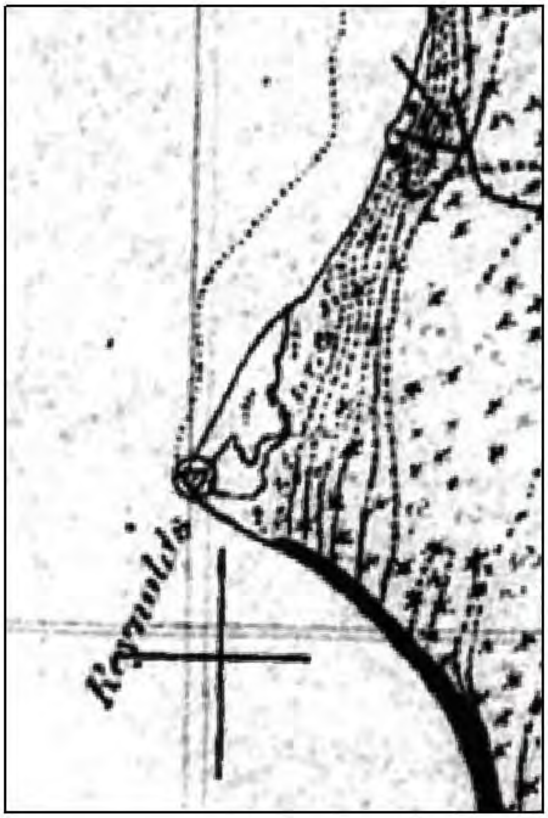
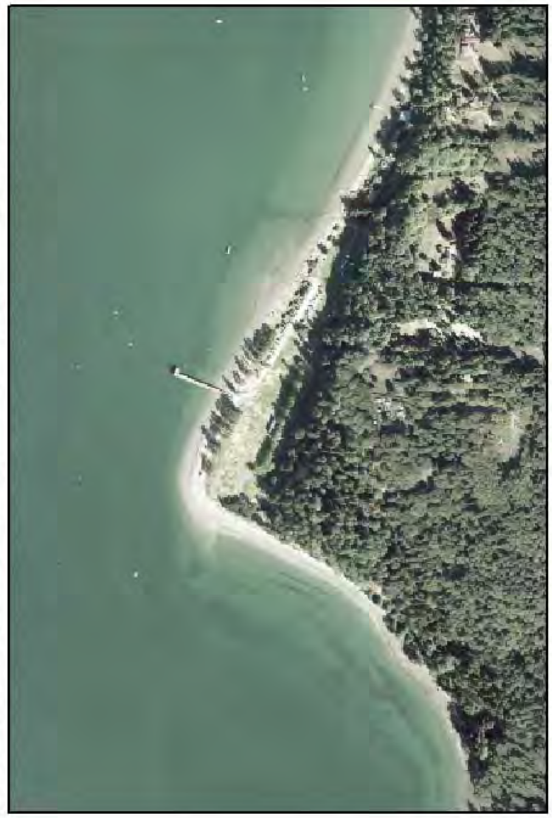
Barrier Lagoon Feasibility Study for Kayak Point County Park - Final Report





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June 21, 2011

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Executive Summary

The objective of this report is to provide coastal geomorphic, engineering, and ecological analysis and recommendations for evaluating restoration of a self-sustaining barrier lagoon at the north end of Kayak Point County Park, WA. The park site historically contained a relatively large barrier lagoon. Restoring a smaller version of a barrier lagoon provides an opportunity to recreate a lagoon and associated tidal wetlands that will provide ecological value to a host of nearshore species by adding more sheltered shallow water habitat, greater complexity, and connectivity to enhance nearshore habitats and provide other potential benefits, including educational opportunities for the public. This study follows other work at the site including coastal geomorphic assessment, and restoration feasibility assessment and design for other portions of the park.

A conceptual 0.6 acre lagoon developed by Snohomish County Parks and a larger 1.0 acre lagoon concept was created by CGS. The second alternative was developed to maximize the lagoon size within the apparent available area. Reference lagoon characteristics were measured for sites similar to the design concepts, including lagoon location, wave fetch, surface area, tidal prism, inlet width, depth, length, and elevations at the constriction point in the inlets. It must be noted that data and relationships between lagoon size and setting to inlet stability are very limited for small Puget Sound region tidal lagoon systems. These data were used by ESA-PWA to quantitatively predict the stability of the proposed inlets and by CGS for a qualitative comparison. Full technical details for the quantitative reference lagoon analysis can be found in Appendix 1 and the results of all work are summarized in this report.

The Bruun stability criterion, based on sediment transport rates, was applied first. For the two proposed lagoon alternatives at Kayak Point, inlet stability was rated poor. The usefulness of the Bruun stability criterion is limited by the ability to accurately predict the longshore sediment transport and other complexities, and can be considered an approximate indicator only.

Based on an estimation of wave power, the majority of the reference lagoons were seen to fall slightly below the line between open and closed inlets, meaning the lagoons were roughly at equilibrium with the wave climate, and subject to only occasional closure. The lagoon proposed by Parks appeared to be just within the stable to seasonally closed range and the expanded 1.0 acre lagoon was slightly farther into the open range. The larger 1.0 acre lagoon would be preferred over the smaller option in order to minimize inlet closure and the potential need for maintenance, however, the inlet for this size lagoon may not be stable, and may close or be intermittent with high precipitation events in combination with storms possibly reopening the inlet. Due to the very limited measurement and science on Puget Sound area lagoon and inlet dynamics and relationships, it is not possible to better predict the trajectory of the two proposed alternatives without a considerable amount of additional data collection and analysis.

A lagoon size greater than 1.0 acre would provide an increased probability of remaining open without maintenance, or to minimize maintenance. The most effective way to maximize lagoon tidal prism is to increase lagoon surface area. As tidal prism is the key factor for inlet stability, sea level rise can be seen as a benefit in terms of the trajectory of the system if a lagoon and inlet are implemented.

Specific recommendations are included in the *Lagoon Design Guidelines* section, including information on: inlet size requirements, lagoon size and location, saltmarsh/wetland fringe, typical cross-sections, inlet location, inlet dynamics and stabilization recommendations, and expected substrate conditions.

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Introduction and Purpose

The objective of this report is to provide coastal geomorphic, engineering, and ecological analysis and recommendations for People for Puget Sound appropriate for evaluating restoration of a self-sustaining barrier lagoon at the north end of Kayak Point County Park, WA (Figure 1). The Kayak Point County Park site historically contained a barrier lagoon, which encompassed a moderately large portion of the park with an inlet well north of the point. Restoring a smaller version of a barrier lagoon provides an opportunity to recreate a lagoon and associated tidal wetlands that will provide ecological value to a host of nearshore species by adding more sheltered shallow water habitat, greater complexity, and connectivity to enhance nearshore habitats and provide other potential benefits, including educational opportunities for the public.

The first four project tasks are included in this draft report. Task five includes two meetings, one of which was already conducted. One public meeting remains to be conducted. The tasks included in this report are:

- Task 1: Results of initial site analysis and data collection
- Task 2: Lagoon feasibility and sustainability analysis
- Task 3: Lagoon design guidelines.
- Task 4: Preliminary cost estimate

The work summarized in this report was carried out by 2 firms, Coastal Geologic Services, Inc. (CGS) and ESA-PWA, who was a sub-consultant to CGS. CGS carried out project management and planning, reference lagoon data collection and compilation, coastal geomorphic assessment and analysis, creation of all main report figures, cost estimating, and report writing. ESA-PWA was the lead on the technical elements of the lagoon stability analysis and inlet stability and sizing calculations. ESA-PWA generated a technical memo summarizing their work and the primary methods, results, and uncertainties associated with the lagoon stability analysis (attached in full as an Appendix), the results of which were summarized in this report.

The intent of this report was to provide Snohomish County Parks with adequate information to decide on whether to proceed with design development and to provide design guidance for developing a final design of a lagoon and inlet at the park that includes a connection to Port Susan with minimal maintenance requirements. However, uncertainty remains as to the geomorphic trajectory of a barrier lagoon inlet if it is implemented, as explained in this report.

Many coastal embayments such as the historic barrier lagoon at Kayak Point have been eliminated or disconnected from the Puget Sound by the placement of fill, tidal barriers, and other stressors. The magnitude of loss to this shoreline type has contributed to the decrease in shoreline length (complexity) and increase in shoreline homogeneity in addition to the physical loss of the habitats found in lagoons (Schlenger et al. in review). Research has documented that barrier lagoons provide valuable nearshore habitat for juvenile salmon as well as other species (Beamer et al. 2003, Beamer and McBride 2007, Redman and Fresh 2005). Reduction in net shore-drift volumes due to bulkheading and other modifications and other site-specific impacts associated with shore modifications can further degrade the structure and processes that support these shoreforms and the valuable habitat functions they encompass.

Previous work for this site includes a coastal geomorphic assessment of the shores encompassing Kayak Point County Park (*Restoration Feasibility Assessment*, CGS/ MacLennan and Johannessen 2008). That work was carried out to determine the drivers of erosion along the park shores, the results of which were used to support restoration recommendations and designs. Four preliminary beach restoration/enhancement design options were provided that aimed to enhance nearshore habitats and prevent further storm damage to park infrastructure. The conceptual restoration alternatives in the 2008 report included road removal or setback in the southern portion of the park, other nearshore habitat improvements, and an alternative that had a moderately large lagoon and inlet within the park. The second phase of the 2008 study contained a sea level rise component (PWA 2008), which addressed each beach enhancement alternative under different (local relative) sea level rise scenarios.

Additional work completed for the park included the *Kayak Point County Park Restoration Feasibility Assessment and Design* (CGS/Johannessen and Waggoner 2010), which provided designs for the southern shore and the point within the park. The final design from that project included road setback, relocation of portions of the park infrastructure in the southern portion of the park, beach nourishment, backshore vegetation enhancement, and other actions for nearshore habitat enhancement.

Lagoon Alternatives and Reference Sites

Two alternative lagoons (at conceptual level) are proposed here for Kayak Point County Park. Conceptual Site Plan 1 (Figure 2) that came from Snohomish County Parks based on their planning process and Conceptual Site Plan 2 (Figure 3), which was created by CGS. Alternative 2 was developed to maximize the lagoon size within the apparent available area. There was concern that the Snohomish County Parks conceptual lagoon may have insufficient tidal prism to overcome the littoral drift at the site, so the larger lagoon was proposed for evaluation and comparison in the stability analysis. The size characteristics of the two lagoons as initially proposed are provided in Table 1, and were subject to change based on the stability analysis results.

Table 1. Proposed lagoons for Kayak Point County Park with an inlet in the northern portion of the Park.

Source	Length x Width (ft)	Area (ac)	Average Depth (ft)	Tidal Prism (ac-ft)	Fetch (mi)	Tidal Range (ft)
Alt. 1: Snohomish Parks	280 x 65	0.6	1.5	0.9	6 SSW 7.6 NW	11.24
Alt. 2: CGS	570 x 70	1.0	1.5	1.5	6 SSW 7.6 NW	11.24

Reference lagoon characteristics were determined by CGS and can be found in Tables 2–4. Data included physical characteristics such as lagoon location, wave fetch, surface area, and tidal prism. The selection of these reference sites was based on an initial search of Puget Sound for lagoons with similar tidal range, size, and fetch as the proposed lagoons (Figures 4). It must be noted that data are very limited for small Puget Sound region tidal lagoon systems both in terms of physical characteristics and stability relationships. All available data were used for this study, including collecting data through both field and remote measurement.

Lagoon and inlet characteristics (Tables 3 and 4) were based on limited bare-earth LiDAR analysis where available that was flown at low water with respect to the lagoon (see notes in table for other sources). Additional measurements were made by CGS from rectified aerial photography. Field visits were carried out for direct measurement of the inlet channels by CGS at Fisherman's Point and Whitney Road for this study (Table 4). Measurements were made in fall 2010 including inlet width, depth, length, and elevations at the constriction point in the inlets near the lagoons. Direct measurements were made in previous studies at Third lagoon and Gulf Road (Johannessen et al. 2009a, Johannessen et al. 2009b). Tidal prism is shown as the volume difference between MHHW and low water surface inside the lagoons. Oblique aerial photographs of the reference lagoons can be seen in Figures 5–7. Additionally, a lagoon had been mapped at Kayak Point by the United States Coast & Geodetic Survey in mapping completed in 1886 (Figure 8).

Table 2. Reference lagoon/estuary geomorphic characteristics. Additional characteristics can be found in Appendix 1.

Lagoon	Location	Fetch max (mi)	Fetch minor (mi)	MHHW (ft MLLW)
Tolo Lagoon	West Bainbridge Is.	6.4 S	2.8 NW	11.76
Gulf Rd	N Whatcom Co.	36.4 WNW	23.5 SW	9.1
Third Lagoon	S San Juan Is.	6.5 NNE	4.3 WNW	7.33
Heyer Pt	E Vashon Is.	16.0 N	6.5 SE	11.68
Fishermans Pt	Dabob Bay	9.8 SSE	3.2 NNW	11.49
Talagwa	Camano Is.	12.7 SE	8.2 NNE	11.22
Whitney Rd Lagoon	Toandos Pen.	16.2 NE	2.8 SE	11.27

Table 3. Reference lagoon/estuary area and approximate tidal prism characteristics (from LiDAR). Kayak Pt data from USCGS T-Sheet #1755 dated 1886.

Lagoon	Location	Surface Area (ft^2)	Surface Area (ac)	Tidal Prism (ac-ft)
Tolo Lagoon	West Bainbridge Is.	54,500	1.25	1.8*
Gulf Rd	N Whatcom Co.	132,000	3.40	1.4
Third Lagoon	S San Juan Is.	107,000	2.46	1.7
Heyer Pt	W Vashon Is.	92,000	2.11	5.6
Fishermans Pt	Quilcene	126,500	2.9	11.7
Talagwa	Camano Is.	168,000	3.9	9.3
Whitney Rd Lagoon	Toandos Pen.	29,400	0.67	0.7
Kayak Pt 1886	Port Susan	78,200 (MHW)	1.8	2.5*

* - Tidal Prism estimated – insufficient data for topographic analysis

Table 4. Reference lagoon/estuary inlet channel characteristics (from LiDAR). Kayak Pt data from USCGS T-Sheet #1755 dated 1886.

Lagoon	Location	Channel Width at MHHW (ft)	Channel Cross Section Area to MHHW (ft^2)	Channel Depth from MHHW (ft)	Channel Length (ft)
Tolo Lagoon	West Bainbridge Is.	12	*	*	220
Gulf Rd	N Whatcom Co.	32	65	3.0	150
Third Lagoon	S San Juan Is.	15	11	1.5	120
Heyer Pt	W Vashon Is.	59	125	3.4	380
Fishermans Pt	Quilcene	50	114	3.4	270
Talagwa	Camano Is.	44	128	5.0	1,100
Whitney Rd Lagoon	Toandos Pen.	16	15	1.5	110
Kayak Pt 1886	Port Susan	30 (MHW)	*	*	670

* No data on channel geometry available

Winds at Kayak Pt County Park

Wind data was available for Kayak Point County Park from a gauge installed in 2001 by Weatherflow, Inc. Data was available for an approximately 9-year period from August 2002 to March 2011. These data were generally collected at irregular intervals by the instruments, and required some processing to develop a representative hourly data set for wave hindcasting. Final processing was performed by PWA for use in the inlet stability analysis (Appendix 1).

Reference Lagoon Analysis Results

Full technical details for the reference lagoon analysis can be found in Appendix 1. The results of that work will be briefly summarized here. Relationships between lagoon tidal prism and both wave power and inlet cross sectional area have been empirically derived (Battalio et al. 2006). The relationships were used by ESA-PWA in the attached memo, utilizing CGS reference lagoon and inlet data, to determine relative inlet stability for the proposed lagoon alternatives. Please refer to Appendix 1 for a complete description of the methods and results of the technical analysis. The findings of the ESA-PWA analysis were the basis of developing conclusions and recommendations in this report. Also note that considerable uncertainty exists in the Appendix 1 work, as noted therein.

ESA-PWA, with assistance from CGS, analyzed an irregularly collected wind dataset from the pier at the park to generate a new wind rose for the site (Appendix 1, Figure 1). This replaced the wind record from Smith Island west of Whidbey Island, and resulted in a much more appropriate wind record for hind-casting wind-generated waves at the site (Appendix 1, Figure 2), and subsequently, estimating the littoral drift rates.

ESA-PWA first examined available calculated data for tidal prism and total annual littoral drift. Appendix 1 stated that:

> For the two proposed lagoon alternatives at Kayak Point, inlet stability is rated poor. Although the gross littoral drift is relatively small, the expected tidal prisms for the two alternatives are also small. The usefulness of the Bruun stability criterion is limited by the ability to accurately predict the longshore sediment transport and other complexities, and can be considered an approximate indicator only.

An estimation of wave power was made based on wave hindcasting from wind and fetch data, and then related to the tidal prism required to maintain a stable inlet (Johnson 1973). The majority of the reference lagoons were seen to fall slightly below the line between open and closed inlets, meaning the lagoons were roughly at equilibrium with the wave climate, and subject to only occasional closure (Appendix 1, Figure 3). The lagoon proposed by Parks appeared to be just within the stable range to seasonally closed range as well, although the data plotted lowest on the graph suggesting that confidence is not high. However, the expanded 1.0 acre lagoon proposed by CGS was slightly farther into the open range. As noted in Appendix 1 (page 5):

> This analysis indicates that the larger lagoon size (1.0 acres) is more likely to stay open under typical wave and tide conditions. The smaller lagoon size is closer to the region where closure is likely. It should be noted that the exact dividing line between open and closed is not known, and there are many inlets that are intermittently open and closed.

The effective tidal prism for the reference and proposed lagoons was then related to inlet area using the relationship developed by Hughes (2002). The majority of the reference lagoons were close to the reference line, which indicates relative equilibrium between tidal prism and inlet cross sectional area (Appendix 1, Figure 4). Both of the proposed lagoons were plotted on the line, indicating they would be close to equilibrium with the chosen inlet area.

The proposed lagoon at Kayak Point County Park, as drawn by Parks (Figure 3), falls within the seasonal to occasionally closed range. As shown by the empirical relationships between inlet parameters, every effort should be made to maximize the tidal prism of the lagoon, as that is the primary driver of the tidal current scour needed to maintain an open inlet. The larger 1.0 acre lagoon would therefore be preferred over the smaller option in order to minimize inlet closure and the potential need for maintenance, however, the inlet for this size lagoon may not be stable, and may close or be intermittent with high precipitation events in combination with storms possibly reopening the inlet. A lagoon size greater than 1.0 acre would provide an increased probability of remaining open without maintenance. The most effective way to maximize lagoon tidal prism is to increase surface area, as the elevation of the lagoon channel where it crosses the beach (referenced as the thalweg, or deepest portion of the channel) will be in dynamic equilibrium with all physical forces, and simply excavating a deeper inlet thalweg will not last more than a short time.

As tidal prism is the key factor for inlet stability, sea level rise can be seen as a benefit in terms of the trajectory of the system if it is implemented. Projected sea level rise would directly increase the tidal prism and hence the stability of the inlet. Sea level rise is projected to occur on the order of 1.5 to 5 ft by 2100.

Also important is maximizing fresh water input into the lagoon in order to enhance the volume of water exchange through the inlet. This would aid in scouring the inlet bottom to provide an offset to sedimentation due to littoral drift. Additional freshwater input would increase the effective tidal prism. However, this is not nearly as high a priority as maximizing the lagoon size, as the amount of freshwater input to the adjacent uplands appears to be fairly small compared to volume of tidal exchange. Maximizing freshwater input would still provide the benefit of lowering maintenance needs slightly. Freshwater input beyond very minimal amounts would also produce estuarine conditions in the lagoon, which would increase the habitat value for juvenile salmon.

Please note that due to limited data on reference lagoons and determination of detailed inlet and lagoon relationships, a high degree of uncertainty exists in the quantitative inlet stability analysis. Previous published and known unpublished studies on lagoon-inlet systems have focused on much larger lagoon sizes in other geographic areas, typically with smaller tidal range and greater wave energy. Another constraint on this study was that recent additional reference lagoon data discovered soon before the study initiation (Whidbey Basin/Island County sites) was found to be of inadequate quality after error checking was carried out by CGS and could not be used. This substantially decreased the reference site data that was expected to be available for use. Overall, it is not possible to put error bars or "to bracket the uncertainty" clearly due to complex interactions of multiple variables in complex and only partly understood systems. We have attempted to describe the analysis, findings, and sources of uncertainly here as well as possible.

Additional detailed measurements at a larger number of lagoon and inlet systems, along with a better understanding of which are open, intermittent, and closed would allow for development of more accurate and appropriate relationships for Puget Sound systems. Also, the determination of littoral drift rates for these sites, which is not a trivial matter for any site in Puget Sound, would be needed to fully utilize new and existing data. At one point in the process, the collection of sediment removal from the boat ramp by Parks staff was mentioned as a potential additional source of data. This information would be qualitatively useful for additional analysis, but due to the very broad nature of the beach and lack of time series data, it would be difficult to infer the littoral drift rate from this type of information.

Unfortunately, due to the very limited data set on reference lagoon inlet systems, the fact that the two proposed lagoons fall so close or virtually on the understood border between open and closed systems, and the lack of study on these small systems, it is not possible to give a clear prediction of the geomorphic trajectory of the two proposed lagoon configurations. A lagoon and inlet system similar or ideally larger than the 1.0 acre alternative may remain open in most conditions but may very well require occasional maintenance in the form of a small backhoe or even shovels to facilitate the release of impounded water on the inside to initiate scouring, which would then reopen the lagoon system again at the park site.

Also important to consider are the habitat value and relative rarity of closed lagoons in current day conditions. These systems have been lost to development at higher proportions than barrier lagoons and other estuarine features in the greater Puget Sound area (Simenstad et al. 2009). These features provide bird and other wildlife habitat as well as fish habitat for a limited number of species.

Qualitative Coastal Geomorphic Inlet Analysis

A qualitative coastal geomorphic comparison is presented in this section between the reference lagoons and the Kayak Point site. Although the reference lagoon and inlet sites were selected to be most similar to conditions at Kayak Point, all vary in one or more ways. This is inevitable with the great amount of variation among the suite of parameters within the crenulated shore of the diverse Puget Sound

Lowlands. This comparison will focus on the few reference sites and specific features most similar to the Kayak Point site.

Of all of the reference lagoons selected for use in this study, the most similar sites appear to be Talagwa, Tolo, and Point Whitney Road. Both the Talagwa and Tolo sites are dominated by southerly wind waves and littoral drift. The northern portion of Kayak Point is also exposed to northerly wind waves, similar to Talagwa, while Tolo does not have a northerly fetch. However the Tolo lagoon is similarly oriented and has similar wave energy to the Kayak Point site. The Point Whitney Road lagoon inlet is more sheltered from southerly winds, but has an adequately greater northerly exposure to make it comparable to the Kayak Point north site.

The Talagwa inlet is in a partial wave shadow from southerly winds similar to the Kayak Point site, although it is in a slightly more sheltered position than the Kayak Point inlet would be. The inlet appears fairly well developed at the Talagwa site, and appears to be mostly fixed in spatial position. The Point Whitney Road inlet may be more similar to what may occur at Kayak Point, as it appears as if the shore is closer to linear and the inlet has been pushed by littoral drift in one direction, possibly with some variation in position over time. Similarly, the Tolo inlet is pushed northward by littoral drift with an intertidal channel that also trends northward, as is anticipated at Kayak Point.

The Tolo inlet is an example of a shallow inlet exchanging a limited volume of water during tide cycles. The Tolo site appears to have a slightly higher elevation inlet bottom and would represent less of a lagoon water surface elevation drop than is anticipated at Kayak Point.

The other reference sites vary more from conditions that Kayak Point, in that they differ in exposure, orientation, up-drift sediment sources, and to the limited extent known, the grain size (for example Gulf Road and Third Lagoon have much coarser grain sizes, based on past field reconnaissance).

Overall, the qualitative analysis of the Kayak Point northern shore relative to the reference sites, along with other Puget Sound region field reconnaissance over the past few decades suggests that the stability of an upper intertidal inlet at Kayak Point is very questionable with the 0.6 acre size. The larger 1.0 acre size appears as if it may not necessarily remain open, but a larger size would be advantageous if at all possible based on qualitative analysis.

Due to the great variation of lagoons and inlets around Puget Sound in areas with generally similar tidal range and fetch, uncertainties still remain in how a lagoon and inlet would respond to prevailing conditions at Kayak Point. Also the complexities revealed with these sites and lack of pre-existing data has demonstrated that a good amount more of quantitative and qualitative research should be carried out in these smaller lagoon systems.

Lagoon Design Guidelines

1. Inlet Size Requirements

Under the larger lagoon alternative (1.0 acre), the lagoon inlet should be sized at 57 ft^2 below MHHW at a width of approximately 27 ft at MHHW (Appendix 1, Table 5). The cross section should be shaped between a trapezoid and a parabola. The inlet bottom (thalweg) would be approximately 5 ft wide with side slopes of 4:1 (horizontal:vertical). These are the recommended side slopes, and we do not recommend steeper side slopes. Overall, this would provide an initial inlet depth of 3.7 ft below MHHW, and therefore approximately 3.7 acre-feet of tidal prism, slightly more than recommended in Appendix 1. The total excavation width would be approximately 60 ft. Maximizing the tidal prism is the best way to ensure inlet stability and therefore lower required maintenance over time. This proposed amount of over-excavation of the inlet would be prudent to allow an additional margin of stability while the lagoon and inlet equilibrate.

Although it is not generally recommended through this study, should the smaller lagoon alternative put forward by Snohomish County Parks be used instead, the inlet should be sized at 35 ft^2 below MHHW at a width of 21 ft at MHHW (Appendix 1, Table 5). Again, a trapezoidal to parabolic section should be used with a thalweg depth of 3.0 ft, a bottom width of 5 ft and side slopes of 4:1 (H:V). This would be a more unstable configuration, as the lagoon would likely lack sufficient tidal prism to overcome littoral transport and maintain the inlet open, as ebb tidal scour would not necessarily be sufficient to remove sediment from the inlet following storm wave-induced sediment transport on the beachface.

2. Lagoon Size and Location

As discussed above, the 2 lagoon alternatives evaluated were not deemed to be clearly stable or unstable, but fall in the range where they may become closed (See Reference Lagoon Analysis Results). A lagoon should be sized to maximize tidal prism by utilizing all available space within the park lowlands. Locating the lagoon at the north end of the park, as proposed, certainly makes sense from a general land use perspective. Extending the lagoon width and also its extent southward would be beneficial. Additionally, consideration of increasing the width of the northern portion of the conceptual 1.0 acre lagoon should be made to create a larger surface area. A simple sketch of a lagoon utilizing most of the area north of the traffic circle is shown in Figure 3. This lagoon is sized at 1.0 acre, and provides approximately (or as much as) 3.7 acre-feet of tidal prism, based on the inlet dimensions recommended above.

The Lagoon should generally be excavated to a depth of 3–5 ft below the inlet elevation. This would provide a large source of standing water within the lagoon for multiple habitat benefits. This water depth will help minimize temperature variation through the tidal cycle, which is a very important consideration for juvenile salmon, a species that should benefit the most from a recreated tidal lagoon in this location. The 3–5 ft depth should also promote colonization by eelgrass, further enhancing the ecological benefits for salmonids.

An additional way to increase the effective tidal prism of the proposed lagoon would be to introduce all feasible fresh water inputs. The Park plan proposed by Snohomish County Parks includes two storm water detention systems in the Park lowlands. Flow from these systems could be routed into the lagoon following primary treatment (settling). Any additional inputs would provide increased ebb scour in the inlet, providing additional inlet stability.

The lagoon would be expected to remain stable through most storm events, although some amount of sedimentation is to be expected in the channel and the area immediately landward (flood tidal delta). However, it is unlikely that dredging or other lagoon maintenance tasks could be permitted.

3. Saltmarsh/Wetland Fringe and 4. Typical Cross Section

The need to maximize tidal prism must be balanced with the area required at approximate elevations for colonization and establishment of fringing wetland vegetation. In other words, additional saltmarsh area comes at the cost of tidal prism, which directly affects the stability of the inlet as discussed above and in Appendix A.

The expected elevation for saltmarsh colonization at Kayak Point, based on observations at other Puget Sound sites, would be MHHW minus 1.5 ft to MHHW plus 2.0 ft, although saltmarsh vegetation may be intermittent in the lower and upper portions of this vertical band. Since MHHW at Kayak Point is +11.24 ft MLLW, low marsh is expected at +9.75 ft MLLW to +11.75 ft MLLW and high marsh at +11.75 ft MLLW to +13.25 ft MLLW. At a slope of 8:1 (H:V) the total saltmarsh band would be up to 28 ft wide. Below approximately +9.0 to +9.75 ft MLLW the slope can be increased to 1:4 in order to provide increased tidal prism. If the inlet were to become closed over time, the wetland would likely be brackish with low salinity, however, similar elevations would be colonized with marsh species in either trajectory.

A typical cross-section was developed cutting through the idealized lagoon from northwest to southeast to illustrate general conceptual slopes and elevation bands appropriate for creating upper intertidal salt marsh and backshore areas for habitat benefit (Figure 9; note that the cross-sections are drawn with a 2 to 1 vertical exaggeration). The lagoon width would vary along its length depending on other park uses that need to be accommodated. As pointed out elsewhere in this section, the size of the lagoon should be maximized and the lagoon cross-section shown in the figure represents a location with less than maximum width.

Below the minimum elevation at the inlet (+7.5 ft MLLW) the slope should be gradually reduced to provide water of between 2 and 5 feet depth. The primary reason for this is to both increase the amount of standing water, thereby reducing temperature fluctuations, and to provide water of at least 2 or 3 to 5 depth for eelgrass colonization. The aquatic vegetation can then assist in increasing oxygen levels, filtering pollutants, and providing cover and forage for aquatic animals.

5. Inlet Location and 6. Typical Cross Section

The historic condition for the lagoon and inlet at Kayak Pt was a lagoon in the south end of the cuspate foreland with an inlet at the north end (Figure 8). This is typical of barrier lagoons, and can be seen at several of the reference lagoons as well (Figures 5–7). The northward net shore-drift (sediment transport) in the area would tend to push the inlet northward over time as sediment is deposited on the south side of the inlet and eroded from the north. Therefore, the most stable location of the inlet would be at the north end of the park. Additionally, significant park infrastructure occupies much of the central and southern portions of the park lowlands. However, the inlet can be expected to move further north under present conditions, so some amount of armoring will be required to prevent erosion to the adjacent properties (addressed in *Inlet Dynamics and Stabilization*, below).

Initially, the inlet should be constructed perpendicular to shore facing directly into Port Susan for ease of design and construction. However, the inlet would be expected to develop more complex geometry, especially in plan view. This is stated as bends will likely form in the inlet channel as bars and very small spits prograde alongshore due to large wave events, and also as the inlet channel adjusts to prevailing conditions.

Typical cross-sections were developed for the inlet at the park based on the reference lagoon analysis information (Figure 10). A cross section was developed running through the beach and into the proposed lagoon. The slopes on the waterward side of the inlet channel thalweg are recommended to be on the order of 30:1(H:V) to ensure that adequate flow occurs. Beyond the channel through the beach berm, a steeper reach (5:1 slope) is recommended to allow for likely sediment infill in the form of a flood tidal delta. Excavation would need to lower the ground surface to this longitudinal channel profile on the order of 4–6.5 ft. Substrate conditions in the inlet are expected to be somewhat coarser than the surrounding upper beach. A natural accumulation of pebble and possibly limited amount of cobble will likely occur in the throat of the channel as finer sediment will be transported out of the throat of the channel due to higher velocity flows.

A typical cross-section was also developed running parallel to the beach backshore crossing the proposed tidal inlet for the larger lagoon alternative (Figure 10). The recommended side slopes of 4:1 (H:V) are illustrated along with a simply constructed initial cross-sectional shape. These are also the steepest recommended side slopes. The cross-sectional shape of the inlet channel will certainly adjust over time and continue to be dynamic beyond the period of initial construction. The total width at the existing approximately +14 ft MLLW backshore would be on the order of 60 ft, as shown in the figure.

Referring back to the initial stability analysis in Appendix 1, the above inlet sizes are slightly larger than the initial assumptions. The deeper inlets described above therefore increase the effective tidal prism of the lagoon (although these inlet depths may adjust over time), and are more likely to lead to stable configurations given the wave conditions at the site. For reference, the historic Kayak Point lagoon had a surface area of approximately 1.8 acres.

The majority of possible maintenance needs will be to the inlet. The primary reason for maintenance is the closure of the inlet, which is a possibility given the restrictions on tidal prism (area) as discussed above.

7. Inlet Dynamics and Stabilization Recommendations

Due to the strong tendency toward inlet migration, as discussed above, some amount of stabilization structure will be required. The expected direction for migration is to the north due to southerly winds, so structure recommendations here will concentrate on limiting northward migration and possibly enhancing stability relative to wave energy from the south. However, despite recommendations made here, the channel should be provided with some room to shift position rather than be completely restricted, as this would provide increased benefits to both habitat and recreation in the area, and limit the amount of exposed armor. It is important to note that Puget Sound region habitat enhancement project proponents are often strongly encouraged by regulators to avoid installing new shore protection armor in order to avoid introducing any new negative impacts of armor.

Under the existing conditions at the site, the inlet can be expected to migrate northward and recommendations made here are that the inlet be placed near the far northern end of the park beach. With private lands located immediately to the north of the park, the inlet will require armoring on the north side to prevent impacts to adjacent properties. The armoring should take the form of an initially buried structure approximately 50-100 ft north of the constructed inlet location. This is recommended in order to provide the required protection while also allowing for room for channel migration, and providing aesthetic value in avoiding exposure of the armor layer.

Under the current level of understanding, the northern armor should be installed by excavation approximately 75-200 ft south of the north park boundary, and no less than 50 ft north of the north bank of the tidal inlet. The spacing should be such that a maximum amount of space is provided for channel migration without posing an undue risk on the adjacent properties to the north. The toe of the structure should be buried to a depth on the order of 2-4 ft greater than the excavated inlet depth. The design for shore protection is beyond the scope of this effort, but a small, buried rock revetment, consisting of well-placed, angular rock could be used, which would also include geotextile and quarry spall foundation. A covering of approximately 12 inches of rounded cobble could be placed over the rockery to provide a more aesthetic appearance should the inlet expose the armoring layer. However, large wave events would likely provide sufficient energy to scatter the cobble and leave the underlying rock exposed on the waterward portion of the shore protection.

Structures may not be required south of the inlet, as the primary concern is northward migration due to southerly waves. However, to further reduce the tendency to migrate northward or southward, a groin or small jetty could be placed to lower the amount of wave energy and sediment transport into the inlet. However, these options are difficult to engineer, and are beyond the scope of this feasibility study.

As the inlet channel will be dynamic and would provide the best habitat conditions with no or minimal armor, installation of a bridge is not recommended for a beach trail. The upper intertidal area will have small and relatively easily crossed channel. The reference lagoon photos show examples of conditions at sites without armor. It is also important to note that the tide is fairly low during most warm weather days and walking on the beach would be available. Therefore it is recommended against installation of a bridge or other permanent park feature crossing the inlet. A bridge would require armor at the banks of the inlet to avoid the need for a very long and expensive span, as well as to prevent migration into bridge supports. Additionally, the installation of a pedestrian bridge of the required length would constitute a substantial cost element.

The lagoon shoreline would not require armoring for erosion protection, as very little wave energy is expected there. However, given the proximity of the lagoon to park infrastructure such as trails and buildings, small rockeries may be used well above the MHHW line to make the grade transition on the landward side and provide flexibility in placement of park amenities. Any such structures should be placed above the expected salt marsh elevation and also adjacent backshore vegetation in order to avoid infringing on critical habitat. Steep slopes may be used with carefully constructed rockeries when railings are used to reduce fall hazards.

8. Expected Substrate Conditions

As the entire Kayak Point shoreform appears to have been deposited through littoral drift and the accumulation of beach ridges, it is anticipated that sediment beneath the proposed lagoon area consists of a mixture of fine gravel and coarse sand in slightly varying proportions based on the exact depositional environment. The exact grain size breakdowns are not known at this time as the only sampling that has occurred was at the beach berm, grain sizes should resemble that of the park beaches, with likely less coarse sediment than in the south beach. It is not anticipated that any imported sediment will be required to alter the grain sizes at the surface of an excavated lagoon, with the exception of the highest elevation areas that will be planted with marine riparian vegetation.

The only area that is anticipated to be subjected to erosion is the immediate inlet area (which is discussed above). Wave energy will not be sufficient to erode the lagoon shore, unless they were to be constructed steeper than recommended above.

The grain size of the intermittently exposed portions of the lagoon shore is not anticipated to vary substantial over time. The sand and gravel that is expected to be exposed if a lagoon is excavated will generally remain in place. Over time, fine sediment is expected to settle in the lagoon and the grain sizes in the lagoon bottom are anticipated to become finer over time-especially below the new water level.

Preliminary Cost Estimate

An approach to roughly estimate total project construction costs was used based on design the barrier lagoon guidelines and the larger estuary discussed in this report. The cost estimate was not on design details, as a design has not been developed. The construction cost estimate used approximate material and labor unit costs as grouped by required restoration action. The cost estimation method used was recently developed by consultant team leads (including Johannessen of CGS) for the Puget Sound Nearshore Ecosystem Restoration Project (PSNERP, through a contract with WDFW) as part of the process for selecting and developing restoration designs for a number of Puget Sound nearshore sites. This method was first applied to a suite of different restoration projects in early 2011. Note this template was simplified to include only the items needed for this project.

The cost estimation methods relied upon estimated volume of materials, approximate cost of material, and additional construction costs—primarily larger items such as large structures. The inputs used for cost estimating included volumes of material, material costs, and construction costs. Volumes of both removal and import were very roughly calculated in CADD using the two typical cross sections and general plan view drawing. Removal and/or demolition of existing day-use park features (such as picnic shelters and benches) were not included. However, the estimated costs for removal of pavement and known small buildings were included based on rough sizes only. Volume estimates for material to be removed from below the ground surface were based on site survey information, other limited measurements, observations, and professional judgment. Volumes for new material items were all rough estimates as design details have not been developed beyond the general concept stage.

Unit costs for the starting spreadsheet were derived from the work completed for PSNERP, without any adjustments made. The labor costs and unit costs were determined by the PSNERP consultant team based on professional experience on past project designs and in-field construction costs. The estimated cost of mobilization, which was a calculated percentage of total in-field work costs, was maintained at 10%, as used in the PSNERP process. However it is not clear if this is the appropriate percentage as the project is within a park and has a steep hill access at the site. All unit costs were then multiplied by material quantities to determine total material costs per action item.

A bridge was not included in the preliminary cost estimate. Also construction of trails, picnic shelters, benches, and other typical park features were also not included. Reconstruction of park roads, utilities, and associated features was also not included.

Large uncertainties remain in many of the quantities as the cost estimate was based on a series of assumptions and incomplete data sources as no lagoon creation design exists. Additionally, the material costs were developed through a Puget Sound wide planning process and may not be most appropriate for this location. It must be understood that construction costs can vary significantly with geographic location, uncertainties associated with a project such as the need for archaeological oversight and economic and industry conditions at the time.

The estimated construction cost using the recent PSNERP consultant team method was approximately $823,000. The material volumes, unit costs, and cost estimates of individual actions are listed in the spreadsheet (Figure 11). In terms of expense in the total cost estimate was excavation and removal of approximately 13,600 cy of soil. The next largest individual cost items were construction of rockery walls ($90,000) in areas such as trail edges on small slopes, followed by pulling up and removing pavement ($78,000). Mobilization and erosion control were estimated to represent approximately $91,000 of that total. The cost of construction the small lagoon size (Parks concept design) would be approximately 75-80% of the cost of larger lagoon size. This amount is not estimated as a direct proportion using the difference in area as there will be a number of features that would need to be the roughly the same level of effort.

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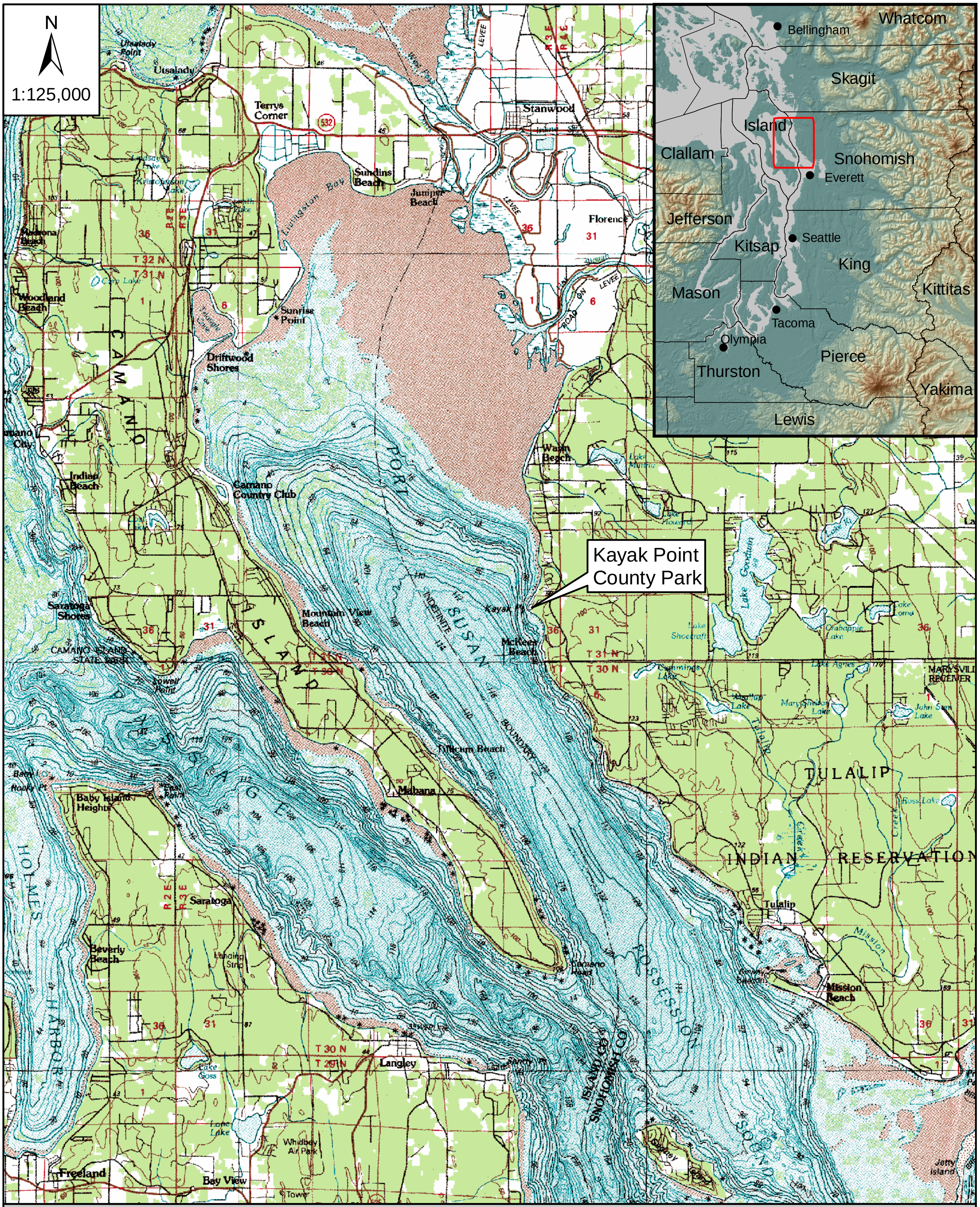

Figure 1. Kayak Point County Park and vicinity

Barrier Lagoon Feasibility Study for Kayak Point County Park

Basemap from USGS 1:250,000 Port Townsend quarter quad. Puget Sound DEM courtesy Finlayson (2005).

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Figure 2. Excerpt of Snohomish County Parks & Recreation conceptual drawing showing a 0.6 acre lagoon, used as Alternative 1.

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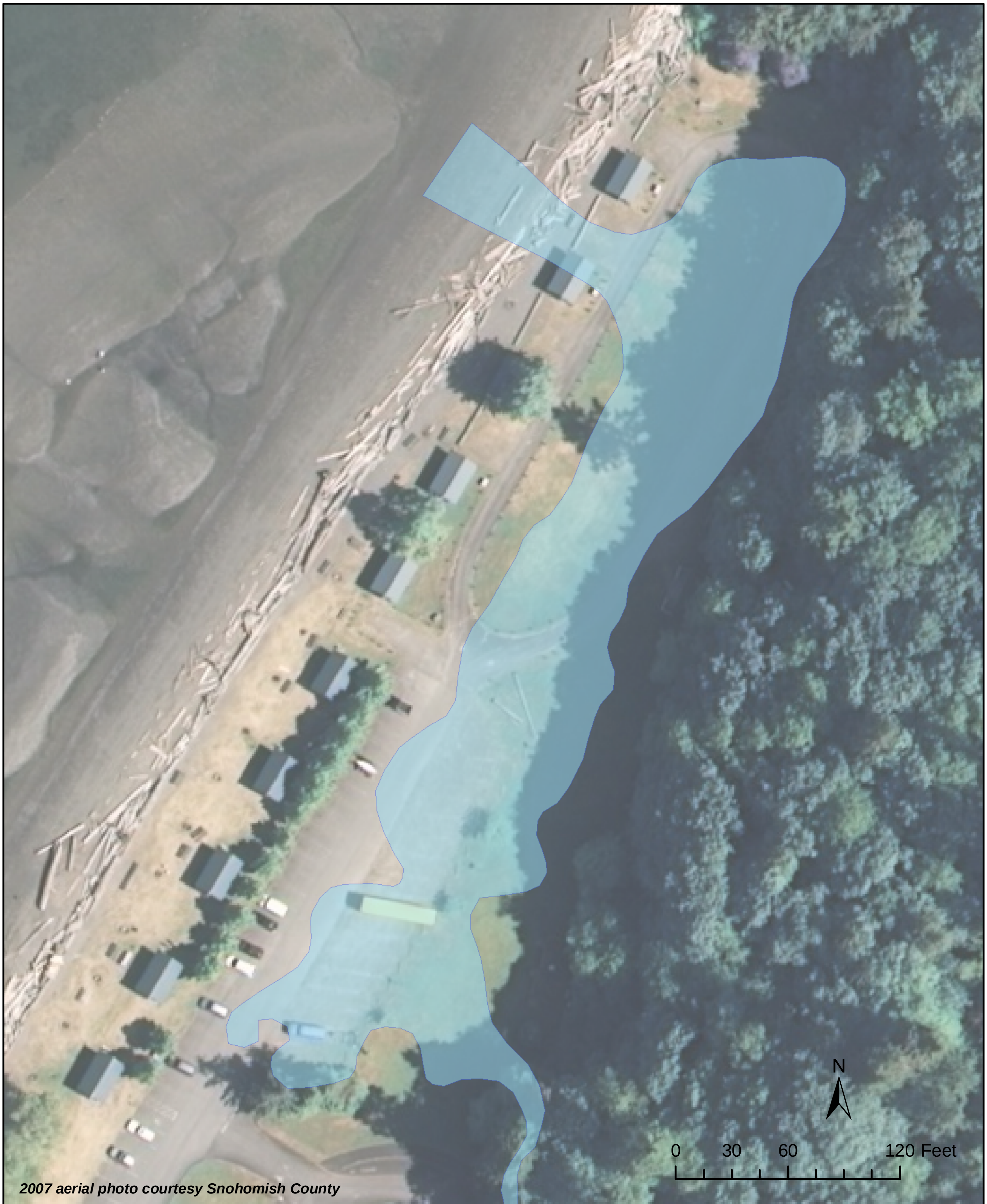

Figure 3. Conceptual outline of a 1.0 acre lagoon utilizingmuch of the park lowland north of the traffic circle, used as Alternative 2.

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Figure 4. Reference Lagoons used in the inlet stability analysis.

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Tolo east looking northeast 8/8/06

Gulf Rd looking northeast 6/28/06

Third Lagoon looking south southeast 8/15/06

Figure 5. Photo Page 1 showing WADOE oblique aerial views of reference lagoons; name of lagoon and date of photo shown. See Figure 4 for lagoon location.

Heyer Pt looking west southwest 7/26/06

Fisherman Pt looking east 6/23/06

Talagwa looking west 7/8/06

Figure 6. Photo Page 2 showing WADOE oblique aerial views of reference lagoons; name of lagoon and date of photo shown. See Figure 4 for lagoon location.

Whitney Rd looking west 6/23/06

Figure 7. Photo Page 3 showing WADOE oblique aerial views of reference lagoons; name of lagoon and date of photo shown. See Figure 4 for lagoon location.

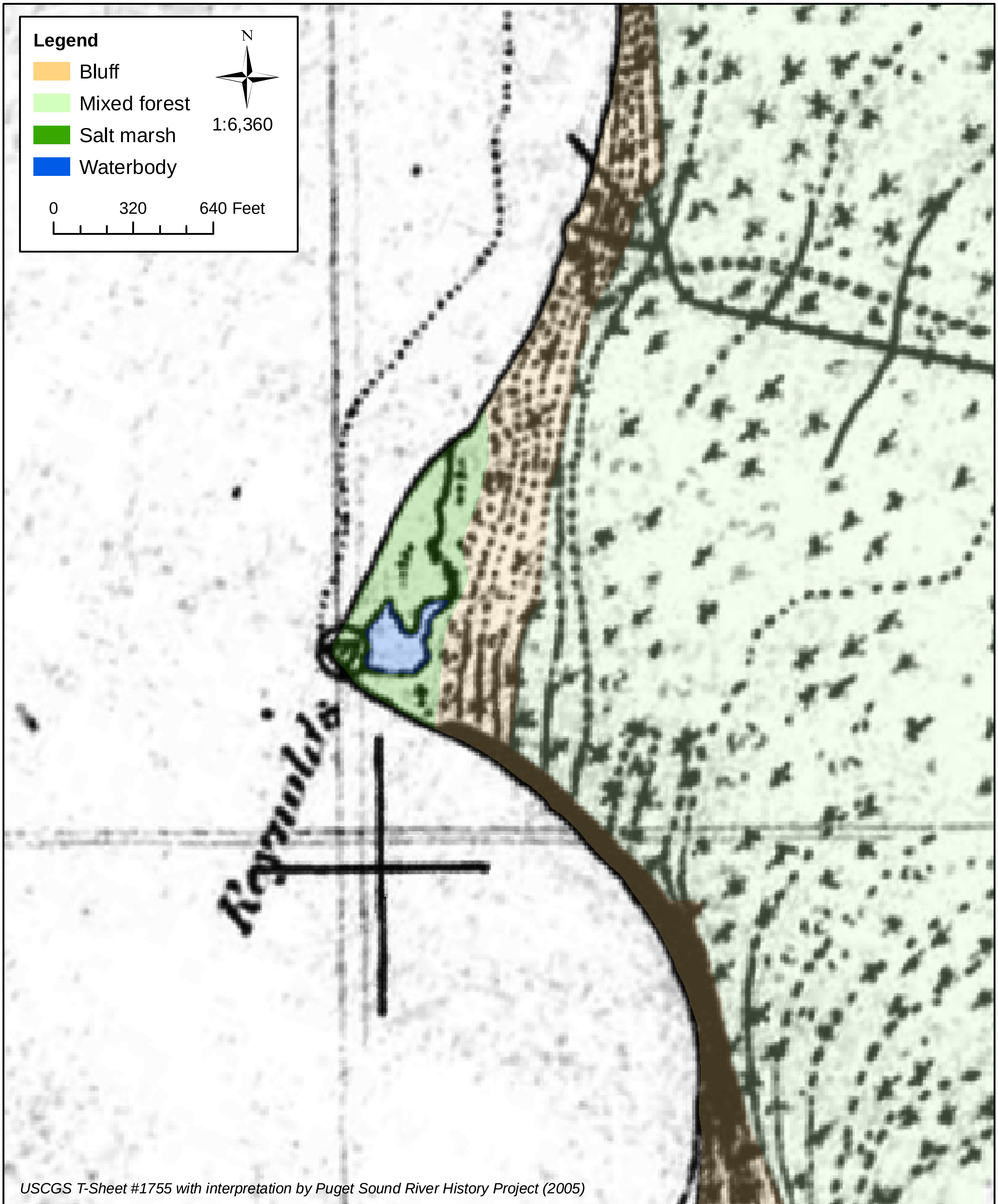

Figure 8. Kayak Point as mapped in 1886 by the US Coast and Geodetic Survey.

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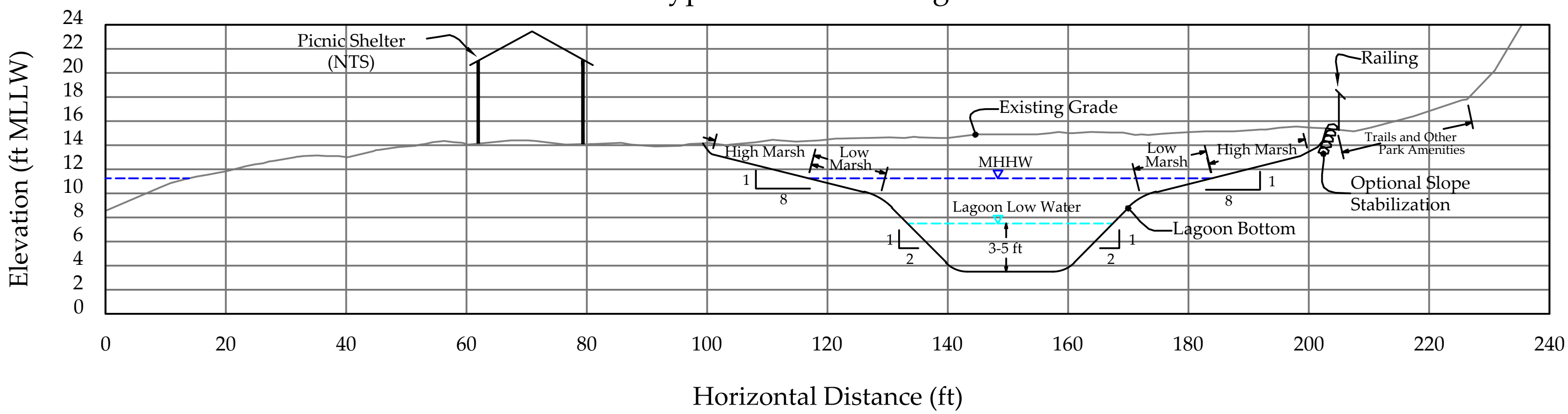
Typical Section of Lagoon



NOTES

- Assume minimum of 3-5 ft of water in lagoon at low tide
- Salt marsh elevations between +9.25 and +13.25 ft MLLW
- Place toe of any optional slope stability structures above +14 ft MLLW to maximize salt marsh habitat and small buffer
- Park using exclusion structures such as railings, fences, or vegetation are recommended, especially during initial vegetation establishment period
- Existing grade shown for reference only based on LiDAR surface (PSLC 2003)

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Barrier Lagoon Feasibility Study for Kayak Point County Park

Typical Section - Lagoon For Both Alternatives

MLLW=0.0'

MHHW = +11.24' MLLW

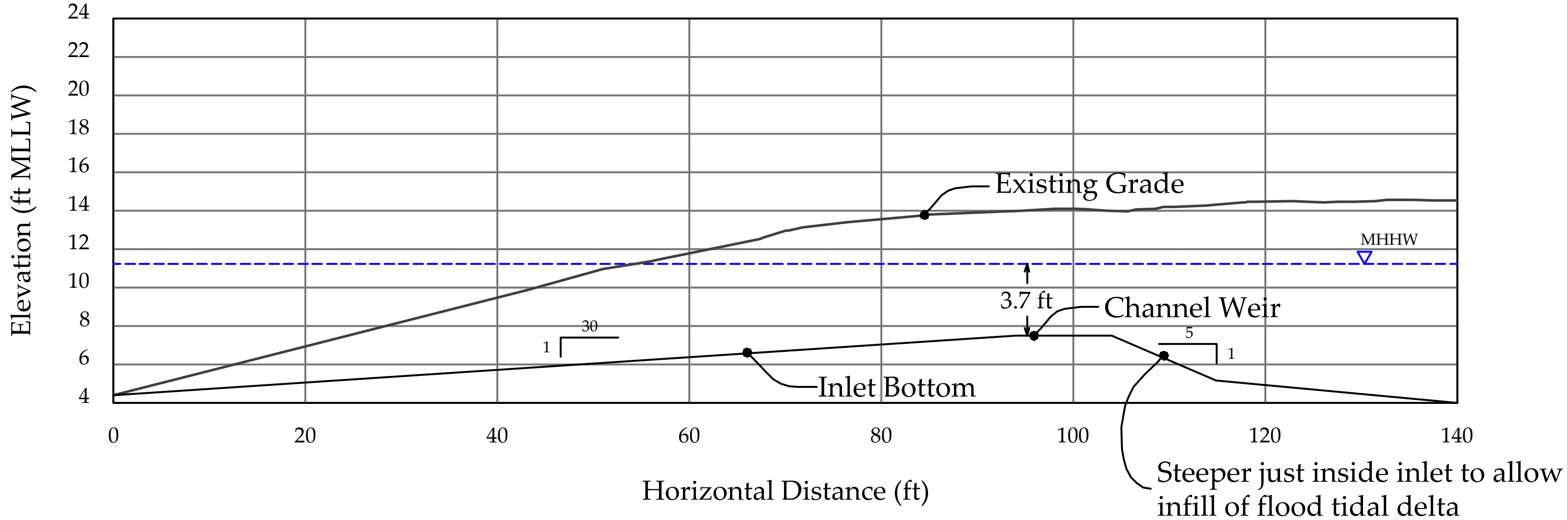
For: People for Puget Sound

~10-045-KayakPtLagoon.dwg

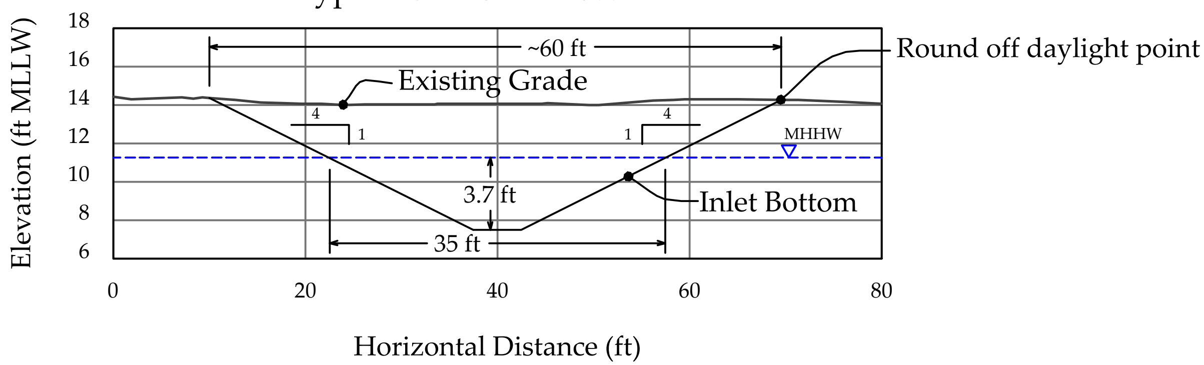
Date: 6/21/11

H:1"=30' V:1"=15'	SECTIONS	Figure 9

Typical Section of Inlet Along Thalweg



Typical Section Across Inlet



NOTES

- Inlet over excavated to allow natural equilibration
- Allow some over excavation of area immediately landward of weir for deposition of flood delta deposits
- Existing grade shown for reference only based on LiDAR surface (PSLC 2003)

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DATUM

MLLW=0.0'

MHHW = +11.24' MLLW

Barrier Lagoon Feasibility Study for Kayak Point County Park

Typical Sections - Inlet for larger 1.0 acre lagoon

For: People for Puget Sound

~10-045-KayakPtLagoon.dwg

Date: 6/21/11

H:1"=20' V:1"=10'	SECTIONS	Figure 10

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memorandum

date March 17, 2011

to Jim Johannessen (Coastal Geologic Services)

from Bob Battalio, PE & Louis White, PE

subject Kayak Point Lagoon Feasibility Study: Lagoon Stability, Sustainability, and Sizing

Introduction

ESA PWA is assisting Coastal Geologic Services Inc. (CGS) and People for Puget Sound on a Barrier Lagoon Feasibility Study for Kayak Point County Park, located in Snohomish County, Washington. This study is a continuation of prior work at Kayak Point County Park completed by CGS and Philip Williams and Associates (PWA), including a conceptual beach and backshore restoration design (CGS 2007) and an assessment of the potential implications of future sea-level rise (SLR) on the Park (CGS 2008[1]; CGS 2008[2]; PWA 2008).

This memorandum addresses barrier lagoon sizing and stability, and updates previous wind-wave and sediment transport estimates with new data and analyses. Reference site data for barrier lagoons in Puget Sound, compiled by CGS, was used to develop design guidelines for small barrier lagoons similar to proposed actions at the Park.

This memorandum is organized to address inlet stability and degree of sustainability for two alternative lagoon sizes. Results of the annual wave climate and an estimate of the local potential sediment transport rates are used to determine the stability of the inlet and to establish the minimum tidal prism required to keep the lagoon inlet open. The cross-sectional area of the lagoon inlet is then estimated based on relationships of tidal prism and cross-sectional area of inlets for several reference sites.

Additional requested design guidance includes:

- The recommended volume of tidal prism needed to maintain a tidal connection to Puget Sound
- The expected equilibrium geometry of a tidal inlet associated with a self-sustaining, tidal lagoon
- The expected connection and lagoon channel migration patterns and armoring recommendations for protection of adjacent park infrastructure

Alternatives and Reference Data

As part of this feasibility study, ESA PWA was directed to evaluate the stability and inlet sizing of two alternative lagoon proposals on the north side of Kayak Point County Park (see Table 1):

(1) A small lagoon with dimensions proposed by Snohomish County Parks, based on their planning process and conceptual Site Plan 2;

(2) A larger lagoon with dimensions proposed by CGS, based on maximizing the lagoon size within the apparent available area.

Table 1. Proposed dimensions of two alternative lagoons for the north side of Kayak Point County Park.

Alternative	Source	Length x Width (ft)	Area (ac)	Avg Depth (ft)	Tidal Prism (Ac-ft)	Fetch (mi)	Tidal Range (ft)
1 – Small	Snohomish Parks	280 x 65	0.6	1.5	0.9	3 SSW 7 NNW	11.24
2 – Large	CGS	570 x 70	1.0	1.5	1.5	3 SSW 7 NNW	11.24

Data for several lagoons in Puget Sound were compiled by CGS to aid in the analyses of lagoon stability and sizing (Table 2). Data in the table represents several tidal and geomorphological characteristics that were used directly in subsequent analyses, or used to infer other necessary parameters for the analyses. This data set was compiled from an initial search of Puget Sound for lagoons with similar tidal range, size, and fetch as the proposed lagoon alternatives. Lagoon characteristics are based on limited bare-earth LiDAR analysis, where available, that was flown at low water with respect to the lagoon. The tidal prism was estimated as the volume difference between mean higher high water (MHHW) and low water surface inside of lagoon.

Table 2. Tidal and geomorphological characteristics for several reference lagoon sites in Puget Sound.

Lagoon	Location	Fetch max (mi)	Fetch minor (mi)	Surface Area (ft^2)	Surface Area (acres)	Tidal Prism (Acre-ft)	Tidal range (ft)	Channel Width at MHHW (ft)	Channel Cross Section Area below MHHW (sf)	Channel Depth below MHHW (ft)	Channel Length (ft)
Tolo Lagoon	West Bainbridge Is.	6.4 S	2.8 NW	54,500	1.25	[1]1.8	11.76	12	[2]10	[2]1.7	220
Gulf Rd	N Whatcom Co.	36.4 WNW	23.5 SW	132,000	3.40	1.4	9.1	32	67	3.5	150
Third Lagoon	S San Juan Is.	6.5 NNE	4.3 WNW	107,000	2.46	1.7	7.33	15	13	2.0	120
Heyer Pt	E Vashon Is.	16.0 N	6.5 SE	92,000	2.11	5.6	11.68	59	127	3.9	380
Fishermans Pt	Dabob Bay	9.8 SSE	3.2 NNW	126,500	2.9	11.7	11.49	50	116	3.9	270
Talagwa	Camano Is.	12.7 SE	8.2 NNE	168,000	3.9	9.3	11.22	44	130	5.5	1,100
Whitney Rd Lagoon	Toandos Pen.	16.2 NE	2.8 SE	29,400	0.67	0.7	11.27	16	17	2.0	110
Kayak Pt 1886	Port Susan	17 SE	7.6 NW	78,200 (MHW)	1.8	[1]2.5	11.24	30 (MHW)	[2]50	[2]3.1	670

[1]Tidal prism estimated based on approximate area; insufficient topographical information
[2]Channel depth and cross-section area below MHHW estimated from regression analysis

Wave Climate and Sediment Transport Rates

Previous estimates of wave height and period were updated to account for a better source of wind data local to Kayak Point. Approximately 9.4 years (August 2001 to February 2011) of 5-minute average wind speed and direction observations were acquired from a Weatherflow station located on the pier at Kayak Point County Park. Direction measurements were limited to 16 bins with angular range of 22.5°, corresponding to points of the compass (e.g. 22.5°, 45°, 67.5°, …, 337.5°, 360°). Hourly measurements were extracted from the data set and used to produce a wind rose of hourly 5-minute average data in miles per hour (MPH) over the period of record (Figure 1). Calm conditions (wind velocity ~0 MPH) were observed for approximately 31.9% of the record;

approximately 11.3% of the record was missing. The wind rose shows predominant wind directions from the southeast (SE) and the north (N) to west-northwest (WNW) sectors. The distribution of winds at Kayak Point is lower in magnitude and directionally unique in comparison to the wind rose from Smith Island, which was used in prior analyses. Therefore, the distribution of wave heights and periods, and thus wave power, has been refined for this study.

Wave heights and periods were estimated using look-up tables that were developed based on parametric deep water wave hindcast equations described in the Shore Protection Manual (SPM 1984). Typically the resulting wave heights represent a fetch-limited condition. Figure 2 summarizes the results of the updated wave analysis: the top panel presents a significant wave height rose, the middle panel presents the significant wave period rose, and the bottom panel shows a wave power rose. Wave power, or equivalently wave energy flux, was calculated from the distribution of wave heights and periods and described by the equation

$$P = \frac{\gamma g H^2 T}{32\pi} \tag{1}$$

where P is wave power in ft-lbf/ft-s, γ is the specific weight of sea water (=1.99 slugs/ft^3), g is gravitational acceleration (=32.2 ft/s^2), H is the deep water root-mean-square (RMS) wave height from a Rayleigh distribution (see Dean and Dalrymple 1984), and T is the deep water wave period (generally considered the peak spectral period, SPM 1984). Table 3 presents a summary of the directional distribution of total annual wave power for the south and north sides of Kayak Point. For the purposes of these analyses, we have assumed that the shore-normal directions for the south and north beaches are 225° (SW) and 292.5° (WNW), respectively, updating prior representation of shoreline geometry. Maximum annual wave power was observed from the SSE and the NNW directions.

Table 3. Annual wave power results from wind wave hindcasting at Kayak Point.

Compass Direction	Annual Wave Power (ft-lbf/ft-yr)	
	South Beach	North Beach
N	-	6.11E+05
NNE	-	2.90E+04
NE	-	-
ENE	-	-
E	-	-
ESE	-	-
SE	2.42E+06	-
SSE	6.88E+06	-
S	2.63E+06	-
SSW	5.26E+06	5.26E+06
SW	6.08E+05	6.08E+05
WSW	8.79E+05	8.79E+05
W	2.81E+06	2.81E+06
WNW	5.77E+06	1.93E+06
NW	5.60E+06	5.60E+06
NNW	-	8.58E+06
Gross	**3.29E+07**	**2.63E+07**

Table 4 summarizes the distribution of potential sediment transport rates on the south and north sides of Kayak Point. Here, negative and positive values indicate transport to the north and south, respectively. The longshore sediment transport rate at Kayak Point County Park was re-calculated to account for the updated wave climate and shoreline geometry. The sediment transport was estimated using a method based on deep water wave statistics, as suggested in the SPM, and a technique was used to smooth the discretized data over the region of incidence (SPM 1984). Values of sediment transport in the table suggest that the net transport along both the north and south shoreline is directed toward the point. However, subtleties in shoreline direction and wave distribution might play a greater role in decreasing the net transport to close to zero. The equation used to calculate of sediment transport rates was developed for sand, with grain sizes smaller than what is observed locally at Kayak Point (median grain size of approximately 2.68mm). Therefore, actual transport rates may be smaller than calculated. However, the use of "percent occurrence" type wind statistics under represents the effects of occasional high winds (e.g. during storms). Gross sediment transport rates were estimated using a smoothing, or spreading, method to account for fluctuations between the discretized directions (SPM 1984). Comparison to methods that typically do not account for fluctuations around the angle of incidence yields gross sediment transport rates greater by approximately a factor of 3. Finally, the actual transport rate can be increased due to perturbations of the shore form due to excavation or deposition. Hence, the rate of transport into an excavated inlet, for example, could be much larger than these calculations might imply.

Table 4. Potential longshore sediment transport rates based on deep water wave statistics at Kayak Point.

Compass Direction	Potential Longshore Sediment Transport Rates (yd^3/yr)	
	South Beach	North Beach
N	-	24
NNE	-	0
NE	-	-
ENE	-	-
E	-	-
ESE	-	-
SE	-3	-
SSE	-286	-
S	-149	-
SSW	-263	-11
SW	+/- 4	-25
WSW	43	-57
W	179	-135
WNW	216	+/- 13
NW	10	243
NNW	-	488
Net	**-250**	**530**
Gross	**1,160**	**1,010**

Inlet Stability and Sustainability

The dynamics of small coastal lagoons vary greatly between sites. Particular lagoon inlets may be continually open with relatively small changes in location and shape, while other inlets are ephemeral and subject to intermittent opening and closing. Inlet stability is frequently presented as a ratio of opposing forces between wave power, which tends to transport sediment into the inlet mouth, and tidal power, which acts to scour the inlet channel. Several formulations involving a combination of wave power, sediment transport rates, and tidal prism or tidal power exist to evaluate stability of inlets (O'Brien 1931; O'Brien 1971; Jarrett 1976).

An inlet stability rating system can be used to classify the inlets as good, fair, and poor by evaluating the ratio of neap tidal prism (small tide range during bi-monthly phases of the moon) to total annual littoral drift (Bruun and Gerritsen 1959; Bruun 1966; Bruun 1978). For the two proposed lagoon alternatives at Kayak Point, inlet stability is rated poor. Although the gross littoral drift is relatively small, the expected tidal prisms for the two alternatives are also small. The usefulness of the Bruun stability criterion is limited by the ability to accurately predict the longshore sediment transport and other complexities, and can be considered an approximate indicator only.

Because sediment transport rates are not always available and are highly uncertain, Johnson (1973) developed a simplified approach of comparing the estimated average annual deep water wave power with the potential diurnal (MHHW to MLLW) tidal prism. Compiling several reference lagoons that exhibit characteristics of being always open, seasonally open, or mostly closed, Johnson concluded that for a given wave power, there appears to be a tidal prism that must be exceeded if the inlet is to remain open. PWA (1999; see also Battalio, Danmeier, and Williams 2006) noted corrections to the data from Johnson (1973) that affect the wave power values reported but not the validity of the approach.

Reference data for Puget Sound are generally not available, and consequently were collected for use in this project. This can be considered as a first step in establishing a database of information on small coastal lagoons in the region. Consequently, uncertainties remain in evaluating the stability of these systems.

Figure 3 presents a Johnson-type chart of the reference lagoons described in Table 2. It should be noted that the data is much smaller in magnitude than larger lagoon systems used in Johnson’s analysis, and that the line was extrapolated to the lower bounds of the data. Wave power for the reference sites was estimated by scaling the wave power estimated for Kayak Point by the relative fetch lengths between the reference site and Kayak Point. Potential diurnal tidal prism was estimated to be about twice the volume of the effective tidal prism estimated for all reference sites. The characterization of the reference sites in terms of whether they remain open or are mostly closed is not certain, although they appear to be open at least most of the time.

This analysis indicates that the larger lagoon size (1.5 acres) is more likely to stay open under typical wave and tide conditions. The smaller lagoon size is closer to the region where closure is likely. It should be noted that the exact dividing line between open and closed is not known, and there are many inlets that are intermittently open and closed.

Tidal Inlet Geometry

Hydraulic geometry relationships between the tidal prism and the cross-sectional area of the inlet channel are common criteria applied to predict tidal inlet stability (Battalio, Danmeier, and Williams 2006). Small lagoon inlets tend to exhibit equilibrium area much larger than predicted by these tidal prism relationships derived for larger inlets (Hughes 2002). Through laboratory studies, Hughes (2002) established relationships similar in form to classic hydraulic geometry relationships, relating the cross-sectional area of the inlet to the effective tidal prism by

$$A_e = 0.65 k_a \left(C_I P\right)^{8/9} \tag{2a}$$

and

$$C_I = \frac{W^{1/8}}{\left[g\left(S_S - 1\right)\right]^{1/2} d_e^{3/8} T} \tag{2b}$$

where A_e is the cross-sectional area of the inlet below mean tide level (MTL), k_a is an empirical coefficient (with a best fit value of 1.34), P is the effective tidal prism, W is the inlet width at MTL, g is the acceleration of gravity, S_S is the specific gravity of the sediment, d_e is the median grain size of the sediment, and T is the semi-diurnal tidal period. The term $C_I P$ is known as the modified tidal prism.

Figure 4 presents the relationship of the cross-sectional area and modified tidal prism for the reference sites presented in Table 2. Suitable values of the parameters used in the Hughes (2002) relationship, Equations 2a and 2b, were determined through a regression analysis of the reference data (e.g. conversion of width, area and depth from MHHW to MTL). Inlet width, cross-section area, and depth were estimated relative to MTL in the lagoon, due to the complication that the inlet thalwegs of the reference sites were above MTL in the sound. MTL in the lagoon was assumed to be located above the lagoon low water level by approximately 30% of the effective tide range. Although the reference data showed that Hughes (2002) underestimates the cross-sectional area of the inlet for a given modified tidal prism, the scatter was within limits observed in his original study. Also, there could be systematic biases in measurement. The grouping of the data indicates confidence with the Hughes relationship. Changing the value of the empirical constant k_a to 9.17 provided a best-fit to the reference data.

The equilibrium cross-sectional area of the two proposed alternatives was evaluated by rearranging the Hughes (2002) equations above and assuming that the cross-sectional area was parabolic. Further regression analysis on the focal parameter allowed a back-calculation of inlet depths, and applying the equations of a parabola yielded the widths and cross-sectional areas of the inlets. Table 5 presents the equilibrium dimensions of the two proposed lagoon alternatives

Table 5. Equilibrium dimensions of the two proposed lagoon alternatives.

Alternative	Width at MHHW (ft)	Depth below MHHW (ft)	Cross-Sectional Area below MHHW (ft^2)
1 – Small	21	2.5	35
2 – Large	27	3.2	57

Implications of Results

The results of the analyses described above suggest that the proposed lagoon alternatives are rated poorly according to the Bruun stability criteria. This means that the inlets may be highly unstable, prone to movement along the shoreline and periodic or permanent closure. Increasing the size of the lagoon tidal prism and footprint could increase the stability but it is likely the alternatives would still be rated poorly. An increase in the tidal prism by approximately 30 ac-ft (this is 20 to 30 times larger than proposed) would shift the Bruun stability criteria to “fair to poor.” For perspective, the size of the historic lagoon was small enough to be “unstable,” and therefore it may not be practical to construct a lagoon to be characterized as “stable” with these methods. This suggests that the lagoon inlet, as proposed, will likely require some amount of periodic maintenance after large wave events that move sediment into the inlet and as the inlet closes. Construction of a larger lagoon to maximize the tidal prism would reduce the risk of inlet closure and would reduce the amount of future maintenance requirements at the site.

Ebb and flood shoals, sand deposits on the sound and lagoon ends of the inlet, respectively, are likely to develop after construction of the lagoon. These features are typically part of the natural path of sediment transport along the shoreline. For constructed inlets, however, the adjacent shore might temporarily experience greater erosion rates than are typically observed until equilibrium is reached. Placement of material on the downdrift shoreline during excavation of the inlet can mitigate for potential erosion impacts to the shore.

Special design actions may be worthwhile to minimize required mechanical actions to keep the inlet open. The first such design action is to locate the inlet in the relatively lower energy environment to reduce the wave exposure. Inspection of the historic map of Kayak Point shows the inlet at the north end of the shore form. This appears to be the lowest energy location. An inlet at this location would therefore be less likely to close, and would be less likely to migrate along shore. We understand the proposed inlet location is slightly farther south on the north shore, in a more exposed location. A small jetty constructed on the updrift side of the inlet (generally considered to be the south side, with the greatest transport potential from south to north), would provide a small zone of reduced wave exposure to reduce inlet closure potential. However, the inlet could migrate northward farther north of this localized shadow, with an increased chance of closure due to friction and other processes. A second jetty or structure to impede migration may not be helpful to impede closure potential, but would impede northward migration. Buried cobble and rock at the northern extent of the Park would prevent migration of the inlet onto private property adjacent to Kayak Point County Park. Given that waves can also come from the north, the jetty would end up on the downdrift side of the inlet. Single jetty systems are therefore considered “tricky” to design and maintain.

A positive aspect of the site is that the system is small enough that it can be maintained easily. If the inlet becomes closed, the lagoon could be reconnected by excavating the channel with a small backhoe, or even possibly shovels. It is possible that the inlet would only close occasionally, but could stay closed for some time. The required frequency of mechanical opening can be estimated if adequate data exist (Battalio, Danmeier, and Williams, 2006).

Further analysis for design is worthwhile. Additional and refined data for reference sites could increase the accuracy of the analysis, including grain size, wave heights, and more accurate estimates of the tidal prism and inlet geometries.

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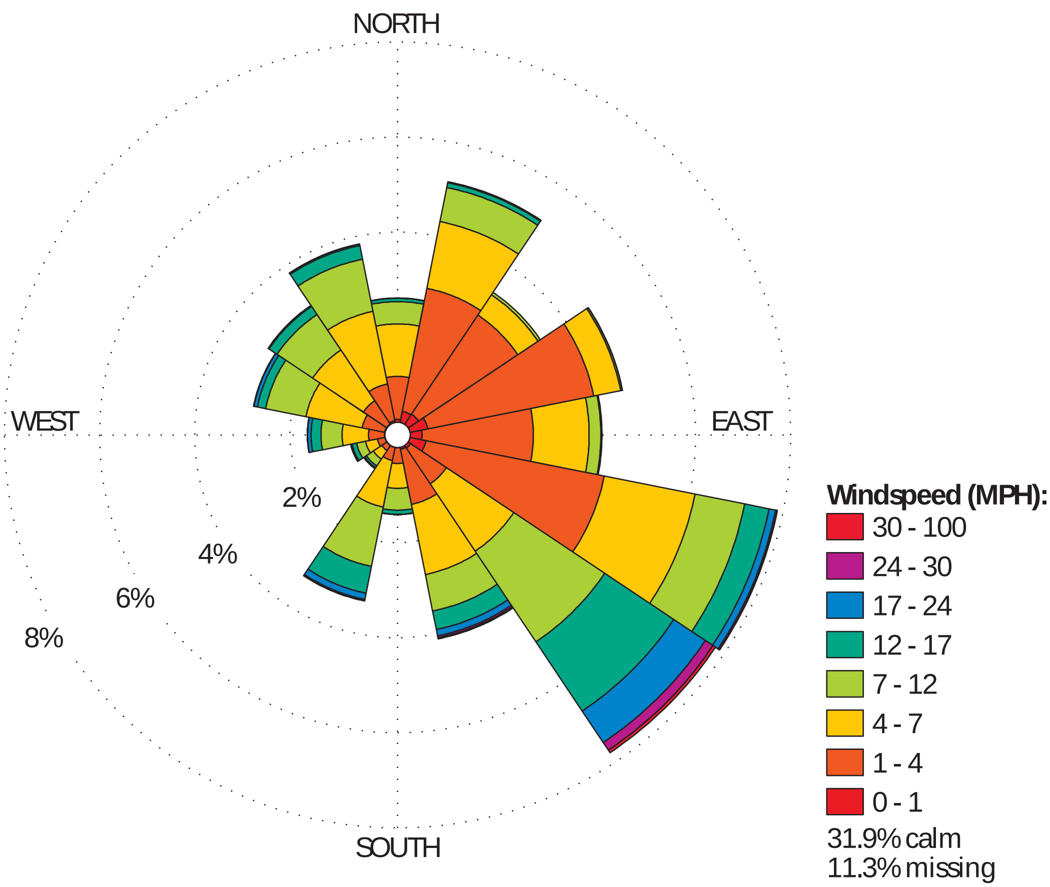


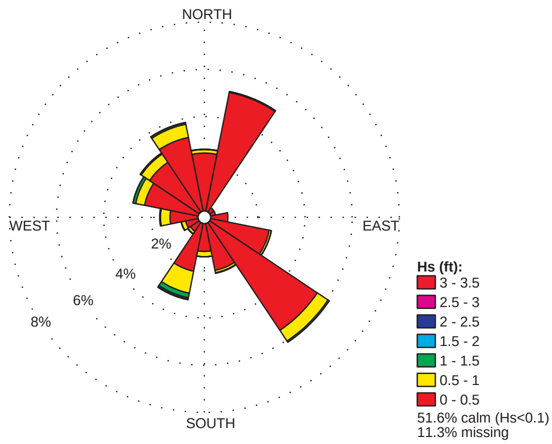
Source: Weatherflow (2011), Kayak Point Wind Gage, Kayak Point County Park, Washington
Notes: Wind rose was created from hourly 5-min average wind speeds in miles per hour. Original wind data set was processed from 9.4 years of observations (Aug 2001 to Feb 2011).

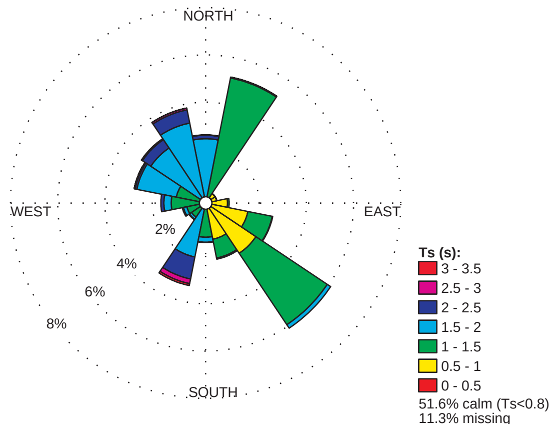
figure **1**
Kayak Point Lagoon

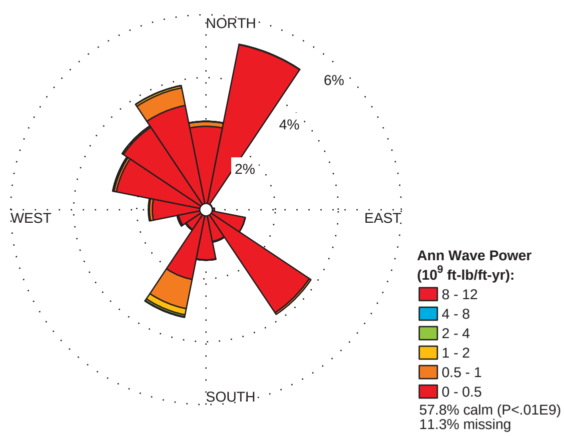
Wind Rose at Kayak Point

ESA PWA Ref# D211110.00

ESA PWA







Source: Weatherflow (2011), Kayak Point Wind Gage, Kayak Point County Park, Washington

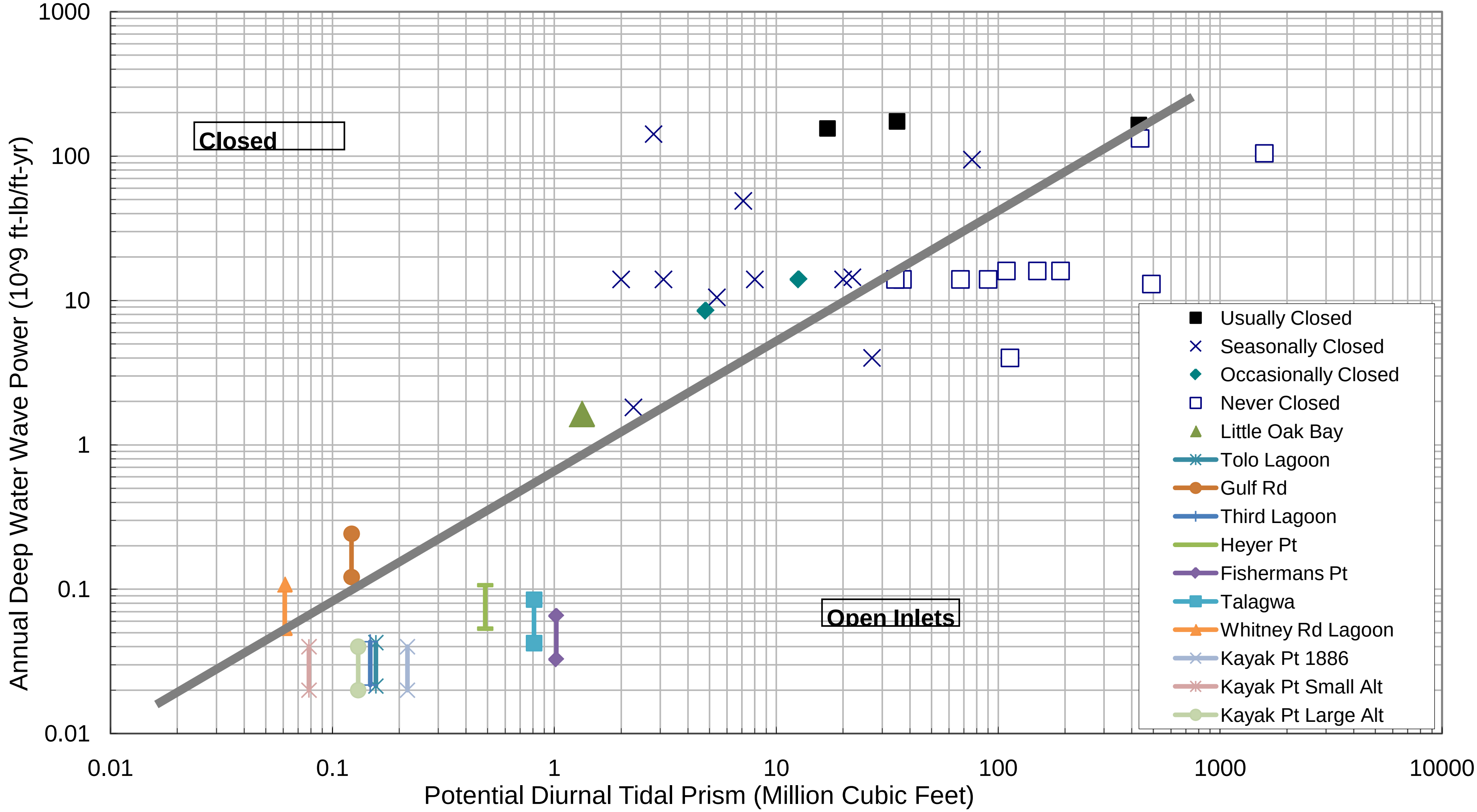
Notes: Wave height and period estimated in wind-wave hindcast look-up tables for deep water conditions.

figure **2**

Kayak Point Lagoon

Wave Height, Period, and Power Rose at Kayak Point

ESA PWA Ref# D211110.00



Notes:
Wave power for Kayak Point estimated from wind-wave hindcasting
Wave power at reference sites in Puget Sound scaled on fetch based on Kayak Point estimate

Source:
Original methodology developed by Johnson (1973)
Reference data compiled by Coastal Geologic Services (2011)

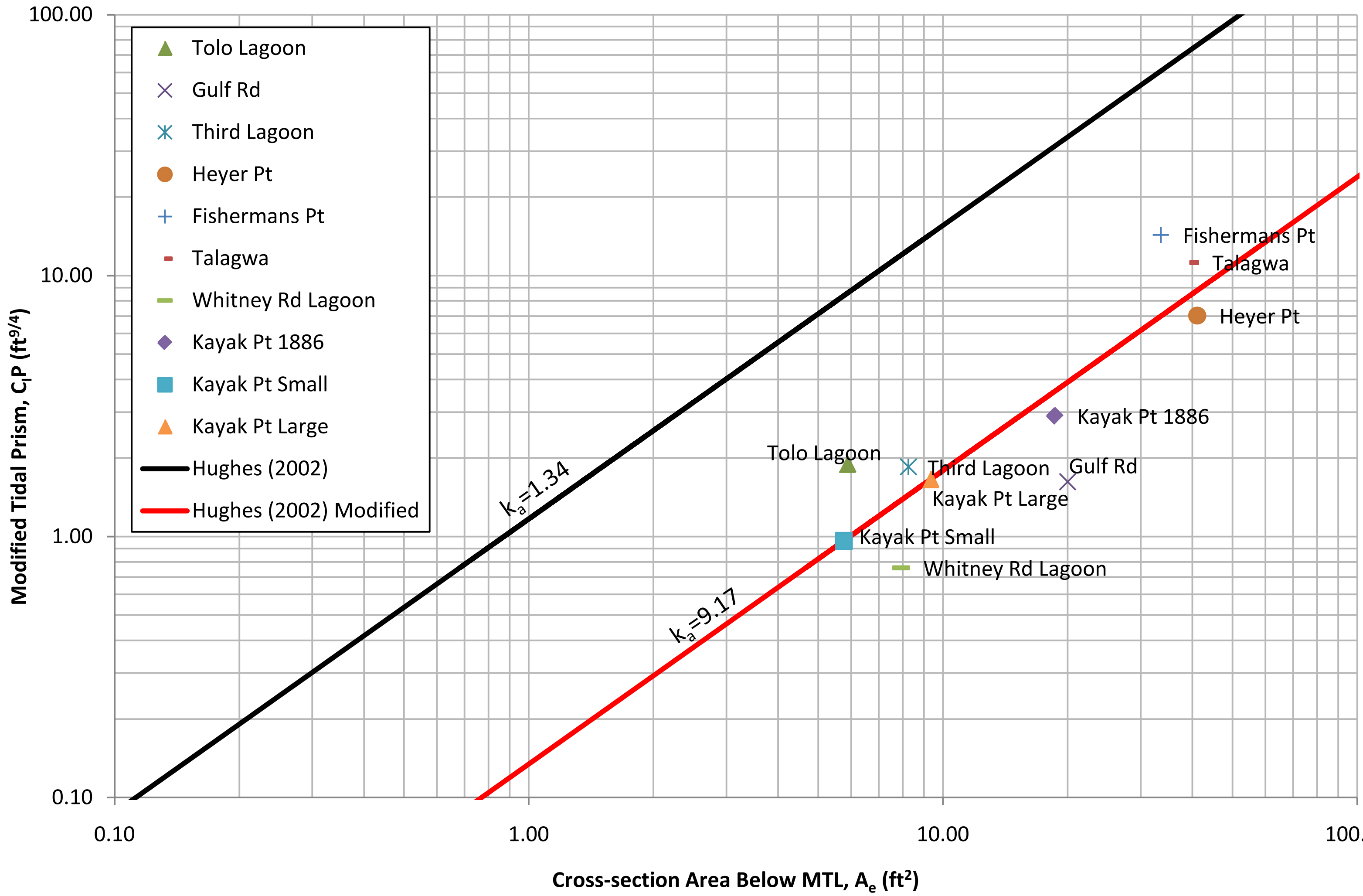
figure **3**

Kayak Point Lagoon

Johnson-type wave power-tidal prism relationship

ESA PWA Ref #: D211110.00

ESA PWA



Notes:
Hughes (2002) Modified was optimized on the variable k_a to provide a "best fit" to the reference data.
Median grain size is assumed to be 2.68mm for all reference sites.

Source:
Original methodology developed by Hughes (2002)
Reference data compiled by Coastal Geologic Services (2011)

figure **4**

Kayak Point Lagoon

Reference lagoon data and Hughes (2002)

ESA PWA Ref #: D211110.00

ESA PWA

NORTH LAWN AREA
- Provide improvements to existing Cascadia Marine Trail campsites and facilities
- Renovate existing restroom structure
- Explore adding showers to restroom facilities or providing stand alone outdoor shower station(s)

EXISTING SHELTERS
- Native plant areas provide separation from adjacent path, add interest and define the space around each shelter
- Maintain open views to the Sound
- Explore off-peak camping at shelters. Add tent or portable shelter walls
- Removal or relocation of 2 northern most shelters may be required, in short term, due to proximity to active beach zone
- Modifications to all shelters may be required, in the long term, due to sea-level rise

CENTRAL LAWN
- Maintain / expand open lawn for picnicking and passive recreation
- Relocated parking provides vehicle-free access to and from waterfront
- Explore tree removal or limbing to create open views to the Sound
- Stormwater wetlands filter run-off from parking area and provide a buffer between roadways and lawn

IMPROVE EXISTING BOAT LAUNCH
- Redesign boat launch approach and parking to improve launch access, increase safety, and reduce congestion
- Dedicated staging lanes provide space for approximately 8 vehicles
- Relocate trailer parking adjacent to ramp to reduce vehicle congestion and launch time
- Additional trailer parking provided on upper level of park
- Explore options for a new elevated boat ramp. Design should limit sediment deposition problems on the ramp while maintaining natural sediment transport processes
- Explore feasibility and long term sustainability of a courtesy dock

EXISTING PIER
- Renovate existing pier building to accommodate concessions or other flexible use
- Explore expansion of pier at shoreline to provide outdoor seating and integrate pier with central plaza space
- Explore raising the plaza grade to permit removal of existing pier entrance ramp and railings

NEW MULTIPURPOSE BUILDING AND PLAZA
- Provides central indoor/outdoor gathering space for a variety of activities and amenities
- Possible uses for new structure include equipment rental, interpretive center, or picnic shelter
- New plaza area provides flexible outdoor space for entertainment, educational activities, equipment staging, portable vending, etc.
- Add kayak launch area south of pier
- Provides opportunity for revenue generation to support park maintenance and operation

ENHANCE EXISTING PLAYGROUND
- New landscape areas separate playground from adjacent pathways and boat launch area
- Plantings improve aesthetics and provide shade
- Explore use of low walls around playground to add seating and define playground space. Walls may also be required to raise surrounding grade for improved drainage

SOUTH LAWN
- Maintain open lawn for informal sports and picnicking
- Raise grade to facilitate proper drainage
- Add low native plantings along paths to enhance walking experience and provide interest
- Over time create and maintain open views to the Sound. Remove existing trees as they die or become damaged

EXISTING BLUFF TRAILS
- Improve trail surface and stairs
- Explore possibility of linking trails to create bluff loop
- Explore possible new trail along south bluff

EXISTING GROUP SHELTER
- Maintain existing shelter
- Modifications may be required, in the long term, due to sea-level rise

CONSOLIDATE PARKING
- Maintain current amount of parking in day use area
- Consolidate parking away from waterfront to expand space for recreation and amenities
- Improve drop off areas to allow better vehicle circulation
- Explore providing several parallel parking spaces in drop off zones for off-peak water viewing
- Provide carts for transport of personal items from drop offs and parking to shelters and picnic areas
- Explore expansion of overflow parking in upper portion of park

INTEGRATED STORMWATER MANAGEMENT SYSTEM
- Currently stormwater from the site flows directly to Puget Sound without filtration
- Replace current system with a series of connected wetlands and bioswales to remove pollutants and improve water quality
- Additional micro depressions within native plant areas collect, filter and infiltrate runoff from surrounding lawn and paths
- Provides wildlife habitat and adds interest to the site
- Supports the health of recreational harvest species and provides educational opportunities

NEW PATH NETWORK
- A new network of paved paths creates a pedestrian friendly park
- Paths provide opportunity for walking and exercise while allowing easy access across the site
- 10' min path width allows multiple uses and maintenance vehicle access.
- Provide system of interpretive kiosks and/or signs. Include current and historical information about cultural and natural resources

SOUTH SHORE ENHANCEMENTS
- Remove existing road and replace with paved path
- Remove existing bulkhead at point and replace with soft armoring storm berm system
- Add native planting areas to enhance habitat and define picnic areas
- Low growing plant species preserve views
- Provide multiple routes for beach access
- Portable picnic tables allow flexible use and removal during storms

KAYAK POINT
County Park
Day Use Area - CONCEPTUAL SITE PLAN
OPTION 1 of 2

June 2010 - DRAFT

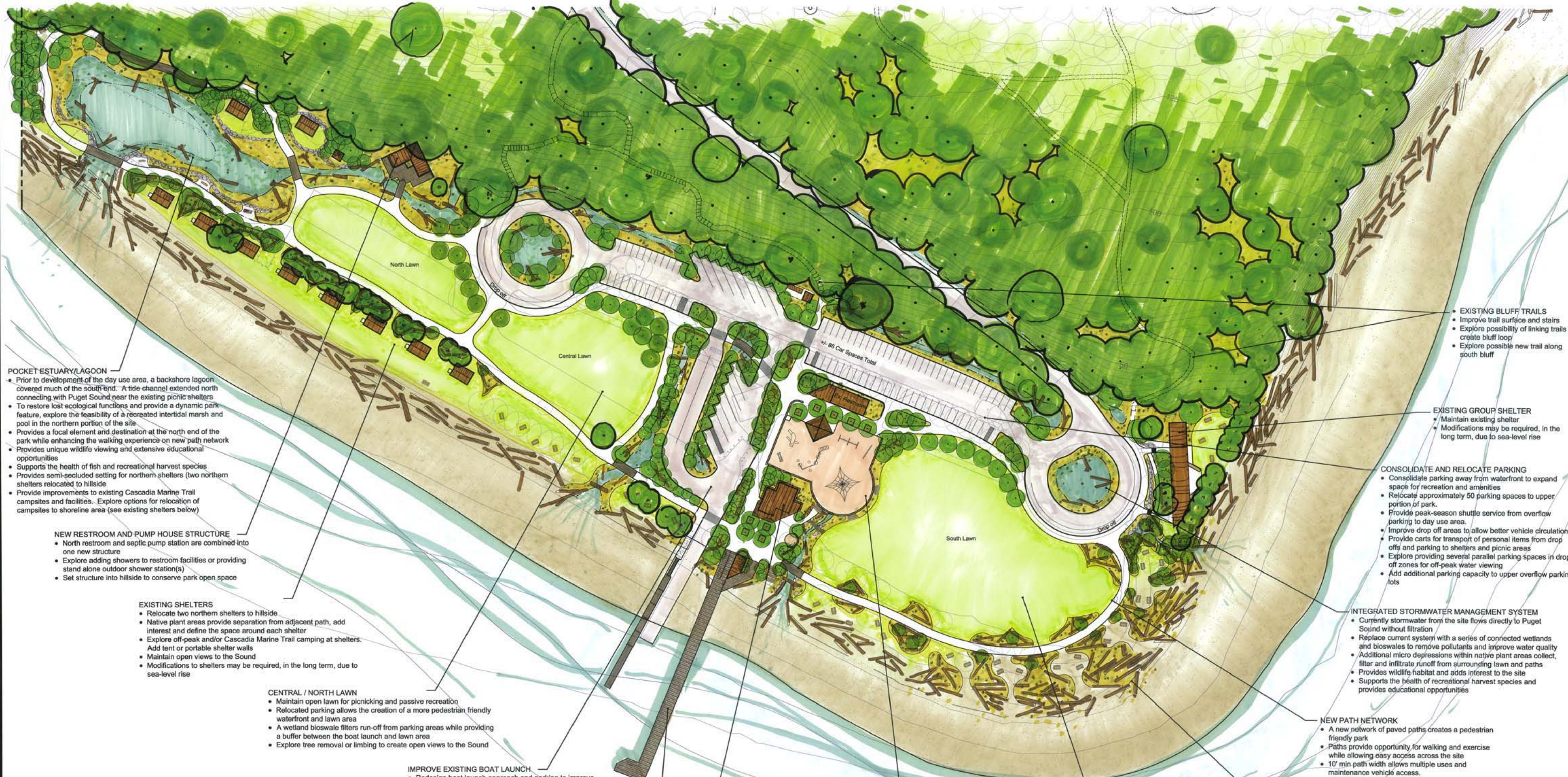
NORTH

0 25 50 125 250
SCALE IN FEET

** Base information obtained from Snohomish Co. Information Services GIS data and field measurements collected by the Parks & Recreation Department. All features shown on this plan are approximate.*

Snohomish County
WASHINGTON
Parks and Recreation Department
6705 Puget Park Drive Snohomish, WA 98296

NO	REVISION	DATE	BY
1	Initial Review	3-25-10	CEM
2	Internal Review	6-8-10	CEM
3	June Submittal	6-15-10	CEM



EXISTING BLUFF TRAILS
- Improve trail surface and stairs
- Explore possibility of linking trails to create bluff loop
- Explore possible new trail along south bluff

POCKET ESTUARY/LAGOON
- Prior to development of the day use area, a backshore lagoon covered much of the south end. A tide channel extended north connecting with Puget Sound near the existing picnic shelters
- To restore lost ecological functions and provide a dynamic park feature, explore the feasibility of a recreated intertidal marsh and pool in the northern portion of the site
- Provides a focal element and destination at the north end of the park while enhancing the walking experience on new path network
- Provides unique wildlife viewing and extensive educational opportunities
- Supports the health of fish and recreational harvest species
- Provides semi-secluded setting for northern shelters (two northern shelters relocated to hillside
- Provide improvements to existing Cascadia Marine Trail campsites and facilities. Explore options for relocation of campsites to shoreline area (see existing shelters below)

EXISTING GROUP SHELTER
- Maintain existing shelter
- Modifications may be required, in the long term, due to sea-level rise

CONSOLIDATE AND RELOCATE PARKING
- Consolidate parking away from waterfront to expand space for recreation and amenities
- Relocate approximately 50 parking spaces to upper portion of park.
- Provide peak-season shuttle service from overflow parking to day use area.
- Improve drop off areas to allow better vehicle circulation
- Provide carts for transport of personal items from drop offs and parking to shelters and picnic areas
- Explore providing several parallel parking spaces in drop off zones for off-peak water viewing
- Add additional parking capacity to upper overflow parking lots

NEW RESTROOM AND PUMP HOUSE STRUCTURE
- North restroom and septic pump station are combined into one new structure
- Explore adding showers to restroom facilities or providing stand alone outdoor shower station(s)
- Set structure into hillside to conserve park open space

EXISTING SHELTERS
- Relocate two northern shelters to hillside
- Native plant areas provide separation from adjacent path, add interest and define the space around each shelter
- Explore off-peak and/or Cascadia Marine Trail camping at shelters. Add tent or portable shelter walls
- Maintain open views to the Sound
- Modifications to shelters may be required, in the long term, due to sea-level rise

INTEGRATED STORMWATER MANAGEMENT SYSTEM
- Currently stormwater from the site flows directly to Puget Sound without filtration
- Replace current system with a series of connected wetlands and bioswales to remove pollutants and improve water quality
- Additional micro depressions within native plant areas collect, filter and infiltrate runoff from surrounding lawn and paths
- Provides wildlife habitat and adds interest to the site
- Supports the health of recreational harvest species and provides educational opportunities

CENTRAL / NORTH LAWN
- Maintain open lawn for picnicking and passive recreation
- Relocated parking allows the creation of a more pedestrian friendly waterfront and lawn area
- A wetland bioswale filters run-off from parking areas while providing a buffer between the boat launch and lawn area
- Explore tree removal or limbing to create open views to the Sound

NEW PATH NETWORK
- A new network of paved paths creates a pedestrian friendly park
- Paths provide opportunity for walking and exercise while allowing easy access across the site
- 10' min path width allows multiple uses and maintenance vehicle access.
- Provide system of interpretive kiosks and/or signs. Include current and historical information about cultural and natural resources

IMPROVE EXISTING BOAT LAUNCH
- Redesign boat launch approach and parking to improve launch access, increase safety, and reduce congestion
- Staging lanes provide space for approximately 8 vehicles
- Relocate trailer parking adjacent to ramp to reduce vehicle congestion and launch time
- Additional trailer parking provided on upper level of park
- Explore options for a new elevated boat ramp. Design should limit sediment deposition problems on the ramp while maintaining natural sediment transport processes
- Explore feasibility and long term sustainability of a courtesy dock

SOUTH SHORE ENHANCEMENTS
- Remove existing road and replace with paved path
- Remove existing bulkhead at point and replace with soft armoring storm berm system
- Add native planting areas to enhance habitat and define picnic areas
- Low growing plant species preserve views
- Provide multiple routes for beach access
- Portable picnic tables allow flexible use and removal during storms

SOUTH LAWN
- Maintain open lawn for informal sports and picnicking
- Raise grade to facilitate proper drainage
- Add low native plantings along paths to enhance walking experience and provide interest
- Over time create and maintain open views to the Sound. Remove existing trees as they die or become damaged

EXISTING PIER
- Renovate existing pier building to accommodate concessions or other flexible use
- Explore expansion of pier at shoreline to provide outdoor seating and integrate pier with central plaza space
- Explore raising the grade of the plaza to allow elimination of existing pier entrance ramp and railings

NEW MULTIPURPOSE BUILDING AND PLAZA
- Provides central indoor/outdoor gathering space for a variety of activities and amenities
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- Provides opportunity for revenue generation to support park maintenance and operation

ENHANCE EXISTING PLAYGROUND
- New landscape areas separate playground from adjacent pathways and boat launch area
- Plantings improve aesthetics and provide shade
- Explore use of low walls around playground to add seating and define playground space. Walls may also be required to raise surrounding grade for improved drainage

KAYAK POINT
County Park

Day Use Area - CONCEPTUAL SITE PLAN
OPTION 2 of 2

June 2010 - DRAFT

NORTH

0 25 50 125 250
SCALE IN FEET

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