FEASIBILITY ASSESSMENT FOR SALT MARSH RESTORATION AT POSSESSION PARK, WHIDBEY BASIN

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Photos by WA Dept of Ecology and Aundrea McBride

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INTRODUCTION AND OBJECTIVES

The purpose of this Feasibility Assessment is to determine if landscape and land use conditions at Possession Park could support the restoration of a small historic pocket estuary to saltwater and tidal influence while concurrently maintaining the existing land use. This feasibility assessment was initiated to direct Port of Everett mitigation funds toward nearshore restoration that would benefit ESA-listed Chinook salmon (Oncorynchus tshawytscha) of mixed origin. Possession Park is located at the southern end of Whidbey Basin on south Whidbey Island (Figure 1). Possession Park was chosen as a potential restoration site because it:

- Is located within an area of assumed mixed juvenile Chinook salmon stock use;
- Is on a juvenile salmon migration corridor;
- Is near the Snohomish River which has source populations of ESA-listed Chinook salmon;
- Has intact, though isolated, tidal channel marsh habitat; and
- Has landowners willing to explore the idea of habitat restoration (Port of South Whidbey).

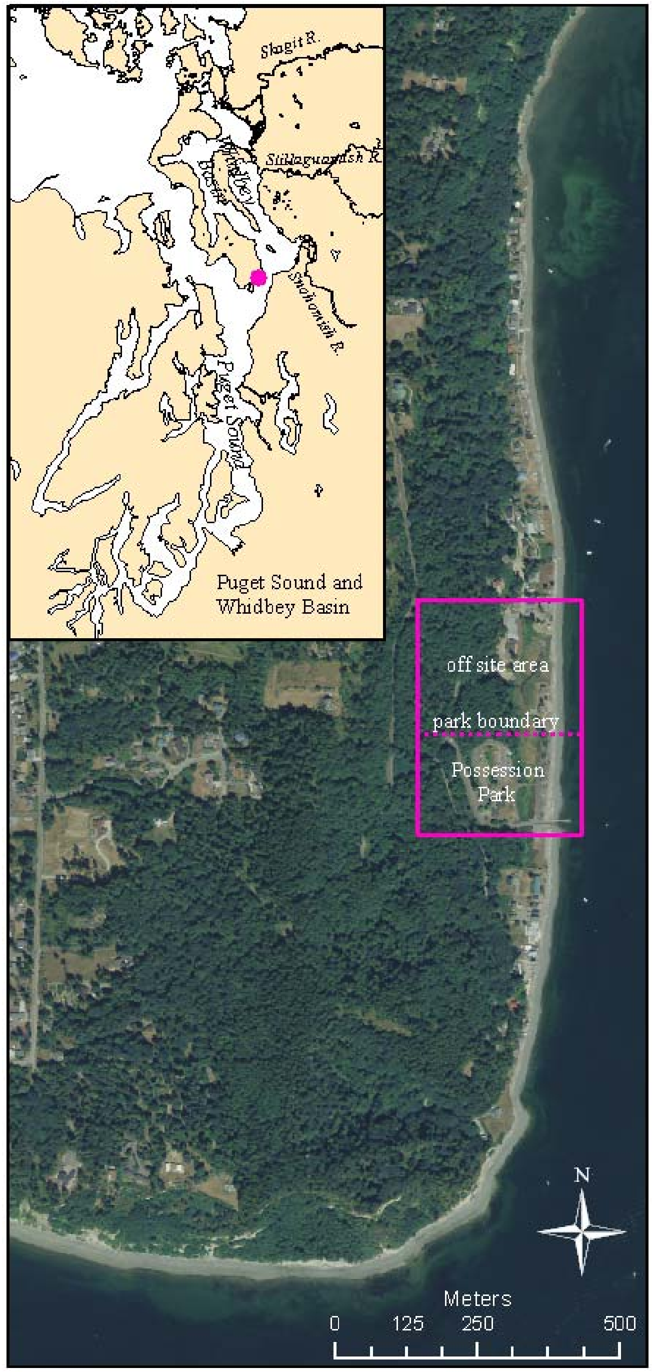

Figure 1. The area under consideration for restoration is the wetlands within Possession Park and, as a separate restoration scenario, the wetlands north of and adjacent to the park. The adjacent area is not owned by the park.

Efforts are underway throughout Puget Sound to develop and implement actions in the nearshore that will benefit nearshore ecosystems and support salmon recovery efforts. Skagit Bay research since 2002 shows that wild fry migrant juvenile Chinook salmon extensively use non-natal pocket estuaries (Beamer et al. 2003). Non-natal pocket estuaries are small estuaries within the landscape that are not associated with salmon-bearing watersheds. Chinook salmon utilize pocket estuaries during the early period of nearshore rearing (Beamer et al 2003 & 2006). This use of pocket estuaries allows them to grow faster and avoid predation by other fish (Beamer et al. 2003 & 2005). Pocket estuaries are also important for maintaining the diversity of Chinook salmon life history strategies and for partially relieving overcrowding at natal river estuaries (Beamer et al. 2005). Human impacts to these habitats region-wide have resulted in fewer, smaller, and more-dispersed pocket estuaries than historically (Beamer et al. 2005 & 2006, McBride et al. 2009). Pocket estuary restoration is important for Puget Sound Chinook salmon population recovery. This feasibility assessment is one part of the regional efforts to restore nearshore habitat for salmon recovery.

Restoration at Possession Park means reconnecting the isolated marsh to tidal inundation from Possession Sound. We examine two scenarios for restoring tidal influence to the marsh: 1) reconnecting only the marsh area within Possession Park; and 2) reconnecting the marsh area within the Park and immediately adjacent to the Park (Figure 1). Restoration scenarios, project objectives, and constraints for implementing restoration at Possession Park were developed by the landowner (Port of South Whidbey) and Skagit River System Cooperative (SRSC). Successful restoration will:

- Restore landscape processes to the extent possible. This means maximizing tidal range and volume; restoring natural freshwater inflow, fluvial deposition and erosion, and estuarine mixing; and restoring or protecting wave erosion and deposition processes. Process-based restoration provides the greatest likelihood of naturally-sustainable habitat restoration.
- Maximize benefits to juvenile Chinook salmon and other fish.
- Protect existing eelgrass beds and existing forage fish spawning beaches.
- Conserve existing sediment and water quality.
- Maximize the potential for habitat function and sustainability through predicted sea level changes over the next 100 years.
- Preserve Park facilities and operations.
- Place no long-term or permanent restrictions on boating or fishing (including shore casting) that do not already exist.
- Minimize or prevent any new required long-term maintenance of Park facilities after restoration.

This is a technical document to provide landowners, restoration practitioners, and restoration funders with necessary information to make decisions about process-based restoration at Possession Park. The feasibility assessment will include an assessment of potential fish use for a restored pocket estuary, a determination of how much pocket estuary habitat could be gained (restoration potential), and an analysis of the sustainability of the two possible restoration scenarios.

POTENTIAL FISH USE OF A RESTORED SITE

Nearshore restoration, and in particular pocket estuary restoration, is important for the recovery of threatened Chinook salmon. Other fish species also use pocket estuaries. We predict that fish, including juvenile Chinook salmon, will use a reconnected marsh at Possession Park based on fish assemblage data from similar and nearby sites. Fish will re-colonize the site once adequate local connectivity to Possession Sound and adequate water depth within the restored marsh are achieved. Local connectivity refers to the accessibility of habitat to fish and is defined by channel depth at high tide of the inlet channel. A deeper channel will have higher connectivity than a shallower channel. Local connectivity is synonymous with the concept of ‘habitat opportunity’, which is defined as the ability of juvenile salmon to “access and benefit from the habitat’s capacity” (Simenstad 2000, Simenstad and Cordell 2000).

The details of how connected, how often, and when within the year this happens all play a role in which fish are present. Therefore, the fish assemblage predicted to use the restored site is somewhat dependent on the type of habitat that forms once reconnected (‘deep’ lagoon vs. ‘shallow’ tidal channel/marsh), the elevation of the inlet channel (local connectivity), and environmental variables such as water temperature and salinity. We use existing data to predict the fish assemblage likely to occupy a restored Possession Park marsh and the seasonality of fish use in the marsh. We also examine the origin of Chinook salmon expected to use a restored pocket estuary at Possession Park and likely seasonal patterns of habitat use.

Fish Assemblage

To predict the general seasonal fish assemblage for a reconnected Possession Park pocket estuary (scenario 1 or scenario 2), we can refer to a compilation of results from three years of fish sampling in pocket estuary habitats throughout Skagit Bay (both lagoon and tidal channel/marsh types of pocket estuaries) (Beamer et al. 2007). For shallow intertidal habitat in lagoon-type pocket estuaries with salinity greater than 20 parts per thousand (ppt), juvenile chum (Oncorynchus keta) and wild Chinook salmon dominate the assemblage early in the year, followed by Pacific staghorn sculpins (Leptocottus armatus) in late spring, shiner perch (Cymatogaster aggregate) and three-spined sticklebacks (Gasterosteus aculeatus) in summer, and surf smelt (Hypomesus pretiosus) in early fall. Pacific staghorn sculpin are the dominant sculpin species in Puget Sound estuaries with salinities >20ppt (Figure 2) (Beamer et al. 2007).

Juvenile Chinook salmon use pocket estuaries for rearing habitat. Juvenile chum are also abundant inside pocket estuaries, but don’t show the same pattern of preference for this kind of habitat as Chinook (Beamer et al. 2006). Juvenile staghorn are a dominant species in lagoons and tidal channel habitats. They are predatory fish, but the juvenile staghorns found in shallow lagoons or tidal channels are too small to prey on juvenile salmon (Beamer et al. 2003). Shiner perch use shallow, protected habitats like lagoons and tidal channels for birthing their young and for nursery habitat (Wydoski and Whitney 1979). Shiner perch are an important forage species for birds, bull trout (Salvelinus sp. (malma or confluentus)), and other predators. Shiner perch often account for most of the fish biomass in nearshore habitats. Three-spined sticklebacks can live their entire life cycle in a lagoon or tidal channel habitat. They are a forage species for birds, coho, and bull trout. Juvenile surf smelt use lagoons and tidal channels as nursery habitat. Surf smelt are an important forage fish for salmon, other fish and wildlife (birds, marine mammals).

We can improve the post-restoration prediction of the fish assemblage at Possession Park by using two “space” (different site) for “time” (the future restored Park) substitution tools. The first tool uses fish assemblage data collected near Possession Park at Elger Bay to represent a pocket estuary that is a ‘tidal channel and marsh’ type pocket estuary like the theoretical restored Possession Park pocket estuary. Results from Elger Bay are likely similar to other pocket estuaries of the same type. Based on Elger Bay data, we can expect juvenile salmon, shiner perch, stickleback, staghorn sculpin, starry flounder (Platichthys stellatus), and arrow goby (Clevelandia ios) to use the restored Park (Kagley et al. 2007). Few smelt were found at Elger Bay compared to the compilation assemblage from Skagit Bay shown in Figure 2.

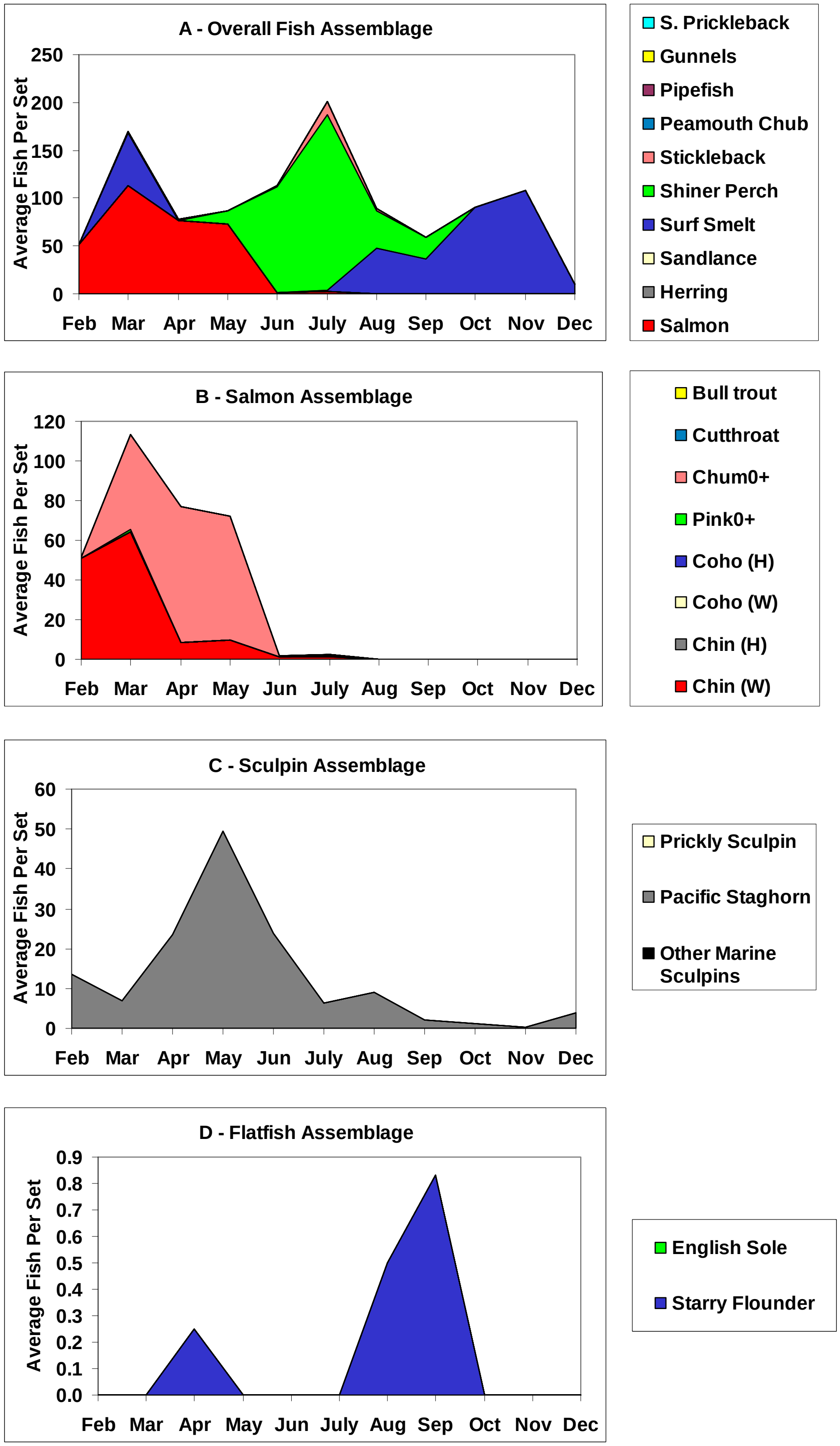

Figure 2. Seasonal fish assemblages for shallow intertidal habitat in lagoon-type pocket estuaries with a salinity greater than 20 ppt (from Beamer et. al. 2007).

The second tool gives a sense of the difference in fish assemblage between sites with the same habitat type, but different tidal elevation, which translates to different degrees of local connectivity and accessibility for fish. Research in the Skagit River delta compared fish assemblage at native marsh blind channel sites of high and low elevation (Beamer et al. 2009). Based on this example we would expect the following assemblage: juvenile salmon, shiners, staghorns, sticklebacks, and juvenile smelt. The difference between high and low elevation sites is that the low elevation sites had shiner perch but not stickleback, while the reverse was true for high elevation sites.

Based on the compilation data, data from a nearby similar site (Elger Bay), and the high elevation *vs.* low elevation marsh comparison, we can conclude that fish will use a restored and connected pocket estuary at Possession Park (scenario 1 or 2) and that the assemblage of fish will include juvenile Chinook salmon, other juvenile salmon, shiner perch, staghorns, sticklebacks, and possibly juvenile smelt. No surf smelt spawning is documented near Possession Park, so use of the restored estuary by smelt is questionable. Also, following the pattern of the high elevation site, Possession Park will likely have more sticklebacks and fewer shiner perch.

Juvenile Chinook Salmon Habitat Use and Origin

The Chinook salmon questions for this assessment center on whether and when juvenile Chinook salmon will use the restored site directly, and if so, from which rivers they originate. Chinook prefer pocket estuary habitat over adjacent intertidal habitat and are more prevalent early in the year in pocket estuaries (Figure 3) (Beamer et al. 2003 & 2006). Thus far, our research has shown that differences in annual Chinook salmon smolt population size and position within the larger landscape relative to source salmon populations influence juvenile Chinook salmon use of pocket estuaries (Beamer et al. 2006). We generally observe higher densities of juvenile Chinook salmon at pocket estuary sites nearest natal Chinook river mouths. We also find that corridor pocket estuary sites (those distant from any natal river) within the Whidbey Basin have consistent juvenile Chinook salmon use, suggesting that corridor sites are also important in the nearshore landscape as salmon travel from their natal rivers to ocean environments. Possession Park is a corridor site for Skagit River and Stillaguamish River fish, and is near the source population from the Snohomish River. Based on fish sampling results from throughout Whidbey Basin, we would expect juvenile Chinook salmon to

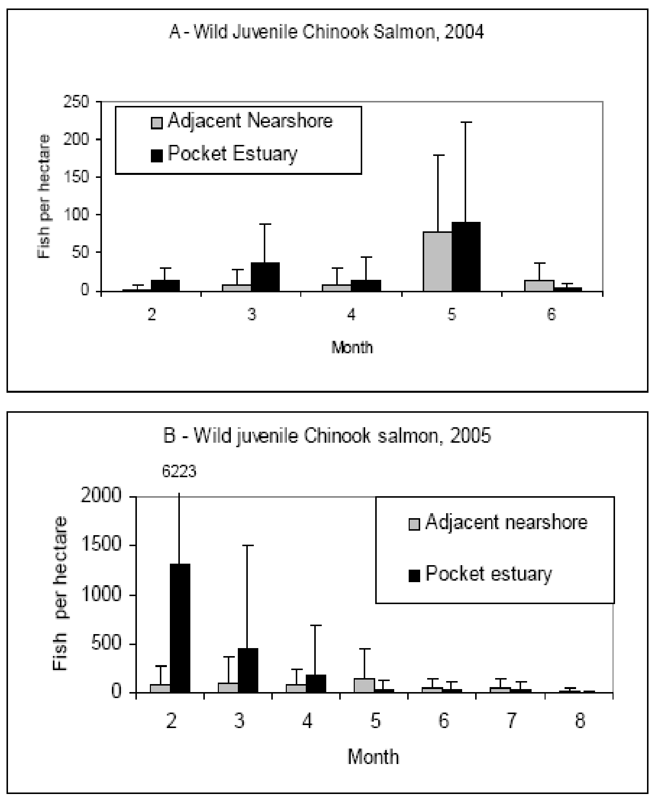

Figure 3. Average wild juvenile Chinook density for 2004 (19 sites) and 2005 (6 sites) pairs of accessible pocket estuary and adjacent beach habitat in Whidbey Basin. Pocket estuary habitat was preferred by the fish (from Beamer et al. 2006).

use Possession Park beginning in February and continuing through April or May, assuming the site were restored with adequate local connectivity (Figure 3) (Beamer et al. 2007 & 2009).

Tissue samples were collected from 19 juvenile Chinook salmon caught on beaches near Possession Park during 2008.[1] The samples were used to determine fish origin based on genetic analysis of DNA (David Teel, NOAA Fisheries, unpub. data). The results show that Skagit River origin Chinook salmon are likely to use the site (if restored with adequate local connectivity) (Figure 4). In addition to Skagit River Chinook salmon, other Chinook populations are likely to use the site, including those from the Skykomish River, South Sound/Hood Canal, and Canada. The source rivers nearest Possession Park make up the largest percentage of the population (Skagit and Skykomish). The Skagit River has the largest population size, including a fry migrant juvenile life history type, which is known to utilize pocket estuaries (Beamer et al. 2003). The results also show a sizable proportion of the Chinook salmon (20% in beach areas near the Possession Park site) as being from a Chinook stock group called "South Sound Falls/Hood Canal." Snoqualmie River origin Chinook salmon look genetically similar to the South Sound Fall/Hood Canal grouping, thus, some (or many) of the Chinook salmon assigned to the South Sound/Hood Canal grouping shown in Figure 4 may be from the Snoqualmie River, a tributary of the Snohomish River which is near Possession Park.

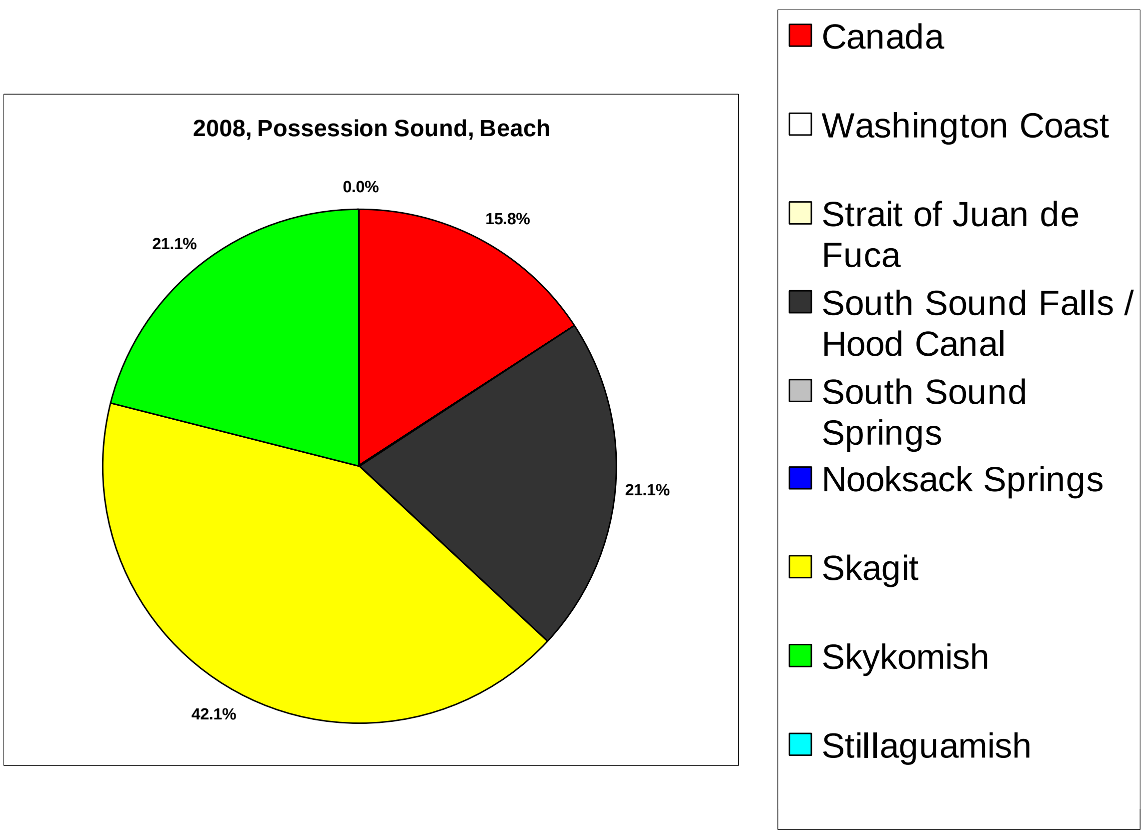

Figure 4. Composition of the origins of juvenile Chinook salmon caught near the study site.

RESTORATION POTENTIAL

We developed an initial estimate of restoration potential—the ‘footprint’ estimate—by researching historic shoreline conditions and examining current elevation, marsh configuration, and land use at the site. The restoration potential equals the area of all uplands and wetlands that could be tidally inundated and connected to create a functional pocket estuary. Upland with structures on it is not considered potentially restorable.

Historic Conditions

We researched historic maps, historic aerial photos and topographic data in LiDAR datasets to reconstruct the historic footprint of the marsh. Historically, the site at Possession Park was a part of a long, linear lagoon behind a spit with a possible opening at its north end (Figure 5). The U.S. Coast and Geodetic Survey (USCGS) map (T-sheet in Figure 5) is an approximation of the shoreline conditions sketched by mappers in the 1880s. The best available interpretation of the old maps and the accompanying field notes from surveyors shows the historic estuary occupied a section of shoreline approximately 667m long and 2.76ha in area (Collins and Sheikh 2005). A sinuous tidal channel was mapped by USCGS down the center of most of the marsh. The exact

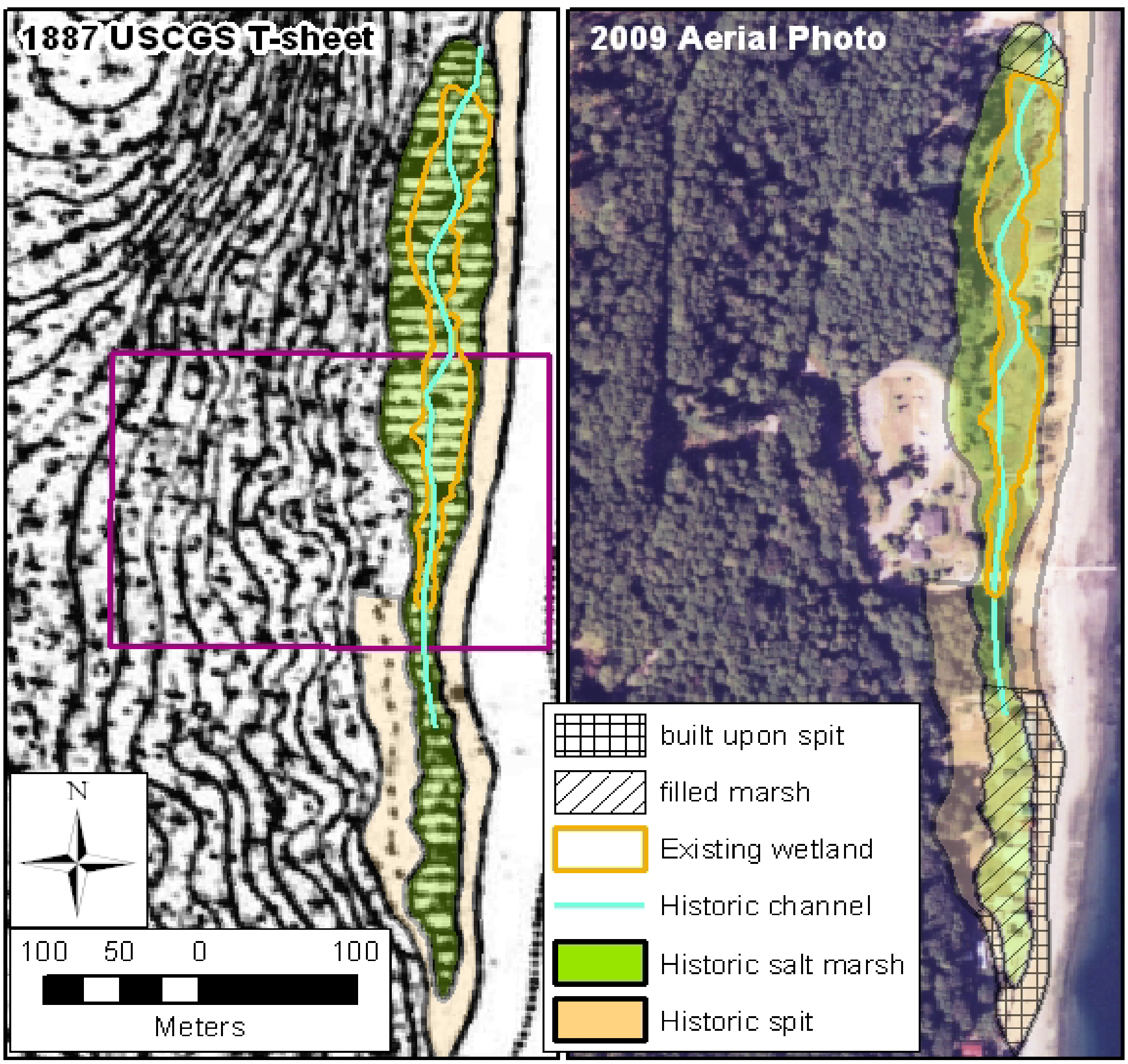

Figure 5. U.S Coast and Geodetic Survey t-sheet (1887), with map interpretation showing likely marsh and backshore areas (after Collins and Sheikh 2005), and habitat loss (displayed over photo). Purple line marks Park boundary.

[1] Ge
Chi... salmon by spatial strata.

location of the opening of the channel into Possession Sound is vague on the historic map, but was likely at the north end of the spit, based on longshore drift direction (to the north). The sinuous form of the historic and existing channel probably indicates moving water and tidal erosion, further supporting the assumption that the marsh was connected to Possession Sound. The spit depicted in the t-sheet extends an additional 600 meters north of the marsh. The historic tidal channel may have followed the edge of the spit, similar to existing sites like Harrington Lagoon. The channel may also have been periodically cut off from Possession Sound by beach sediments deposited during storms.

Current Conditions

Currently, Possession Park includes part of an isolated freshwater-to-brackish wetland behind a backshore berm (Figures 6 & 7). The entire wetland is 371m long and 0.79ha in area. The portion of the wetland area inside Possession Park is 188m in length and 0.34ha in area. Water within the marsh is essentially ponded; however, the morphology of the open water areas is a sinuous channel, a relic of the historic tidal channel when water flowed in and out of the marsh. The marsh and channel are almost all below Mean High Water (MHW) in elevation (Figure 8). Undercut banks and water-flattened vegetation indicate that the marsh surface is sometimes wet. Higher water (i.e. on the marsh surface in addition to in the channel) may be freshwater runoff, but is more likely a combination of freshwater runoff, marine storm surge overtopping the berm, and tidal groundwater infiltrating the marsh through a permeable berm.

A small amount of freshwater enters the marsh via a small stream at the south end of the marsh. There is no indication of the stream in the historic record, but that is likely a mapping data resolution issue and not definitive evidence of the absence of a stream in the past. The roadside ditch adjacent to the Park entrance road flows into the drainage. Flow is intermittent (depending on storms and saturated ground). The marsh also receives freshwater from runoff, including parking lot runoff. Cattails, a salt-intolerant species, grow at the south end of the marsh, where the stream trickles in.

The backshore berm is what USCGS mapped as a spit in 1880. The crest of the berm is approximately 10.5 feet above Mean Lower Low Water (MLLW), which is within the reach of extreme high tides and storm surges. Storm surges occasionally overtop the berm and deposit small driftwood in the marsh (Figure 6). The lowest point on the berm is near the foot bridge. Picnic tables and a walking/park vehicle trail occupy the top of the berm. Driftwood accumulates two or more logs deep along the beach face (Figure 6).

Figure 6. Top row: Sinuous channels and freshwater marsh at Possession Park with emergent marsh vegetation, including cattails (foreground of upper right photo). Center row: Small- and medium-sized driftwood in the marsh near the foot bridge, including recently-deposited driftwood ‘pavement’ at the low point on the berm (center right photo). Bottom row: Beach face and berm with large driftwood and picnic tables (for scale).

Figure 7. Field map of the existing marsh at Possession Park and adjacent areas. An open water channel meanders through freshwater emergent wetland vegetation (cattails, water parsley, rushes, and sedges). Driftwood is abundant in the marsh. Potential outlet channels for on-site restoration (scenario 1) and total marsh footprint restoration (scenario 2) are shown crossing the existing berm. Orange dot indicates sediment sample location.

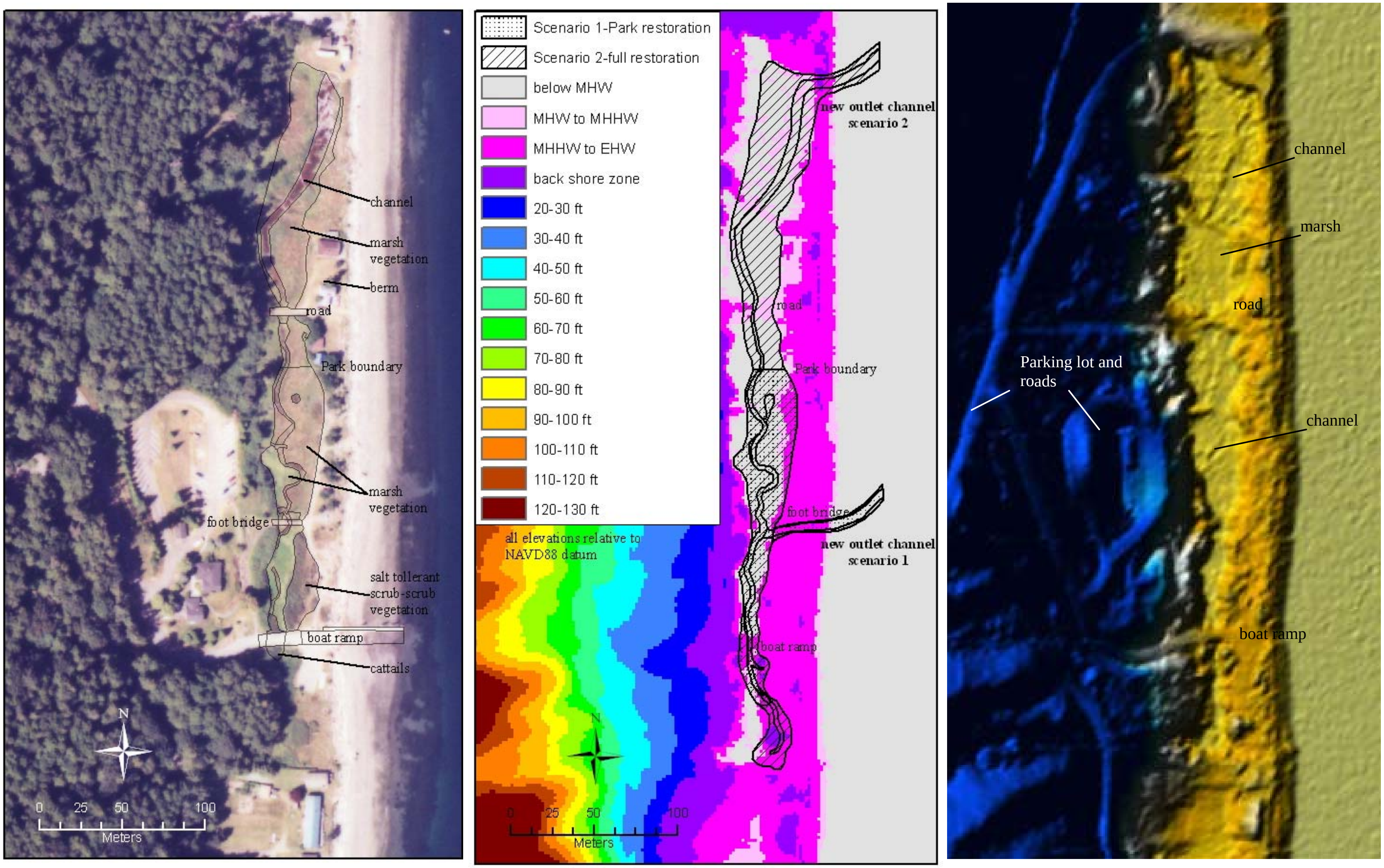

Figure 8. Aerial photo of the Park and adjacent wetland (left); corresponding LiDAR imagery (Island County 2002) depicting land elevations overlain with potential restoration scenarios (center); and a hill shade rendition of the same LiDAR imagery (right). The hill shade clearly shows features visible in the photo such as roads, channels, and the boat ramp. We used existing conditions and LiDAR data to arrive at the two restoration scenarios. Though historic conditions were a guide in identifying Possession Park as a potential restoration site, current conditions, including elevation data from LiDAR, were the basis for developing restoration scenarios. Inlet locations were based on the existing low spot on the berm in the Park and on the likely historic configuration of the inlet at the north end of the berm.

RESTORATION FEASIBILITY

Possession Park was historically a pocket estuary with some degree of connection to Possession Sound, therefore we know that landscape processes historically created and maintained a pocket estuary. Surface area still exists that could become pocket estuary habitat again. We next apply results from a hydrodynamic model and sediment sampling to determine if breaching the berm would, in fact, inundate the marsh, and if that breach would create a pocket estuary with adequate connectivity and sustainability by natural processes.

Tidal Inundation (Will the site get wet?)

Hydrodynamic model results indicate that the existing marsh surface would be flooded by high tides once the berm is breached (Figures 9 and 10). The marsh would also drain completely, or nearly so, at low tide. The model is based on existing marsh elevations as represented in Island County LiDAR data, tidal patterns for Whidbey Basin, and a schematic cross section for an inlet channel (Figure 11).

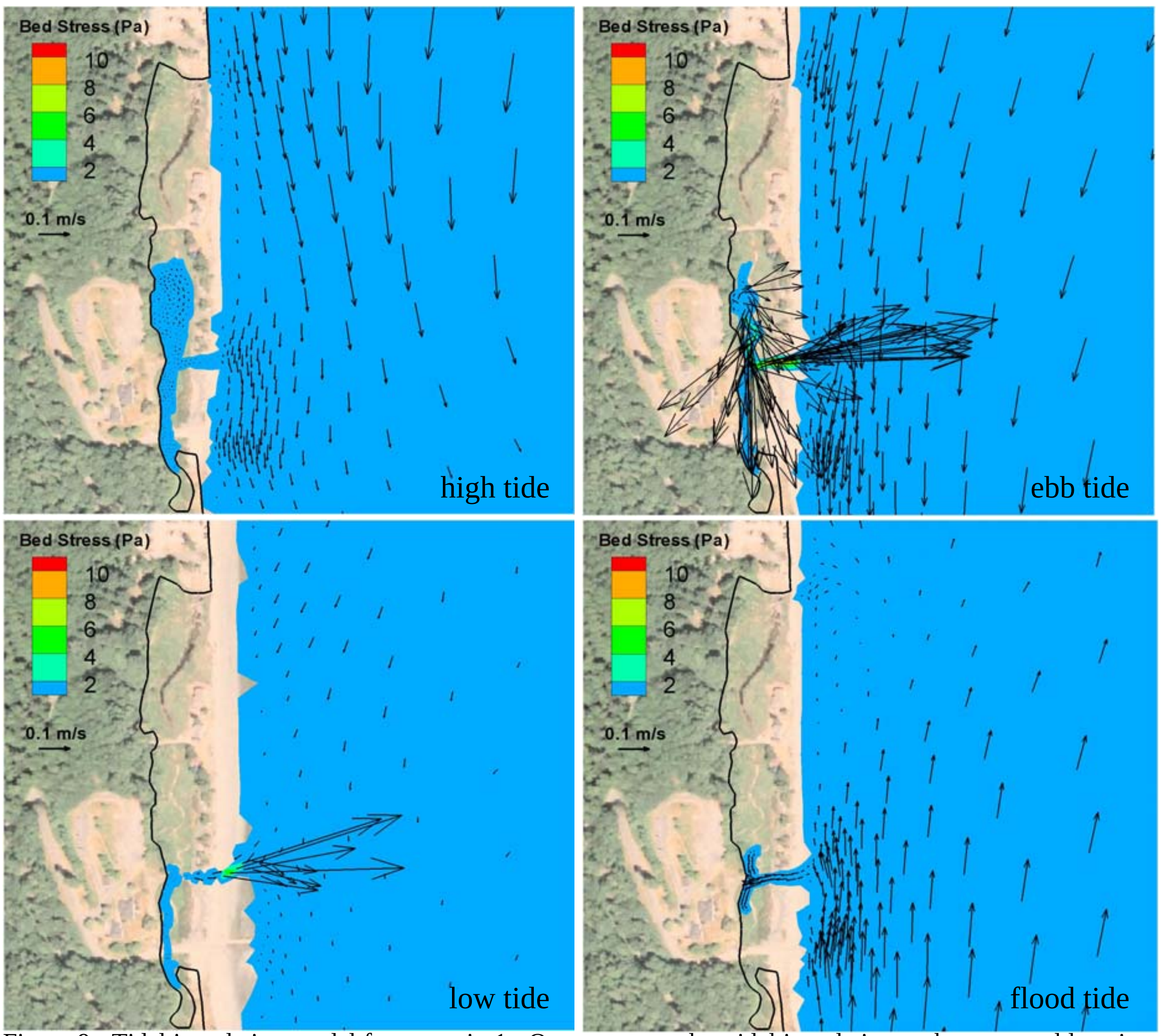

Figure 9. Tidal inundation model for scenario 1. Once connected to tidal inundation at the proposed location, the entire existing marsh surface would be flooded at high tide. Longer arrows indicate higher flow velocity. Arrow direction indicates tidal flow direction across the marsh surface. Colors indicate bed shear stress—maximum occurs at the inlet channel during ebb tide. The diagrams represent water on the marsh surface and do not represent bridges or other built structures.

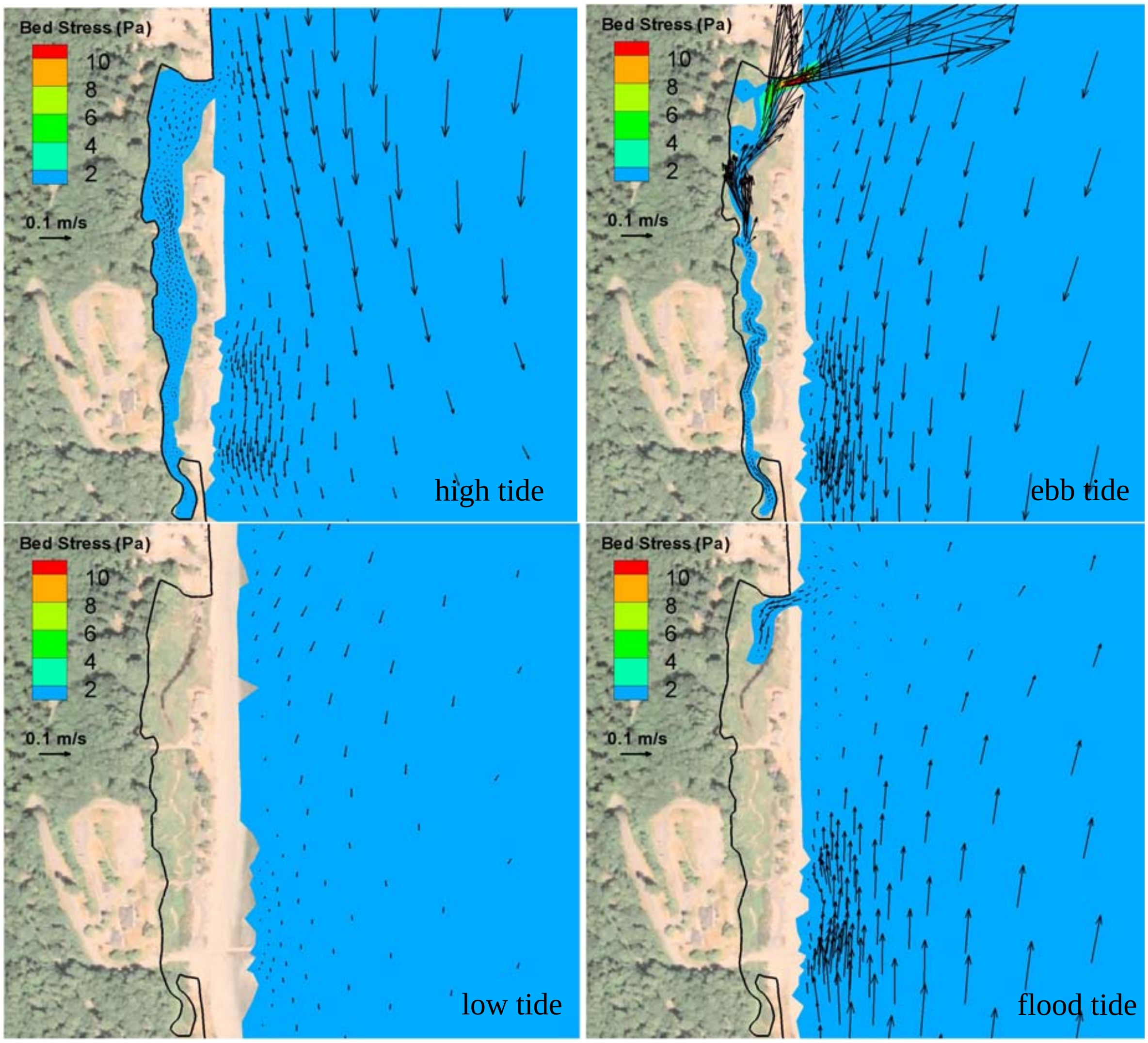

Figure 10. Tidal inundation model for scenario 2. Once connected to tidal inundation at the proposed location, the entire marsh surface of the existing marsh would be flooded at high tide. Longer arrow length represents higher tidal velocity. Arrow direction indicates tidal flow direction. Colors indicate bed shear stress—maximum bed occurs at the inlet channel during ebb tide. The diagrams represent water on the marsh surface and do not represent bridges or other built structures.

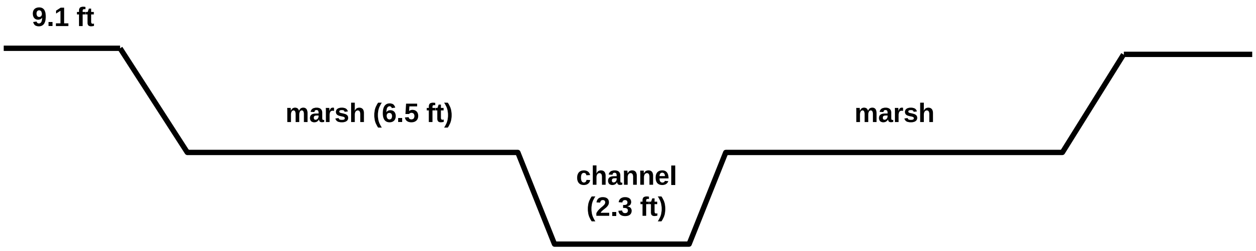

Figure 11. Schematic cross section of a tidal channel and marsh elevations within a pocket estuary used for hydrodynamic model runs.

Inlet Sustainability (Will the channel stay open?)

Restoration of pocket estuary habitat depends on the sustainability of an inlet channel. Sediment moving along the beach outside the pocket estuary can be deposited in the inlet channel at a rate and of a size that exceeds the potential tidal energy in the channel to clear out those sediments. If this is the case, then longshore sediment drift will prevent a pocket estuary from maintaining a connection to open water. Therefore, in pocket estuary habitat restoration design the inlet must be designed such that potential energy in the channel will be high enough to move the size and volume of sediment likely to land in the channel.

The typical approach for evaluating tidal inlets is to design an inlet channel size based on (predicted) tidal prism. Several researchers have established and documented the hydraulic geometry between tidal prism and channel cross-sectional area (i.e. O'Brien 1931, Byrne et al. 1980). All these models were developed for designing large tidal inlets (navigable) on sandy coasts. Restoration workers in San Francisco Bay tidal marshes revised hydraulic geometry relationships for smaller systems (2ha to 5,700ha) (Williams et al. 2002). Though the San Francisco Bay examples are closer to a pocket estuary scenario like Possession Park (0.34 to 1.01ha), the hydraulic geometry developed in San Francisco Bay is still for larger-area and finer-grained sediment sites and for a smaller tidal range than in Puget Sound. Our situation is different from both the 'navigable' and the 'San Francisco' types of models because we are evaluating a small channel and marsh along a gravel coast where longshore transport could dominate channel power/tidal prism because the grain size is coarse, the channel flow is highly variable, and sediment input to the channel via longshore transport could be larger than the total channel volume. There are no hydraulic geometry relationships established for sites like Possession Park.

We decided to examine the question of restored channel stability using two approaches:

1. We quantified beach face sediment grain size distribution and analyzed critical shear stress within the tidal inlet using a hydrodynamic model developed for the proposed channel and marsh configurations; and
2. We compared the proposed pocket estuary channel shape and size to similar, functioning pocket estuaries in the Whidbey Basin to make some rudimentary estimate of hydraulic geometry relationships for small pocket estuaries with sustainable inlets within the Whidbey Basin and greater Puget Sound.

<u>Sediment Grain Size and Hydrodynamic Model Analysis</u>

The first method for evaluating channel stability examines sediment grain size on the beach, determines the shear stress necessary to move those sediments (resistance to erosion), and then compares that shear stress to the erosive power in the proposed inlet channel as predicted by a hydrodynamic model. Erosive power equals the bed shear stress on sediment grains, resulting from water velocity in the channel as the tide ebbs. There are many nuances to sediment and water interactions within a pocket estuary and particularly in its inlet channel. This approach does not consider freshwater inputs, sediment input to the marsh, or the sporadic, event-driven nature of sediment movement up- and down-drift alongshore (parallel to the shoreline). We will, however, be able to give a general estimate of how stable the channel is likely to be compared to the sediment known to be moving alongshore at the site.

We collected bulk grain size samples at approximately MHW (mean high water). We attempted to sample at a beach elevation within the most active transport zone, where wave energy is highest and most persistent. At the time we sampled (March) the beach was coarsest between approximately Mean Higher High Water (MHHW) and Mean Higher Low Water (MHLW), indicating the highest energy on the beach face was in that zone. The elevation range for the coarsest sediments will vary seasonally and with erosion events. Overall, the Possession Park beach face was very poorly sorted (many grain sizes mixed together), with sorting increasing (becoming more uniform in grain size) both higher and lower in elevation across the beach from the coarsest zone (Figure 12). Sediments just below the wood line at the base of the berm consisted of well-sorted pea gravel or mixed gravel. The 'coarse' zone on the beach consisted of medium to coarse gravel armoring sand and gravel. Below MHLW the sediments graded to sorted sand. The sample location was selected to represent the coarsest mobile sediments. The sample was collected approximately five meters down-drift (north) from the boat ramp (Figure 7). Sediment up-drift from the boat ramp had been disturbed by ramp clearing activities. The influence of ramp clearing activities on beach sediment five meters down-drift from the ramp is unknown.

Figure 12. Grain size varied from sand to coarse gravel. Top: sorted sand below MHLW. Center: poorly sorted sand and gravel at approximately meat tide. Bottom: poorly sorted sand and gravel in the high energy zone of the beach face between MHHW and MHLW. Coarser sediments armored (covered as a veneer) finer sediments. Boot for scale.

The sediment was sampled using a *frequency-by-weight* bulk sampling method (Church et al. 1987). In this method, a specific weight of material is excavated from the beach surface to a depth of 1 foot. The amount of material to sample is based on the largest particle on the surface: the sampling volume equals 100 times the weight of the largest particle collected from the surface in the area to be sampled. This amount ensures a representative sample and a robust particle size distribution estimate (Church et al. 1987). It means one large sample can adequately characterize the grain size distribution of sediment. The Possession Park sample weighed 150 pounds. Beach sediment make-up changes from one season to the next and from one year to the next depending on erosion events. This snapshot—one bulk sample collected in March—is probably adequate to represent coarser sediment conditions at Possession Park: winter season is generally coarser than the summer beach profile; and a storm that probably mobilized coarse sediment immediately preceded sampling.

We sieved the total amount of sample on sieves ranging from 0.355mm (medium sand) to 25mm (coarse gravel) mesh size. The coarsest fractions (25mm and 19mm) were sieved wet; coarse clasts were rinsed to remove fines and fines were collected in a bucket. Sediment

<19mm to 0.355mm were air dried and sieved by hand or with a sieve shaker. Each size fraction was weighed (Figure 13). Possession Park sediments are comprised mostly of gravel (77%). The sand fraction makes up 23% of the sediments. A grain size frequency (by weight) diagram was constructed (Figure 14). The grain size frequency diagram does not 'tail out' as is typical because the coarsest sediments were not fractioned out above 25mm (note how large the >25mm size class is in Figure 13). The frequency plot is adequate for determining D_{50} and D_{75}. D_{50} is the median grain diameter, where 50% of the sample by weight is finer than that diameter. Similarly, 75% of the weight of the sample is finer than D_{75}. However, it might be useful to know D_{95} for determining if the inlet channel would remain open over nearly the entire range of sediments found on the beach. Interpolating from the frequency plot, D_{50} = 8.75mm and D_{75} = 24mm.

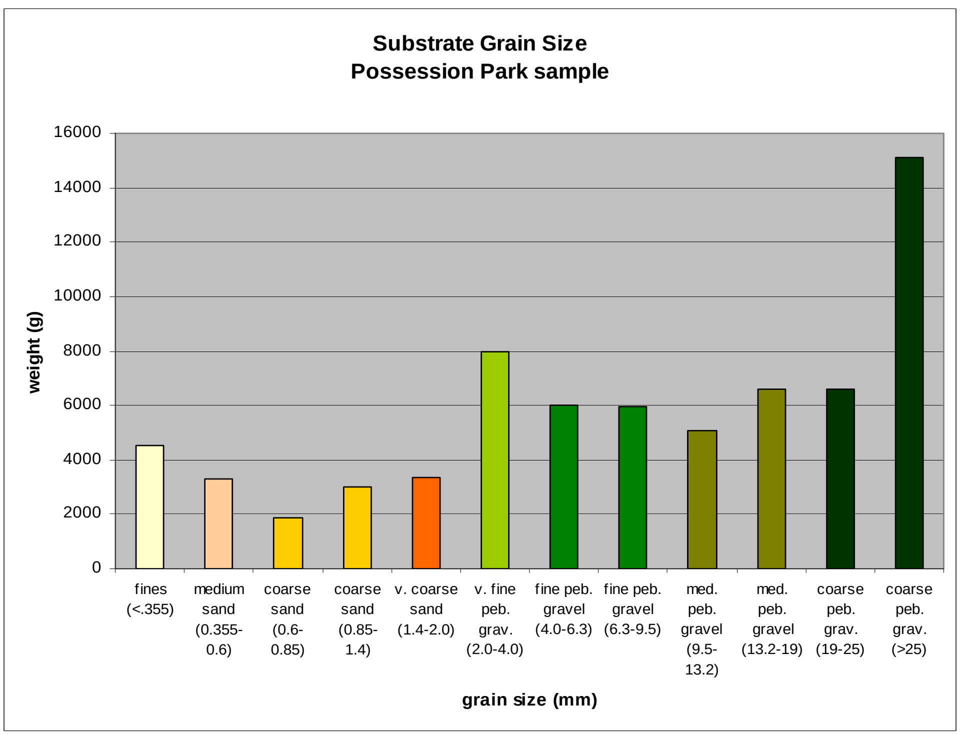

Figure 13. Grain size composition by weight fractions. Green bars are gravel (2.0->25mm). Cobbles may be present, but sizes >25mm are not differentiated. Orange bars are sand (<2.0). Silt and clay were not differentiated (sediment <0.355 in diameter).

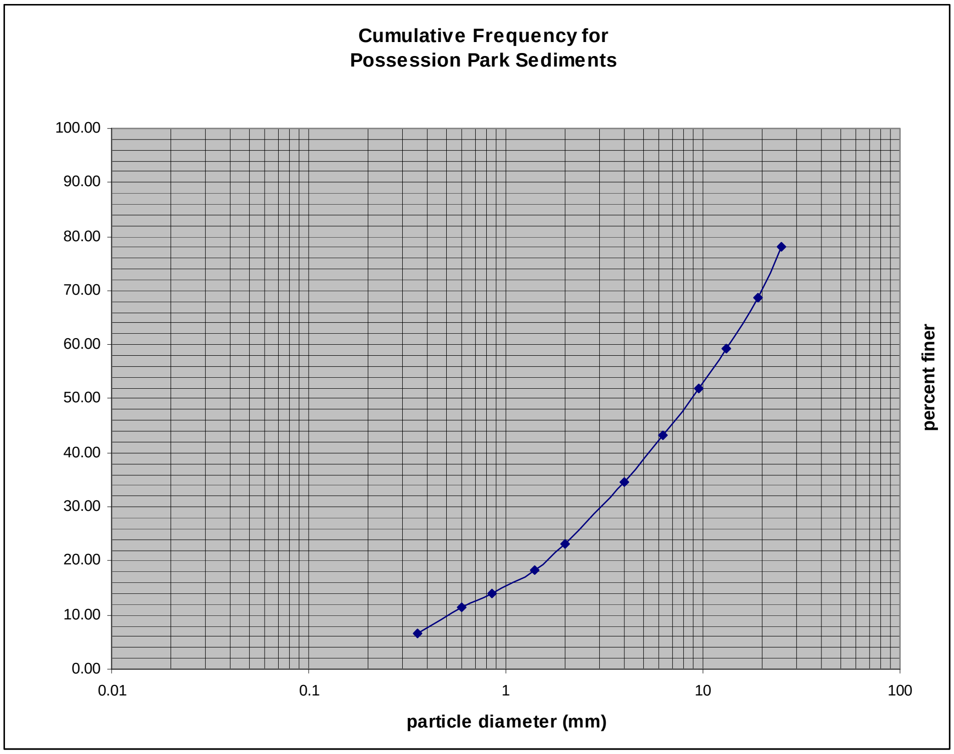

Figure 14. Grain size frequency as weight % finer (y-axis). D_{50} = 8.75mm (fine pebble gravel). D_{75} = 24mm (coarse pebble gravel).

We calculated critical shear stress (τ_{crit}) for D_{50} and D_{75} (Table 1). τ_{crit} is the shear stress required to move a particular grain size. The equation for determining if tidal flow in the channel will move the beach sediment of a given size (or less) is:

$$\tau_{crit} = \mathrm{R}g(\rho_s - \rho_f)D_\mathrm{j}$$

where τ_{crit} = the critical shear stress value for the D_j measured in Pascals,
j =the grain diameter cumulative frequency by weight (dimensionless),
ρ_s = the sediment density (2.65 kg m^{-3}),
ρ_f = the density of marine water (1.025 kg m^{-3}),
g = the acceleration due to gravity (m/sec^2), and
R = 0.003 is Shield's parameter for gravel dominated sediments.

Table 1. Comparing τ_{crit} to the bed shear stress calculated by the hydrodynamic model.

Scenario	τ_{crit} D_{50} (PA)	τ_{crit} D_{75} (PA)	τ_{bed} from model (PA)	peak velocity from model (m/s)
1	4.18	11.47	10	1.77
2	4.18	11.47	10	1.59

We then compared (τ_{crit}) to the bed shear stress predicted by the hydrodynamic model. Battelle Pacific National Laboratory created a hydrodynamic model for Possession Park based on LiDAR elevations, the schematic marsh cross section (Figure 11), and the two restoration scenarios (Figures 15 & 16). The model's predictive capability was calibrated using an existing model for Whidbey Basin (Yang and Khangaonkar 2008 and Yang et al. 2009). The purpose of the model was to predict inlet channel velocities and bed shear stress within the channel over the tidal cycle so that we could compare bed shear stress (τ_{bed}) to τ_{crit} for the sediment moving down the beach and likely to deposit in the inlet channel. Tidal channel velocity is 0.2m/s at the inlet channel (site s2 shown in Figures 15 and 16) for the longest duration: 68% of the time for scenario 1 and 55% for scenario 2 (Figures 15 & 16). For scenario 1, the tidal inlet reaches a peak velocity of 1.77m/s for less than 1% of the tidal cycle. The peak velocity for scenario 2, 1.59m/s, is achieved for 3.5% of the tidal cycle.

The bed shear stress in the inlet channel is 10 PA at peak velocity during the ebb tide. Comparing that to τ_{crit} D_{50} and τ_{crit} D_{75} (4.18 and 11.47, respectively), the peak velocity could move 50% or more of the weight of the sediment entering the channel, but neither restoration scenario's tidal inlet channel would have the power to clear the coarsest 25% of the sediments moving down the beach because τ_{crit} D_{75} is greater than τ_{bed} . Even if the channel could move the coarse fraction at its peak velocity (there being only a 1.47 Pascals (PA) difference between the τ_{crit} for D_{75} and the τ_{bed}), the peak velocity in the channel is maintained for so short a duration that coarse sediment would always be accumulating. Sediment does not move down the beach as though it were on a conveyor belt; while sand and silt may move more or less continuously, coarse sediment like gravel and cobble moves in pulses related to storm events. It is possible that the sporadic transport of gravel could improve the inlet channel's chances of staying open. Examining τ_{bed} along with storm frequency may improve accuracy in predicting whether the channel will remain open.

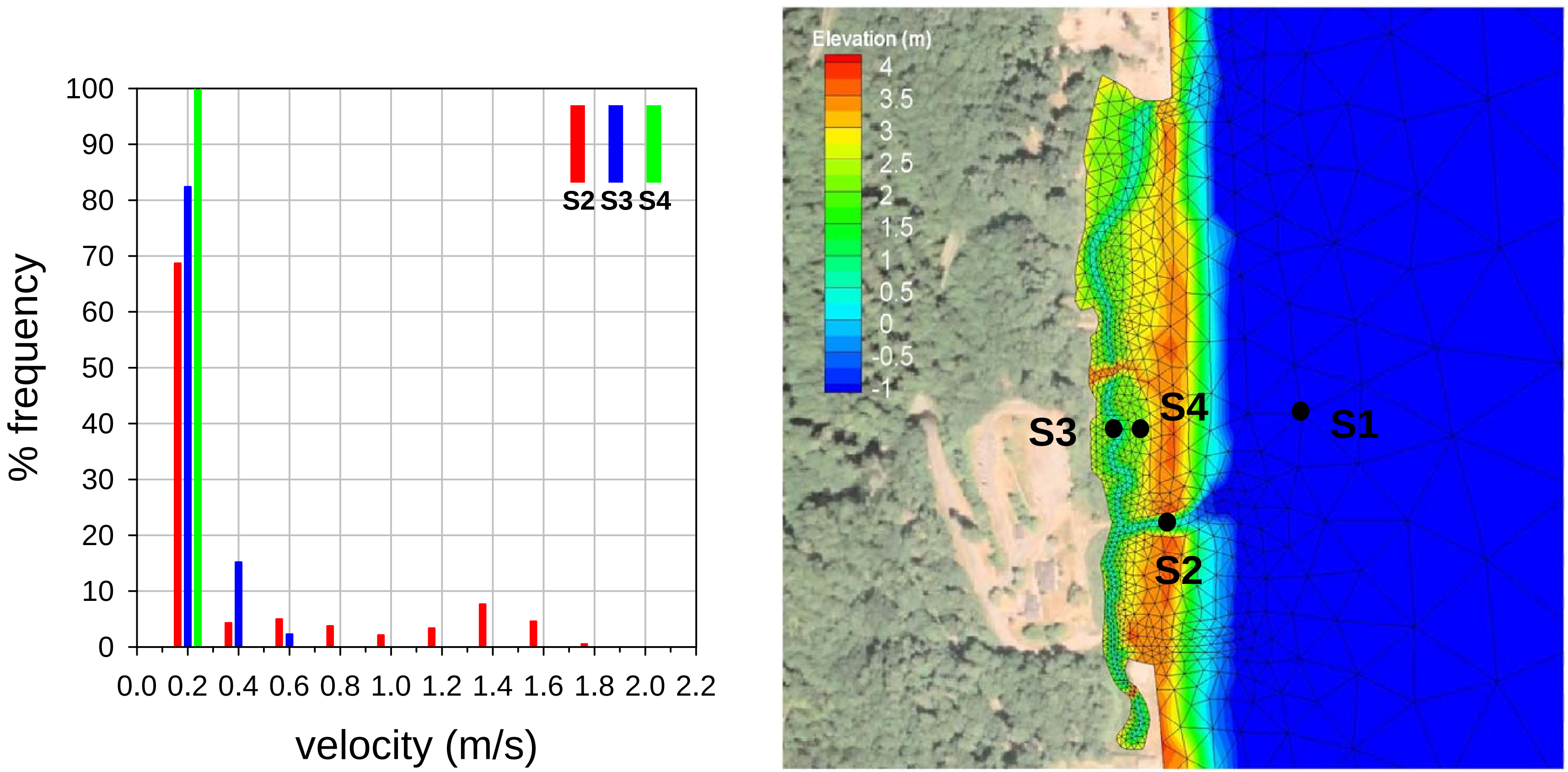

Figure 15. Scenario 1 hydrodynamic model results: predicted bed surface velocity in Possession Sound in front of Possession Park (s1), the inlet channel (s2), the tidal channel (s3), and the marsh surface (s4). The red bar shows velocity frequency at the inlet. The higher velocities are infrequent.

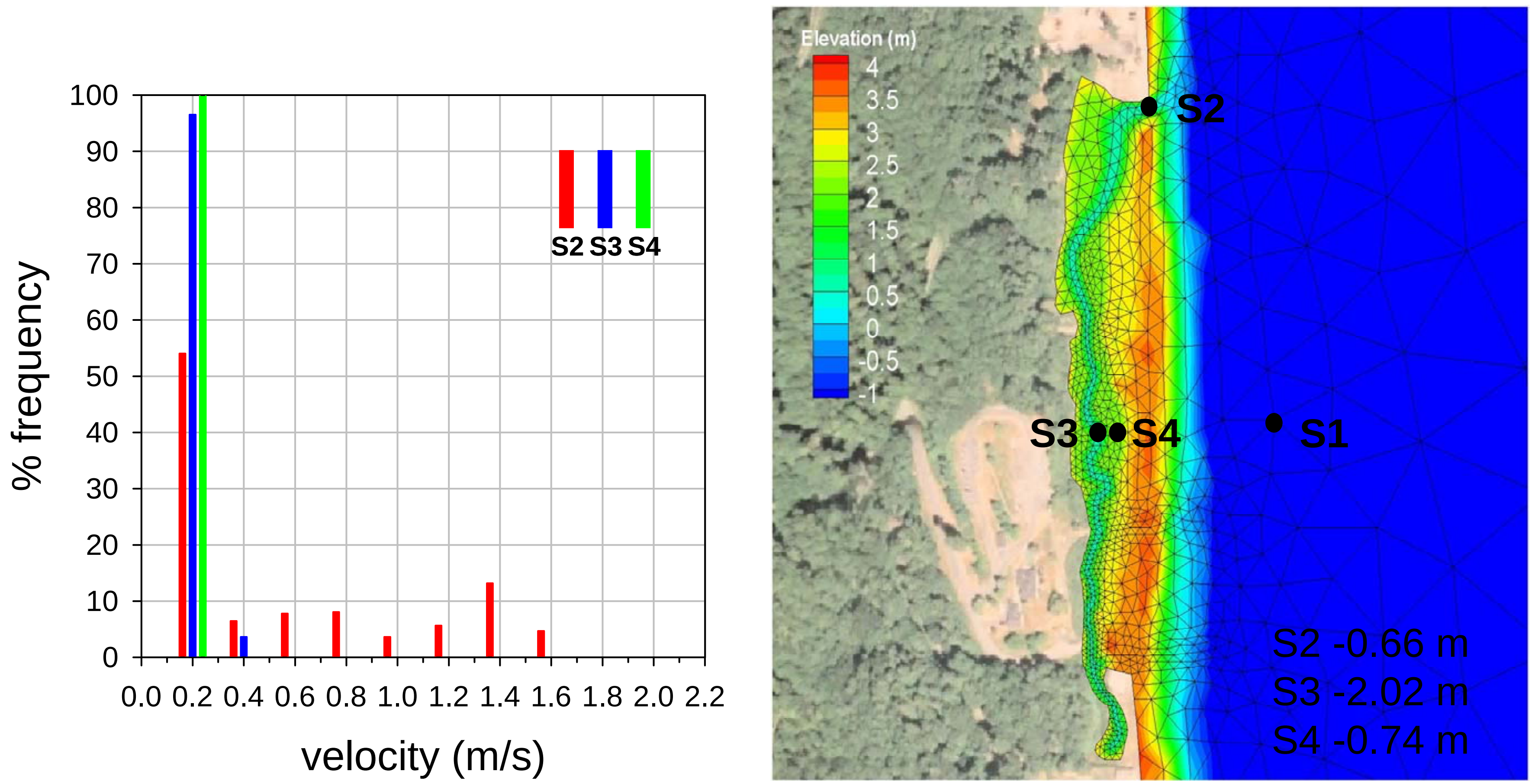

Figure 16. Scenario 2 hydrodynamic model results: predicted bed surface velocity in Possession Sound in front of Possession Park (s1), the inlet channel (s2), the tidal channel (s3), and the marsh surface (s4). The red bar shows velocity frequency at the inlet. The higher velocities are infrequent.

Comparing Restoration Scenarios to Existing Pocket Estuaries in Whidbey Basin

By using two methods to analyze restoration feasibility (the previous inlet stability analysis and this comparison exercise) we strengthen our prediction about Possession Park restoration outcomes. Our second approach to predicting the feasibility of restoration at Possession Park compares both restoration scenarios to other pocket estuaries in Whidbey Basin. If the restoration scenarios for Possession Park are similar to other pocket estuaries that currently have sustainable inlet channels and are accessible to fish, it follows that Possession Park should be sustainable. We took size measurements of existing pocket estuaries and compared those to Possession Park restoration scenarios to see if the size of a restored Possession Park pocket estuary is typical of a sustainable pocket estuary. We also attempted to develop hydraulic geometry relationships for Whidbey Basin using Whidbey Basin pocket estuaries. Locally derived hydraulic geometry relationships will help us predict what the inlet channel width will be when at equilibrium. The regression could also serve as a tool for restoration planning at other sites.

We selected 11 sites within Whidbey Basin that ranged in size (intertidal area) from 0.44ha to 93.20ha. We measured inlet channel width and depth in the field and mapped pocket estuary area from aerial photos. We attempted to take channel measurements at the hydraulic control for the pocket estuary. Sometimes this was difficult to determine. We developed a regression for the relationship between pocket estuary area and inlet channel width (Figure 17). The R^2 value for the regression is poor (0.473), probably due to the small number of sites and high variability between sites in nearshore processes and conditions, including longshore sediment dynamics. However, the significance level is high ($p = 0.013$).

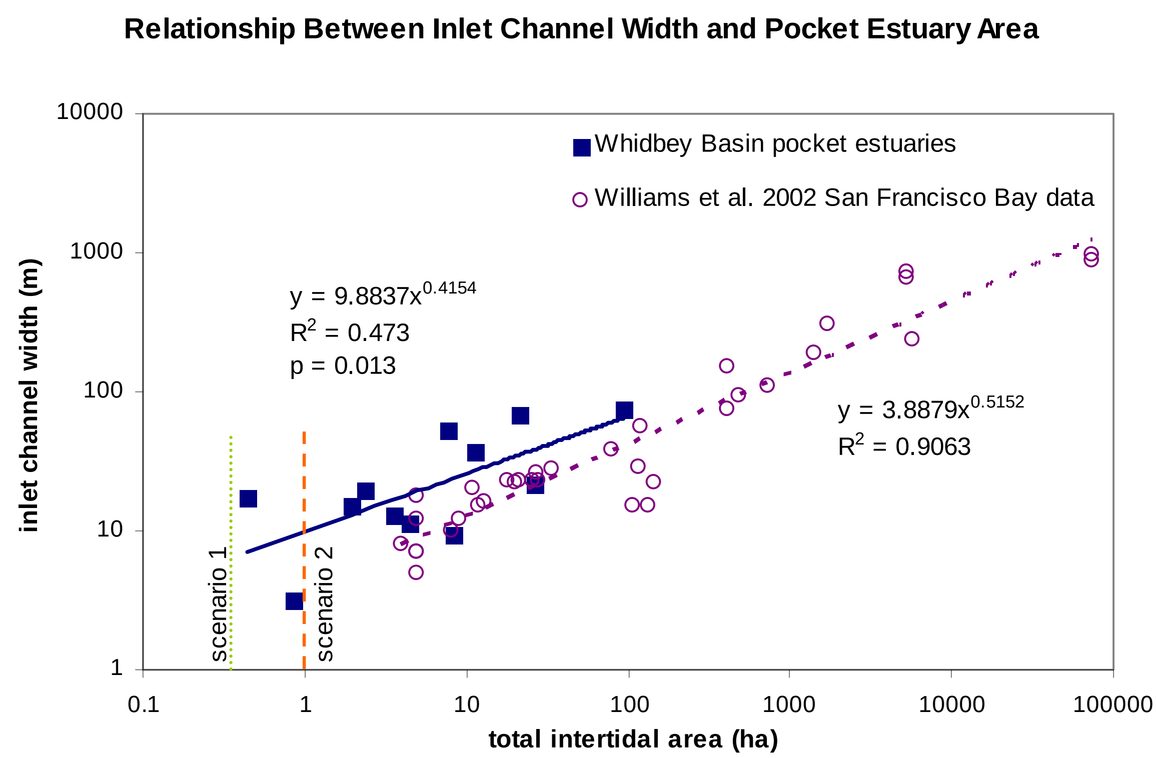

Figure 17. Inlet channel width *vs.* total intertidal area for Whidbey Basin pocket estuaries (blue squares) and San Francisco Bay tidal marshes (purple circles). Regression lines are plotted for each dataset. The R^2 value for the Whidbey regression is poor; however the relationship is significant ($p = 0.013$). Total intertidal areas for restoration scenario 1 (green vertical line) and scenario 2 (orange line) are plotted for comparison.

We also made use of 35 channel width and area measurements from Williams et al. (2002) collected in San Francisco Bay. We plotted that regression, with an R^2 of 0.9063, and compared that to our regression. The two regression lines are nearly parallel, but offset (Figure 17). The Williams et al. (2002) regression would predict a narrower sustainable channel width than the preliminary regression for Whidbey Basin pocket estuaries. The offset between the lines may be partially accounted for by different tidal ranges between the datasets—1.8m to 2.9m in San Francisco Bay compared to 3.8m in Whidbey Basin. The larger tidal range would result in higher energy and thus wider inlet channels for pocket estuaries of similar sizes.

We plotted the two restoration scenarios based on their intertidal area footprint to see where they fell on the Regression line for the Whidbey Basin model. Restoration scenario 1 is smaller than the smallest site we used for the regression, making it a risky size for a restored pocket estuary. Scenario 2 is in the range of other Whidbey Basin sites. The last two Whidbey Basin pocket estuaries plotted, and the only sites smaller than scenario 2, are unusual because they are tidal channel marshes in a highly modified environment. The larger of the two is an old restoration site and was created by removing fill. It may or may not be at equilibrium, following its creation 15 years ago. Comparing sizes between Whidbey Basin pocket estuaries implies that restoration scenario 1 is too small to be sustainable and restoration scenario 2 is marginal for being sustainable based on size.

CONCLUSIONS

A restored marsh would support fish, including juvenile Chinook salmon, if directly connected to Possession Sound with enough local connectivity via that inlet channel; however the pocket estuary inlet would not be sustainable over the long term. Restoration solely within the boundaries of Possession Park by reconnecting the marsh to tidal inundation is probably not sustainable because the small area (and thus tidal prism) of the site is not sufficient to maintain an open inlet channel. The Park marsh is smaller than any other pocket estuary sites in Whidbey Basin that are currently connected to marine water. A solution to the site's limitations for sustainable restoration could possibly be engineered by dredging out the inlet channel, creating longshore sediment diverters, periodically dredging the inlet channel, or even piping saltwater into the site, bypassing the tumultuous upper beach. However these kinds of solutions add cost and complexity to the project, do not meet the initial objectives of natural process restoration or 'no new maintenance' for the Park, and the long term outcomes as far as sustainability and benefits to fish are harder to predict.

Scenario 2, restoring the entire existing marsh footprint, may be feasible, but is marginal. The scenario 2 tidal prism is larger than scenario 1 and the duration of peak velocities in the channel capable or moving sediment out of the inlet is longer. However, channel flow conditions never reach the threshold necessary to move the coarsest 25% of the weight of sediment on the beach. If an inlet channel could be designed such that the already frequent clearing of the boat ramp could include clearing the inlet channel of the coarsest sediment, restoration may be possible and sustainable. The site area is just barely larger than the 1.2ha size limit observed in existing, functional Whidbey Basin pocket estuaries, so the size of scenario 2 is not a definite indicator of failure, but it is also not a clear predictor of success. Scenario 2 is further complicated politically because land ownership is not all with the Port of South Whidbey. However, Possession Park is located in a part of Whidbey Basin where very little pocket estuary habitat exists (Figure 18). Where nine lagoon/marsh-type pocket estuaries used to exist between the Snohomish River mouth and Possession Point, now there are only three. Where 12 pocket estuaries used to line the coast of south Whidbey Island from Holmes Harbor to Possession Point, now there are none (McBride et al. 2009). Therefore restoring pocket estuary habitat at Possession Park, even if it takes a semi-engineered solution, may be an important opportunity for improving the landscape-scale connectivity between pocket estuary habitats.

Regardless of what course of action Port of South Whidbey chooses, Park management would be improved by depositing sediment currently scraped off the boat ramp down-drift of the ramp rather than what is currently practiced (as of 2008) (Figure 19). This way the ramp clearing activities would work with northward longshore drift. If sediment is deposited south of the ramp it will either block sediment transport by acting as a jetty or will be moved back onto the ramp by waves hindering longshore transport to the rest of the drift cell. Depositing ramp clearings down-drift of the ramp will keep the sediment moving in the drift cell as it should.

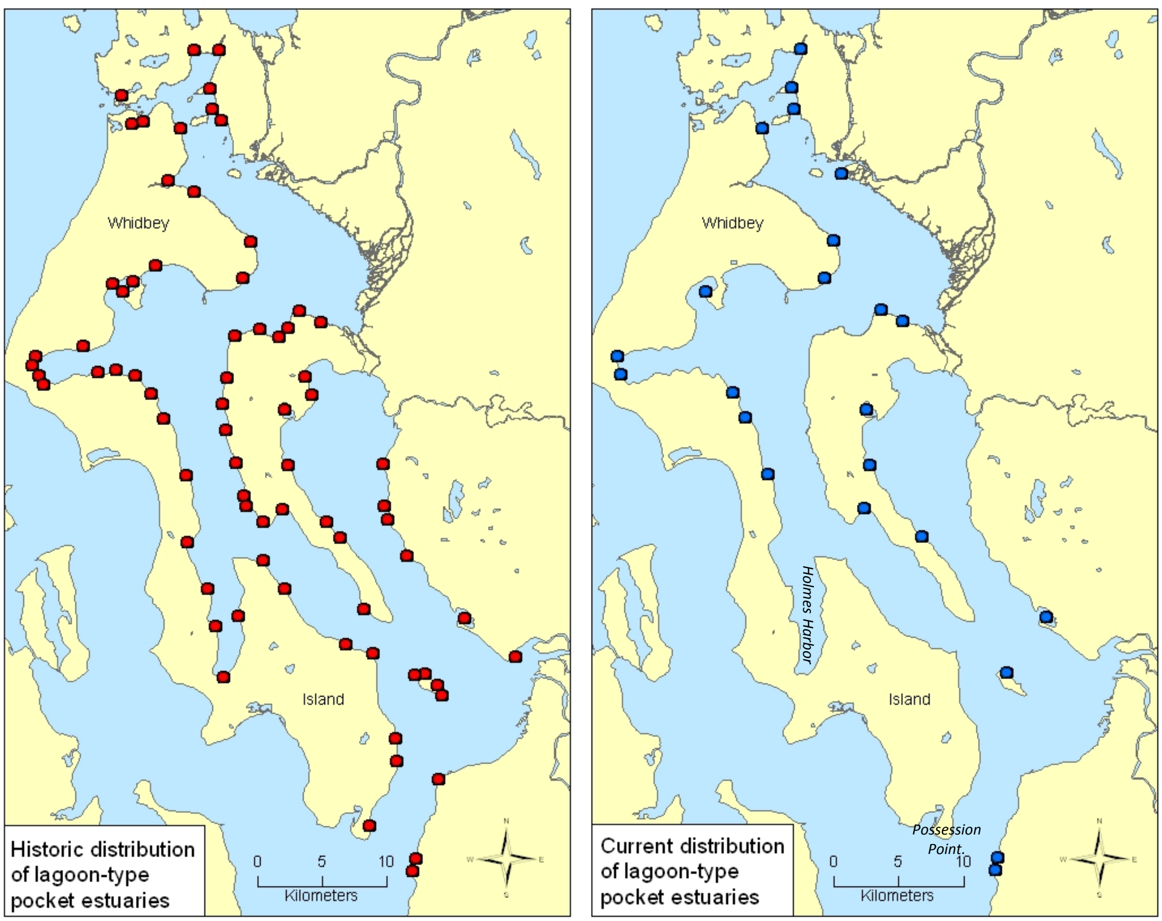

Figure 18. Historic distribution of lagoon or tidal channel marsh-type pocket estuaries (left map) compared to current lagoon or tidal marsh-type pocket estuary distribution (right map) shows that landscape-scale connectivity between pocket estuaries has decreased, as has total pocket estuary habitat area; pocket estuaries are fewer in number and farther between than historically (McBride et al. 2009).

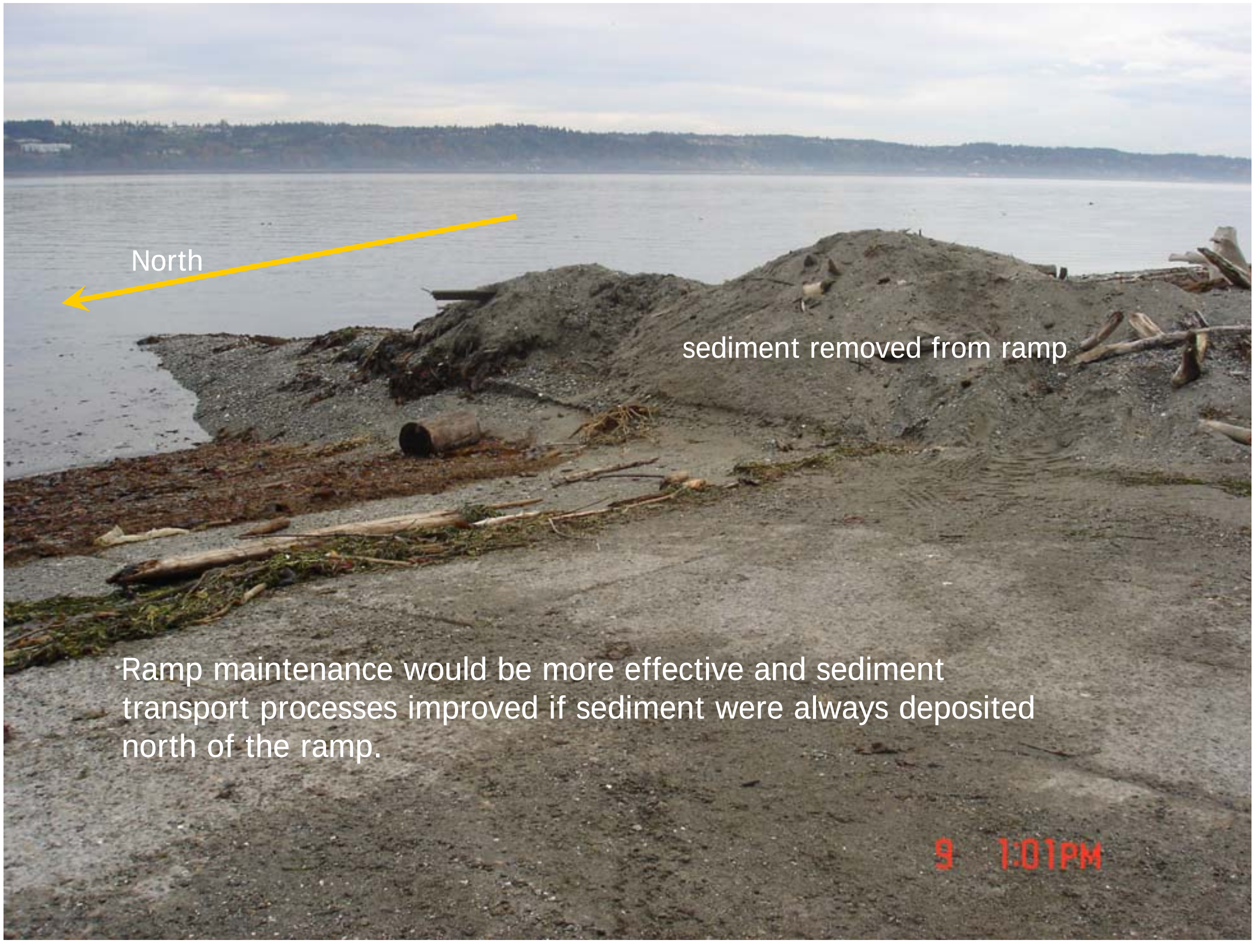

Figure 19. Photograph taken from the top of the boat ramp looking southeast. The photograph was taken a few days after the ramp had been cleared and sediments deposited along the south side of the ramp.

REFERENCES

Beamer, EM, A McBride, R Henderson, and K Wolf. 2003. The importance of non-natal pocket estuaries in Skagit Bay to wild Chinook salmon: an emerging priority for restoration. Skagit River System Cooperative, LaConner, WA.

Beamer, E, A McBride, C Greene, R Henderson, G Hood, K Wolf, K Larsen, C Rice, and K Fresh. 2005. Delta and nearshore restoration for the recovery of wild Skagit River Chinook salmon: linking estuary restoration to wild Chinook salmon populations. Appendix to the Skagit Chinook Recovery Plan. Skagit River System Cooperative, LaConner, WA.

Beamer, EM, A McBride, R Henderson, J Griffith, K Fresh, T Zackey, R Barsh, T Wyllie-Echeverria, and K Wolf. 2006. Habitat and fish use of pocket estuaries in the Whidbey Basin and north Skagit County bays, 2004 and 2005. Skagit River System Cooperative, LaConner, WA.

Beamer, E, C Rice, R Henderson, K Fresh, and M Rowse. 2007. Taxonomic composition of fish assemblages, and density and size of juvenile Chinook salmon in the greater Skagit River estuary: Field sampling and data summary report. Skagit River System Cooperative, LaConner, WA.

Beamer, E, J Haug, C Rice, and K Wolf. 2009. Nearshore fish assemblages in reference and Spartina removal sites located in south Skagit Bay. Skagit River System Cooperative, LaConner, WA.

Byrne, RJ, RA Gammish, and GR Thomas. 1980. Tidal prism-inlet area relationships for small tidal inlets. Proceedings of the 17th Conference on Coastal Engineering, Vol. 3. American Society of Civil Engineers, New York.

Church, M, DG McLean, and JF Wolcott. 1987. River bed gravels: sampling and analysis. Pages 43-79 *in* Sediment Transport in Gravel Bed Rivers. John Wiley and Sons.

Collins, BD, and AJ Sheikh. 2005. Historical reconstruction, classification, and change analysis of Puget Sound tidal marshes. Puget Sound River History Project, University of Washington, Seattle. Submitted to Washington Department of Natural Resources, Olympia.

Island County LiDAR dataset. 2001-2002. Puget Sound LiDAR Consortium, http://pugetsoundlidar.ess.washington.edu/.

Kagley, A, T Zackey, K Fresh, and E Beamer. 2007. Juvenile salmon and nearshore fish use in shoreline and lagoon habitat associated with Elger Bay, 2005-2007. Skagit River System Cooperative, LaConner, WA.

McBride, A, S Todd, O Odum, M Koschak, and E Beamer. 2009. Developing a geomorphic model for nearshore habitat mapping and analysis. Skagit River System Cooperative, LaConner, WA.

O'Brien, MP. 1931. Estuary tidal prisms related to entrance areas. Journal of Civil Engineering 1:738-739.

Simenstad, CA. 2000. Commencement Bay Aquatic Ecosystem Assessment: Ecosystem Scale Restoration for Juvenile Salmon Recovery. School of Fisheries, University of Washington, Seattle.

Simenstad, CA, and JR Cordell. 2000. Ecological assessment criteria for restoring anadromous salmonid habitat in Pacific Northwest estuaries. Ecological Engineering 15(3-4):283-302.

Willams, PB, MK Orr, and NJ Garrity. 2002. Hydraulic geometry: a geomorphic design tool for tidal marsh channel evolution in wetland restoration projects. Restoration Ecology 10(3):577-590.

Wydoski, RS, and RR Whitney. 1979. *Inland Fishes of Washington*. University of Washington Press, Seattle and London.

Yang, Z, and T Khangaonkar. 2008. Modeling tidal circulation and stratification in Skagit River estuary using an unstructured grid ocean model. Ocean Model., doi: 10.1016/j.ocemod.2008.07.004.

Yang, Z, T Khangaonkar, M Calvi, and K Nelson. 2009. Simulation of cumulative effects of nearshore restoration projects on estuarine hydrodynamics. Ecol Model., doi: 10.1016/j.ecolmodel.2008.12.006.