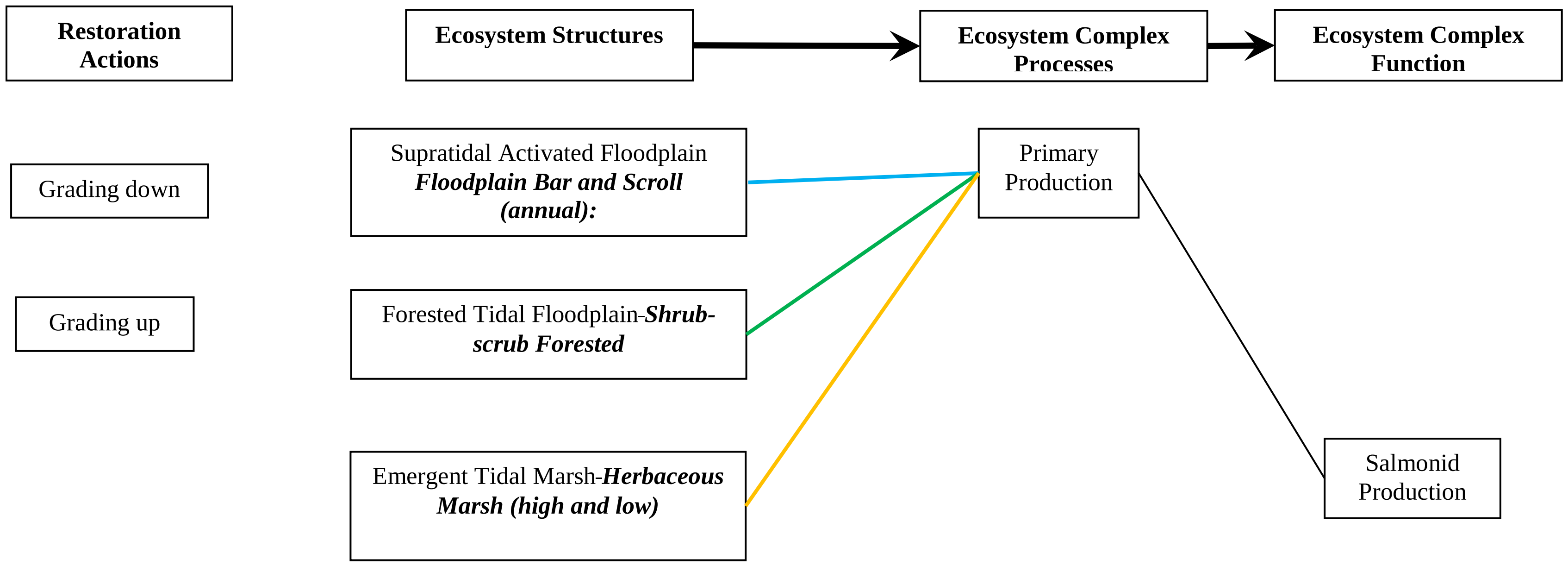


figure **3.3**

Lower Columbia Design Guidelines

PNNL Conceptual Model

PWA Ref# 2023-00



Restoration Actions

Ecosystem Structures

Ecosystem Complex Processes

Ecosystem Complex Function

Grading down

Grading up

Supratidal Activated Floodplain ***Floodplain Bar and Scroll (annual):***

Forested Tidal Floodplain-***Shrub-scrub Forested***

Emergent Tidal Marsh-***Herbaceous Marsh (high and low)***

Primary Production

Salmonid Production

figure ***3.4***

Lower Columbia Design Guidelines

Reduced Macrodetrital Inputs

PWA Ref# 2023-00

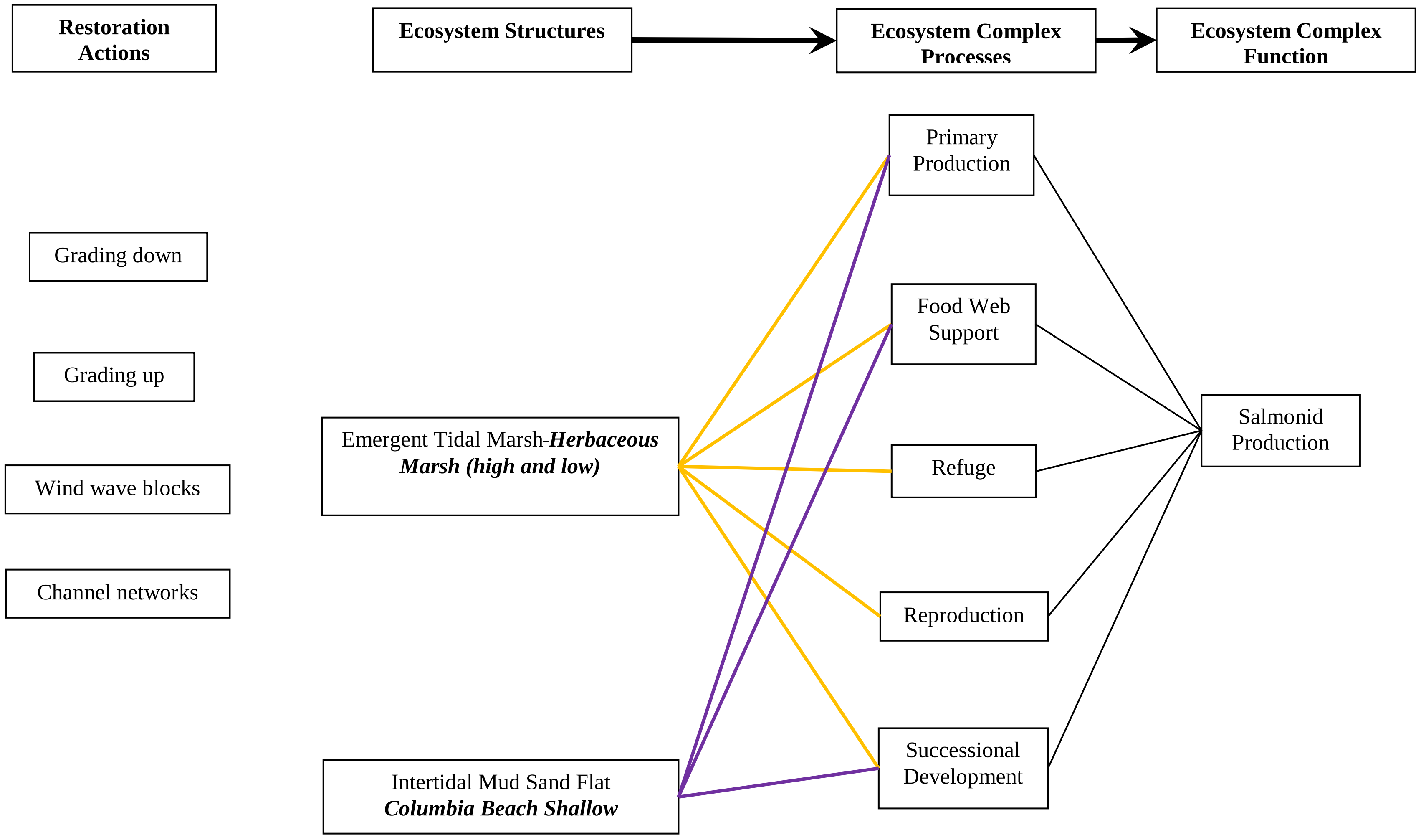


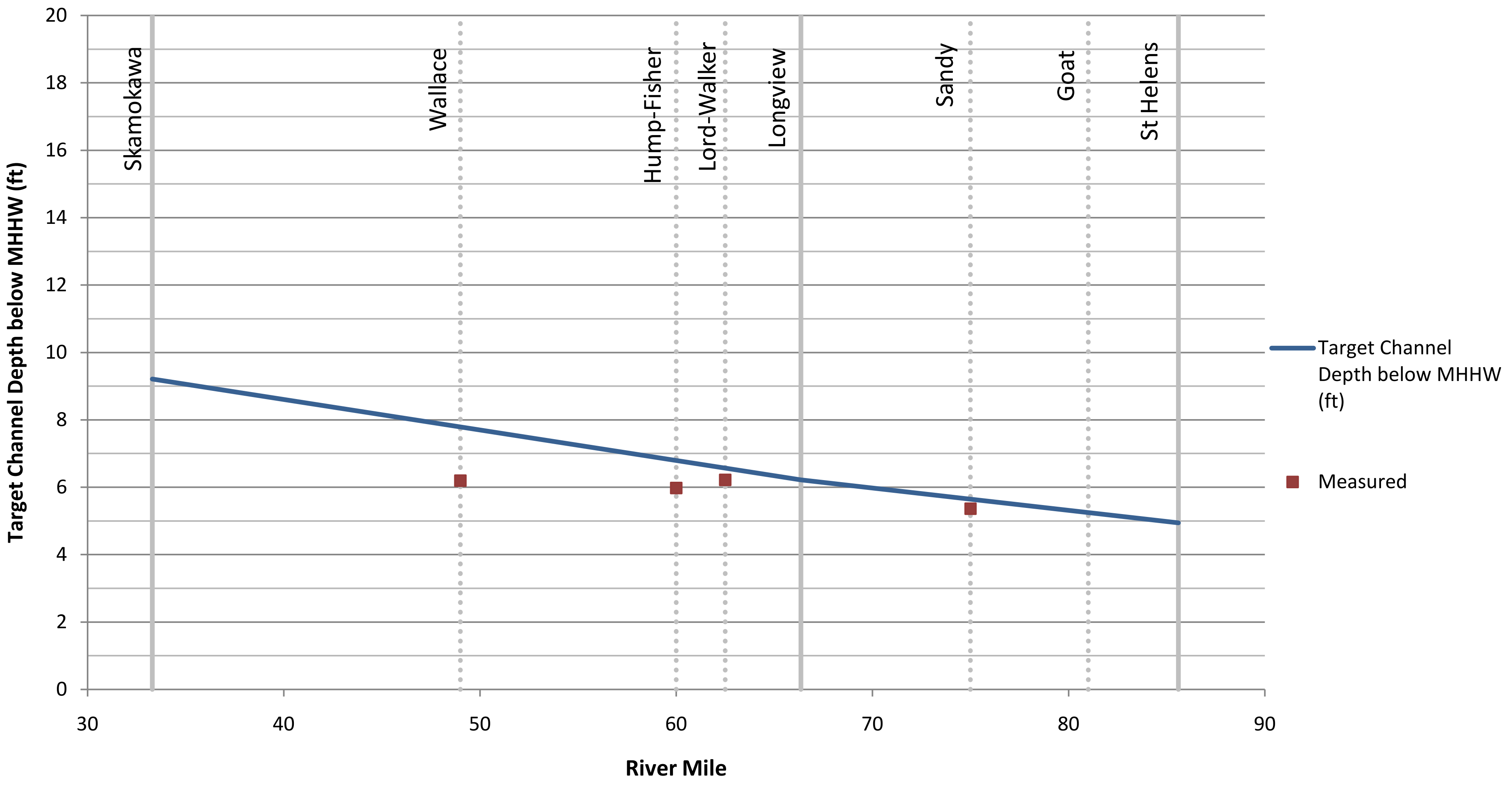
figure **3.5**

Lower Columbia Design Guidelines

Reduced Off-Channel Habitat

PWA Ref# 2023-00

\\sfo-file01\esapwa\Data\projects\2023_Lower_Columbia_Design_Guidelines\Report\Phase 2\FINAL\New Figs\3.5.docx



Notes: Target channel depth is approximately 1.6 ft (or 0.5 m) below MLLW
Source: River miles from USACE

figure **4.1**

Lower Columbia Design Guidelines

Target Channel Depth with River Mile

PWA Ref #: 2023

ESA PWA

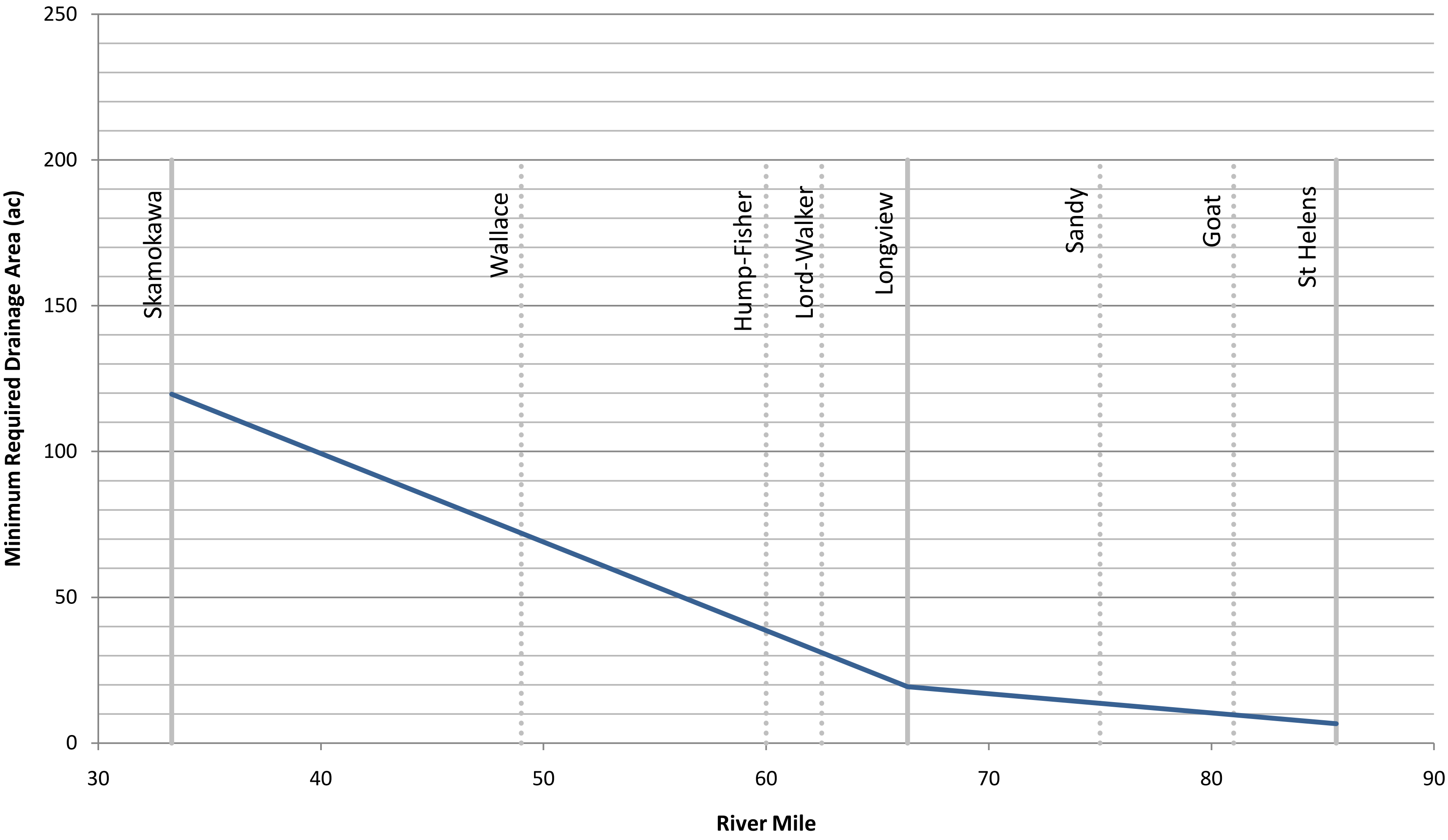


figure **4.2**

Lower Columbia Design Guidelines

Minimum Drainage Area to Support Target Depth Channels

PWA Ref #: 2023

ESA PWA