Sandy Point Entrance Channel Topographic/Bathymetric Change and Trends

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December 31, 2013

Introduction

The purpose of this report is to continue an evaluation of topographic and bathymetric change in the entrance channel at the southern extent of the Sandy Point peninsula on the Lummi Indian Reservation. The study area includes the spit north of the channel, known locally as Cape Horn, the channel, and surrounding shores (Figure 1). Analysis included in this report is based on past work performed by Coastal Geologic Services, Inc. for the Lummi Indian Business Council (Johannessen and Chase 2005, Johannessen and Waggoner 2007) and more recent topographic and bathymetric data collected in September 2013 by Pacific Surveying & Engineering. Aerial photographs were not used for quantitative analysis, but were reviewed at times to allow for examination of spit morphology.

Coastal processes analysis and shoreline change work along the Sandy Point peninsula has been performed by Coastal Geologic Services for the Lummi Nation since 1995. This report is an extension of past mapping and analysis efforts conducted for the Lummi Nation, and represents the greatest level of quantitative analysis performed to date on the coastal geomorphology overview of the Sandy Point channel area.

Coastal Geomorphology Overview

The Sandy Point peninsula is a 2-mile long sand and gravel spit. The formation of the Sandy Point peninsula has been examined by Jacobson (1980), Dr. Maurice Schwartz (1983), and Johannessen (2002). Sandy Point was formed out of sediment that was derived primarily from bluff erosion in the Point Whitehorn-Cherry Point-Neptune Beach area (Jacobsen 1980). The action of northwest wind waves on the beachface causes sediment to be transported southward (littoral drift) towards Sandy Point (Jacobsen 1980). The long-term effect of this process is known as net shore-drift, which explains the formation of the Sandy Point peninsula.

Over the past 4,000 to 5,000 years, Sandy Point progressively prograded (extended) southward over the Lummi River delta (Schwartz 1983, USACE 1983). Prior to human modification, Sandy Point was originally a barrier beach that fronted a broad expanse of delta and salt marsh. Sandy Point is a relatively low-elevation landform. The average elevation of the high portions of the point was probably on the order of 10–12 ft mean lower low water (MLLW) prior to the addition of fill. Sandy Point was overwashed periodically by storm waves, including within living memory (Schwartz 1983).

Photographs from the 1940s and early 1950s show the nature of the formation of Sandy Point. A great number of recurved spits advanced to the south and southeast, representing various temporary shoreline positions (Johannessen 2002). These show up in the early aerial photographs even though the center of the spit was diked along the bayside and converted into pasture. Examination of a portion of the aerial photo set revealed that Sandy Point was still increasing in area with accretion on the south shore by natural coastal processes up until the artificial entrance channel was dredged near the southwestern tip of the peninsula in 1958 (Johannessen 2002). Air photos and comparison of surveyed topographic maps has revealed that the large majority of the surface of Sandy Point has been artificially filled (raised) by deposition of channel and canal dredge spoils, and likely by fill that would have been trucked in.

Methods

Cape Horn Accretion Rates

Ten maps/data sources were examined to quantify erosion/accretion trends along the shoreline of Sandy Point (Table 1). All data sources prior to 2013 were documented in previous reports on this subject (Johannessen and Waggoner 2007). The 2013 Pacific Surveying and Engineering (PSE) survey was provided as a digital terrain model developed by PSE, and used unchanged in this analysis. All maps were qualitatively checked for accuracy, omitting changes that were due to inaccurate surface comparison. In some cases features were not included in all maps because the original mapping did not cover all areas.

One longitudinal transect at Cape Horn (Transect H) was used from previous studies. The spit has recently trended more to the west since 2006, so a pivot point was introduced into the transect for measurement of spit progradation. The +8 ft MLLW elevation contour was deemed the best elevation for upper beach change, as it appeared to be an elevation (near mean high water) where careful surveying was usually conducted. The +8 ft MLLW contour was used from various years to calculate the accretion rates for Cape Horn by measuring the distance of the contour from an arbitrary starting point along the profile. Short-term and long-term accretion/erosion rates were calculated by dividing the difference in length by the number of years between measurements.

The estimated time for the progradation of Cape Horn to reach South Cape was determined by the "trajectory" of spit progradation and the distance along the trajectory.

The distance along the longitudinal profile from the +8 ft MLLW contour on Cape Horn to the +8 ft MLLW contour on South Cape was measured as the distance for Cape Horn to potentially reach South Cape. The average rates, as well as a linear and logarithmic trend of individual rates, were used to estimate when Cape Horn may reach South Cape.

Table 1. Data sources for channel entrance shoreline change analysis. Years with asterisk: maps not used due to inadequate coverage (1963) or inadequate detail (2000).

Year	Source	Data Format	Collection Method	Coverage	Data Utilized
1962	McElmon	Paper map	Photogrammetry?	N & S cape	Contours +5' to +14' MLLW, 1' contour interval from +10' to +14' MLLW.
1963*	McDaniel	Paper map	Ground survey	N cape	Top of Bank
1966	McDaniel	Paper map	Ground survey	N cape	Contours 0' to +14' MLLW, 1' contour interval. Top of Bank (+14' MLLW).
1972	McDaniel	Paper map	Ground survey	N cape	Contours at +1' and +8' MLLW. Top of bank.
1982	COE	Paper map	Photogrammetry w/field check and bathymetry spot elevations	N & S cape	Contours 0' to +14' MLLW, 2' contour interval. Bathymetry spot depths down to –46' MLLW.
1996	Walker & Associates	CAD	Photogrammetry	N & S cape	Contours +6' to +19' MLLW.
1997	PSE	CAD	Ground survey	N cape, Channel	Contours –6' to +10' MLLW, 1' - contour interval.
2000*	Walker	CAD	Photogrammetry	N & S cape	Contours +3' to +17' MLLW, 2' contour interval.
2002	PSE	CAD	Ground survey	Channel, S cape	Contours –11' to +17' MLLW, 1' contour interval. Top of Bank, toe of bank, edge of veg.
2006	PSE	CAD	Ground survey	Channel	Contours –5' to +16 MLLW, 1' contour interval, digital surface model (DSM)
2013	PSE	CAD	Ground survey	Channel, N & S Cape	Contours –9' to +14' MLLW, 1' contour interval, DSM

COE = Army Corps of Engineers
CGS = Coastal Geologic Services, Inc.
PSE = Pacific Survey and Engineering, Inc.

Entrance Channel Profiles

Profiles were drawn across the entrance channel between Cape Horn and South Cape, to analyze channel infilling. The cross sectional area of the three profiles through the channel was calculated as the total area below +8 ft MLLW and 0 ft MLLW. The change in both the cross sectional area and the location of the channel were examined over the time period where good data existed. Horizontal boundaries were placed for consistent comparison of channel cross sectional area. The cross sectional area was calculated by taking the area below +8 ft MLLW to each surface starting 80 ft along the profiles and ending 340 ft along the channel profile (260 ft total length).

Cape Horn Volumes

The volume of Cape Horn was calculated by finding the volume of the spit above -10 ft MLLW within AutoCAD. Areas for the spit volume began approximately 250 ft along profile H and encompassed the spit down to -10 ft MLLW on the end and edges and to the center of the entrance channel (Figure 2). The 1996/97 surface used 1997 direct rod survey measurements and 1996 upland (photogrammetry) data, but the lowest subtidal portions of the spit were not all surveyed. Most of the years did not include complete coverage down to -10 ft MLLW on the eastern side of Cape Horn. The spit side slopes without data were projected down to –10 ft MLLW using lower beachface slopes.

Entrance Channel Shoaling

Surfaces created for the Cape Horn volume change work were used (1982 and 2002 surfaces) to create an additional surface change map for 2006-2013 for the channel area within AutoCAD. Calculations performed on South Cape beaches and uplands were omitted to exclude surface change calculations where erosion had occurred due to wave attack. Similarly, North Cape upland areas were omitted to exclude areas where fill was added to the uplands. A total volume change number was calculated for the entrance channel area within AutoCAD.

Results

Cape Horn Accretion Rates

Current topography and bathymetry is shown in Figure 2. Cape Horn short-term rates (Table 2), and long-term rates (Table 3) accretion rates were calculated for profile H, which runs longitudinally down the middle of Cape Horn spit with a single pivot point used to follow the clockwise trend in spit progradation (Figure 2). The +8 ft MLLW shoreline for different years are all shown in Figure 3.

Simple long-term averaging of the data from 1962 to 2013 resulted in 9.0 ft/yr of progradation (horizontal accretion) for Cape Horn (Table 3). Fitting a linear trendline to the 1962 to 2013 data resulted in an average rate of 9.2 ft/yr. Although a logarithmic and polynomial regression was performed, neither proved better than the simple linear.

Table 2. Historic accretion lengths and short-term rates of +8 ft MLLW contour at Sandy Point using maps in AutoCAD. Lengths are relative to 1962, with S indicating the start of data. Rate data are relative to the previous year with data.

Transect	1962	1966	1972	1982	1996	1997	2002	2006	2013
H: Cape Horn Progradation Length (ft)	S	58.1	83.0	227.7	378.5	385.4	391.5	419.8	460.3
H: Cape Horn Progradation Rate (ft/yr)	S	14.5	4.1	14.5	10.8	6.9	1.2	7.1	5.8

Table 3. Historic accretion rates of +8 ft MLLW contour (long term) at Sandy Point using maps in AutoCAD (ft/yr).

Transect	1962–1982	1962–2013	1972–2013	1982–2013	1996–2013	2006–2013
H: N. Cape spit - Cape Horn tip	11.4	9.0	9.2	7.5	4.8	5.8

Despite the extension of the canal network and subsequent increase in tidal prism between 1966 and 1970 (Johannessen 2003), both the 1962 to 2013 and 1972 to 2013 data were very similar (Table 3). However, past analysis has considered the data from 1972 to be a better rate for predictive purposes due to the modifications, and is used here. Simple long term averaging of the data from 1972 to 2013 resulted in 9.2 ft/yr of accretion for Cape Horn (Tables 3 and 4a), a very slightly higher rate than from 1962 to 2013. Fitting a linear trendline to the 1972 to 2013 data resulted in an average rate of 9.1 ft/yr. Again, neither a logarithmic nor polynomial regression provided a better fit than linear, so linear regression was used.

Table 4a-c. Calculated timing of Cape Horn to reach South Cape

a. 1972 to 2013 data

Rate Description	Rate (ft/yr)	R^2 value**	Year*
Average linear growth rate of +8' MLLW contour along Pr-H	9.2	NA	2030
Linear trendline rate fit to +8 ft MLLW data along Pr-H	9.1	0.94	2026

b. 1996 to 2013 data

Rate Description	Rate (ft/yr)	R^2 value**	Year*
Average linear growth rate of +8' MLLW contour along Pr-H	4.8	NA	2089
Linear trendline rate fit to +8 ft MLLW data along Pr-H	4.7	0.95	2091

c. 2006 to 2013 data

Rate Description	Rate (ft/yr)	R^2 value**	Year*
Average linear growth rate of +8' MLLW contour along Pr-H	5.8	NA	2040
Linear trendline rate fit to +8 ft MLLW data along Pr-H	5.8	0.95	2040

* Year when +8' MLLW (2006) contour would reach +8' MLLW (2006) contour on S. Cape along profile H.
** An R^2 value of 1.0 would be a perfect fit; the closer to 1.0 the closer the trendline fits the data

Potential Channel Closure

Using accretion rates from 1972 to 2013, and two slightly different averaging methods to project into the future, Cape Horn would potentially reach South Cape some time in 2030 (Table 4a, Figure 4). As shown in Table 4b, more recent accretion trends between 1996 and 2013 show a slowing in the progradation of Cape Horn. The 1996–2006 accretion trend projects that Cape Horn will reach South Cape between 2089 and 2091 (Table 4b and Figure 5). The 2006-2013 accretion trend projects that Cape Horn will reach South Cape by 2040 (Table 4c and Figure 6). The slowed accretion rate after 1996 may be a manifestation of the substantially reduced width of the entrance channel near Cape Horn. Fairly rapid tidal currents have been observed here, and the limited channel cross sectional area and the moderately large tidal prism of the basin may be causing enough scour of the channel bottom and tip of the spit to result in the reduced accretion rate.

The calculated times for Cape Horn to reach South Cape do not account for future anthropogenic modifications (dredging, beach nourishment, etc.) that may occur. More importantly, progradation of Cape Horn across the inner portion of the entrance channel may be limited due to tidal currents scouring the channel and eroding the tip of the Cape Horn spit as it progrades, as discussed above. While net shore-drift sediment input likely remains constant over the long-term, the location of sediment deposition appears to have shifted somewhat as the channel narrows. Increase tidal flow velocities have resulted in additional deposition to the ebb and flood tidal deltas. Should Cape Horn prograde most of the way across the channel entrance and severely limit tidal flow, it is possible that the spit could be breached by storm waves and a new channel could form closer to the north end of the spit, which would in turn likely migrate southeastward. Further movement of the channel may also result in erosion of the north shore of South Cape, particularly if the current South Cape riprap structure becomes undermined and fails. In that event, a breach may open in South Cape, causing relocation of the channel to that area.

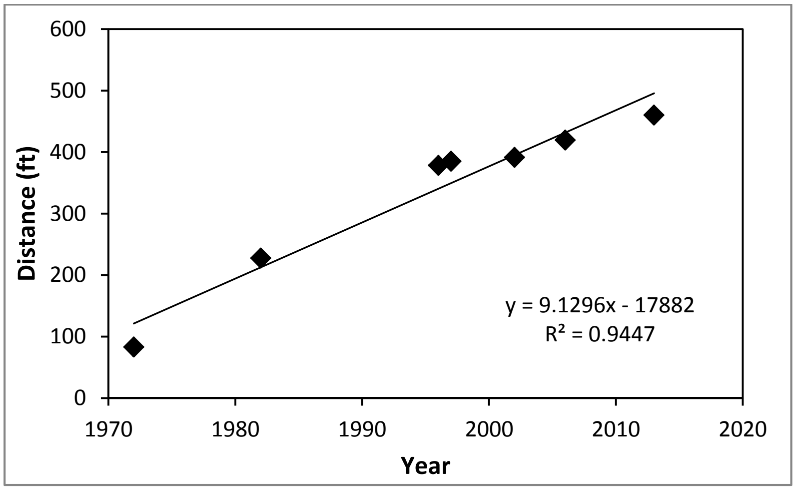

Figure 4. Distance of the +8 ft Contour along Transect H for 1972 to 2013. Linear regression and equation shown.

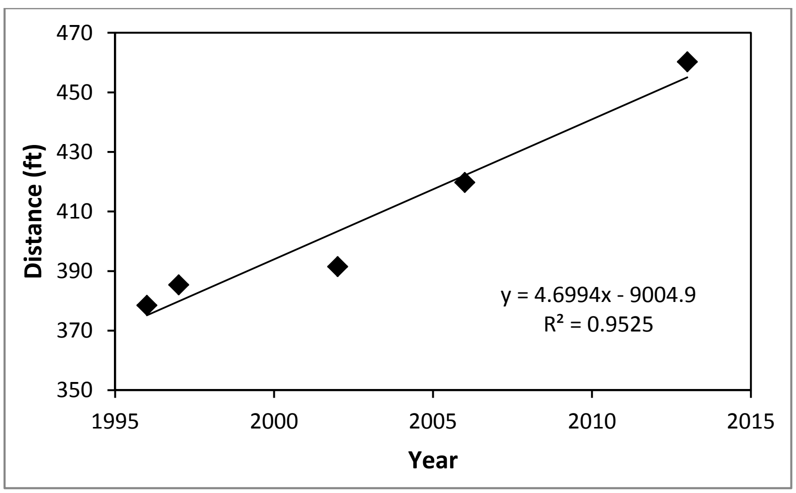

Figure 5. Distance of the +8 ft Contour along Transect H for 1996 to 2013. Linear regression and equation shown.

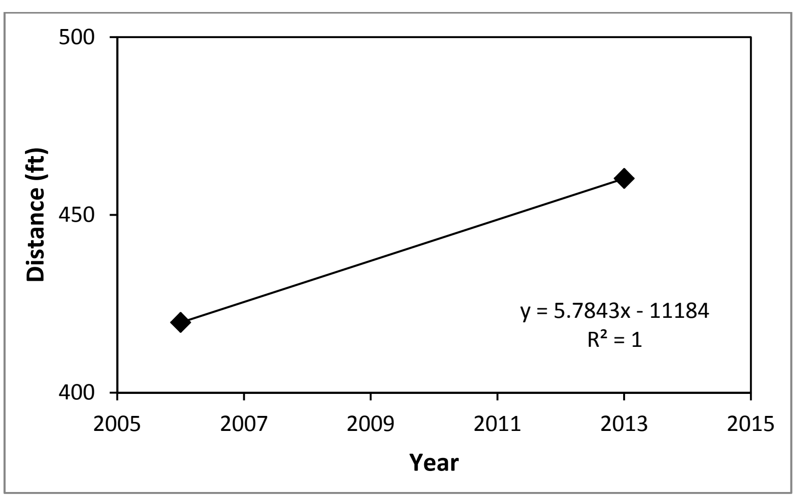

Figure 6. Distance of the +8 ft Contour along Transect H for 2006 to 2013. Linear regression and equation shown.

Entrance Channel Profiles

The geomorphic trends at the entrance channel and at southern Cape Horn were examined using 5 cross section profiles cut through the 1982, 1996/97, 2002, 2006, and 2013 surfaces. The cross sections were moved toward the inside to follow the trend of spit progradation (Figure 2).

The entrance channel profiles show the channel shifting toward South Cape as the Cape Horn spit has prograded southeastward (Figure 7). At the same time, the channel has tended to shoal, with a bottom ranging from -8.8 ft MLLW in 1982 up to -2.8 ft MLLW in 2013. The channel has also tended to narrow, resulting in an overall loss of cross sectional area. The total cross section has been reduced by 49–59% of its area below +8 ft MLLW, and 75–83% below 0 ft MLLW (Table 5). While the rate of cross section reduction has lowered somewhat since 2002, the channel filling remains steady. The long-term rates suggest that without dredging the channel bottom may rise above 0 ft MLLW by 2016, and to above +8 ft MLLW by 2024, but again, the shoaling rate will also likely decrease due to increased tidal velocities with a smaller channel cross section.

Table 5. Cross sectional area (square feet) and rates (SF/YR) of channel below +8 ft MLLW and 0 ft MLLW, 150 ft to 350 ft (200 ft long) along each channel cross section. Negative rates indicate a decrease in channel area.

	Channel Cross Section (Profile)					
Year	**1**		**2**		3	
Channel Cross Sectional Area (SF)						
Max Elev (MLLW)	+8	0	+8	0	+8	0
1997	1611	381	1929	576	2346	786
2002	1233	195	1881	623	2027	670
2006	1077	144	1358	253	1591	422
2013	826	95	827	114	955	130
Cross Sectional Area Change Rate (SF/YR)						
Max Elev (MLLW)	+8	0	+8	0	+8	0
1997 to 2002	-75.6	-37.2	-9.6	+9.4	-63.8	-23.2
2002 to 2006	-39.0	-12.8	-130.8	-92.5	-109.0	-62.0
2006 to 2013	-35.9	-7.0	-75.9	-19.9	-90.9	-41.7
1997 to 2013	**-49.1**	**-17.9**	**-68.9**	**-28.9**	**-86.9**	**-41.0**

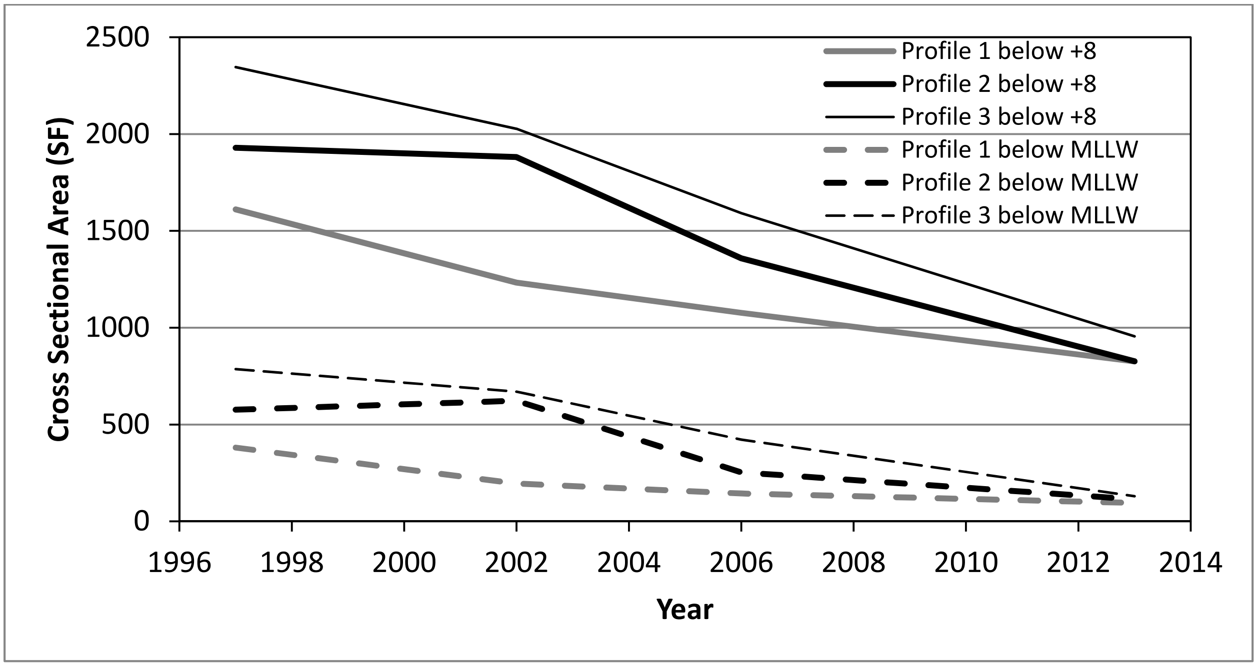

Figure 8. Plot of the cross sectional area (square feet) below +8 ft MLLW and 0 ft MLLW.

Geomorphic Change

The 1962 topographic map by McElmon (Figure 3, red shoreline) showed the complete absence of Cape Horn. Examination of the historic air photos (introduced in Johannessen 2002) revealed that the spit did not begin to form until 1970–1972, starting in the area east of the rock breakwater on the north side of the channel. After the broad spit platform was deposited—a necessary precursor to progradation of the supratidal spit (Greenwood and Davidson-Arnot 1979)—accretion of the southeast trending spit began around 1978. In 1982, the time of the first comprehensive mapping, Cape Horn had already started encroaching into the original channel significantly, and continued prograding in a fairly consistent direction through 2006. Between 2006 and 2013 the spit had begun to curve toward the south, potentially due to increased influence of ebb tidal flow caused by constriction of the channel (Figure 2). Another source of spit curve may be relatively strong northeast windstorms, which would cause short-term sediment transport toward the outside of the channel.

Surface change analysis was performed to examine changes in elevation and bathymetry spatially for the most recent period between 2006 and 2013 (Figure 9). This type of presentation shows the changes discussed above over the greater entrance channel area. Trends seen during the previous periods (Johannessen and Waggoner 2006) continued into the period from 2006 to 2013. Accretion was concentrated at south and southwest Cape Horn, while some minor erosion was seen on the southeast and east side of the spit (Figure 9). The narrowest portion of the entrance channel experienced shoaling of up to 1 ft vertical. Two large scour holes were seen at either end of the channel, which had shifted toward the south. As the channel has shifted, new areas of sediment were exposed to tidal flow. West of the channel, additional accretion of up to 2 ft in depth can be seen in the ebb tidal delta. The majority of the comparison area remained stable with less than 1 ft of vertical change.

The net volume change at Cape Horn and the entrance channel between 2006 and 2013 was about 6,200 CY of accretion (9,076 CY fill, 2,921 CY cut, rounded to 6,200 CY). The size of this area (Figure 9) and the inclusion of eroded areas resulted in a realistic net accretion total. For example, the erosion that occurred north of the entrance channel was likely deposited near the inner channel and this erosion area offset some of the accretion. Therefore, the infilling rate should be representative of a good portion of the net shore-drift rate, excluding some of the low tide terrace transport. The average channel area accretion rate over the 2006 to 2013 period was therefore 879 CY/YR, which was close to the previous estimate of 962 CY/YR for the period between 1982 and 2006. Using very rough channel dimension estimates, Schwartz (1983) estimated that the channel area infilling rate was approximately 1,957 CY/YR up to 1983. The earlier period has been shown to have more rapid accretion, such that these numbers are generally consistent.

Cape Horn Volumes

The volume of Cape Horn has steadily increased over time (Table 6, Figure 10). The volume of Cape Horn increased from 22,174 CY in 1972 to 80,043 CY in 2013. The greatest rate of volume increase was from 1972 to 1982 (Table 6). This was likely due to anthropogenic impacts during development in the early 1970’s. The overall average of volume growth of Cape Horn was 1,411 CY/yr (1972–2013 average). Due to modifications prior to 1970, and the fact that the accretion rate is more consistent after 1982, the 1982–2013 rate of 983 CY/YR is probably more representative of the current long-term rate.

Table 6. Cape Horn spit accretion/ volumes (CY) and rates (CY/yr) relative to the most previous data.

Year	Volume above -10 MLLW (CY)	Short-term Rate (CY/yr)	Rate since 1972 (CY/yr)	Rate since 1982 (CY/yr)
1972	22,174	-	-	-
1982	49,562	2,739	-	-
1997	59,258	646	1,483	-
2002	65,922	1,333	1,458	818
2006	74,553	2,158	1,540	1,041
2013	80,043	784	1,411	983

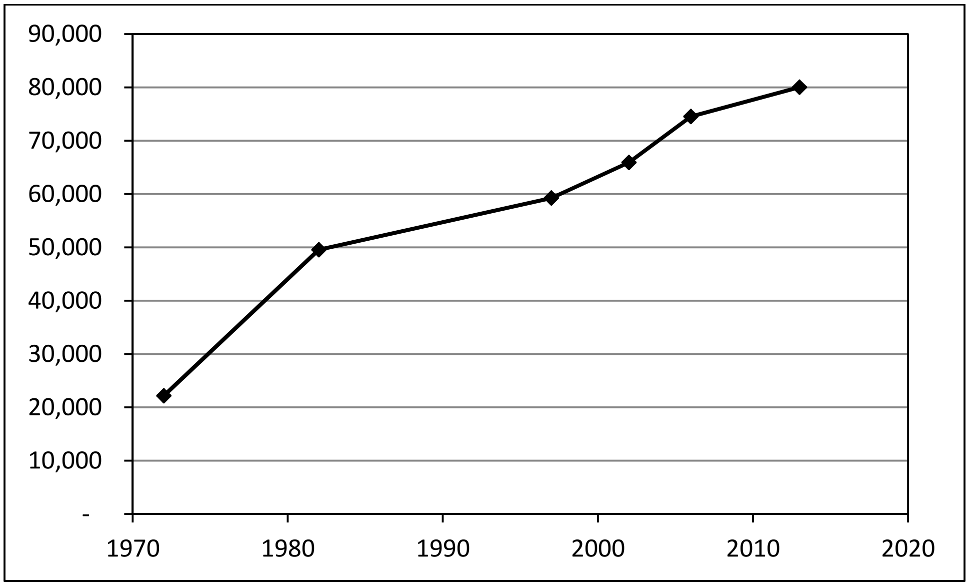

Figure 10. Cape Horn volume estimates from 1972 to 2013 in cubic yards (CY).

Schwartz (1983) used rough estimates of the progradation of Cape Horn between 1962 and 1982 to calculate an accretion rate of 462 or 667 CY/YR, using different areas. Schwartz did not use surface change analysis, instead he used approximate spit geometry. As stated earlier, the use of data prior to 1982 does not represent current conditions as well, but the more accurately measured accretion rates presented herein are noticeably greater than the estimates provided by Schwartz.

Summary

Sandy Point is a 2-mile long sand and gravel spit located on the Lummi Indian Reservation. Examination of historic aerial photographs revealed that Sandy Point was still accreting on the south shore by natural coastal processes until the artificial entrance channel was dredged around 1958. Dredging of canals and extensive filling of the uplands occurred on North Cape and South Cape between 1966 and 1970. During this time the interior canals were extended on the order of 3,000 ft to the north and air photos from this period show noticeable sediment plumes entering the channel entrance that may have been indicative of measurable sedimentation in the channel (Johannessen 2002). It is also possible that dredging of the channel occurred at this time. Due to the modifications between 1966 and 1970, the post 1972 data reflect the unmodified accretion of Cape Horn. As Cape Horn has prograded further south into the entrance channel, the rate of progradation appears to have slowed somewhat due to channel bottom scour and erosion of the top of the prograding spit, caused by the relatively large tidal prism within Sandy Point and corresponding high tidal velocities. Increased velocities have shifted some of the sediment accretion away from the spit and onto the ebb and flood tidal deltas. The 2006 to 2013 data all follow a similar trend of slowed progradation, and appear to provide a more accurate projection of progradation into the future.

Examination of the historic aerial photographs (Johannessen 2002) revealed that the spit on the north side of the entrance channel, called Cape Horn, did not begin to form until 1970–1972, starting in the area east of the rock breakwater on the north side of the channel. After the broad spit platform was formed, accretion of the southeast trending (supratidal) spit began around 1978. In 1982, the time of the first comprehensive mapping, Cape Horn had already started encroaching on the original channel significantly, and continued prograding in a fairly consistent direction through 2006. However, by 2013 the spit had begun to curve toward the south, further increasing the tendency toward channel closure. The curve may be the result of increased ebb tidal velocities, short-term reversal of sediment transport toward the southwest during strong northeasterly wind storms, or a combination of both.

The estimated time for Cape Horn to reach South Cape was determined by the "trajectory" of spit progradation, the distance along the trajectory, and the rate of spit progradation. The distance from the tip of Cape Horn at the +8 ft MLLW contour to the shore to the south was 662.2 ft in 2013. Cape Horn has extended into the entrance channel area to the south at a horizontal rate of approximately 4.7 ft/yr since 1996. Using horizontal spit accretion data from 1996 to 2013, Cape Horn would potentially reach South Cape between 2089 and 2091. This is approximately 20 years sooner than the estimate made by Johannessen and Waggoner (2006), although still much later than has been previously made by Johannessen (2003), and it reflects the apparently slower rate of spit advance seen since 1996. The short term accretion rate between 2006 and 2013, using the recent more southward trend of North Cape progradation yields potential closure of approximately 2040 (over a shorter distance; Figure 2).

The controlling depth of the entrance channel has decreased over time, changing from elevation -12 ft MLLW in the late 1950's, to -9 ft MLLW in 1982, to elevation -4.5 ft MLLW in 1997, to -2 ft MLLW in 2006, and finally -1 ft MLLW in 2013. Minor scouring at either end of the entrance channel occurred due to the strong tidal currents, even as the area of the channel cross section decreased. The outer scour hole moved 40–50 ft to the southwest, and the inner scour hole 40 ft to the south. The cross sectional area in the inner channel was the smallest in 2013, down to 28% of the 1982 area (below +8 ft MLLW) and on the order of roughly 10% or the original circa 1958 channel area. The rate of channel infilling has decreased slightly over time, suggesting that channel infilling will continue into the future despite the scouring effects due to the tidal prism (volume of tidal water in the Sandy Point canals), although apparently at decreasing rates.

Surface change analysis was performed to examine changes in elevation and bathymetry spatially over the whole entrance channel area. Changes between 1982 and 1997 were dramatic with up to 12 plus feet of vertical accretion at the tip of the spit, extending to the channel bottom and over to South Cape. Accretion of 1 to 3 ft occurred in the outer channel area, located 200 to 500 ft west of the south jetty. The areas of accretion made the entrance channel shallower in both areas where depth was already limiting the channel function. In 2013, the outer channel had shoaled to -1 ft MLLW, maintaining this as the shallowest portion of the entrance channel.

The volume of Cape Horn has steadily increased over time. The rate of volume increase has fallen from the 2002 to 2006 rate of 2,158 CY/YR down to the current rate of 784 CY/YR. This lower rate is close to the long-term rate since 1982, which was 983 CY/YR. The spit accretion has slowed, but the net shore-drift sediment input has likely remained relatively constant. Some of that sediment has likely been transported by increased tide channel flow to the ebb and flood tidal deltas rather than the spit. However, current sea level projections for the Pacific Northwest include rising sea levels and increased storminess (National Academy of Sciences 2012). Under these projections the accretion rate will likely increase.

Conclusions

Cape Horn should continue to prograde in the same generally southward direction into the future as a significant volume of net shore-drift sediment continues to be transported from the north to Cape Horn and into the channel entrance. Based on accretion patterns at Cape Horn since 1972, the navigation channel will likely continue to narrow and become more sinuous in the coming decades. Tidal current velocities in the inner channel are also expected to increase. Therefore, the inner channel should become more difficult to navigate as it becomes more narrow and sinuous, and currents increase. In the outer channel (western portion), further shoaling is expected to occur as mostly sand is deposited in this broad area without high tidal current flow.

Several methods of estimating the timing for Cape Horn to potentially reach South Cape and close the entrance channel were presented in this report. Based on trends since 1996, this could occur between the year 2040 and 2091. These calculations do not account for any future anthropogenic modifications (dredging, beach nourishment, etc.). Most predictions are later than those earlier forwarded by Johannessen (2003), and appear to reflect the increasing tidal current as the channel narrows, caused by the large tidal prism. Erosion of the nearby north shore of South Cape could extend this date further into the future.

Progradation of Cape Horn across the inner portion of the entrance channel may be limited due to tidal currents scouring the channel at a greater rate than in the recent past such that the time for potential channel closure is likely later than predicted in this analysis. As Cape Horn progrades most of the way across the channel entrance and closer to South Cape, it is possible that the spit could be breached by storm waves and a new channel could form closer to the north end of the spit, that would in turn likely migrate southeastward. The new channel would likely be no deeper than the present channel, and would also likely be narrow.

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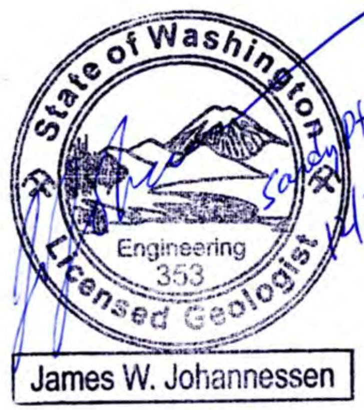
Coastal Geologic Services, Inc.



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ATTACHMENTS:

Figure 1. Study area location map of Sandy Point.

Figure 2. Sandy Point: 2013 topography and bathymetry.

Figure 3. Sandy Point: Historic Shorelines for +8 ft MLLW contour.

Figure 7. Sandy Point: Channel cross-sections

Figure 9. Sandy Point: Surface change analysis 2006-2013.

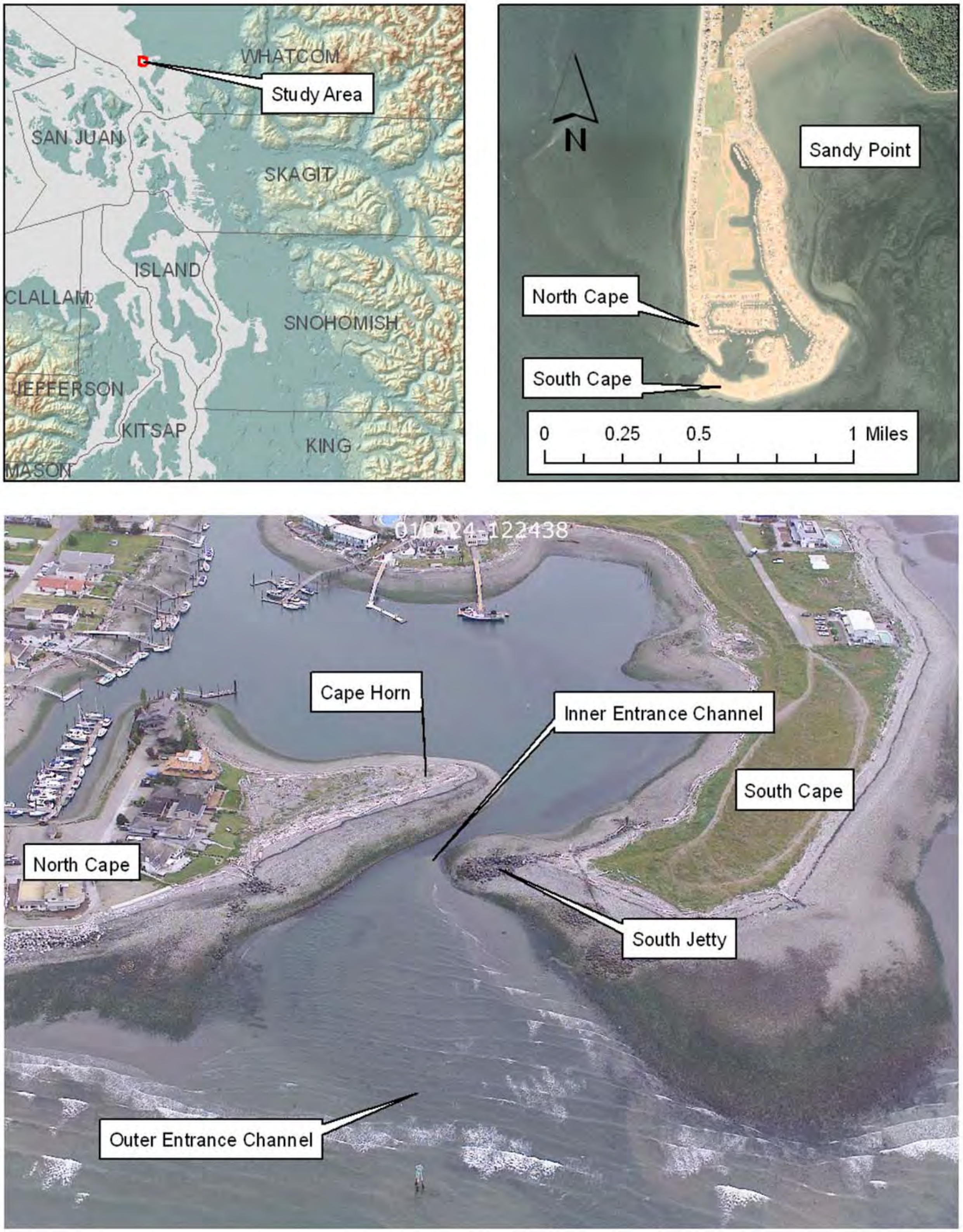
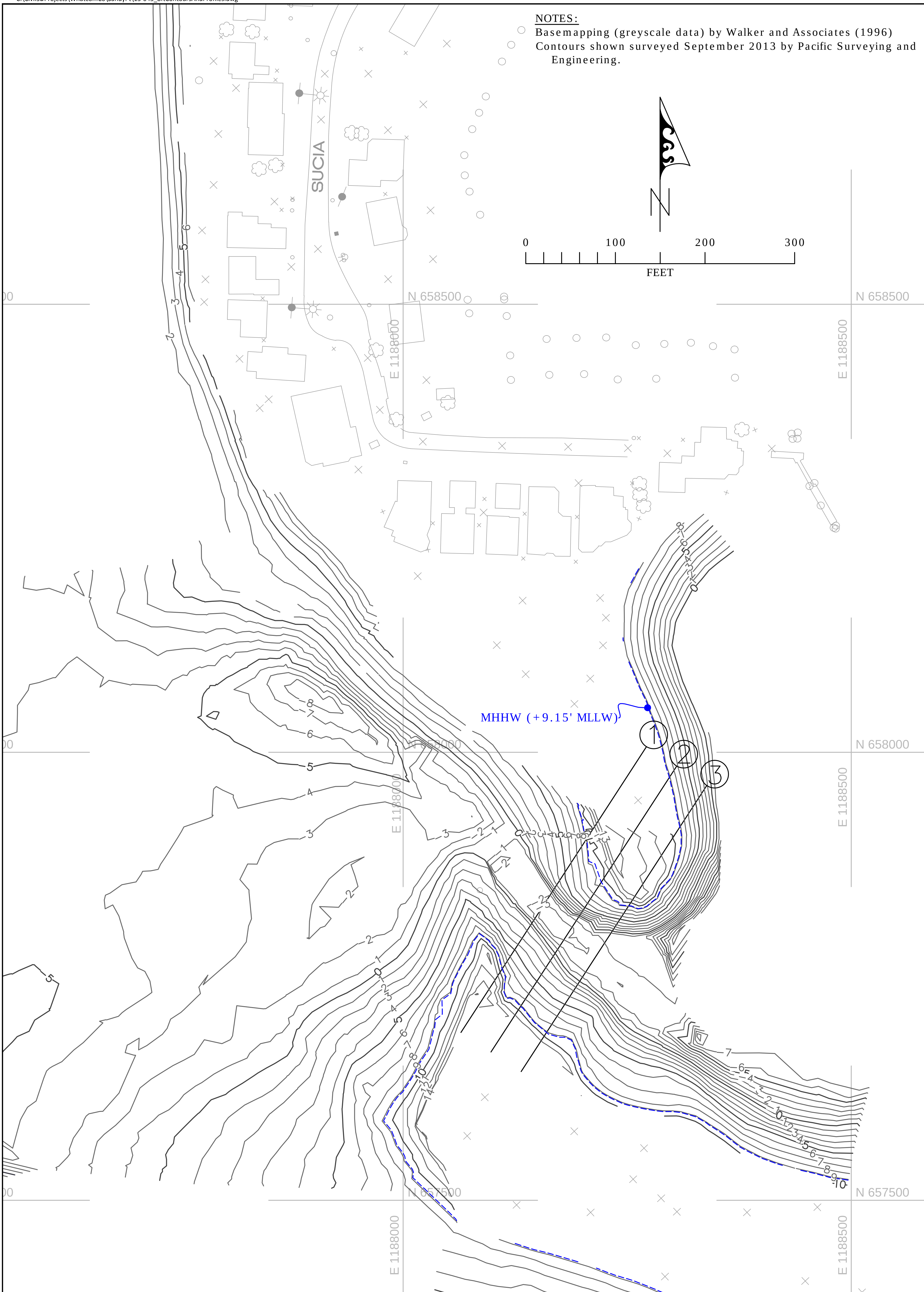


Figure 1. Study area location maps for Sandy Point and Lummi Reservation, with features discussed in this report.

C:\Civil3DProjects\WhatcomCo\SandyPt\13-045_8ftContoursAndProfiles.dwg



SANDY POINT ENTRANCE CHANNEL

2013 Topography and Bathymetry

Client: Lummi Natural Resources Dept.

FIGURE: 2

DATE: 12/20/13

SCALE: AS NOTED

MLLW=0.0'

DRAWN BY: JFW
DESIGNED BY:
CHECKED BY: JWJ
DATE SURVEYED: 9/9/13

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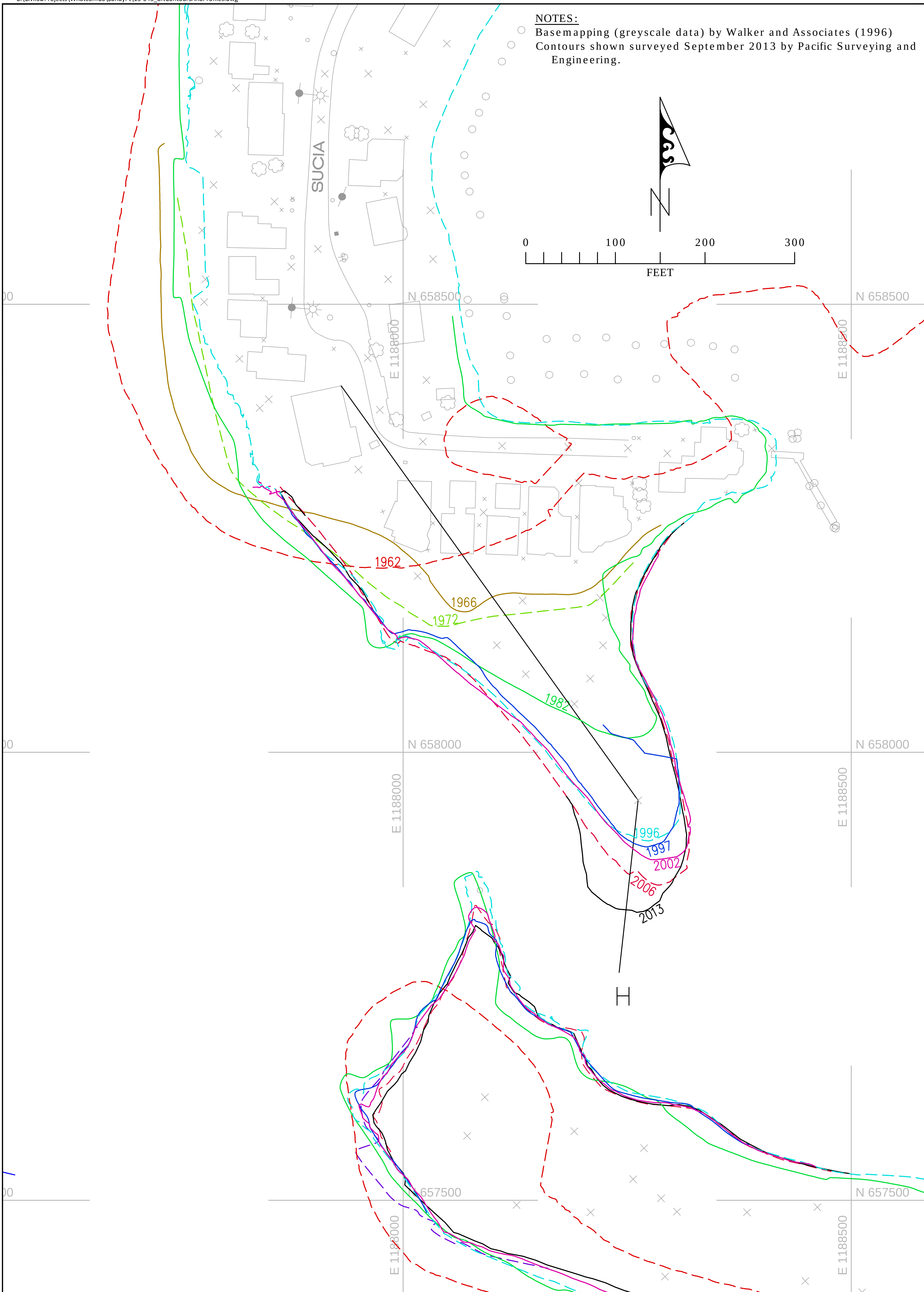
NOTES:
Basemapping (greyscale data) by Walker and Associates (1996)
Contours shown surveyed September 2013 by Pacific Surveying and Engineering.



SANDY POINT ENTRANCE CHANNEL

HISTORIC SHORELINES

+8 ft MLLW Comparison 1962-2013

Client: Lummi Natural Resources Dept.

FIGURE: 3

DATE: 12/20/13

SCALE: AS NOTED

MLLW=0.0'

DRAWN BY: JFW
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CHECKED BY: JWJ
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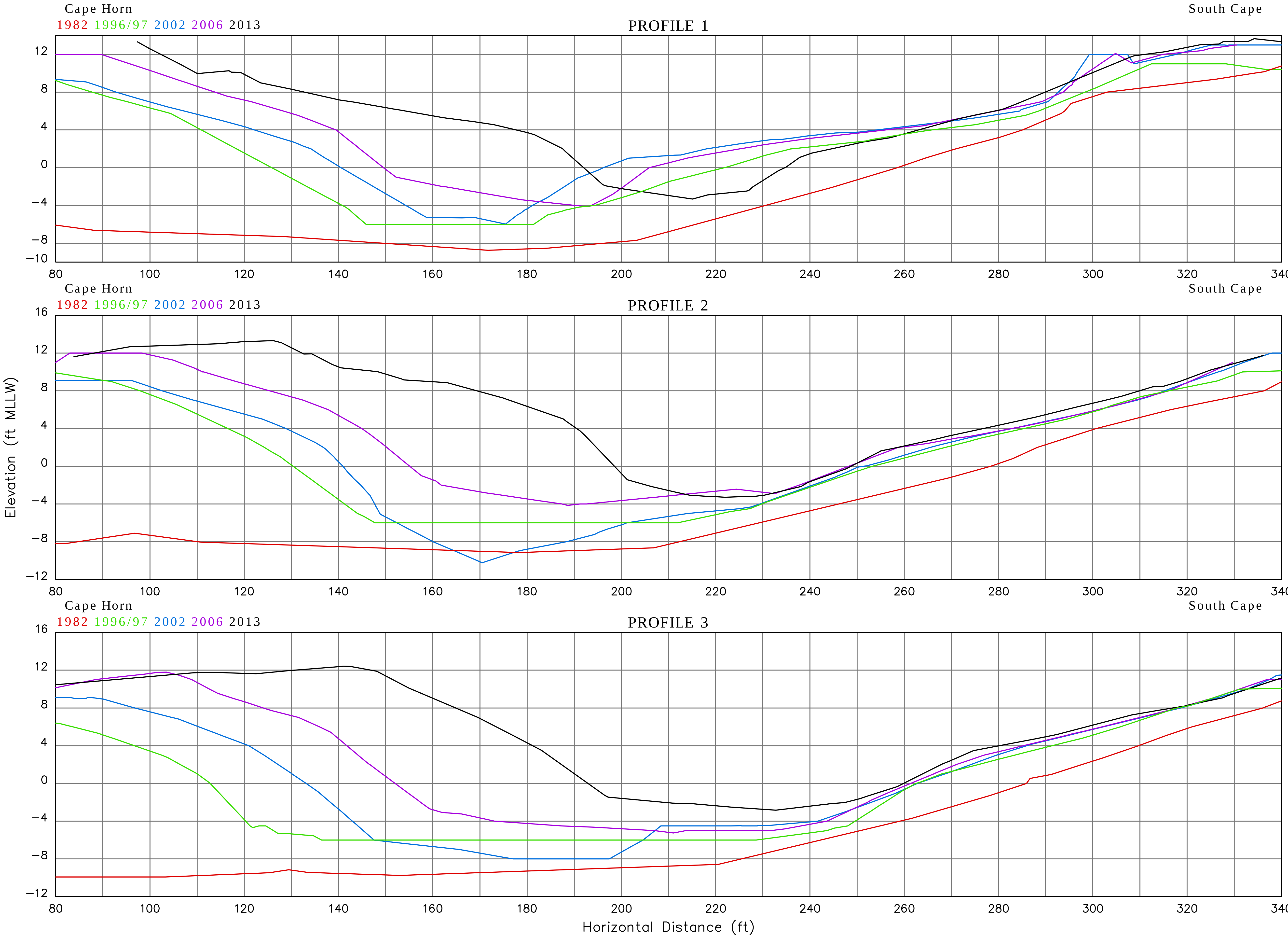

SANDY POINT ENTRANCE CHANNEL

CHANNEL CROSS SECTIONS

1982-2013

Client: Lummi Natural Resources Dept.

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MLLW=0.0'

SCALE: AS NOTED

DATE: 12/20/13

FIGURE: 7

C:\Civil3DProjects\WhatcomCo\SandyPt\13-045_8ftContoursAndProfiles.dwg

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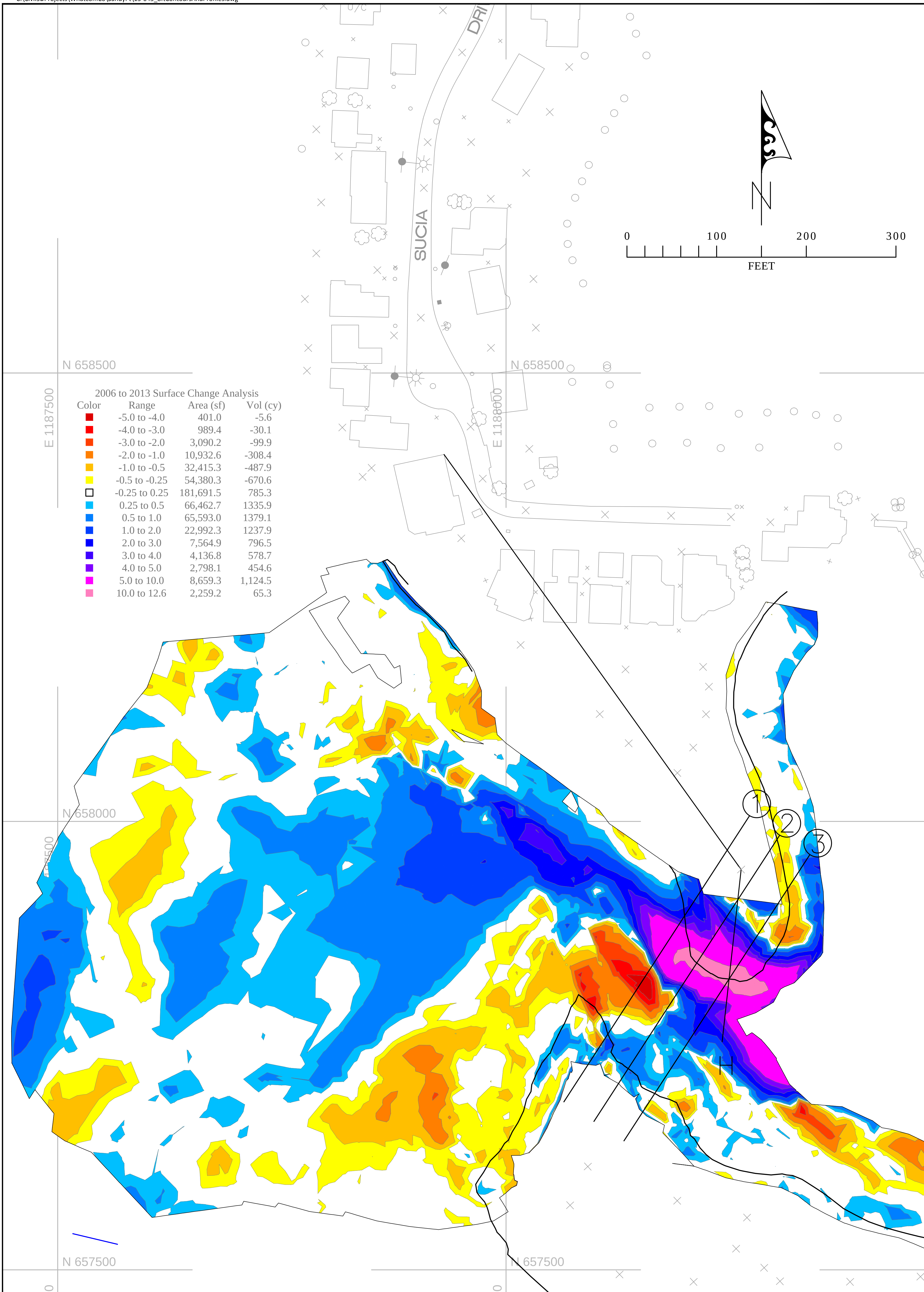

2006 to 2013 Surface Change Analysis

Color	Range	Area (sf)	Vol (cy)
	-5.0 to -4.0	401.0	-5.6
	-4.0 to -3.0	989.4	-30.1
	-3.0 to -2.0	3,090.2	-99.9
	-2.0 to -1.0	10,932.6	-308.4
	-1.0 to -0.5	32,415.3	-487.9
	-0.5 to -0.25	54,380.3	-670.6
	-0.25 to 0.25	181,691.5	785.3
	0.25 to 0.5	66,462.7	1335.9
	0.5 to 1.0	65,593.0	1379.1
	1.0 to 2.0	22,992.3	1237.9
	2.0 to 3.0	7,564.9	796.5
	3.0 to 4.0	4,136.8	578.7
	4.0 to 5.0	2,798.1	454.6
	5.0 to 10.0	8,659.3	1,124.5
	10.0 to 12.6	2,259.2	65.3

FIGURE: 6

DATE: 12/20/13

SCALE: AS NOTED

MLLW=0.0'

SANDY POINT ENTRANCE CHANNEL

Surface Change Analysis

2006 to 2013

Client: Lummi Natural Resources Dept.

DRAWN BY: JFW
DESIGNED BY:
CHECKED BY: JWJ
DATE SURVEYED: 9/9/13

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