FEASIBILITY ASSESSMENT FOR SALT MARSH RESTORATION AT CAMANO ISLAND STATE PARK, WHIDBEY BASIN

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August 2010

Photo from Washington State Department of Ecology Coastal Atlas

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INTRODUCTION AND OBJECTIVES

The purpose of this Feasibility Assessment is to determine if landscape and land use conditions at Camano Island State 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. Camano Island State Park (Camano ISP) is located along Saratoga Passage on Camano Island, Whidbey Basin (Figure 1). The Park was chosen as a potential restoration site because it:

- Is located within an area assumed to be used by mixed juvenile Chinook salmon stocks;
- Is on a juvenile salmon migration corridor;
- Has likely had historic tidal channel marsh habitat; and
- Has landowners willing to explore the idea of habitat restoration (Washington State Parks).

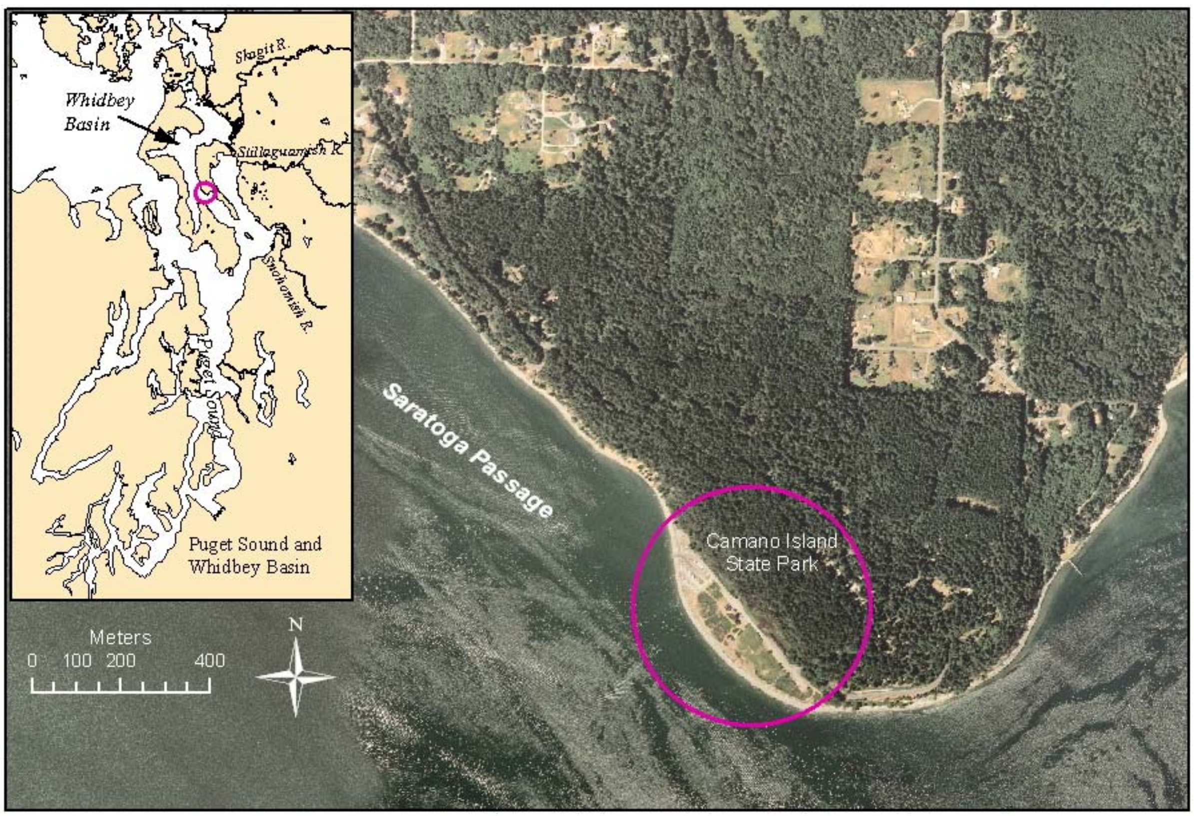


Figure 1. Location map.

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 Camano ISP means possibly excavating and then reconnecting the low marshy areas of the park to tidal inundation from Saratoga Passage. Restoration scenarios, project objectives, and constraints for implementing restoration at the Park were developed by the landowner (Washington State Parks) 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 **new** long-term or permanent restrictions on boating or fishing.
- 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 Camano ISP. 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 a possible restoration scenario (inlet channel stability).

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 Camano ISP based on fish assemblage data from similar and nearby sites. Fish will re-colonize the site once adequate local connectivity to Saratoga Passage 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 it is 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 Camano ISP 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 Camano ISP and likely seasonal patterns of habitat use.

Fish Assemblage

To predict the general seasonal fish assemblage for a reconnected Camano ISP pocket estuary 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 aggregata) 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 staghorns 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, 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 (Salvelinus malma or confluentus). 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 Camano ISP by using two “space” (different site) for “time” (the future restored Park) substitution tools. The first tool uses fish assemblage data collected near Camano ISP at Elger Bay to represent a pocket estuary that is a ‘tidal channel and marsh’ type pocket estuary like the theoretical restored Camano ISP 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.

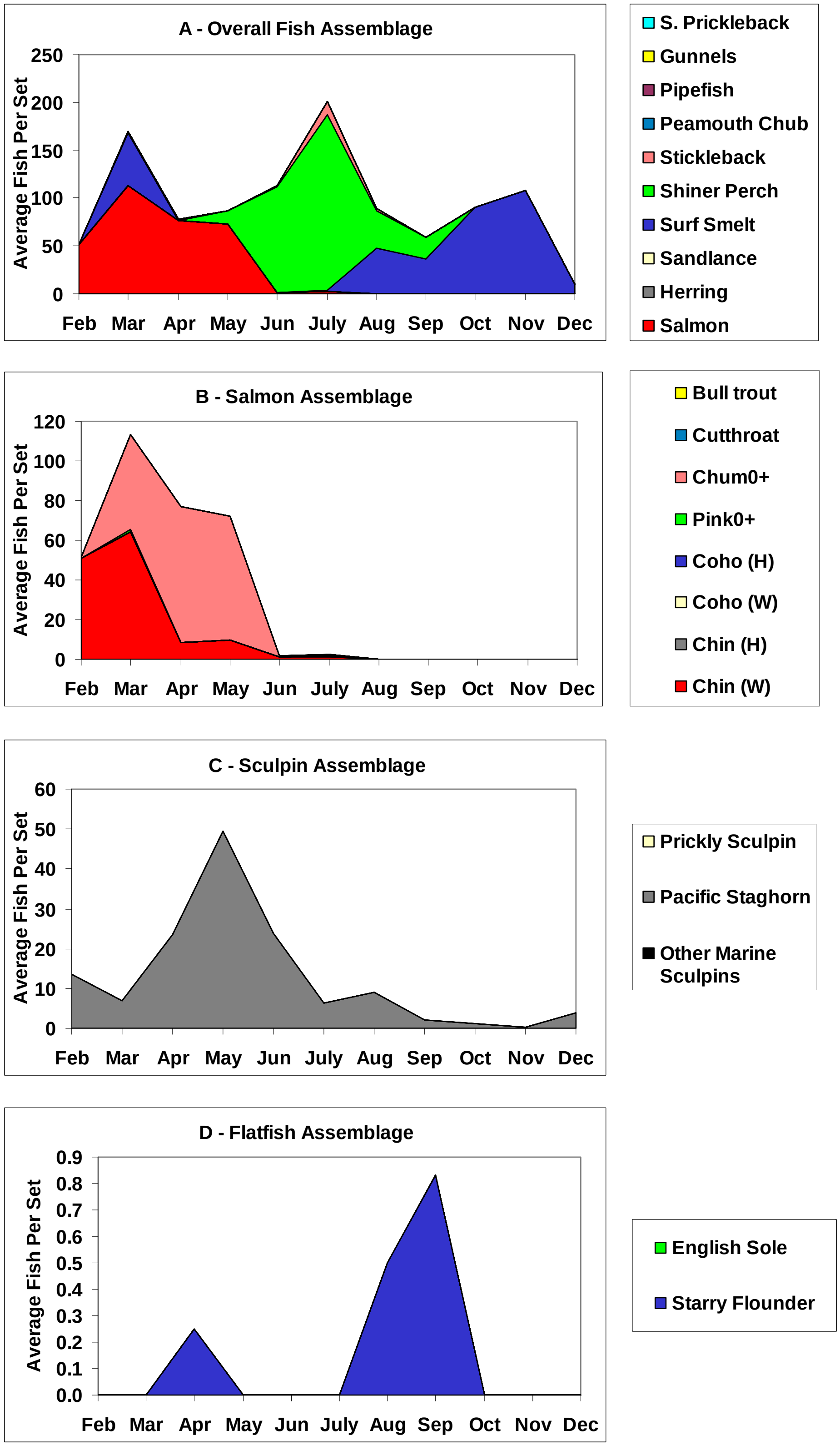


Figure 2. Seasonal fish assemblages for shallow intertidal habitat in lagoon-type pocket estuaries with a salinity greater than 20 ppt (from Beamer et. al. 2007).

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 Camano ISP and that the assemblage of fish will include juvenile Chinook salmon, other juvenile salmon, shiner perch, staghorns, sticklebacks, and possibly juvenile smelt. Surf smelt spawning was not documented near Camano ISP at Elger Bay, so use of the restored estuary by smelt is questionable. Also, following the pattern of the high elevation site, Camano ISP 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 the salmon 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. Camano ISP is a corridor site for Skagit River, Stillaguamish River, and Snohomish River fish. Based on fish sampling results from throughout Whidbey Basin, we would expect juvenile Chinook salmon to use Camano ISP 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).

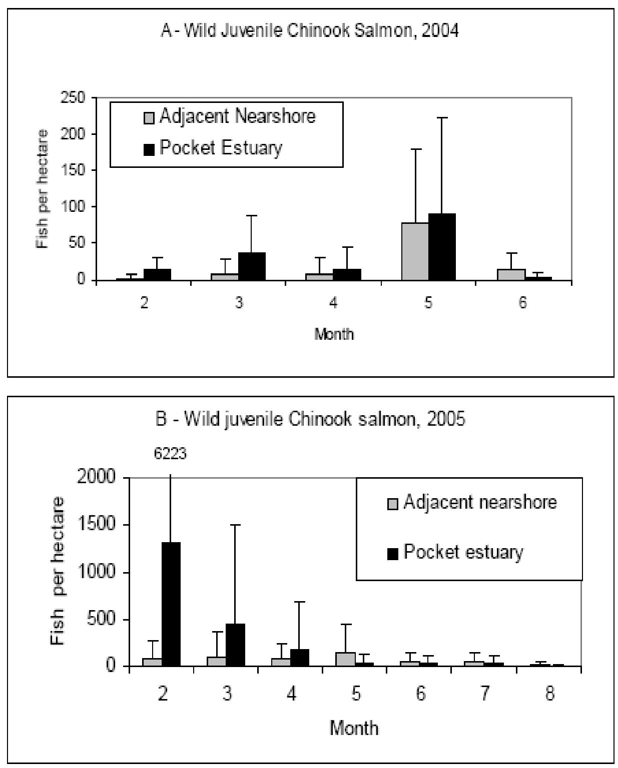


Figure 3. Average wild juvenile Chinook density for 2004 (19 sites) and 2005 (6 sites) pairs of accessible pocket estuary and adjacent beach habitat in Whidbey Basin. Pocket estuary habitat was preferred by the fish (from Beamer et al. 2006).

Tissue samples were collected from 65 juvenile Chinook salmon (56 fish from beaches along Saratoga Passage, 9 from lagoon/tidal channel habitat in pocket estuaries along Saratoga Passage[1]) caught during 2008. The samples were used to determine fish origin based on genetic analysis of DNA (David Teel, NOAA Fisheries, unpub. data).

Our results show that source rivers nearest the site (Skagit, Stillaguamish, and Skykomish) contribute the largest percentage of the Chinook salmon population. Skagit River origin Chinook salmon are likely to make up the highest percentage of the Chinook salmon assemblage found in a restored Camano ISP pocket estuary (Figure 4). This makes sense because 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 show a sizable proportion of the Chinook salmon (20% in beach areas near the CISP 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. Fish from Canada and the outer Washington coast were caught at beach sites. These fish may also use restored habitat at Camano ISP if they are within the vicinity of the site early in the year and are fry-sized.

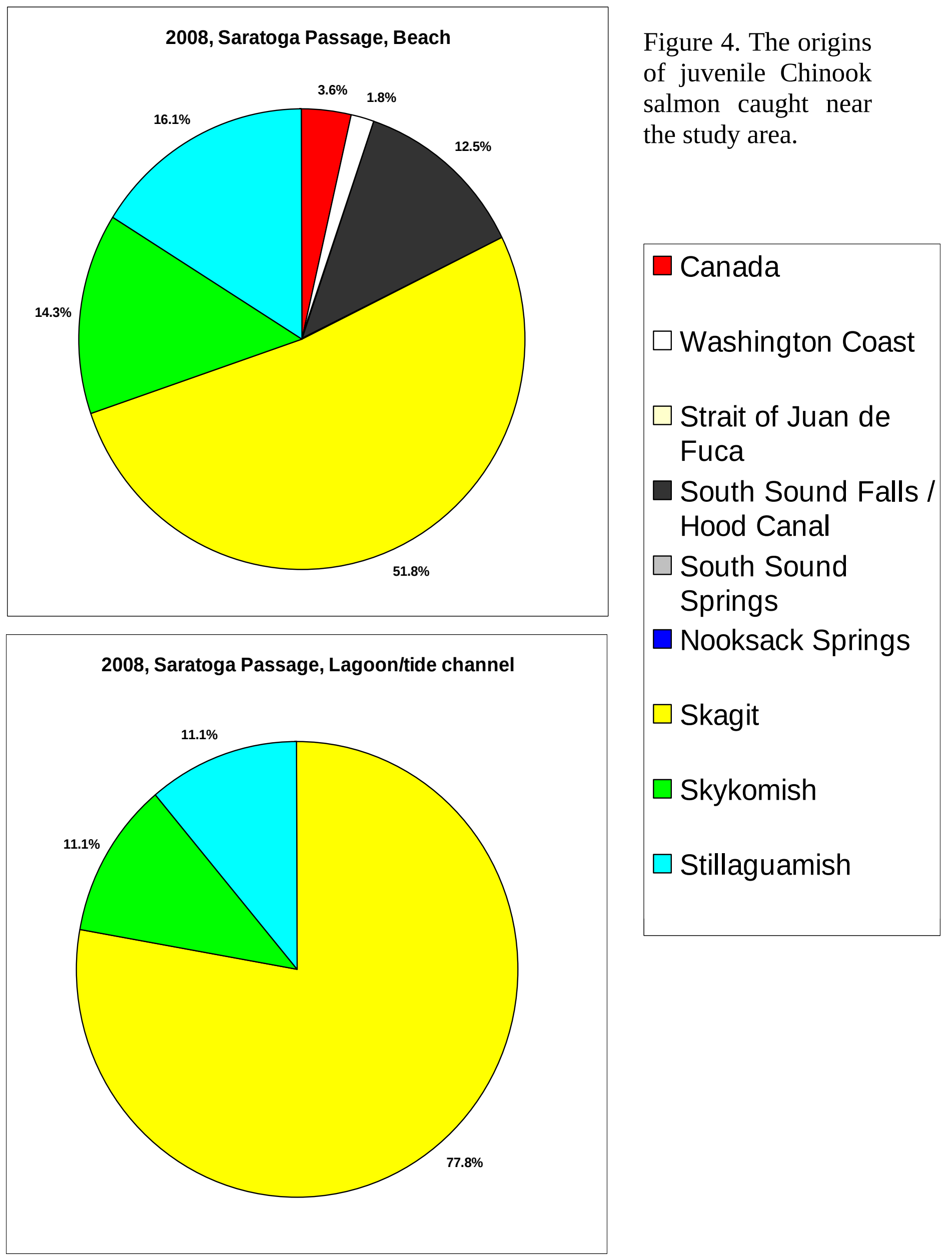


Figure 4. The origins of juvenile Chinook salmon caught near the study area.

[1] Generally, we like to have 30 fish samples to accurately estimate the origin composition of groups of juvenile Chinook salmon by spatial strata.

RESTORATION POTENTIAL

Camano Island State Park includes an upland camping area that is at the top of a high bluff, and a shoreline day use area that occupies a small coastal landform. The coastal landform is the part of the park under consideration for restoration (site). We develop 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. In addition to defining the restoration potential of the site, we describe landforms and hydrology to provide a starting point for restoration design.

Site Geomorphology and Hydrology

Currently, the coastal landform is a low, sometimes marshy, bluff-backed grassland behind a spit (Figures 5 and 6). At the drift cell scale, Camano ISP is a depositional landform where sediment accumulates on the beach face and in the backshore (Figure 6-bottom left). Driftwood accumulates two or more logs deep along the beach face (Figure 6). Sediment sources for the depositional landform at Camano ISP are located approximately 200m east of the site (Figure 7). The bluffs at Lowell Point are made of actively eroding glacial and interglacial sediments (outwash) (figure 6-bottom right). Sediment moves west and north to the spit at Camano ISP. The bluffs are an important sediment source for the entire drift cell, which extends north to Brown Point on the Skagit River Delta (Figure 7). A stream flows down the bluff at the eastern edge of the site and empties into a wetland at the base of the bluff. It has no surface connection to Saratoga Passage or to the other low areas of the Park. The stream occupies a deeply incised gorge, so it is not a new stream. The road bed follows the gorge for the lower few hundred meters (Figure 5).

Camano ISP is highly altered from its pre-development condition (Figure 5). An access road, two parking lots, and a restroom building are built almost entirely on fill (Figure 6-top left). A freshwater wetland occupies the space between the road/parking lot and the bluff. The open areas of the park are all below Mean Higher High Water (MHHW). Some of the low areas may be borrow excavations from when the road and parking lot were built. A boat ramp crosses the spit near the north end of the Park. The crest of the spit is approximately 11 feet above Mean Lower Low Water (MLLW), which is within the reach of extreme high tides and storm surges. The lowest point on the spit is at the boat ramp. The ramp may have been built at the low spot or it may have created the low spot. Picnic tables and trails occupy the top of the berm. There is also a picnic shelter on the spit.

Historically the site at Camano Island State Park was almost certainly a tidal channel marsh complex connected to Saratoga Passage at its northwest end and protected by a broad spit. The historic t-sheet (Figure 8) was not mapped at a scale to show the marsh; however, sites of similar size and configuration in the region have existing marsh or strong evidence of historic marsh habitat (Arrowhead Lagoon, historic Utsalady Point, Lone Tree Point). Camano ISP may have followed the pattern of those other sites. If so, the historic marsh has been cut off from tidal inundation and historic channels have been paved, partially filled, or left as relict swales. Figure 9 shows some of the historic pocket estuary features. The historic form on the pocket estuary can also be seen in elevation data (Figure 10). Most of the site is still below MHHW (Figure 11). Park staff report that the eastern half of the low area floods in winter, probably from a combination of high stream flow and runoff, groundwater intrusion, and saltwater coming over and through the spit during winter high tides and storms. Wet depressions in the southern ‘play field’ (near the road) have *salicornia* (a salt marsh plant) mixed in with the grass (Figure 6). The shape of some low areas may be left over from this site’s past. Vegetation in the northern half of the park marks out a sinuous shallow depression in darker, more water tolerant plants compared to the immediately adjacent vegetation. The s-shaped vegetation pattern is probably a relict channel (Figure 10). The form of the relict channels indicates moving water – only moving water will carve a sinuous channel.

Possible Restorable Footprint

Existing land use, topography, and hydrology determine the restoration potential of this site. We derive a possible restorable footprint from these landscape data. We hypothesize that 1.77 ha (4.37 acres) of nearshore habitat for juvenile Chinook salmon and other species could be gained if this site were connected to tidal influence (Figure 11). The restoration potential footprint is a theoretical design on which we can test hypotheses about the feasibility and sustainability of pocket estuary habitat creation (or restoration, as the case may be) at Camano Island State Park. The restoration potential footprint was developed as follows:

- The footprint starts with existing low areas as the theoretical marsh surface (green marsh pattern in Figure 11).
- A theoretical channel is represented draining the marsh and wetland areas and connecting all to Saratoga Passage (blue channel within green patterned marsh area in Figure 11).
- The footprint connects the existing bluff wetland to other low areas (blue channel within the marsh footprint in Figure 11).
- The proposed footprint excludes all existing structures, roads, and parking lots, except the southwest corner of the north parking lot near the boat ramp (Figure 11 top inset).
- This footprint assumes bridges or some kind of water conveyance will replace fill where the road and trails cross theoretical waterways (i.e. where the channel draining the bluff wetland joins the main tidal channel).
- The inlet channel shown in the restoration potential footprint is one possibility. The location was chosen to take advantage of a low area on the spit. The low area may have been created by boat ramp construction. It also makes sense to locate the inlet north of the boat ramp to take advantage of sediment dynamics around the boat ramp and adjacent docks that might protect a potentially precarious inlet.

Figure 5. Site map. Sediment moves from the bluff to the spit. The spit is an accretion shoreform (net sediment gain). The pink area behind the spit is low (below MHHW) as is the wetland (green area). The possible relict channel is mapped on darker vegetation that stands out against the pervasive vegetation in the low areas. The shape of the vegetation is typical of tidal channels (sinuous). The stream continues up the slope beyond what is shown. The parking area, restroom building, road and some trails are on fill. The north parking lot is uneven in elevation and has low spots.

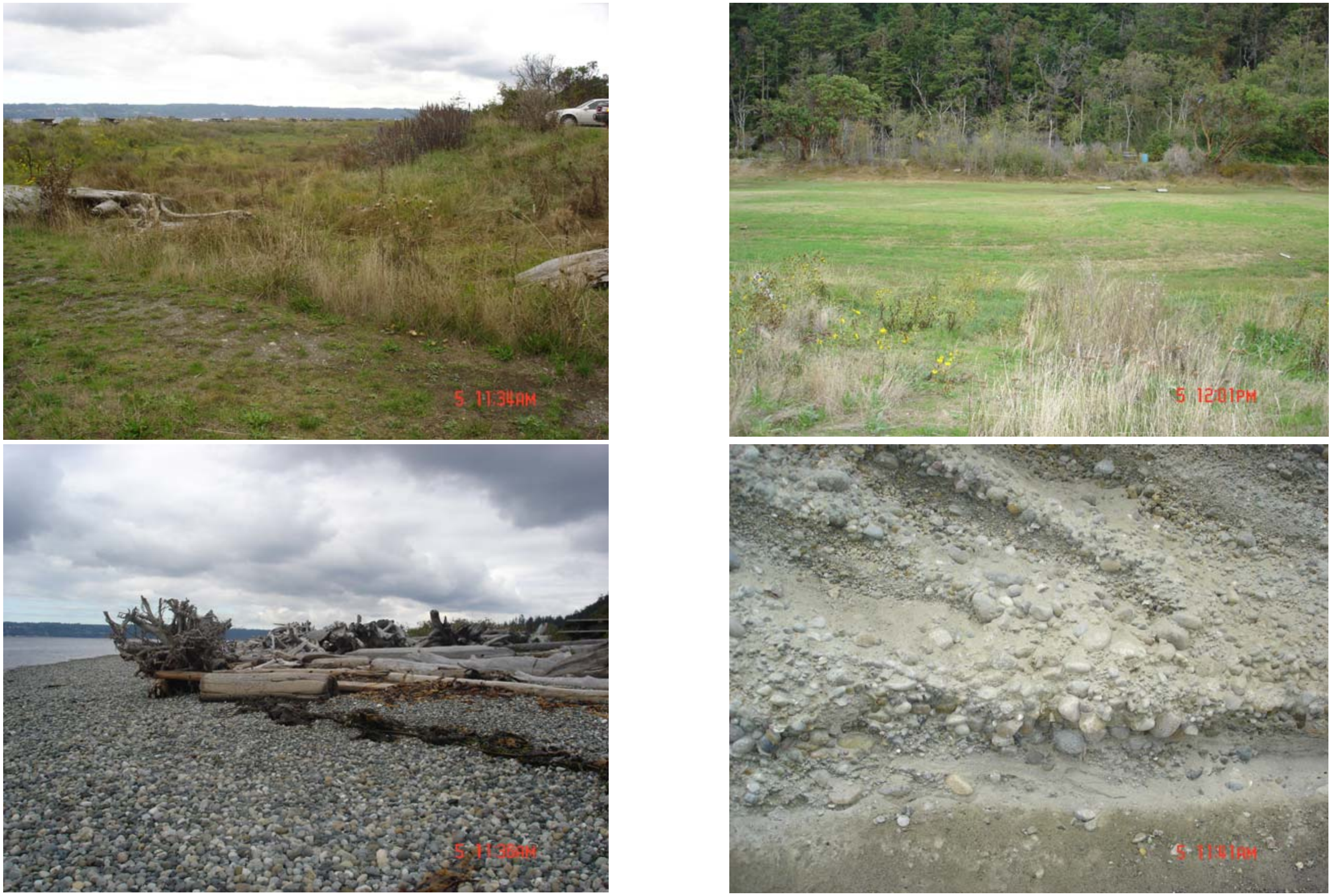


Figure 6. Site photographs. **Top left:** In the foreground are the spit and possibly some fill. The photo shows the southern end of the parking lot and the high fill it is on. Also note the large driftwood on the spit (possibly moved there by people, more likely natural). In the background are the spit extending along the horizon and the low area behind the spit. **Top right**: From the spit looking toward the bluff, this photo shows the low grassy area. Note wet spots close to the road/bluff edge of the grass (dark spots). **Bottom left**: The beach face of the spit is coarse gravel and cobble. A thick line of driftwood is present at the extreme high water line. This photo was taken close to the sediment source at the southeast end of the spit. **Bottom right:** This is a close up of outwash deposits in the bluff south of the spit. This is the source material for the spit and the rest of this Camano Island drift cell that extends north to Brown Point on the Skagit delta.

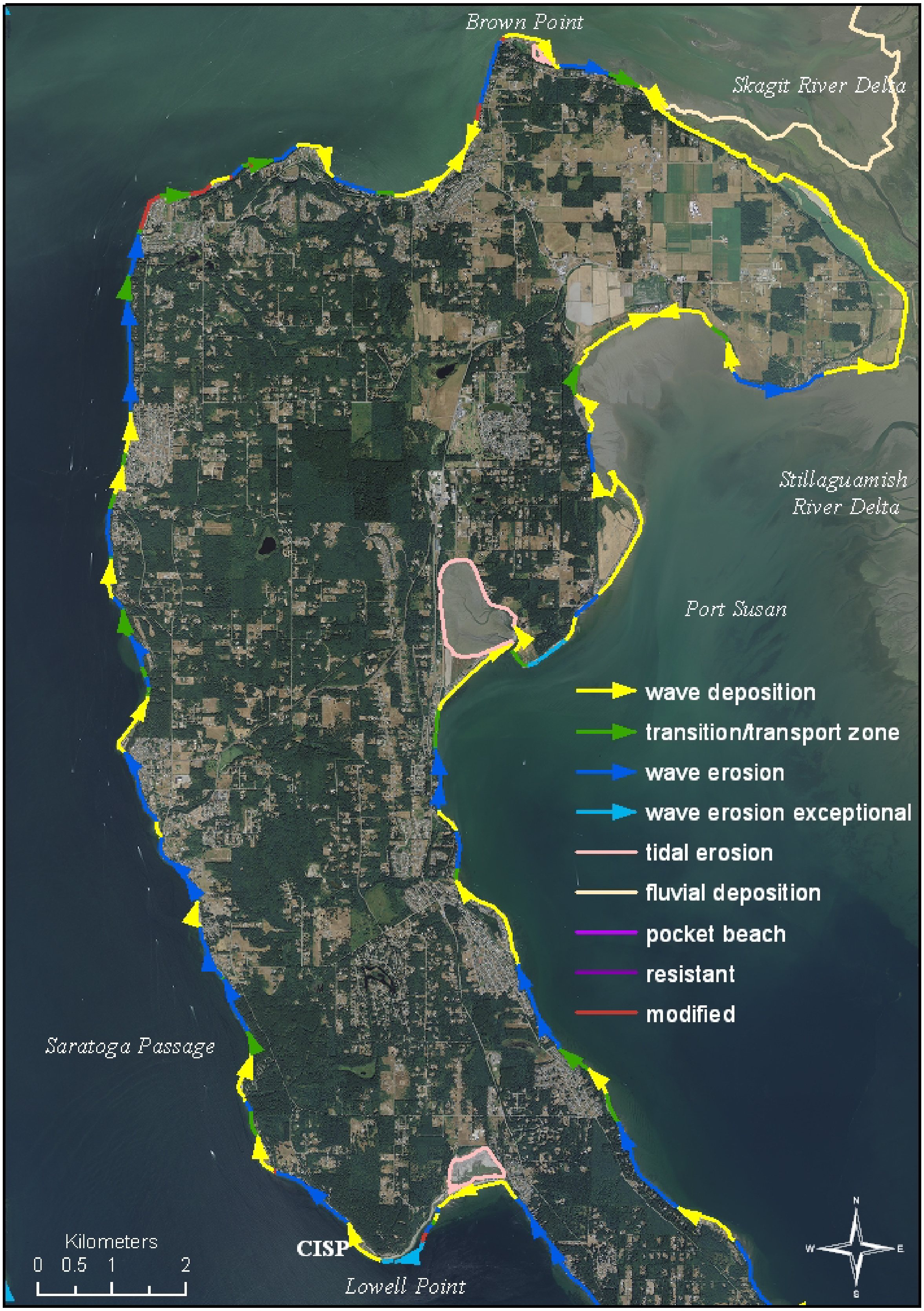


Figure 7. Sediment sources for the spit at Camano Island State Park (CISP) are immediately to the south and east, at Lowell Point (blue lines, wave erosion). The spit at CISP is a depositional landform (net sediment gain). The drift cell that begins at Lowell point extends all the way to Brown Point to the north.

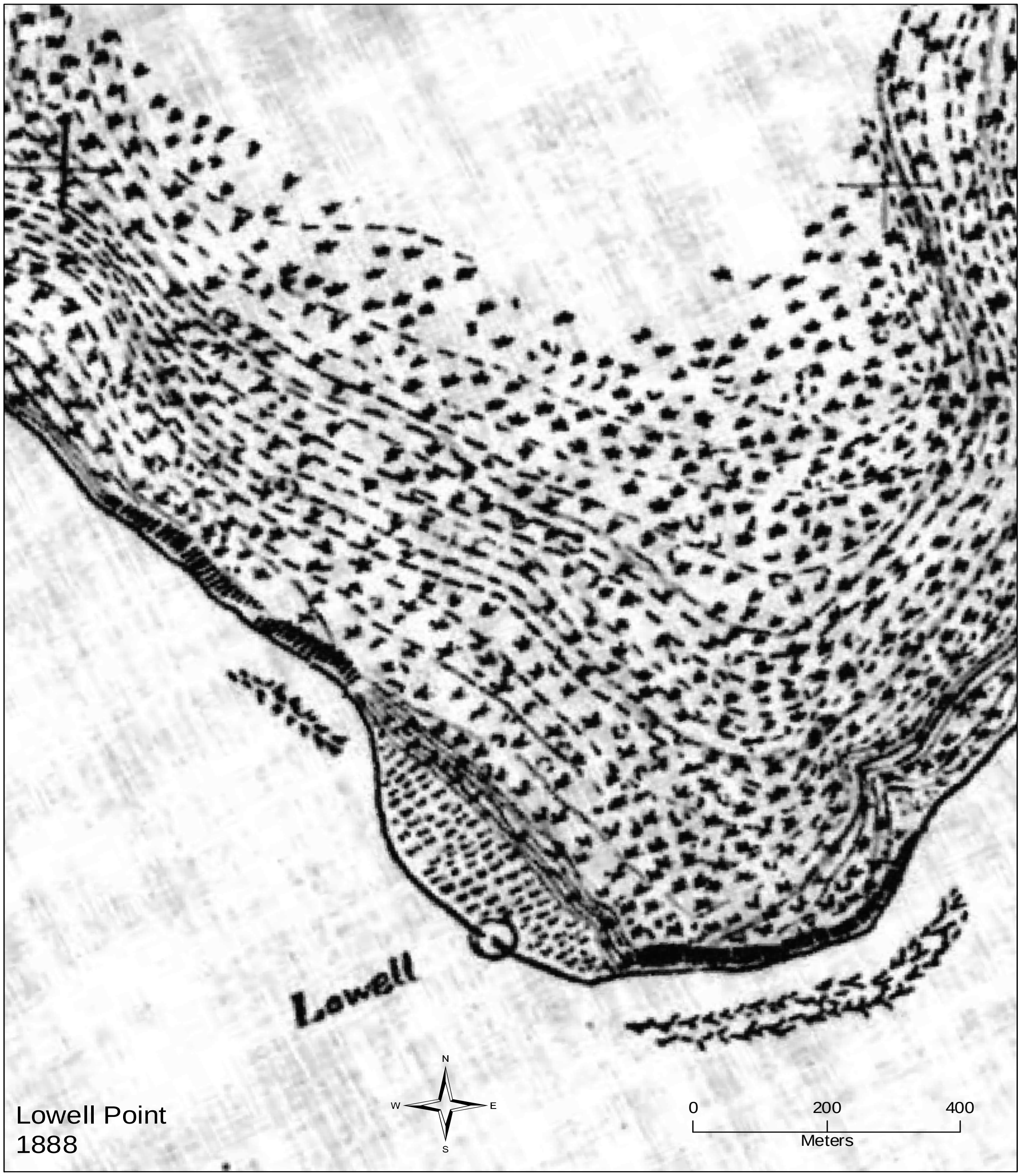


Figure 8. U.S. Coast and Geodetic Survey t-sheet map from 1888. This map is at too coarse a scale to show marsh and channel habitat. The map indicates a low grassy area without trees (Collins and Sheikh 2005).

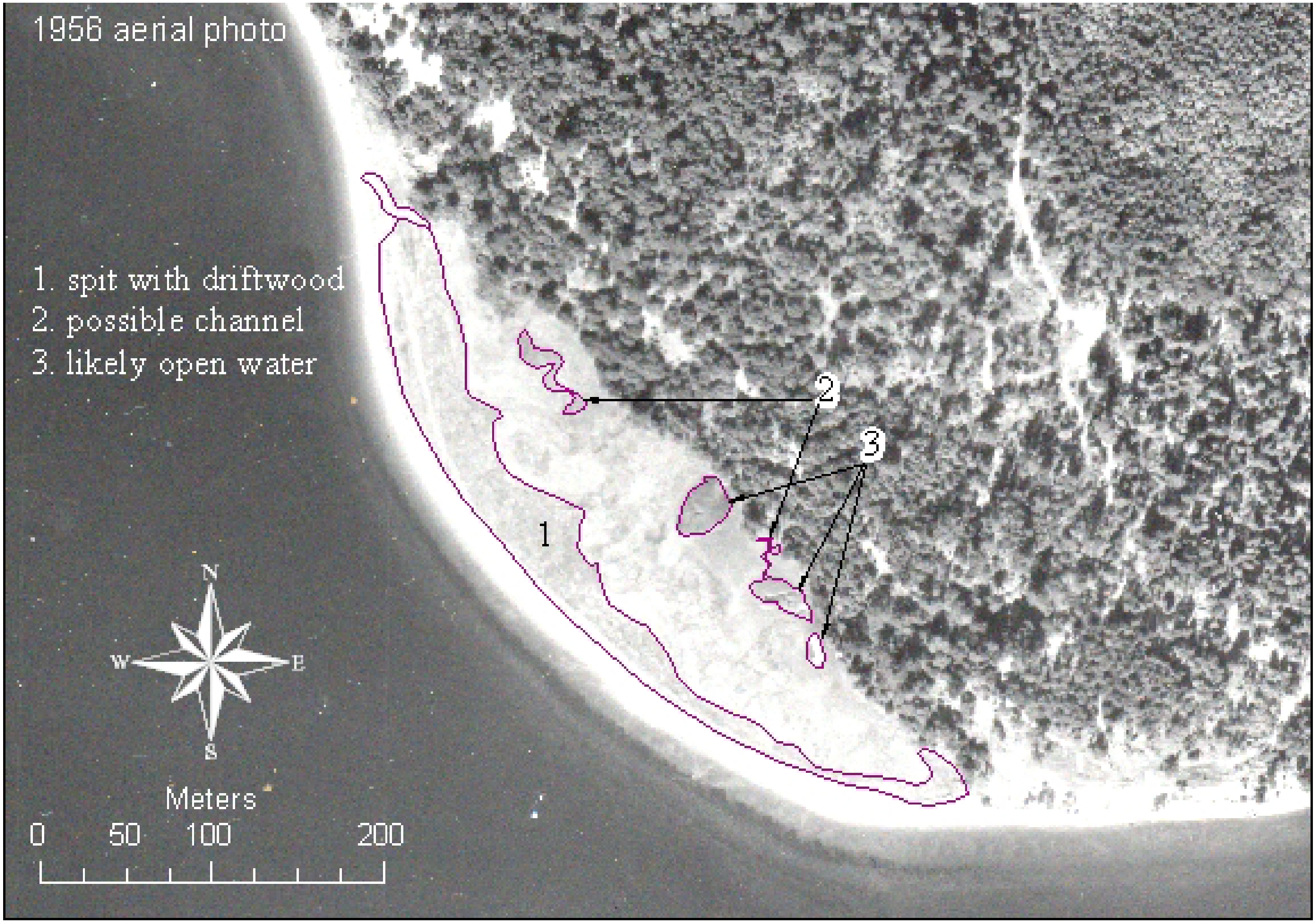
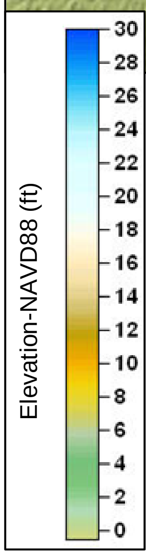


Figure 9. Interpretation of 1956 aerial photo. There is evidence that water, specifically moving water that made sinuous channels, existed at the site (squiggles on photo). Bright white areas can indicate the reflection off water. Other water areas are darker than the surrounding mottled white area. Driftwood logs are visible on the spit. Moving water most likely drained to Saratoga Passage.



1. parking lot
2. road
3. restroom building
4. trail
5. possible relict channel
6. low grassy field
7. wetland
8. stream gorge
9. beach
10. spit
11. boat ramp
12. bluff

Figure 10. Shaded relief of 2001-2002 LiDAR (Island County) and 2009 aerial photo interpretation of subtle landforms at Camano ISP that indicate the site's potential for restoration. Low areas shown on the LiDAR (light grey-green) are areas likely to be tidally flooded if the spit is breached. All of the existing Park buildings are on higher ground (dark gold): the picnic shelter is on historic spit (above MHHW) and the bathroom is likely on fill above MHHW. The southern parking lot is on fill and in the backshore zone (above MHHW). The north parking lot is part on historic spit and part below MHHW. The road is on fill and makes a straight dike-looking feature across the site. It is above MHHW until it gets to the north end of the Park. There is a dip in the road at the north end of the south parking lot that is probably related to undermining of the road by wetland water trying to flow under the road. This happens at the point where the historic photo shows the largest impoundment of water spanning across what is now the road. The trail from the road to the picnic shelter also stands out as a narrow spine of land crossing what is otherwise below MHHW. These two obstructions to water flow will need to be considered when designing a plan for tidal inundation of the site. The spine of the spit is clearly visible in the LiDAR. Note the boat ramp crossing the spit. *See tidal elevation map in Figure 11.*

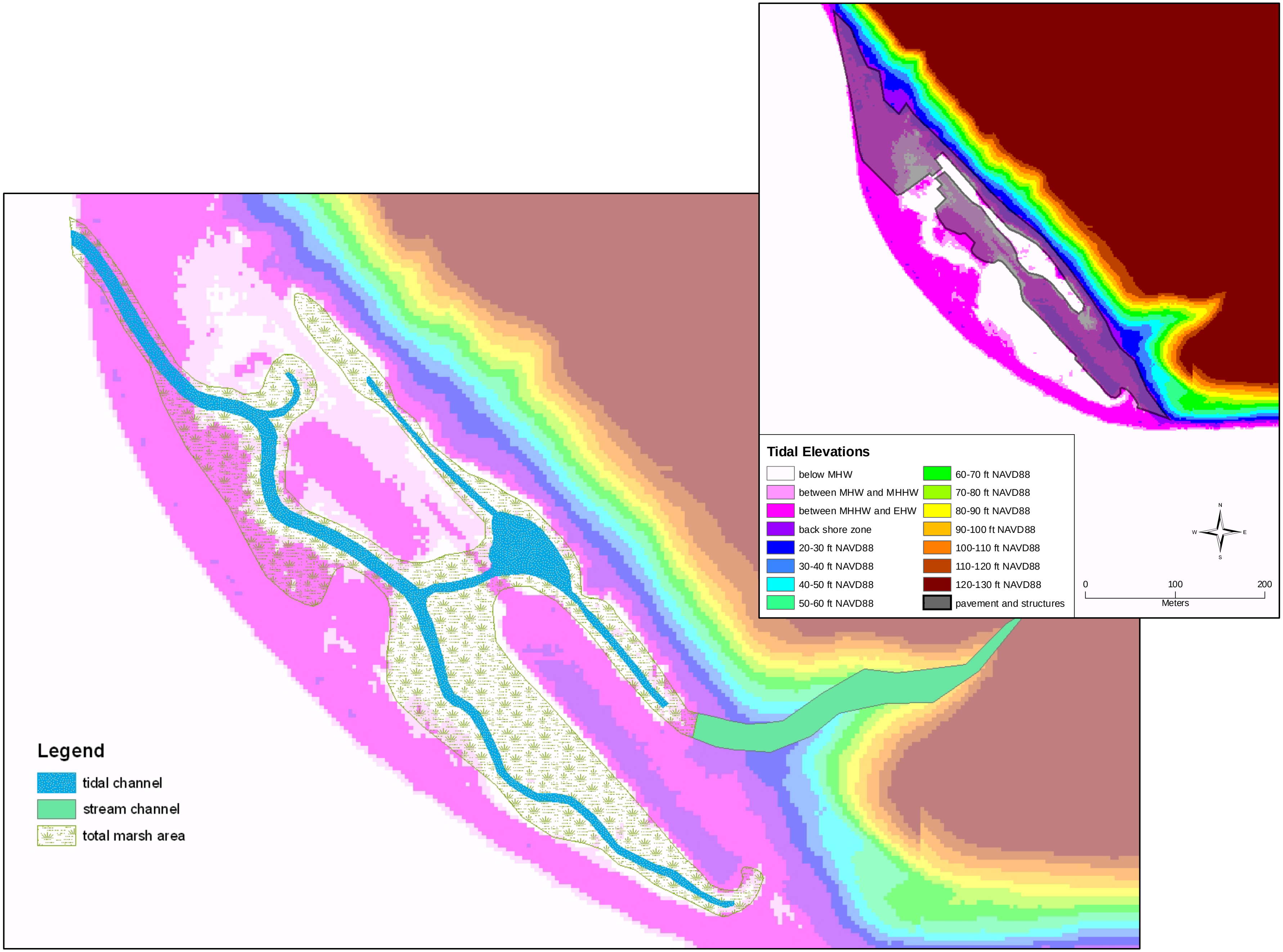


Figure 11. Restoration potential—a footprint of potentially restorable land—based on LiDAR data (Island County 2002). A theoretical tidal channel is represented on the north end, draining the marsh and wetland areas and connecting all to Saratoga Passage. The footprint excludes all existing structures, roads, and parking lots, except the southwest corner of the north parking lot (top inset). This assumes bridges or some kind of water conveyance will replace fill where the road and trails cross theoretical tidal channels.

RESTORATION FEASIBILITY

Sufficient area exists in Camano ISP to provide pocket estuary habitat. We next apply results from a hydrodynamic model and from sediment sampling to determine if breaching the berm would, in fact, inundate the proposed footprint (Will the habitat get wet?), and if that breach would create a pocket estuary with adequate connectivity that can be sustained through tidal exchange (Will the inlet channel stay open?).

Tidal Inundation (Will the site get wet?)

The hydrodynamic model is based on existing marsh/grassland elevations as represented in Island County LiDAR data, tidal patterns for Whidbey Basin, and a schematic cross section for an inlet channel (Figure 12). Changing channel morphology and resulting velocity changes over time are not accounted for in our hydrodynamic model (the model produced velocity predictions for a single, static cross-section). Because the site has no existing tidal channel, one would need to be excavated through the low areas according to the schematic diagram (Figure 12). Model results indicate that the proposed footprint would be flooded by high tides once the berm is breached (Figure 13). The footprint would also drain completely, or nearly so, at low tide. The arrows in Figure 13 indicate tidal water flow direction and velocity. Velocity is highest at the inlet channel mouth. As velocity increases, so does the erosive power of the water exiting the pocket estuary.

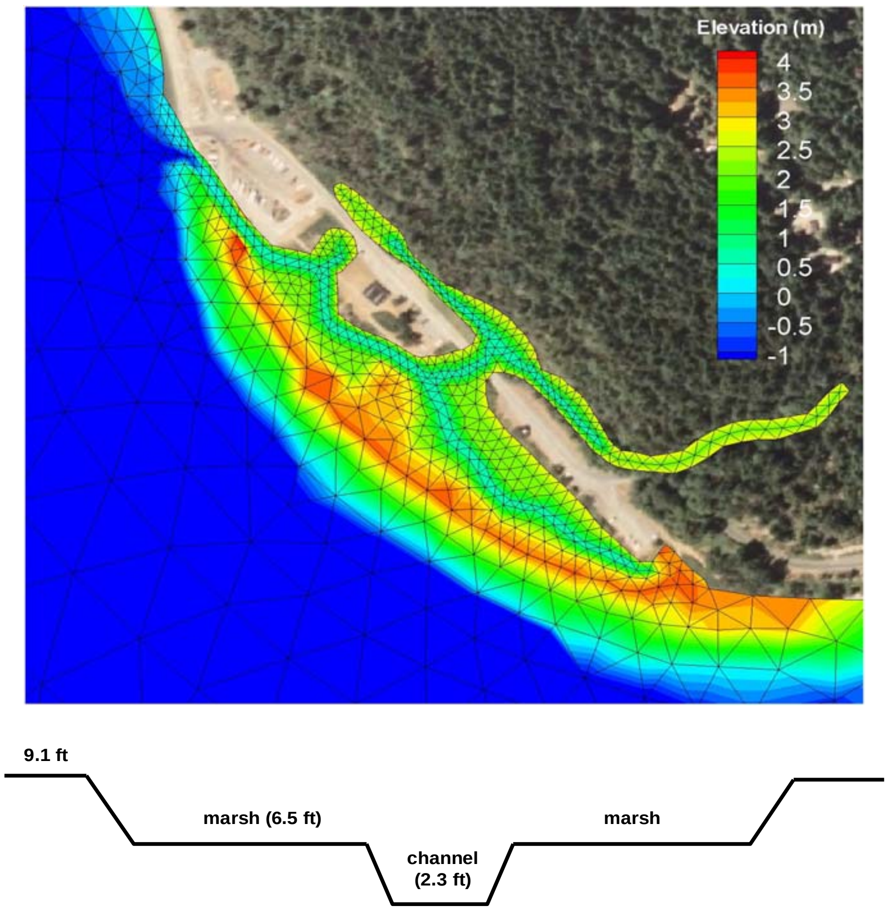


Figure 12. Hydrodynamic model set up. Upper diagram: grid and elevations based on LiDAR and the potentially restorable footprint. Lower diagram: schematic cross section of tidal channel and marsh elevations within a pocket estuary used for hydrodynamic modeling.

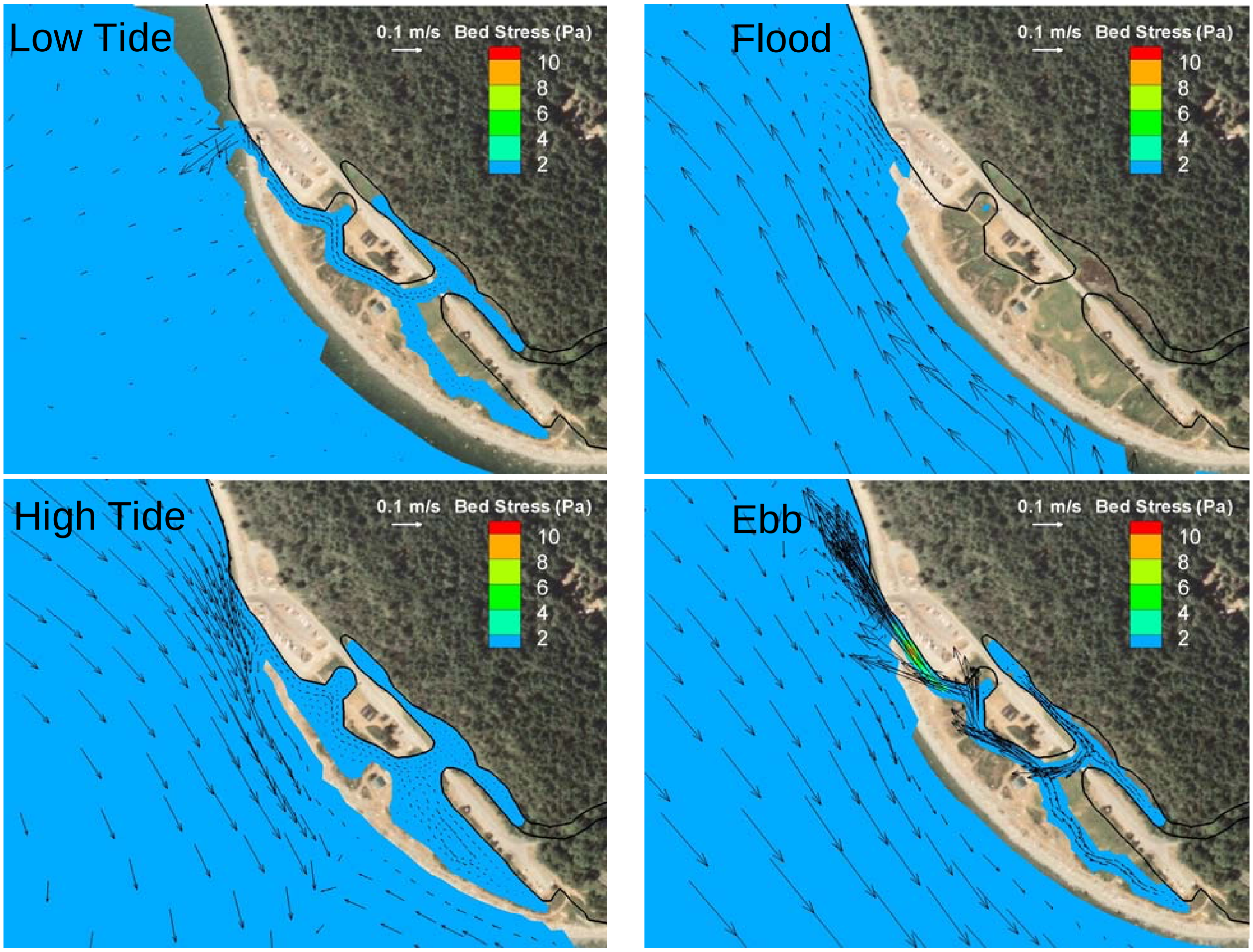


Figure 13. Tidal inundation model for the restoration potential footprint. Once connected to tidal inundation at the proposed location, the entire footprint would be flooded at high tide. Longer arrows indicate higher tidal velocity. Arrow direction indicates tidal flow direction across the marsh surface. Colors indicate bed shear stress—maximum occurs at the inlet channel during ebb tide. The diagrams do not represent bridges or other built structures.

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). These models were developed for designing large (navigable) tidal inlets 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 Camano ISP (1.77ha), 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 site along a gravel coast where longshore transport could dominate channel power/tidal prism, as 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 Camano ISP. 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.

Sediment Grain Size and Hydrodynamic Model Analysis

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 moving alongshore at the site.

The sediment was sampled using a *frequency-by-weight* bulk sampling method (Church et al. 1987). In this method, a specific weight amount of material is excavated from the beach surface to a depth of one 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 sediment grain size distribution. The Camano ISP sample weighed 68.85 pounds. We arrived at this weight by averaging the weight of the 6 largest cobbles we found on the beach.

We collected a bulk grain-size sample at approximately Mean High Water (MHW). 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. Beach sediment composition 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 Camano ISP: winter season is generally coarser than the summer beach profile. Sediment composition also varies spatially across the site. The beach gets finer-grained from south to north, as one moves away from the sediment source bluffs, where coarse grains are initially deposited. The very coarsest grains form a lag deposit at the base of the bluff (they 'lag' behind while the rest of the sediment moves on because wave energy is not high enough to move them). Our sample site was 5m up-drift of the boat ramp, and is finer-grained than the south beach. Any potential pocket estuary inlet channel would be located at the north end of the site in keeping with net shore drift and with other comparable pocket estuaries. The sample we took represents north beach conditions. We chose a site up-drift from the ramp because the ramp and adjacent docks impact sediments down-drift.

Overall, the Camano ISP beach face was poorly- to moderately-sorted (meaning how mixed the grain sizes are), with sorting increasing (becoming more uniform in grain size) both up and down beach from the coarsest zone (Figure 14). 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 fine to coarse gravel-armoring sand and fine gravel. Below MHLW the sediments graded to sorted sand. The sample location was selected to represent the coarsest mobile sediments. We processed the 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 15). Camano ISP sediments have a poorly-sorted grain-size distribution. Approximately 16% of the sediments are coarse gravel and up (>19mm), 18% are medium gravel (9.5mm to 19mm), and 28% are fine gravel (1.4mm to 9.5mm). The sand fraction makes up 37% of the sediments (<1.4mm, various shades of orange in Figure 15).

Figure 14. Grain size varies from sand to coarse gravel at the sample site. Coarser sediments armor finer sediments.

We constructed a grain size frequency by weight diagram (Figure 16). The grain size frequency diagram covers from the 5^{th} percentile to the 90^{th} percentile. The lower and upper most ranges would have been further differentiated by adding more sieve sizes to the analysis—if finer and coarser sieves had been used, respectively. The range achieved with the sieves we used is more than adequate to evaluate the sediment present on the beach and to determine D_{50} and D_{90}. D_{50} is the median grain diameter, where 50% of the sample by weight is finer than that diameter. Similarly, 90% of the weight of the sample is finer than D_{90}. This is nearly the entire range of sediments found on the beach.

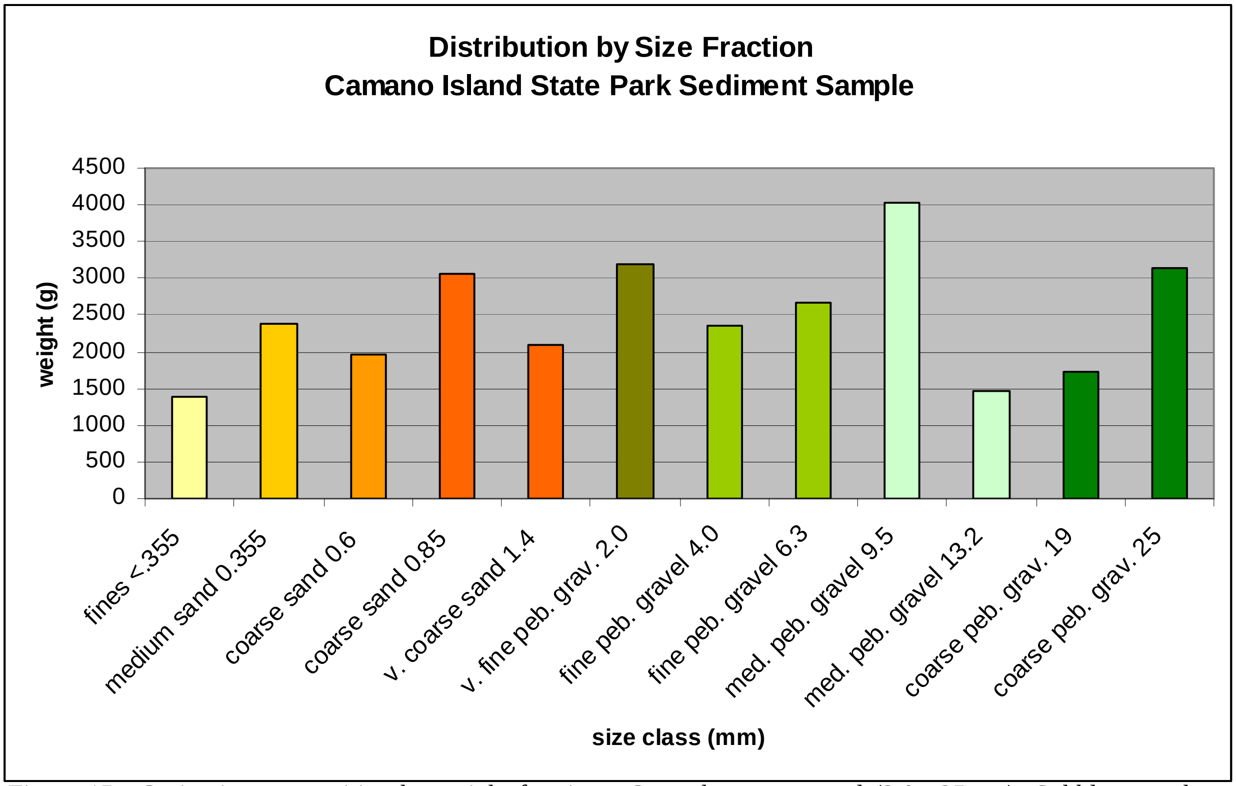


Figure 15. Grain size composition by weight fractions. Green bars are gravel (2.0->25mm). Cobbles may be present, but sizes >25mm are not differentiated. Orange bars are sand (<2.0). Silt and clay were not differentiated (sediment <0.355 in diameter).

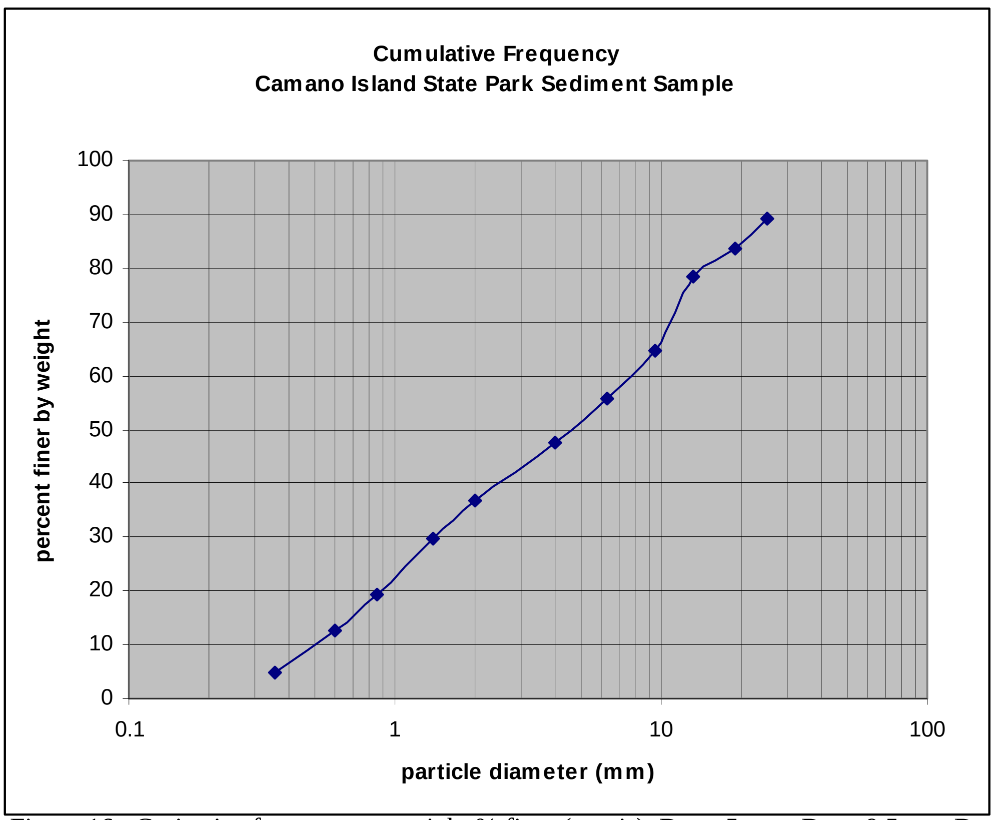


Figure 16. Grain size frequency as weight % finer (y-axis). D_{50} = 5mm. D_{65} = 9.5mm. D_{90} = 25mm.

We calculated critical shear stress (τ_{crit}) for several D_j values (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 (% finer than) by weight,
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.

We then compared (τ_{crit}) to the bed shear stress predicted by the hydrodynamic model. Battelle Pacific National Laboratory created a hydrodynamic model for Camano ISP based on LiDAR elevations, the schematic marsh cross section (Figure 12), and the restoration scenario (Figure 11). The model's predictive capability was calibrated using an existing model for Whidbey Basin (Yang & Khangaonkar 2008, Yang et al. 2009). The purpose of the model is to predict inlet channel velocities and bed shear stress within the channel over the tidal cycle so we can 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 Figure 17) for the longest duration: 70% of the time (Figure 17). The tidal inlet reaches a peak velocity in the inlet of 1.97m/s for less than 1% of the tidal cycle. The bed shear stress in the inlet channel is 10 Pascals (PA) at peak velocity during the ebb tide.

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

Grain size fraction by weight	Grain diameter (mm)	τ_{crit} (Pascals)	τ_{bed} (Pascals)	peak velocity from model (m/s)
D_{50}	5	2.39	10	1.97
D_{65}	9.6	4.59	10	1.97
D_{80}	13.5	6.45	10	1.97
D_{85}	20	9.56	10	1.97
D_{90}	25	11.95	10	1.97

Comparing τ_{bed} to τ_{crit} for D_j (Table 1), the peak velocity could move 85% or more of the weight of the sediment entering the channel, but the modeled tidal inlet channel would not have the power to clear the coarsest 10% of the sediments moving down the beach because τ_{crit} D_{90} is greater than τ_{bed}. The duration of the peak velocity compared to the amount of sediment in each fraction will determine how much of the 90% of sediment is moved. That amount plus the 10% of the sediment that would not be moved equals the amount of sediment that would accumulate in the channel. 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.

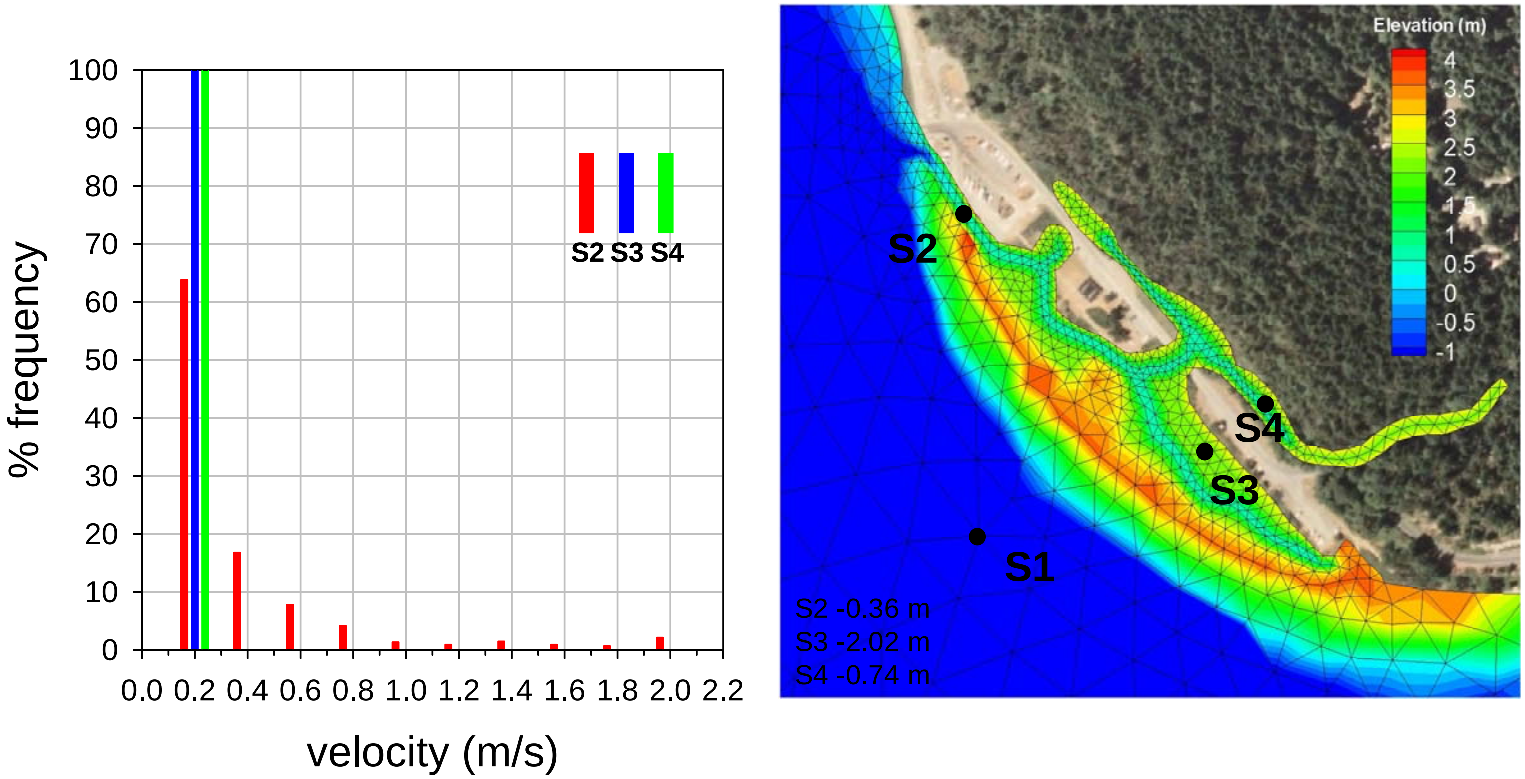


Figure 17. Hydrodynamic model results: predicted bed surface velocity in Saratoga Passage in front of CISP (s1), the inlet channel (s2), the tidal channel (s3), and the marsh surface (s4). The red bar shows velocity frequency at the inlet. The higher velocities are infrequent.

Comparing Restoration Scenarios to Existing Pocket Estuaries in Whidbey Basin

Using two methods to analyze restoration feasibility (the previous inlet stability analysis and the following comparison exercise) strengthens our prediction about Camano ISP restoration outcomes. Our second approach for predicting the feasibility of restoration at Camano ISP compares the restoration footprint to other pocket estuaries in Whidbey Basin. If the restoration footprint for Camano ISP is similar to other pocket estuaries that currently have sustainable inlet channels and are accessible to fish, it follows that Camano ISP would be sustainable. We took size measurements of existing pocket estuaries and compared those to the Camano ISP restoration footprint to see if the size of a restored Camano ISP 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 point for the pocket estuary (the high point in the channel behind which water is impounded in the pocket estuary). Sometimes this was difficult to determine and thus a potential source of error in determining the comparable channel width. We developed a regression for the relationship between pocket estuary area and inlet channel width (Figure 18). 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 ($p = 0.013$).

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 18). 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 Camano ISP restoration potential footprint to see where it falls on the regression line for the Whidbey Basin model. Camano ISP is in the range of other Whidbey Basin sites. However, it lies close to the lower end of the regression line. The last two Whidbey Basin pocket estuaries plotted, and the only sites smaller than Camano ISP's restorable footprint, are unusual because they are tidal channel marshes in a highly modified environment (Swinomish Channel's Swadabs Marsh and Old Bridge Marsh). 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. More pocket estuary points added to the area-inlet width graph will elucidate if the regression is valid and if sites like Swadabs Marsh and Old Bridge Marsh are outliers or not.

The Camano ISP restorable footprint is almost the same size as Arrowhead Lagoon, located near the end of the same drift cell at Brown Point (Figure 19). The two sites are very similar in their configuration and elevation as well. Arrowhead Lagoon is closer to a natal Chinook salmon river. Camano ISP has more freshwater input, which is important to fish and adds to the hydraulic head within the pocket estuary. The Hydrodynamic Model did not account for freshwater inputs. Arrowhead has a more protected inlet compared to the proposed restoration scenario for Camano ISP. Arrowhead is sustainable, which may imply that Camano would be also.

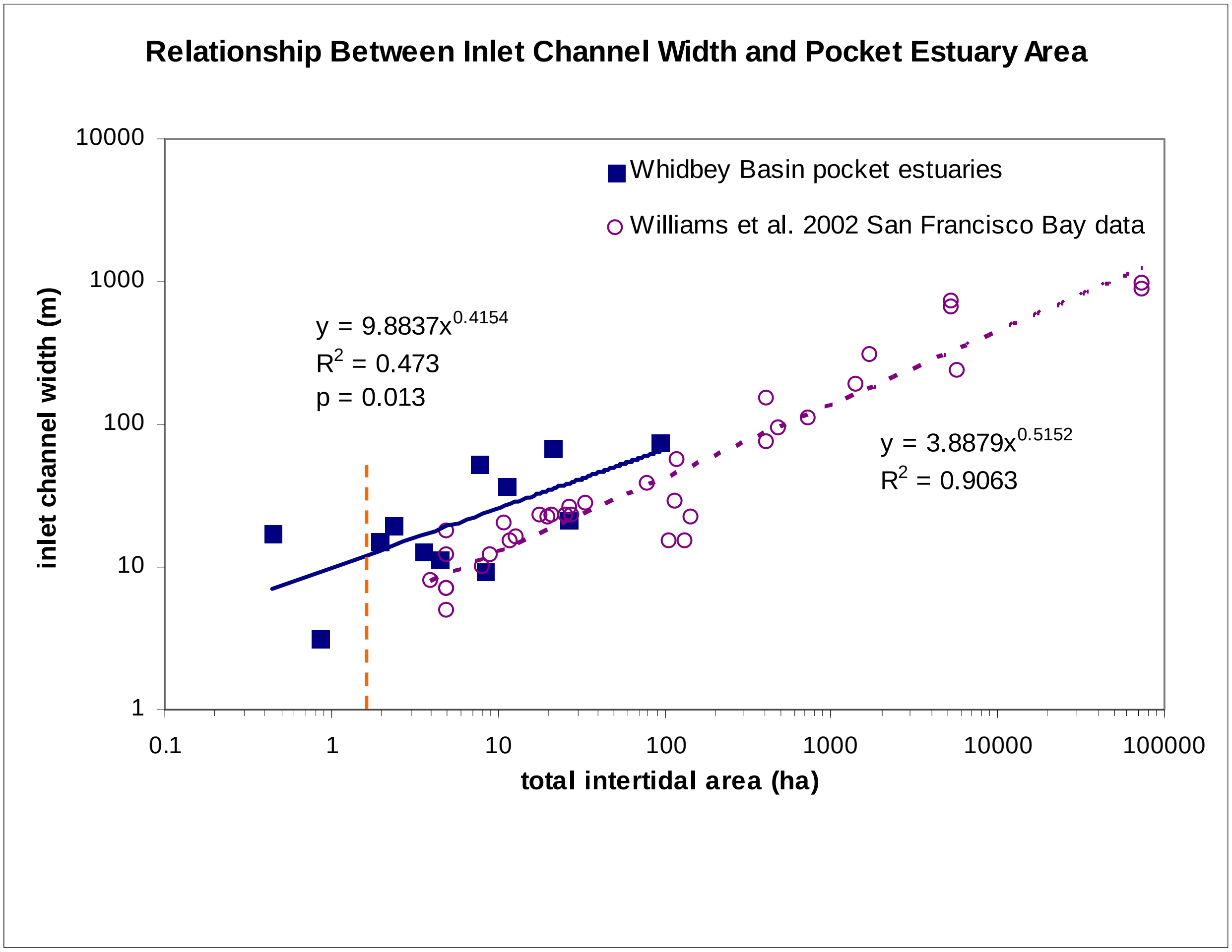


Figure 18. Inlet channel width *vs.* total intertidal area for Whidbey Basin pocket estuaries (blue squares) and San Francisco Bay tidal marshes (purple circles). Regression lines are plotted for each dataset. The R^2 value for the Whidbey regression is poor; however the relationship is significant ($p = 0.013$). Total intertidal area for the Camano ISP restoration potential footprint (orange line at 1.77ha) is plotted for comparison.

Figure 19. Arrowhead Lagoon (top photo) and Camano ISP (bottom photo). Arrowhead Lagoon is 1.95ha in area, compared to the restoration potential footprint area of 1.77ha at Camano ISP. Both sites formed behind curved spits, adjacent to headlands (as opposed to forming behind shore-parallel spits or at cuspate forelands). Both sites are/were high intertidal tidal channel-marsh habitats. Arrowhead Lagoon is modified: a dike bisects the historic intertidal footprint.

CONCLUSIONS

The body of evidence examined for this Feasibility Assessment indicates that salmon habitat restoration at Camano ISP by reconnecting low areas to tidal inundation is tentatively both possible and sustainable, with certain caveats. A restored marsh would support fish, including juvenile Chinook salmon, if directly connected to Saratoga Passage with enough local connectivity via that inlet channel. Elger Bay, located just east of Camano ISP, supports juvenile Chinook salmon and other fish (Figure 20). Additionally, Arrowhead Lagoon, which is of similar configuration and elevation to the restoration potential footprint for Camano ISP, is used by juvenile Chinook salmon. Chinook salmon using restored pocket estuary habitat at Camano ISP are likely to originate from the Skagit, Stillaguamish, and Snohomish Rivers (Figure 1).

Even though we don't have definitive historic data at Camano ISP outlining the clear extent of lost pocket estuary habitat, we were able to create a plausible *restoration potential footprint* model of what Camano ISP could be if pocket estuary habitat was a priority use for the site. With respect to intertidal footprint area, the restoration potential footprint at Camano ISP is near the lower end of what we see in existing pocket estuaries. Size alone does not predict success for restoration at Camano ISP. Camano ISP is very close in size to Arrowhead Lagoon (Figure 19). A dike bisects Arrowhead Lagoon, so the relationship between its current area and tidal channel and marsh area may be a relict of the historic lagoon. However, the fact that Arrowhead Lagoon is still connected after 50 years of being diked bodes well for restoration at Camano ISP.

The hydrodynamic model developed for Camano ISP, based on existing elevation data and excavating a channel, indicates that the existing marsh/grass surface would flooded with the tides. Comparing hydrodynamic model results to sediment data, we see that the ebb tide could clear 85% of the sediment mass entering the channel. The remaining 15% would be too coarse for the site's restored tidal prism to move. The higher velocity ebb tide will clear any sediment brought in by the slower flood tide. The coarsest sediments will come into the channel via longshore transport during storms.

The coarsest 15% of sediments likely to accumulate in the channel could be mitigated by locating the inlet north of the boat ramp and docks. The docks have rubber skirts along their base that obstruct or divert the coarsest sediment. Coarse sediment accumulates up-drift from the docks and is currently cleared by Park staff. If the coarse sediment being cleared were deposited down-drift from the inlet, it could solve the problem of the coarsest 15% of sediments. Because the coarsest fraction of sediments moves infrequently (during major storms), the inlet may remain open much more than 85% of the time, and just need clearing rarely. Storm frequency data is currently unavailable to refine sediment transport models.

Because so much pocket estuary habitat in Whidbey Basin has been lost, restoration at Camano ISP could be significant for Chinook salmon recovery and thus could warrant restoration in spite of the tentative prediction of success (Figure 20). Elger Bay is less than 2km from Camano ISP and is used by juvenile Chinook salmon, however it is only 1 of 3 remaining pocket estuaries along west Camano Island where once there were15 pocket estuaries (Figure 20). Arrowhead Lagoon is the next nearest site, at 23km traveling along the shore as small fish tend to do (Figure 20). In all, Saratoga Passage has lost 78% of its historic pocket estuary habitat. Adding pocket estuary habitat to the landscape at Camano ISP would increase the landscape-scale connectivity of these habitats and add to the total area of available habitat for juvenile Chinook salmon and other fish migrating through Saratoga Passage.

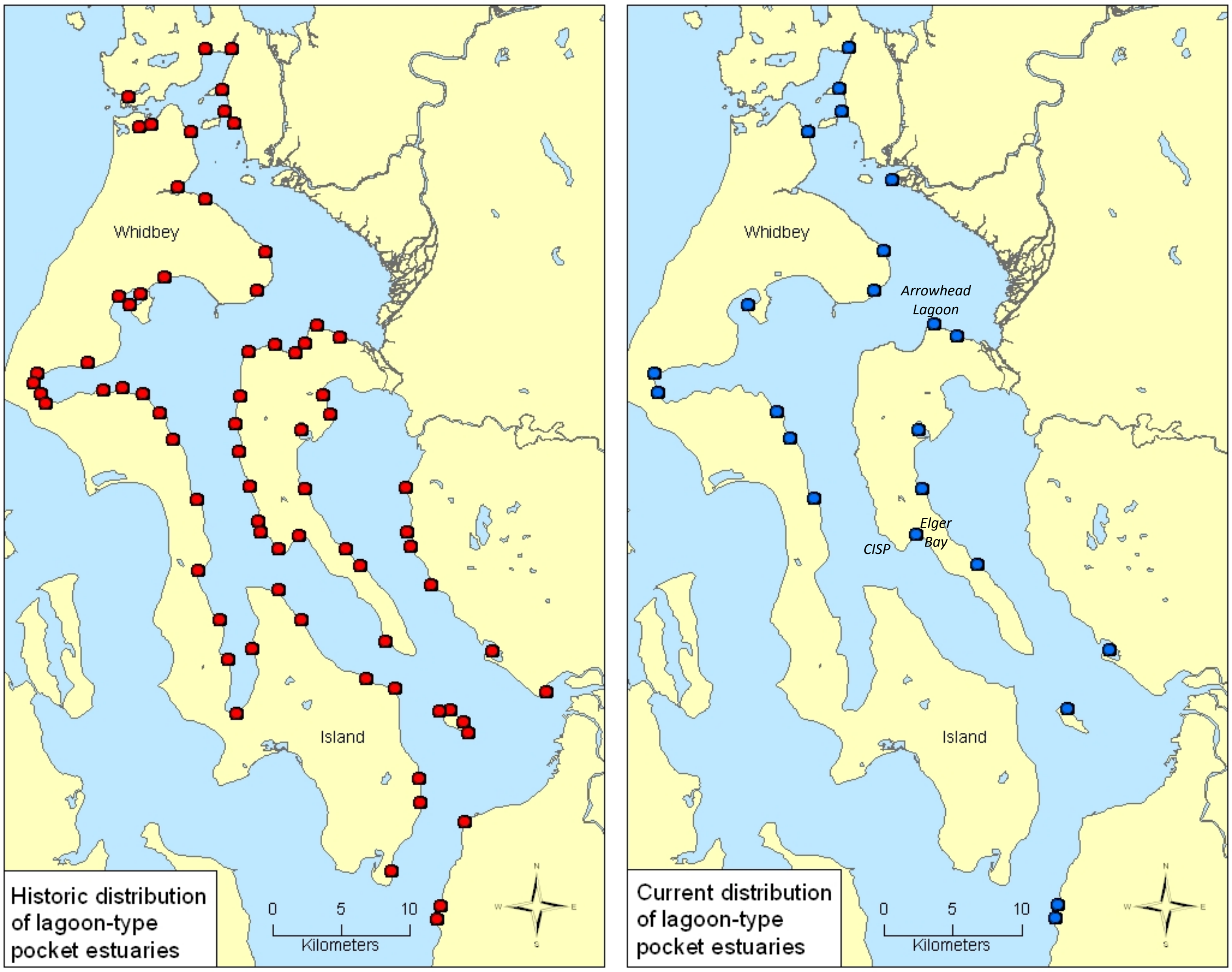


Figure 20. Historic distribution of lagoon or tidal channel marsh-type pocket estuaries (left map) compared to current lagoon or tidal marsh-type pocket estuary distribution (right map) shows that landscape-scale connectivity between pocket estuaries has decreased, as has total pocket estuary habitat area; pocket estuaries are fewer in number and farther between than historically.

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