HOOPER BAY COASTLINE MODELING

AKDOT Project No. 57419

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Introduction

The airport at Hooper Bay has been undergoing erosion on its northern end—located on the upper beach—for several years. Several methods of shore protection have been attempted over the years to slow or eliminate the erosion. One included the installation of a sheet-pile wall on the north end of the runway where encroachment of that end onto the beach has resulted in a major problem. There is concern that the sheet wall may fail leaving the airport directly exposed to storm surges and accompanying waves.

The primary goal of this investigation is to provide our best estimate of shoreline position over the next one hundred years. This is very speculative as it must be based on what is occurring today and what has happened over the documented or inferable past. It cannot allow for changes that might occur as the list of possibilities is nearly boundless.

To accomplish this primary goal, several pieces of information must be gleaned or calculated from the existing data base which includes:

- A series of aerial photographs dating from 1951 to 2007.
- Analysis of the beach sediment to determine its size and variability.
- A wind record from the airport from 1992.
- Photographs and verification from a short field trip.

A secondary objective was to offer possible shore protection methods that could assist in protecting the exposed northwestern end of the runway. The idea was to propose a groin or groin system either just north or south of that exposed runway end to retain beach sediment as it is transported past this area. After noticing the salient just south of the runway in one of the photographs used in our proposal, it seemed clear that sediment moving south would be incorporated in the salient and essentially no longer available to be re-transported north when winds were favorable for such transport. Therefore, a groin or a groin field to retain this material might be beneficial. Similarly, if the majority of the transport was to the north, a groin north of the runway end and south of the river might be beneficial.

The analysis later revealed that the salient was not stationary, but moving northward which altered our thinking about proposing remediation. It became quite likely that the salient would preclude the need for erosion control measures at this time and would likely soon be providing protection for the northwest end of the runway that would last for many years in the future.

To achieve the objectives of this report, the work plan as listed below was conducted and will be described in more detail later:

- The existing data pertaining to the beach and the erosion will be described including the results of a field trip taken to assess the overall condition of the beach.

- The sediment sources and sinks will be documented in a sediment budget estimate in the area of the major ongoing erosion.
- The major features that play a role in the state of the beach will be described and the impact assessed.
- The effect of long-term changes of sea level will be described and evaluated.
- The probable development of future shoreline positions and the resulting nearshore profiles will be presented.

The last item will be done in light of the existing and predicted beach changes. The profiles will be based on the equilibrium beach profile (EBP) concept where profile shape is dictated mainly by sediment size.

The report is organized so that the next section presents the assumptions and the conclusions of the analysis and this will be followed by discussions or descriptions of:

- The Hooper Bay coastal area,
- A history of the runway and the efforts to control the erosion,
- The field trip conducted on June 29-30, 2011,
- Previous analyses conducted,
- The various analytic analyses applied in the present investigation and the results.
- Appendices:
    - Detailed trip report,
    - The role of the salient in stabilizing the beach.
    - Sediment transport equations.
    - The effect of the river's ebb tide shoals.

It has been informative to examine this beach system as it presents an example of a moving beach salient not encountered in the past and is worthy of future study not only due to its rarity, but also because of its importance to this system.

Conclusions and Recommendations

This report addresses the ongoing coastal processes along the beach that fronts the Hooper Bay airport with special attention to the erosion at the northwest end of the runway. A series of observations and calculations were made during this analysis which will be discussed in later sections. The assumptions that have led to these conclusions are also presented in this section. These include:

- The beach at Hooper Bay is composed of uniformly fine sand with a median diameter of 0.18 mm.
- The background beach erosion rate is 2 feet per year.
- The rate of northward migration of the salient is 150 feet per year.
- 19 years of wind data are sufficient to make long-term predictions regarding longshore transport.
- Open water can be assumed to exist at Hooper Bay from May 15th to November 15th.

The correctness of the last assumption was difficult to verify. The Alaska Marine Ice Atlas[1] suggests that there is 25 to 50 percent ice coverage in the Hooper Bay area by November 15th. This amount of coverage should permit sediment transport. It also states that there is on average 50 to 75 percent coverage remaining on May 15th. On June 1st the coverage is between 25 and 50 percent. The most logical dates are probably June 1st to November 15th. However, few storms occur from late spring to mid-summer so the dates May 15th to November 15th should be quite accurate. The period was shortened to June 1st to October 31 as there may be ice remaining near shore even if it is open in deep water. Again this is an area that could use additional information. A sensitivity check was done by repeating the sediment transport analysis for the period June 1 to October 31 and got a significantly lower sediment transport quantity but its net direction remained to the south. The reason for the lower values is due to the active storm period in late fall so a two-week change to the assumed open water window can make substantial changes in the sediment transport results.

Based on these assumptions and the best judgment of the investigators, the following conclusions and recommendation were inferred from the analysis:

- The sediment transport rate averaged over 18,000 yd^3 per year to the south. A rate of about 2,000 yd^3 was calculated using the shorter period of June 1 to October 31.
- The uniformity of sediment size allowed for only one feasible beach and nearshore profile.
- A plausible set of shoreline positions based on the estimated erosion rate and the salient migration rate have been presented that suggests that as the salient moves somewhat

[1] [1] LaBelle, Joseph C., James L. Wise, Richard P. Voelker, Robert H. Schulze and Gary M. Wohl. 1983, Alaska Marine Ice Atlas, AEIDC, University of Alaska

more to the north, the northwest half of the runway should be safe from further erosion for 25 plus years.

- To ensure that the northwest portion of the runway is safe from erosion for the next 5 to 10 years, the entire runway should be shifted 1,000 feet to the south along its present alignment. Available funding may influence the implementation of this recommendation.
- More observations should be made annually to check on the position of the salient, to measure the sheet piling freeboard, and to attempt to validate the sediment transport direction. While our best professional estimate is that the transport direction is to the south, the evidence is not conclusive and recent climate changes could influence the direction and magnitude.
- The present sheet piling should provide adequate protection for several years, but the northwest end will be susceptible to overtopping and will require routine maintenance to remove sand from overtopping waves and wind borne processes to ensure aircraft safety.
- Sea level should rise at the world-wide documented average rate of about 8 inches per 100 years. No acceleration based on global climate models is warranted in light of recent analysis of the existing data.

Some of these conclusions and recommendations require additional comments. For example, the recommendation has been made to move the runway 1,000 feet along its alignment to the south and simultaneously suggests that the sheet piling appears to be quite capable of providing protection for several more years. These two comments appear inconsistent. It has been assumed that as the salient continues to move northward, it will begin protecting the northwestern end of the runway within a few years. This is based on its northward movement at an average rate of 150 feet per year since it was first observed in a 1951 aerial photograph.

From 1951 to 2005 the rate was clear. However, a 2007 position coupled with an estimate taken in 2011 indicated a possible slowing of the past rate to perhaps only 45 feet per year. Clearly short term changes in the migration rate are likely to have occurred during the period from 1951 to 2005 but were not seen because of the lack of intervening photography. However, since at least 1977 there has been a substantial change in Alaska's weather patterns as reflected in its average temperatures and for at least the last 5 years ice coverage has been less than in previous years. Since 2005, the salient has shown a slower migration rate than during the 1951 to 2005 period . If this reduction in rate is real and persists it may take several more years before it provides protection to the northwest runway end than if it continues at the faster rate. This uncertainty reinforces the recommendation to shift the runway alone its alignment to the south.

Continued observations are recommended because climate changes could alter the ice season such that the past beach processes are significantly modified. This might cause the runway to receive less protection from the salient and the northern portion would continue to be eroded.

If no additional northward migration of the salient occurs and no southward shifting of the runway is undertaken, the northern portion of the runway would eventually require additional protection. Our recommendation, without additional information, would then be to add a groin to the south of the north end of the runway and observe its behavior. If it begins to fill substantially on its north side, then it is intercepting southward-directed transport. It should be artificially filled on its north side to hasten its effect on providing protection for the northwest end of the runway. Its south side should be inspected for complimentary erosion, and if it is occurring then consideration should be given to adding additional groins. The groins' spacing and size would be evaluated from the behavior of the first groin, on the sediment size and on the inferred wave patterns.

The report has presented an equilibrium profile that has general applicability on the entire beach due to the uniform beach sand size. The original request was to provide a series of profiles for 25, 50, 75, and 100 years in the future. However, due to this uniformity of the profile, the series of profiles was replaced by the expected position of the future shorelines for the same intervals.

The beach erosion analysis has suggested that the salient would likely cause beach accretion in front of the airport for the next 25 years and during subsequent years the beach would experience varying levels of erosion.

The behavior of the salient's migration up the beach (north) for over 60 years is very significant. Its influence on the runway beaches seems to be increasing. The influence seems to be beneficial in that it is providing protection to part of the runway now and may expand the protection to the remaining part of the runway soon and suggests that reduction of the salient by "beach mining" could have a detrimental effect and should be strongly discouraged as removal would provide less sediment to protect the runway.

Hooper Bay Setting

The community and airport are located on the north side of Hooper Bay on the seaward margin of the Yukon/Kuskokwim Delta in western Alaska (Figure 1). Hooper Bay is the water body of approximately 35 square miles notched into the Bering Sea shoreline. Hooper Bay is also a community of nearly 1,200 residents situated on the northern shoreline of the bay. The airport is about a mile west of the community. It is about 4,000 feet long and topped with asphalt (Figure 2). It is roughly parallel to the shoreline but is angled slightly so that its southern end is about 1,000 feet from the beach and its northern end is directly on the beach.

Figure 1 Hooper Bay is located in southwest Alaska.

Both the community and airport are located on a peninsula that extends into the Bering Sea. Kokechik Bay is located north of the peninsula about 10 miles from the airport. The outer shoreline of this peninsula seems to have been strongly shaped by longshore sediment transport[2]. The northern shoreline is directed to about 3°T, while the southern shoreline (along the airport) is directed about 20° to the west at about 343°T. Over many years, it appears that net longshore transport direction has been to the north on the northern shoreline and to the south along the airport beach and the southern beach system. Transport along both beach systems have resulted in the extension of spits into their respective bays. There appears to be a relatively abrupt angle change where the two beaches merge at Dall Point.

[2] Longshore transport is the transport associated with breaking waves on the beach. The breaking waves set up a long shore current and lift the beach sediment into the water column which is then transported by the current.

Figure 2 Hooper Bay and features referenced herein.

Airport History

A good history of the runway, the erosional problems on its north end and the attempts to provide protection have been documented in an ADOT&PF Issue Paper entitled *Hooper Bay Airport Relocation*.[3] The runway was constructed in 1950 and the earliest aerial photography of the area is 1951 and neither the runway nor its access road to the village is shown. In the Issue Paper, the first mention of the runway was that prior to 1959 the runway was just a 50- by 1,600-foot gravel landing strip. According to the paper during that same year, the runway was increased to 100 by 4,000 feet without runway safety areas. In 1972 the access road was constructed and the runway was surfaced with asphalt.

In the same year, an attempt to curtail the erosion on its north end using 55-gallon drums was initiated. The erosion continued reducing the effective runway to 3,900 feet. The first attempt at serious erosion protection occurred in 1981 when ADOT&PF laid down 550 feet of concrete matting. This was followed up with a City of Hooper Bay project consisting of another 1,450 feet of concrete matting. This matting was extended an additional 400 feet further south in 1991 bringing the total length of matting to 2,400 feet.

[3] Gary Lincoln, Alaska Dept. of Transportation & Public Facilities, Aviation Design Section, November 2010

The erosion at the north end continued to be a problem. A 2011 field trip for this project (to be described next) confirmed that failed matting could be seen on the beach at the north end of the runway. In 1996, ADOT&PF installed 1,000 feet of sheet-pile wall on the northwest side and north end of the runway. This was meant as temporary protection from the erosion until the runway could be moved to a more inland location. Some of the failed concrete matting dislodged for the piling installation was placed at the toe of the pile as a scour blanket.

Storm surges typically inundate the access road on a frequent basis and following a severe storm in 2005 ADOT&PF increased the road elevation with an emergency repair done in 2006. The road was constructed of larger material than the beach sand and is annually resurfaced with sand. When the road is flooded, there is no access between the community and its airport.

The Issue Paper goes on to describe the community's need for a new, more reliable, runway and access road and since Hooper Bay is the largest community nearby, it is naturally situated to serve as a hub for several smaller communities in the area. To serve this role, it requires good and dependable airport access. This could require more extensive runway facilities that are always accessible.

Field Trip of June 29-30, 2011

A detailed accounting of this field trip will be appended (Appendix A) to this report. The following is a general description of pertinent facts gleaned from that trip. On June 29th we began a beach survey at the northern end of the runway. The runway makes a 10° angle with the beach dune line so while its northern end is directly on the dune line, its southern end is about 700 feet inland of that line. Since the beach widens to the south, the distance to the water line is much further than 700 feet.

The first thing that was noticeable was the failed concrete matting still covering portions of the beach at the runway's north end. The upper beach was located at a vertical distance of 10 feet below the top of the sheet-pile wall. The amount of exposure decreased southward as the runway moved further landward. At a distance of just less than 350 feet south of the sheet-wall corner, the top of the sheet wall became completely covered with as much as a foot of sand and vegetation. Moving on south it remained covered for just over 100 feet and then became exposed for the remainder of its length. This indicated that while the erosion was occurring on the north side, accretion had occurred just a few hundred feet south. The accretion is likely to be relatively permanent as the vegetation was able to become established. Further south, it probably appeared much like it did when installed as its condition appeared to be good.

Also immediately obvious was the small size of the beach sand. This is mainly responsible for creating mild beach slopes. The average slope for 8 beach profiles spaced 400 to 600 feet apart show an average slope of just over 1:100. The slope gets progressively milder to the south as the

beach width increases. Presumably the milder slope is related to its width and seems to be related to the fact that as the beach gets wider there is a higher portion of the beach below the highest location on the upper beach. This higher elevation is related to the last high (storm) water level. On the other hand, the milder portion is dependent on the day-to-day tidal variation. The beach appears to be getting wider as it approaches the salient further south.

As mentioned, the dune remnants become visible adjacent to the sheet piling within 340 feet south of the northwest corner. Here, the dune, the top of the sheet piling and the top of the runway are all at about the same elevation. This continues for about 1,000 feet along the beach. At this point (which is about the southern extent of the sheet piling near the runway), the dune elevation begins to rise above the runway elevation.

The runway is about 200 feet inland of the dune line at this point. This rise above the runway elevation continues and at a point just south of the south end of the runway, where a vehicle trail exists through the dunes, the dunes rise 30-40 feet above the runway and are much more extensive. While this height was estimated, it was much higher than a point further up the beach that was measured to be 18 feet above the secondary dune system. The beach dunes are about 700 feet from the runway at its south extent.

The concrete matting has been placed on the main dune for a distance of 2,400 feet south of the north end of the runway according to the Issue Paper. However, during this field trip, the end of the matting appeared to be over 2,700 feet from the end of the runway. It was likely placed on the seaward face of the main beach dune system. The vast majority of this matting has been subsequently covered with accreted material and much of that is vegetated. At only a few places along the dune system up to the apparent southern extent of the matting was it clearly visible. Where it was visible, it appeared to be in good condition.

Also proceeding south along the beach, there seemed to be a secondary dune system fronting the primary dune system much of it with ample vegetation. This began about 1,800 feet south of the northwest runway corner and continued for about 1,500 feet to the south. It ended in the vicinity of the trail through the dunes and then picked up again on the other side of the trail where the dunes were actually higher than on the north side of the trail. This secondary system appeared to have become established after the concrete matting was installed. This is seen in several photographs in the Appendix A.

Previous Beach Analysis

Very little scientific work has been done on the beaches at Hooper Bay that would add much to this airport erosion report. Researchers at Purdue University have expressed an interest in providing scientific data and analysis contingent on a grant that has been requested. As a

precursor to that work, they have assembled a small amount of data on both tidal elevations and on beach sediment size analyses.

According to their grant request, they indicate that the tidal range is just over 2 feet and that 50 percent of the beach sediments are less than 0.18 mm in diameter. They have also documented a 2005 storm that caused extensive flooding, particularly on the low-lying roads including the access road to the airport.

Present Analysis

This section presents the results of aerial photographic analyses, wind and wave studies, and a sediment transport analysis. These studies and analyses are integral to providing shoreline and bottom profile predictions for a portion of the beach that has or may have a direct effect on the runway stability.

Beach Salient

Readily apparent from examination of the aerial photography is the large salient[4] presently located on the shoreline south of the runway. The term salient does not imply any type of origin, but, unlike the majority of salients, it does not seem to be associated with an offshore feature that disrupts the incoming wave energy. The origin of the salient is unknown and can be only be left to speculation. Also it seems to be moving north at a rapid pace as will be discussed below. Additional information concerning its historic movement is presented in Appendix B. It has moved nearly two miles since its first observation in the earliest available photograph in 1951. At that time, it was located near the end of the spit extending into Hooper Bay.

The base of the salient from a 2007 photo appears on the order of 6,000 feet long and its cusp protrudes about 2,000 feet seaward. It probably contains over 1,000,000 to 2,000,000 yd^3 of sand. The tip of this salient was located about 2,000 feet south of the south end of the airport in the 2007 photo. There is some indication that the distance is just about half of that today.

Six aerial photographs were inspected to determine the migration characteristics of the salient in the shoreline adjacent to the Hooper Bay Runway. In addition, a GPS reading in October 2011 allowed determination of a recent position. Unfortunately, some of these photographs were of such low quality or did not include the main points of interest to allow meaningful information to be obtained. Table 1 summarizes the results of the analysis and Figure 3 is a plot of the five points from which data could be obtained. It is noted that the 2005 and 2007 points should be considered as essentially one point. The greater distance for the 2007 location compared to the

[4] A salient is a protrusion on a shoreline generally associated with an offshore feature that disrupts the incoming wave energy producing a region in its shadow zone where sediment for either direction is arrested. This causes a pileup of beach sediments in this region and thus a protrusion is formed.

2005 distance reported in Table 1 is considered a reflection of the difficulty in defining the point or cusp of the salient.

Table 1 Analysis of Hooper Bay Aerial Photography

Photography Date	Distance from Road Alignment to Salient (ft)	Comments
1951	10,200	Runway Not Constructed
1968	?	Salient Point Not Shown in Photograph
1975	?	Salient Point Not Shown in Photograph
1994	?	Salient Point Not Shown in Photograph
2005	1,550	Good Photograph
2007	1,632	Good Photograph
October 2011	1,300	Based on GPS Coordinates Taken on Site

It is seen that the salient has migrated to the north at an average rate of approximately 150 ft/yr. If this rate continues, the beach at the northern end of the runway will increase and the runway will not be threatened.

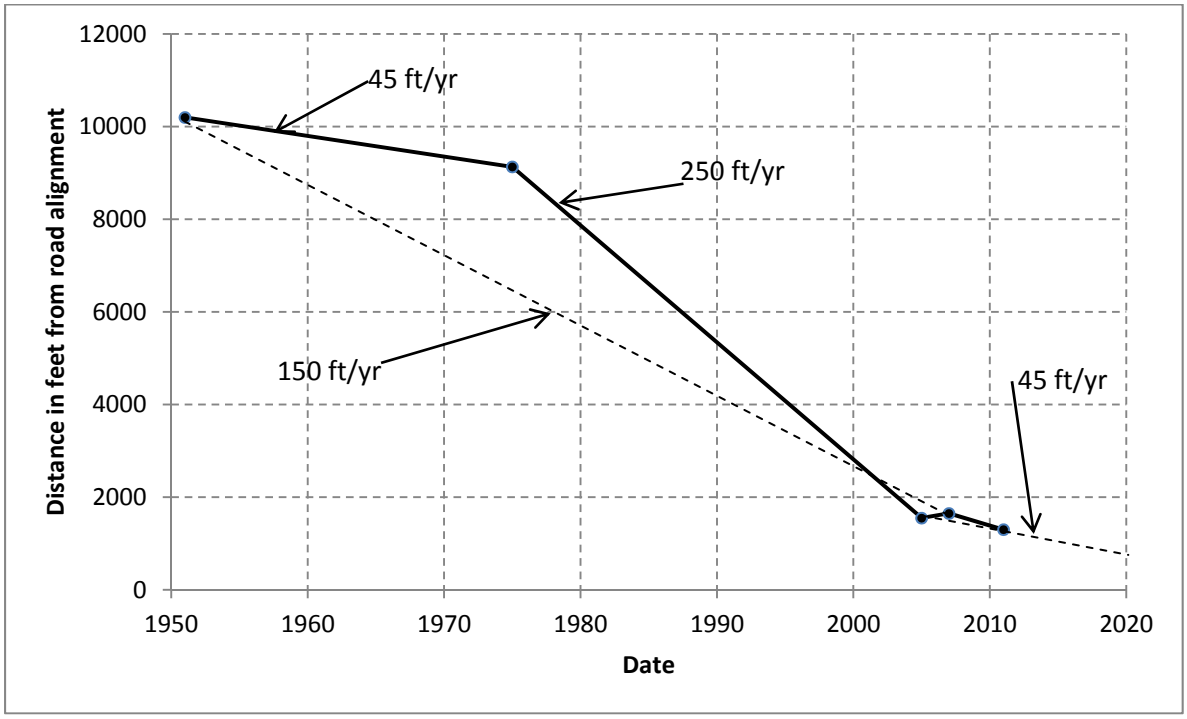

Figure 3 Locations of Hooper Bay salient relative to road alignment versus time.

However, it is likely that the wider beach will be somewhat temporary (on the order of one or two decades) and it may be preferable to address this problem now. The following section provides an interpretation of the origin and migration of the salient.

Interpretation of Salient

The salient is believed to have originated as an ebb tidal shoal at the north end of the Hooper Bay entrance. As the shoal volume grew, the waves drove the shoal ashore forming the feature of interest. The explanation of the cause of the northward migration of the feature is not apparent but may be related to tidal currents and/or waves. Figure 4 shows the feature in proximity to the entrance of Hooper Bay in 1951. Also apparent in this photograph is that the south end of this peninsula has accreted as evidenced by the growth lines. This growth is perhaps a result of the relative sea level fall in the area resulting in an excess of sand in the profile of the system. Figures 5 and 6 present aerial photographs in 2005 and 2007.

If this interpretation is correct, it is likely that the salient appearance and migration is part of a long-term cyclic phenomenon.

Once the salient has formed, it widens the immediately adjacent shorelines and "draws" sand from those shorelines located farther away. As the salient approaches the north end of the runway, this area will benefit more and more by the proximity of the salient. It is possible that this is already occurring as the Issue Paper already mentioned states "*Beaches are dynamic with periods of erosion and accretion; recent images appear to show some accretion, but this gain could be lost in a single large storm.*"[5]

[5] Gary Lincoln, op. cit.

Figure 4 Aerial photograph of 1951 showing salient located at north end of entrance to Hooper Bay. Note "growth lines".

Figure 5 Aerial photograph of 2005 showing salient located about 1,500 feet south of road alignment.

It is likely that the northwest corner of the airport which is presently experiencing the worst erosion will soon begin to experience the beneficial effects of the northward migrating salient. If the salient continues on its present rate of migration, the cusp of the salient will be just offshore of this area in about 25 years. This is especially so if that value is near the historical value of 150 feet per year. If it subsequently continues on north, it would experience benefits for probably another 25 years as the tail of the salient continues north.

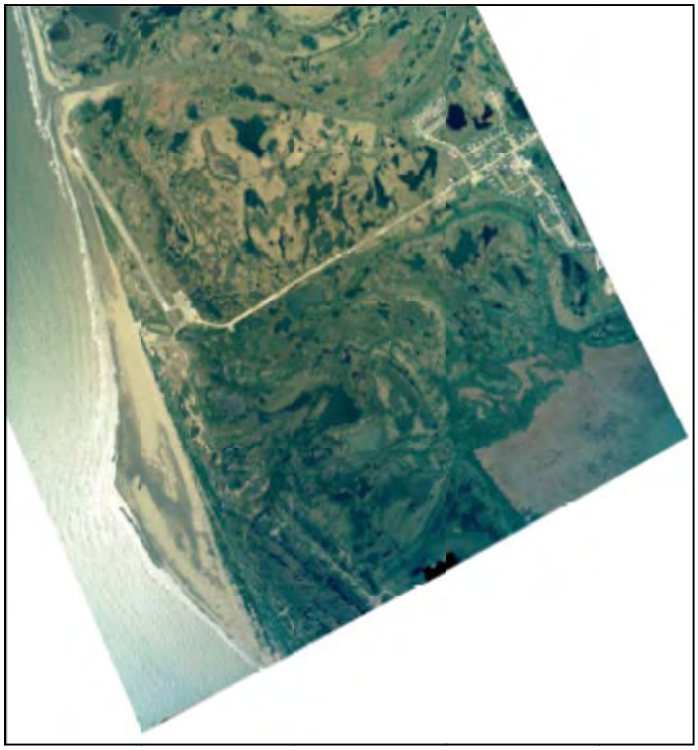

Figure 6 Aerial photograph of 2007 showing salient located about 1,600 feet south of road alignment.

Sediment Budget

A complete sediment budget would include all the sources and sinks for beach sediments as well as the pathways for gaining or losing sediments. Sources could include sediments entering the beach system from rivers, offshore sources, or erosion of the beach berms or dunes. Sinks could include offshore bars, sediment trapped by natural or manmade barriers, material that is transported offshore via canyons, accretion on a beach, or material forming flood tide or ebb tide shoals associated with rivers or inlets. Often to get a complete budget would require a lengthy and comprehensive measurement program and analysis. For example, to get a reasonable estimate of longshore transport rates may require many years of wind and/or wave data, offshore bathymetry and sediment analyses. Given these caveats, a general sediment budget for the Hooper Bay area was attempted. It consists of determining the background erosion rate, determining the likely sediment sources and sinks, and analyzing the sediment transport. Each will be described below.

Background Erosion Rate:

Erosion rates determined by comparing vegetation lines between the 1951 and 2005 photos are difficult due to the influence of the migrating salient which tends to mask changes. The changes are masked because any place reasonably close to the airport is strongly impacted by the salient's 2005 position. For example, an examination of a point about midway along the runway shows

that the vegetation line actually accreted seaward over the period between 1951 and 2005 at a rate of 0.75 feet per year.

It seems that the only place where an unbiased estimate of the erosion rate is possible is just north of the river located near the north end of the runway. Comparing the vegetation line there with a small pond feature further shoreward between 1951 and 2005 photos gives a background erosion rate (or, equivalently, recession rate) of 2 feet per year. Using this rate along the runway and assuming the dunes along this portion of the beach average 12 feet high, the annual per foot contribution is thought to be less than a cubic yard per foot (2ft * 12ft / 27ft^3/yd^3). Unfortunately, this is based on a single point and additional points would be needed to increase confidence in this estimate.

River Source and Sink:

Assuming that the net drift is from north to south (this will be described below), then any portion of that material that is moved offshore by the river and deposited in "ebb-tide" shoals is not available to maintain neutral equilibrium along the airport beach. These shoals represent a sediment sink. A separate discussion of these shoals is presented as Appendix D which suggests that the shoals play a minor role in the coastal processes.

Similarly, some additional material brought to the beach from land erosion via the river should be a source for the "down-drift" beaches. Neither of these two contributions (one negative and the other positive) is believed to be significant to the overall sediment budget and would require more surveying and sampling to determine their true contribution.

Beach Salient:

A large amount of beach material can become incorporated in a feature such as the beach salient. Once it is in equilibrium, the overall effect on the beach may be relatively small because as an amount of material is incorporated on its upstream side, an equal amount is eroded off its downstream side. It is possible that this mechanism is responsible for its movement up the beach. A stationary salient arising from an offshore disturbance may behave quite differently, but even it, at some point, will reach equilibrium.

However, locally it can have a major impact. If the salient was not present, some of the material that was transported down the beach would be compensated for by sediment being transported in the other direction when winds dictate. On Alaskan beaches, this compensation does not always occur as the beach and nearshore areas are often frozen for half of the year when the major part of the reverse transport would occur. Consequently, the flow in one direction is often nearly equal to the net transport. The length of the salient is about 6,000 feet and its cusp is located about 1,500 feet seaward of the natural beach line. Assuming that the average height is 4.5 feet,

the total volume is about 1,500,000 yd^3 or about 250 yd^3/ft of beach. This represents a huge beach nourishment amount.

Sediment Transport[6]:

The transportation of sediments is typically estimated using long-term wind records. These winds are used to develop a similarly long-term wave record. As the waves approach shore and eventually break, they release energy that generates a longshore current. This current then moves the sediments along the beach primarily as they are raised off the bottom by the breaking waves. Under certain wave conditions, the sediments can be simultaneously transported on- or off-shore.

The wind record in this case consists of winds collected at the airport for the last 19 years. They have been conditioned to represent a single value for each hour of the record. Typically the winds offshore where waves are generated are greater than those collected at a land site (even one close to the waterline). The winds can be modified to reflect this difference. Only the time period between May 15 through November 15 is assumed to account for the winter conditions at Hooper Bay. The direction of the transport up or down the beach is relative to the wave direction relative to the azimuth of the outward beach normal; in our case, the outward normal has an azimuth of 252°.

Table 2 Analysis of Sediment Transport

Year Range	Transport in yd^3/yr		
	Toward North	**Toward South**	**Net**
1992-2001	285,840	-248,890	36,950
2001-2010	223,690	-296,700	-73,010
1992-2010	255,230	-273,820	-18,590

These values are not conclusive. The average net transport for the entire time period is nearly 18,590 yd^3/yr to the south, but the two 10-year periods (including 1 overlapping year) are quite different. The first (1992-2001) suggests that the annual net transport is significantly to the south, while the second period (2001-2010) is to the north at about half the transport for the first portion. The net transport is to the south. This suggests that short records can have significant errors which should decrease as the record length increases. Inspection of aerial photographs of the deflection of the river mouth supports the direction of this net longshore sediment transport.

Profiles for the Next 100 Years

As part of the deliverables, it was agreed to provide profiles for the next 25, 50, 75, and 100 years corresponding to each 500 feet along the runway alignment. The purpose of this is to determine how quickly the dune system separating the runway from the beach will erode.

[6] Sediment transport equations will be included in Appendix C.

Normally this would be accomplished by collecting vertical elevations at each of these locations along each 500-foot spaced line to serve as a baseline and then project this line into the future based on the assumed rate of lateral erosion and on the beach and nearshore profile predicted from equilibrium beach profile concepts.

Determining overall erosion for the present case is both easier and harder to accomplish than the normal approach. It is easier because the uniformity of the beach sediment sizes makes for a relatively simple beach profile; but it is harder because the salient is likely to completely mask the effects of the background erosion rate for many years in front of the airport. While it is likely to continue traveling north at its calculated rate of about 150 feet per year, it is certainly possible that recent weather changes could slow the rate of travel, speed it up or even make it move back south. For the purposes of this analysis, the average northward migration rate has been assumed.

During this field program, beach profiles were acquired at roughly 500-foot spacing; however, these could not be extended out into the nearshore region due to inclement weather. Observations of breaking wave conditions indicated that the lower nearshore profiles were likely to continue on at about the same or less slope as found on the lower beach. These profiles are determined and maintained by the beach grain size. Normally beaches are composed of a broad size range with the larger material found on the higher portions of the beach and the finer near the waterline. The beaches at Hooper Bay are composed of fine material of nearly uniform size. Previous studies have indicated that 50 percent of the beach material has a diameter less than 0.18 mm.

Since only the average grain size was used to create the equilibrium profile, all of the profiles would have the same theoretical shape. However, even with nearly uniform beach material, there is no likelihood any two profiles will be the same. This is true in both time and space; slight variations in grain size can result in minor differences in the profile and so can natural randomness. Given the uniformity of the grain size on this beach, the most logical way to depict the profile is to use an average. This equilibrium profile is shown along with the average measured profile shown in Figure 8.

Therefore the more important variable is likely the starting point of these profiles and that would be determined by how much erosion or accretion has or will occur on the shoreline. The starting point should be represented by the shoreline. The goal here is to present a credible approach to determining this shoreline position. The shoreline will be assumed to be a line close to the common elevation along the beach which represents some high water line. This is where we began the profiles during the short field trip. The elevations were not surveyed and so were

during

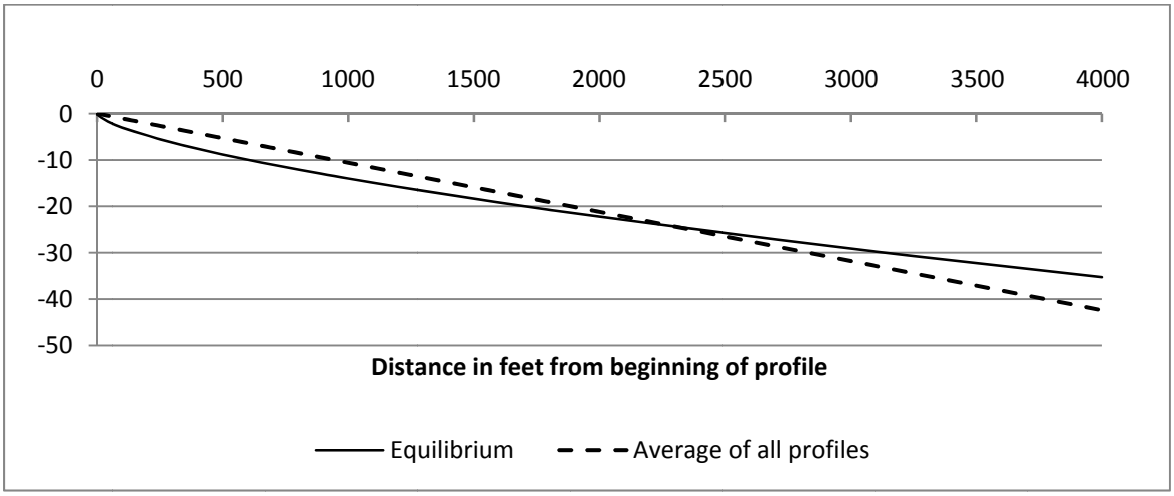

Figure 8 Equilibrium profile compared to profile derived from the average beach profile slope.

not exactly the same from point to point, but it was felt that they were close to the same elevation. This is used as the assumed baseline for the present condition.

Once this baseline is established, the rate of beach erosion (or accretion) is determined and then a new starting point is established for subsequent profiles. This is done for each 25-year interval. In the present case, the uniformity of the beach sand makes determining the profile slope rather

easy as stated above. Normally, that would be expected to be more or equally as difficult as establishing the shoreline.

In the present case, the migration salient complicates the effort. Since the exact cause of this feature or its mode of motion is unknown, it is not certain whether it will continue to migrate northward and, if so, whether its rate will be the same as it has been in the past. Given the scarcity of good photography, it is unknown how steady the migration rate has been.

Another unknown is what will happen when the salient encounters the river just north of the runway. This is a relatively small stream, but the salient is not particularly fast moving so it may have time to move relatively large quantities of the salient's material offshore particularly during stream flooding periods. The sediment transport analysis suggests that the long-term transport direction is to the south. The salient's travel direction is in the opposite direction. If both are true, then it is behaving as do some ripples on the bottom of a stream under critical flow conditions or as some sand dunes that travel upwind.

For the purpose of this report, it will be assumed that the future migration rate will be the same as the long-term rate (from 1951) which is about 150 feet per year. It will further be assumed that the background beach erosion rate is two feet per year as stated above. Since 2004 there is some indication that the salient's migration rate may have slowed. That condition will not be considered in this analysis as it would require more observation (over several years) to determine with confidence and it would produce a better situation with regard to erosion along the runway beaches as it would ensure that the salient remained immediately seaward of the runway for a longer time span.

Figure 9 presents the assumed shoreline positions for the present case and for 50-, 75-, and 100-years in the future from the seaward edge of the runway (shown as the black line at the top of the drawing). This figure is to provide general lengths only and is not intended to be a scaled design-quality drawing. The shaded area above the shorelines in the figure, and east of the shoreline in reality, depicts the sand-dune system that exists between the beach and the runway. The more lightly shaded area below that represents the beach. These shoreline positions are based on the assumed position of the salient combined with an assumed erosion rate of 2 ft/yr. The shoreline for 25-year period has not been presented as it is during this period when the salient moves completely in front of the runway beaches and all of that shoreline will be significantly displaced seaward. In other words, the shoreline there will be substantially accreted.

For the next 25 years (50-year shoreline), only the south half (actually a bit less than half) will no longer be impacted by the presence of the salient and will begin to experience erosion at the background rate. The southern-most runway section will experience about 10 years of

background erosion for a total of 20 feet of erosion. It becomes progressively less to the north until there is no erosion for just more than half of the northern part of the runway.

The 75-year shoreline shows that for the portion that became exposed during the previous 25-year period will experience the full 25 years of erosion (or 50 feet) during this period. In addition, the salient should have completely moved on north of the north end of the runway.

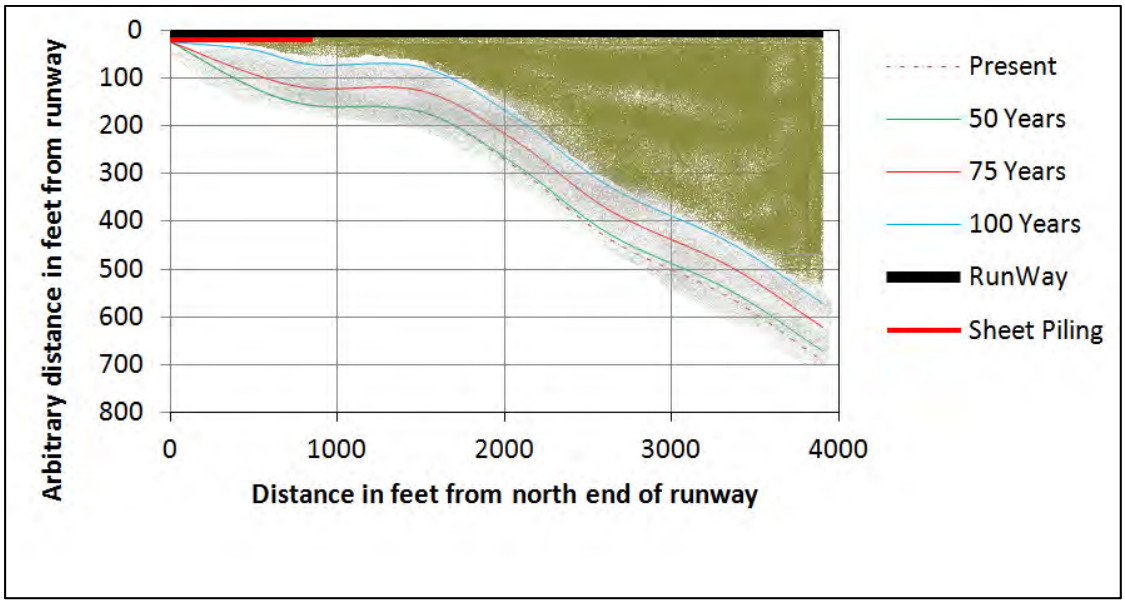

Figure 9 Likely future shoreline positions along the runway beach. The edge of the runway is the thicker black line at the top of the figure.

There will be a recession of all portions of the northern part of the runway except where the shoreline is established by the sheet-pile wall. This case only applies to a short portion on the north end of the runway.

For the next 25 years (100-year shoreline), the entire part of the runway will recede at the background rate except for those portions protected by the sheet-pile. These are all shown in Figure 9.

If the salient does not continue to move further north or if it should begin to move south, then as a rough approximation one could assume a 200 foot recession of the shoreline wherever the seawall is not present. It is clear to see that this would erode into much of the existing runway even assuming that the existing sheet piling wall was able to resist erosion along its face. The runway well south of the end of the wall would be eroded if no additional shore protection was provided.

Sea Level Change in Vicinity of Hooper Bay

Tide Gage Records in Proximity to Hooper Bay:

This section examines the available data relative to sea level change in the vicinity of Hooper Bay. The three nearest tide gages are at Nome, AK located approximately 204 miles north of Hooper Bay, Ratmanova, Russia located 380 miles north-northwest of Hooper Bay and Womens Bay, on Kodiak Island located 540 miles southeast of Hooper Bay. The available average monthly records for these three gages are presented in Figures 10, 11 and 12.

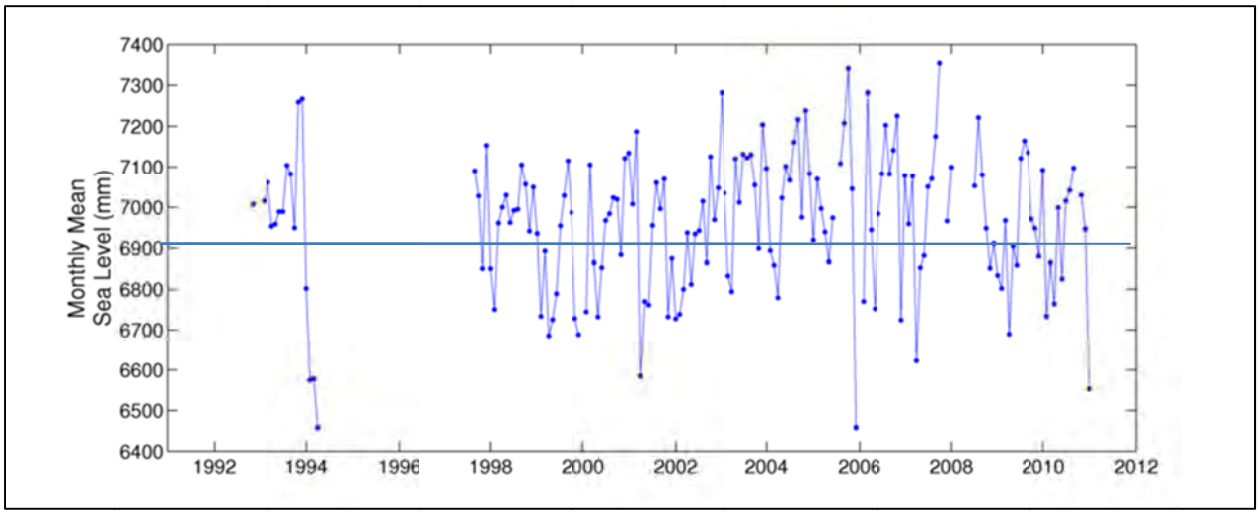

Figure 10 Available monthly average tide gage record for Nome located 205 miles north of Hooper Bay.

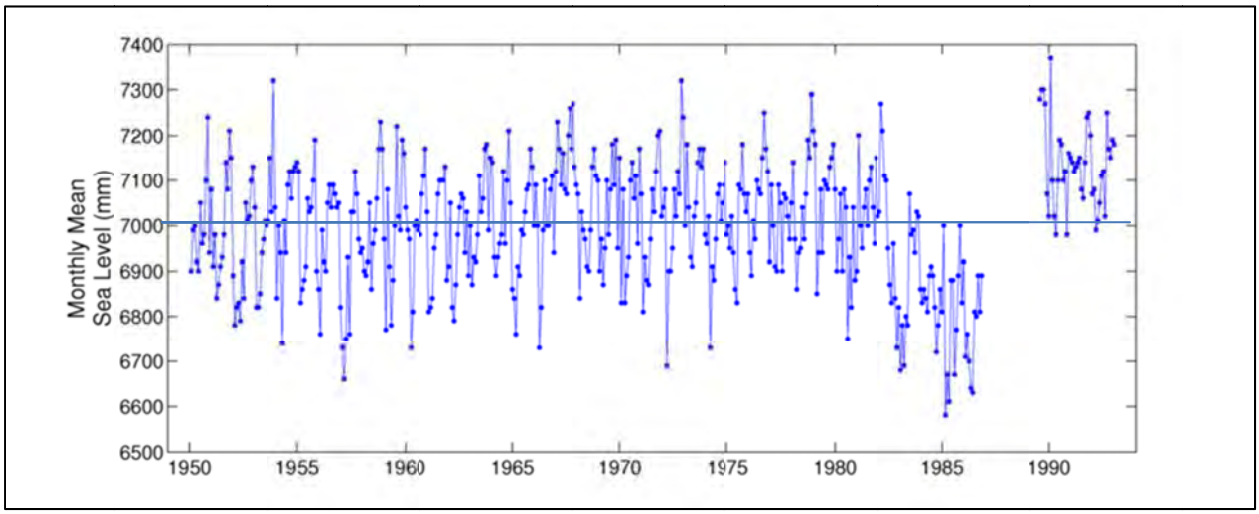

Figure 11 Available monthly average tide gage record for Ratmanova, Russia located 380 miles north-northwest of Hooper Bay.

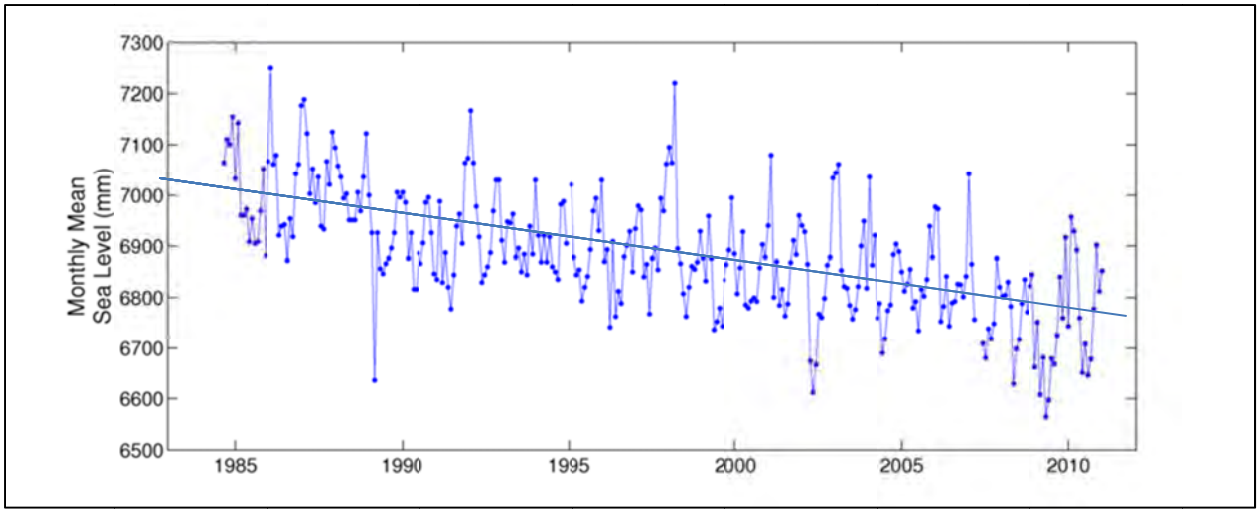

Figure 12 Available monthly average tide gage record for for Womens Bay on Kodiak Island located 540 miles southeast of Hooper Bay.

Interpretation of Tide Gage Records:

Nome, AK (Figure 10)

This is the closest tide gage to Hooper Bay and provides a nearly continuous record from 1998 to 2011, but is a fairly short record for determining reliable trends. Although some oscillations are evident, it is not possible to discern a reliable trend.

Ratmanova, Russia (Figure 11)

This tide gage provides a nearly continuous record from 1950 to 1986. Although there are indications of longer term oscillations and a downward trend near the end of the continuous record, these features do not inspire confidence in identifying a reliable trend. The shift in the tide data from 1986 to 1990 is suspect suggesting the tide gage may have been disturbed.

Womens Bay on Kodiak Island, AK (Figure 12)

This provides a nearly continuous record from 1984 to 2011. This record is characterized by a definite downward trend of approximately 8.6 mm/yr which is very likely due to post-glacial rebound. However, due to the long distance of this gage from Hooper Bay, it is not appropriate to consider these results to apply at Hooper Bay.

Glacial Isostatic Adjustment:

Peltier[7] has published calculation results of Glacial Isostatic Adjustment (GIA) based on earth models representing the slow response of the earth surface due to the unloading from melting of the ice sheets that formed during the last ice age. Examination of these results indicates that the

[7] Peltier, W.R., *Global glacial isostatic adjustment and modern instrumental records of relative sea level history*, Chapter 4, International Geophysics, v 75, 2001, pp.65-95

GIA values are fairly small ranging from -0.12 mm/yr to + 0.13 mm/yr for the three gages examined here. The "+" signs in these values indicate a lowering of the earth's surface. Thus, these GIA results do not indicate significant contributions from vertical land motion.

Summary of Sea Level Change:

Based on the information reviewed above, it appears that the relative sea level in the vicinity of Hooper Bay is reasonably stable, say within ± 2 mm/yr. This is equivalent to an increase in sea level of about two-thirds of a foot per century.

Discussion

This objective of this study was to predict the amount of erosion that is likely to occur on the shoreline along the runway at Hooper Bay. Erosion has been a problem on the north end of the runway for several years and attempts to mitigate the erosion have dated back to the early 1990s at least. The most successful of these is a sheet-pile wall installed by ADOT&PF. Because the community of Hooper Bay has plans of becoming a commercial hub in the area, a reliable airport is of great importance. If the main airport remains in place, erosion may continue to be a problem once the protective effects of the salient have ceased.

It appears that the present runway is not in imminent danger of being put out of service by erosion concerns at the runway itself. The sheet piling appears to be in good condition and further exposure, unless it is sufficient to cause failing, will not cause increased overtopping. There is even good evidence to suggest erosion may not be a concern for many years due to events that seem to be occurring on the beach.

The investigation has noted that a large sand wave in the form of a migrating salient is moving northward along the beach. Its present position seems to be having accretive effects on at least the southern half of the runway today and probably substantially more than that. Evidence that supports this is primarily from the aerial photography. This is further supported by the probability that the beach in front of the seawall has not seemed to have been lowered much, if at all, in elevation since a previous field investigation by ADOT&PF in 2004. This latter observation has not been proven as the vertical distance between the top of the sheet piling and the beach was not documented in 2004. However, photographs taken at this earlier time show no discernable changes at the northern end of the runway when compared to the ones taken in 2011. A third piece of evidence is that in the 1990s a total of about 2,700 feet of concrete matting was placed on the seaward face of the beach dunes starting near the northern end and going south. The matting at the northern end failed, but the majority of the matting is still intact and for the most part is buried below accreted sands and is not even visible. It outcrops only at a few locations today.

The obvious reason for this improved beach condition is that the salient is continuing to move north. Its lateral extent along the beach is greater than the length of the runway; it is nearly 6,000 feet long. It presently contains one to two million cubic yards of sand which represents an extremely large beach nourishment.

This study has demonstrated that the beach material is both fine and uniform. Being fine, it produces a mild beach and nearshore profile slope; being uniform the profile from one location on the beach is similar to adjacent ones. The mildness of the profile was noted on the beach face through a series of profiles during this project's supporting field trip. Also it was noted that this mild slope was carried offshore by the fact that waves were breaking well offshore at all locations along the beach including seaward of the salient. A local helper from the community during the field trip indicated that fishing skiffs and dories had to traverse this area far offshore.

The sediment sources and sinks in the area are few. Beach erosion is likely the major source of beach material while the river contribution is probably only a minor source. Also the shoals off the river are small and probably represent only a minor sink. A more noticeable sink occurs on the spit system that develops at the mouth of Hooper Bay. It appears that the area continues to grow and draw sediment away from the beach. The salient represents both a temporary sink and a temporary source of beach sediment. Sediment moving down the beach as littoral or longshore transport is stopped on reaching the salient. It probably is not available to help maintain the beach equilibrium as the wind direction changes as it becomes locked into the salient. In this mode it acts as a sink. As this feature continues to move north, however, it acts as a source to the beaches it encroaches upon.

The large size of the salient combined with its rate of travel (considered to be 150 feet per year) means that it can affect a wide area of the beach for many years. Assuming that it is now affecting more than half the runway, over the next 25 years it will affect the entire runway. The entire beach along the runway should show accretion from its present position at the end of that 25-year span. During the following 25 years all but the southern half of the runway will continue to show accretion over their present positions.

For the subsequent 50 years, various degrees of erosion will be experienced along the runway beaches. Assuming that the sheet-pile did not corrode, only the area protected by this wall would not experience erosion. However, given that most of the runway has several hundred feet of dunes to buffer it from the beach, no noticeable erosion problems should exist on the runway from at least 1,000 feet from its northern up to its southern end. These assumed shoreline positions are shown in Figure 9.

Even assuming that the north end of the runway may soon be somewhat safer due to the encroachment of the salient, in the short term (and perhaps longer should the northward migrate

rate slow down) that area will be susceptible to overtopping and may continue to be a maintenance problem.

The key assumptions in this analysis is that the background erosion rate, as determined from a single point on the aerial photographs, of 2 ft/yr is correct and does not change, and that the northward migration rate of the salient continues at 150 ft/yr. There is some indication that this rate is slowing and that should represent a net positive for the runway as it would extend the time before erosion began again on the runway beaches due to the passing of the salient. On the other hand, if the direction of the salient changed and it was redirected to the south, it would have a detrimental effect on the runway beaches. Because of the uncertainty of the salient's formation and mode of movement, a definitive statement of the validity of these assumptions is not possible.

Future sea-level increases could also have an effect on the beach and might tend to increase the rate of erosion. However, there does not seem to be a marked increase in the expected rate of sea level rise as it seems to continue to rise at the near historical rate of about 8 inches per century. There have been numerous claims that the current global warming would necessitate the increased rate of sea-level rise, but that is simply not borne out by the global tide evidence.

Appendix A-Trip Report to Hooper Bay

On June 29-30 a field trip was conducted in Hooper Bay to assess the erosion there putting special emphasis on signs of erosion or accretion on the beach directly in front of the Hooper Bay airport.

June 29th, 2011 Hooper Bay

On the first day, I had hired a local, Harvey Hill, to transport me and my equipment to the beach with the intent of making a brief overview of the beach and then later in the day to use Harvey's boat to collect nearshore bathymetry. The wind was making the nearshore waters very choppy. Because of the mildness of the nearshore bottom, the waves appeared to be in a continuous breaking state for several hundred feet as they came ashore. Harvey was clearly reluctant to use his boat with the waves breaking over such a broad region. It was finally decided for personal safety and for the safety of his boat and motor to delay collecting bathymetry and to instead collect beach profiles. A total of eight were collected along the runway beach (roughly every 500 feet).

This first set of photographs was taken as we moved southward from the north end of the runway. The WP prefix represents a waypoint and the PH represents a photograph.

PH115 was Harvey standing on remnants of concrete matting previously placed to curb erosion at the end of the runway. This was a few feet north and down slope from the northwest corner of sheet piling. The river mouth was visible a few hundred feet north of and behind Harvey.

Figure 1 Photograph 115 showing remnants of failed concrete matting.

WP256—1st Profile PH117-118 continued to pan clockwise to dune on north end of runway. The corner of sheet piling was visible in PH118. The top of the corner was 10 feet vertically above the beach.

Figure 2 Photographs panning clockwise from beginning of first profile to northwest corner of sheet piling.

To develop the profiles, we used a hand level to measure elevations every 25 feet perpendicular to the beach face. The most recent debris line was used as a reference for the starting point of the shoreward end on the first two profiles. On subsequent profiles, as the beach became wider and, where there were two distinct sets of dunes, a point closer to the first level (referred to as the secondary dunes) were used as the starting points. The horizontal distance between this point and either the toe of the sheet piling or the toe of the dunes increased significantly from about 50 feet at the north end to two to three hundred feet on the beach on the south end of the runway.

WP257—2nd Profile PH119 was looking up at the dunes. The dune was about 8 feet high.

Figure 3 The beginning of the second profile. The distance to base of dune has increased significantly.

WP258—3rd Profile PH120-PH121

Figure 4 This was the third profile. First picture was looking up at dune and second was look down the profile.

The beach has widened substantially at this point. This profile began higher on the beach than the last debris line which can be seen just beyond the rod man, Harvey. Harvey was standing 100 feet seaward from the beginning of the profile. The vertical distance from the toe of the dune to its crest was about 6.2 feet. However, its toe was at a higher elevation that the previous profile. This trend for the dune's toe to be at a higher elevation at one profile than it was at the previous profile continues southward along the beach. The beach dune was slightly greater than 100 feet from the runway at this location.

WP261—4th Profile PH122 The vertical distance from dune toe to crest was about 6.9 feet.

Figure 5 This was looking toward the dunes.

WP262—5th Profile

Figure 6 First figure was looking up at dune and second was toward north from the crest of the dune.

The first photograph (PH123) shows that a secondary dune system was beginning to form seaward of the primary system. The second photograph in this figure (PH124) shows the back side of the dune drops off into a swale landward of the crest. The vertical distance from crest to trough was about 4 feet. From the trough the system rises again before reaching the runway about 400 more feet. On the seaward side of the dune the vertical distance from its toe to its crest was about 6 feet.

WP263–No Profile End of concrete matting.

Figure 7 This outcropping of the concrete matting (shaded on dune) was about 75-100 feet long.

This represented the southern-most location of the concrete matting. It appears in good shape.

WP264—Close to 6th Profile The secondary dune system was well established here. Secondary (lower) dune system was about 3 vertical feet from toe to crest; there was a slight trough between primary and secondary dunes. The vertical distance from toe to crest on the primary dunes between 12-15 feet.

Figure 8 Standing of crest of secondary dunes looking north.

WP265—6th Profile Profile began at toe of lower dune.

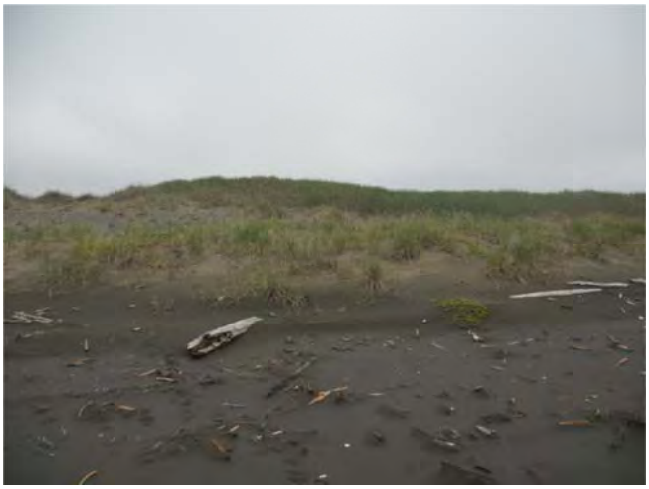

Figure 9 This was looking from the beach across secondary dunes to primary dunes.

WP268—7th Profile This was about 75 feet from the toe of the dunes.

Figure 10 The secondary dunes have disappeared.

WP269—8th Profile This was the final profile. The vertical distance from the toe to crest of the dunes here was about 22 feet.

Figure 11 This was looking up at the dunes.

This profile was 650 feet long. The initial profile, on the north end of runway, was less than 100 feet long. Beyond the waterline there was a secondary bar.

June 30th

On the second day I returned to the beach alone to collect more photographs and make additional beach observations. It was clear that, like the previous day, there would be no offshore bathymetric work due to the wave conditions.

WP273 On southeast corner of runway.

Figure 12 This was looking toward north end of runway.

Beach dunes are visible on the left side of photograph.

WP274 On gravel section about 10 feet north of pavement. The gravel section was 3,275 long.

Figure 13 This was looking south from the point on the runway where the gravel section begins.

This was about where the dunes become nearly level with the runway and remain so all the way to the northern end of the runway. The dunes south of this point were higher that the runway.

WP276 Standing on top to sheet piling at its southern end.

Figure 14 This was looking south along the runway (PH149) and slightly toward the beach (PH150).

The beach dunes were about equal to the runway elevation here. Second photograph was looking toward the seaward end of the salient, although it is not clearly visible due to its low elevation and distance from this location.

Figure 15 this was from the southern end of sheet piling looking north.

Several pictures taken from here (picture #146-picture #152). The beach dunes were about 160 feet west of the runway at this point. The drift wood can be seen starting to stack up against the sheet piling about 150-200 feet to the north.

WP277 PH153 was standing on top of sheet piling at the point where the dunes disappear. For about the previous 100-foot section to the south, the sheet piling was buried under up to several inches of sand and vegetation.

Figure 16 The dune ends from here to the corner of the sheet piling about 335 feet to the north.

WP278 This was the physical end of the runway safety area. The fill extends a few hundred feet to the north end of the sheet piling.

Figure 17 The end of the runway was 275 feet to the north.

WP279 This was the northwest corner of the sheet piling.

Figure 18 Standing near the northwest corner of the sheet piling.

The beach from the toe of the sheet piling out to between 75 and 100 feet does not appear to be wetted under normal tides. The top of the sheet piling was vertically separated from the beach face by 10 feet at the corner where it was the most exposed.

WP281 This photograph was looking up at the dune/sheet piling located at WP277. This was the point where the dunes first appear and continue to widen as one travels to the north end of the runway. This point appeared to be exactly as it did in a 2004 photograph. Two major surge events have occurred since that time (2005 and 2008).

Figure 19 Dunes begin from this point and increased to the south. Concrete matting remnants were visible.

WP282 Additional failed concrete matting strewn on the beach.

Figure 20 This point was 430 south of the NW corner of sheet piling (SPC).

WP283 and WP284

Figure 21 Photograph on left and right were 535 and 645 feet from the SPC, respectively.

WP285 and WP286

Figure 22 Photograph on left and right were 785 and 910 feet from the SPC, respectively. Concrete matting seen in left photo.

WP287 and WP288

Figure 23 Photograph on left and right were 1,015 and 1,115 feet from the SPC, respectively.

Dune heights vary between 4 and 6 feet high.

WP289 and WP290

Figure 24 Photograph on left and right were 1,230 and 1,355 feet from the SPC, respectively.

Dunes beginning to get somewhat higher in right photograph.

WP293 and WP 294 Secondary dune system was beginning to form.

Figure 25 Photograph on left and right were 1,735 and 1,895 feet from the SPC, respectively.

WP295 and WP296 Secondary dunes were increasing.

Figure 26 Photograph on left and right were 2,005 and 2,145 feet from the SPC, respectively.

WP297 and WP298

Figure 27 Photograph on left and right were 2,310 and 2,455 feet from the SPC, respectively.

WP299 and WP300

Figure 28 Photograph on left and right were 2,590 and 2,730 feet from the SPC, respectively.

Concrete matting remains visible in both photographs Dunes on right hand photograph were over 20 high; it also has the southern-most outcropping of the concrete matting.

WP301 and WP302

Figure 29 Photograph on left and right were 2,965 and 3,050 feet from the SPC, respectively.

WP303 and WP304

Figure 30 Photograph on left and right were 3,200 and 3,435 feet from the SPC, respectively.

In the right hand photograph the secondary dunes were about gone. Maybe their loss was related to the cut through the dunes for beach traffic which was just a little further ahead.

WP305

Figure 31 Photograph on left was looking straight into the cut that serves as the beach access road.

The dunes north of the cut were about 30 feet high and appear to be 40 feet or more high on the south (right hand photograph) side of the cut. The north side of the salient was well formed here. I did not get the picture of the dunes on the north side of the cut. The distance from the SPC was 3,655 feet.

Appendix B-The Role of the Salient in Stabilizing Hooper Bay Beach

Some uncertainty exists regarding future behavior of the salient. While it has been established that the salient originated near the north end of the entrance to Hooper Bay and has migrated northward, available information for quantifying the motional characteristics is not adequate to quantify the migration speed with confidence as shown in Figure B-1 where it appears that there may have been three migration rates over different periods as summarized in Table B-1. The migration rates shown in Figure B-1 range from 45 ft/year to 250 ft/year, more than a factor of 5 although the average speed over the 60 year period is approximately 150 ft/year.

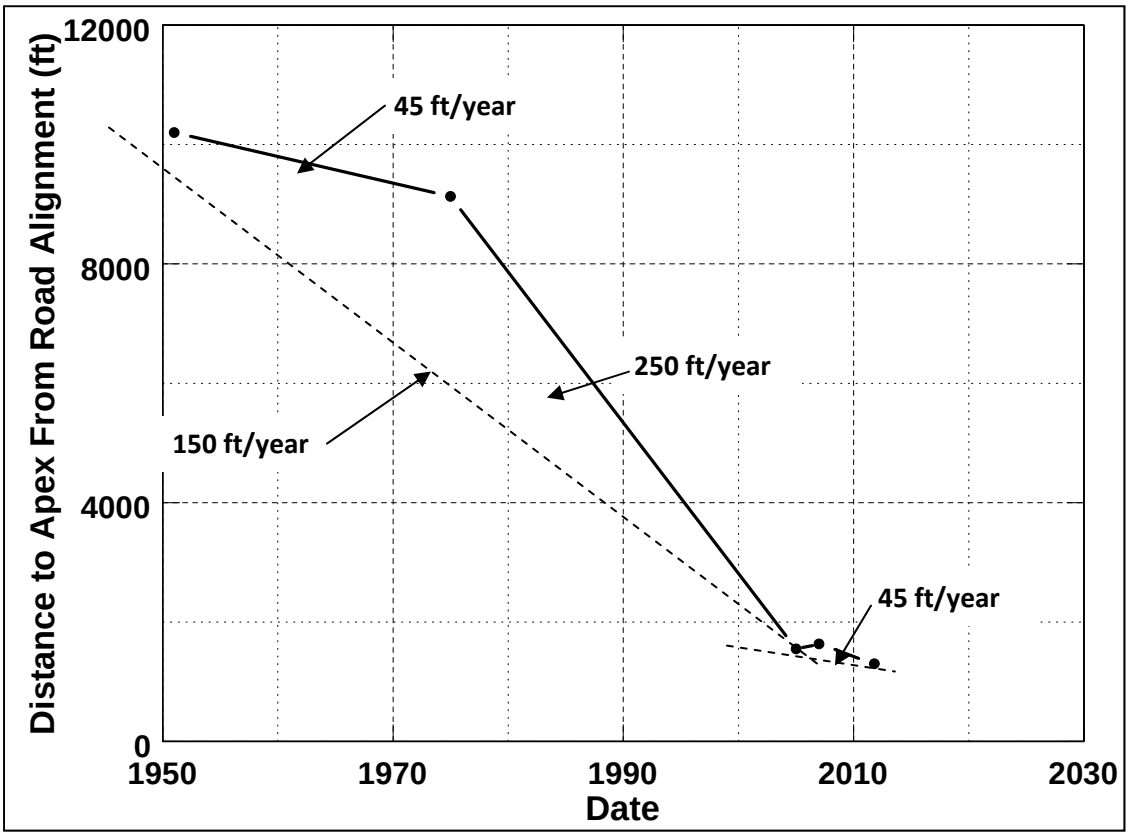

Figure B-1. Locations of Hooper Bay salient relative to road alignment versus time.

Table B-1 Salient Migration Rate (ft/year)

Photography Date	Migration Rate (ft/year)
1951- 1975	45
1975 - 2005	250
2005 - 2011	45
2007	1,632

The future salient migration characteristics are relevant to identification of a best course of action in protecting the north end of the runway because the salient position affects the shoreline characteristics in the vicinity of the runway. Figure B-2 shows various scenarios with the salient translated northward without change of form by distances of 1,000 and 2,000 ft. The small river to the north of the runway is expected to be displaced northward, then to return to its present location as the salient migrates farther northward.

Figure B-2 indicates that as the salient continues to migrate northward, the beaches in the vicinity of the north end of the runway will become substantially wider. In fact, this effect may have commenced as indicated by the comment in the 2010 Issue Paper on "Hooper Bay Airport Relocation" where it is stated "*Beaches are dynamic with periods of erosion and accretion; recent images appear to show some accretion, but this gain could be lost in a single large storm.*"

The nature of the salient migration as discussed above suggests two alternatives to addressing the present erosion problem: (1) Delay any action while conducting observations of beach conditions in the vicinity of the north end of the runway, or (2) Extend the south end of the runway a distance, say 1,500 feet, and deactivate the same length of the north end of the runway.

The attractiveness of the first alternative is that the steel sheet piling protecting the north end of the runway appears sound and thus the area is in no immediate danger. It appears that at the present rates of migration, the north end of the runway will be protected for at least 50 years for a migration rate of 45 ft/year. As the salient migrates northward, the beach at the southern end of the runway will narrow. Thus, extending the runway south could expose the south runway end to erosive conditions within the coming decades especially if the more rapid migration rates occur. This option would also include annual inspections of the sheet piling and the beach with an occasional aerial survey.

The merits of extending the runway southward include an early "fix" to the current erosion problem at the north runway end.

Figure B-2. Salient position in 2005 and shorelines with northward displaced salients of 1,000 and 2,000 feet.

Appendix C-Sediment Transport Equations

Start with the sediment discharge equation based on breaking wave energy.

$$Q = K\frac{H_b^2 C_{G,b}\sin(\beta-\alpha_b)\cos(\beta-\alpha_b)}{8(S-1)(1-p)}$$

where subscript "b" denotes breaking. Suppose the wave data are available at location "2" and that we consider straight and parallel bottom contours.

Conservation of Energy

$$H_b^2 C_{G,b}\cos(\beta-\alpha_b) = H_2^2 C_{G,2}\cos(\beta-\alpha_2)$$

Snell's Law

$$\frac{\sin(\beta-\alpha_b)}{C_b} = \frac{\sin(\beta-\alpha_2)}{C_2}$$

Substituting in the above for Q,

$$Q = K\frac{H_2^2 C_{G,2}\sin(\beta-\alpha_2)\cos(\beta-\alpha_2)}{8(S-1)(1-p)C_2}C_b$$

Now to develop an equation for C_b, use Conservation of Energy Equation and Spilling Breaker assumption: $H_b = \kappa h_b$

$$\frac{\kappa^2 C_b^5\cos(\beta-\alpha_b)}{g^2} = H_2^2 C_{G,2}\cos(\beta-\alpha_2)$$

or

$$C_b = \frac{H_2^{0.4} C_{G,2}^{0.2} g^{0.4}\cos^{0.2}(\beta-\alpha_2)}{\kappa^{0.4}\cos^{0.2}(\beta-\alpha_b)}$$

Substituting Eq. (3) in Eq. (2) yields

$$Q = K\frac{H_2^{2.4}C_{G,2}^{1.2}g^{0.4}\sin(\beta-\alpha_2)\cos^{1.2}(\beta-\alpha_2)}{8(S-1)(1-p)C_2\kappa^{0.4}\cos^{0.2}(\beta-\alpha_b)}$$

and considering that

$(\beta-\alpha_b)\approx 0$, $\cos^{0.2}(\beta-\alpha_b)\approx 1$. Thus,

$$Q \approx K\frac{H_2^{2.4}C_{G,2}^{1.2}g^{0.4}\cos^{1.2}(\beta-\alpha_2)}{8(S-1)(1-p)C_2\kappa^{0.4}}\sin(\beta-\alpha_2) = BB\sin(\beta-\alpha_2)$$

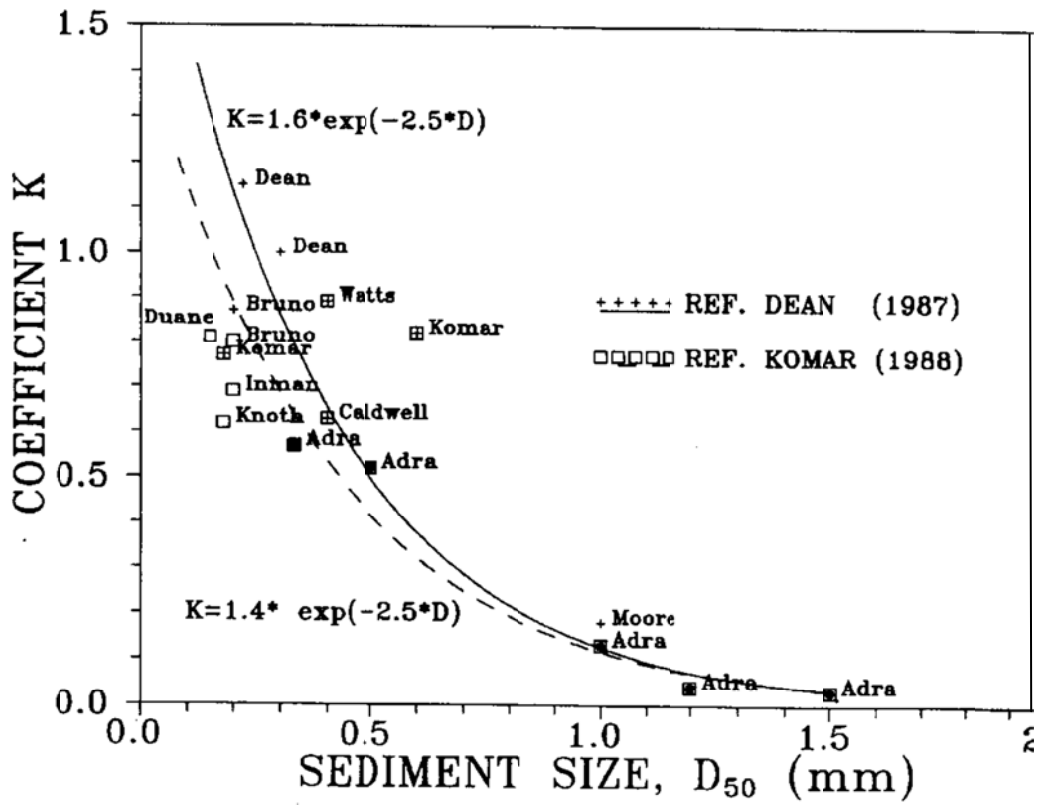

Figure 1 Coefficient K versus median grain diameter, D_{50}

Appendix D-The Effect of the Ebb Tidal Shoal on Coastal Processes

Introduction

Ebb tidal shoals (ETS) can be considered as "sand bridges" across which the net longshore sediment transport occurs. In the case of inlets connected to a bay, Walton and Adams (1976) have shown that the volume of an ebb tidal shoal is related to the tidal prism of the inlet. In the case of the small river to the north of the Hooper Bay runway, the volume in the ebb tidal shoal is probably related more to the water and sediment discharges by the river and the waves and net longshore sediment transport. If the net longshore sediment transport were large and the waves small, a larger ebb tidal shoal (sand bridge) would be required to transport the sand.

Characterization of the Ebb Tidal Shoal of Interest

Eight aerial photographs were examined in an attempt to determine the role of the ebb tidal shoal on the coastal processes of the area. Scaling from several aerial photographs indicates that the river width is on the order of 150 to 180 feet. Results from examination of eight aerial photographs are discussed below.

Figure D-1 presents a 1951 aerial photograph in which it is seen that a small bar has displaced the river mouth to the south. Although the month associated with this photograph is unknown, the ebb tidal shoal as reflected by the breaking waves shows only little difference from the areas to the north and south. Thus, on this basis, both the river flow and the volume of sand in the ETS are considered to play relatively insignificant roles in the coastal processes of the area.

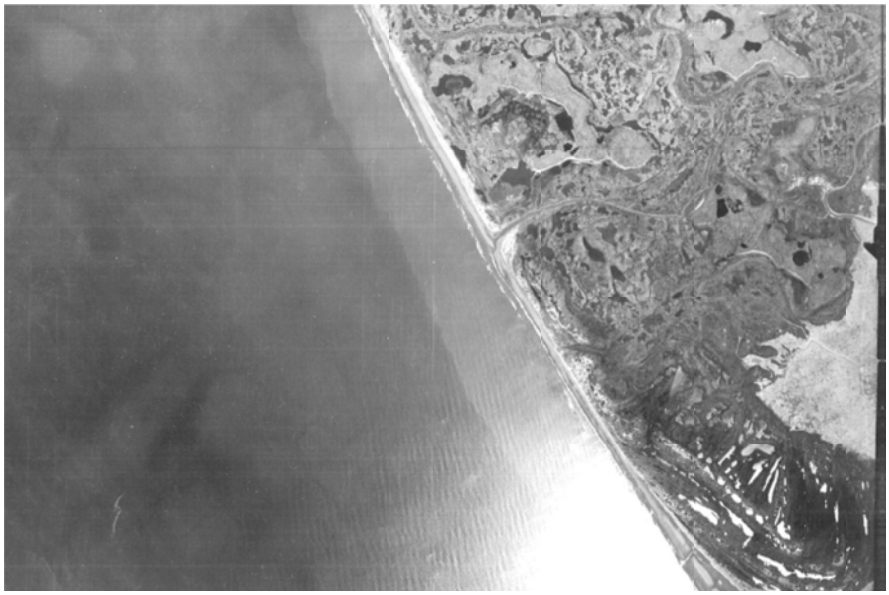

Figure D-1. Aerial photograph of area of interest, 1951. Note relatively small difference in shoal at river outlet and areas to north and south.

Figure D-2 presents a photograph taken on June 1, 1968 in which it is seen that the expression of the ETS is quite small. Again, the river cut through the bar is deflected toward the south.

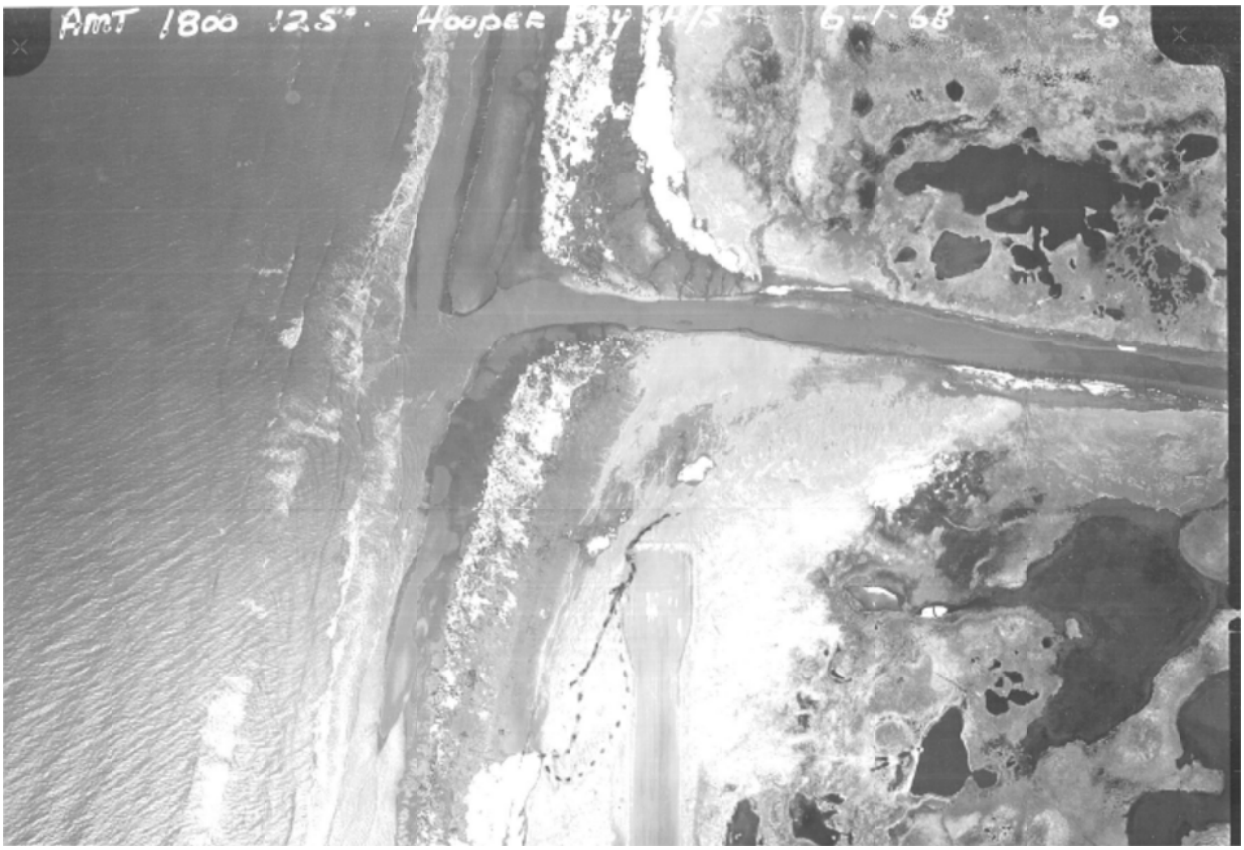

Figure D-2. Aerial photograph taken June 1, 1968. Note a small indication of an ETS and that the river cut through The bar is deflected toward the south.

Figure D-3 presents an aerial photograph taken July 22, 1975. The photograph appears to have been taken at low tide and long waves are present. The river mouth in this photograph is unusually wide, suggesting that a significant storm may have preceded this photograph. Any expression of the ETS is small.

Figure D-4 presents an aerial photograph taken September 9, 1975. The channel is deflected quite substantially toward the south and only a small ETS is observed.

Figure D-3. Aerial photograph taken July 22, 1975. Appears to be at low tide with reasonably large waves. Note that no significant ebb tidal shoal is evident.

Figure D-4. Aerial photograph taken September 9, 1975. A reasonably small ETS is present and the channel is deflected toward the south.

Figure D-5 presents a 1994 aerial photograph which appears to have been taken at low tide and in which the bar/ETS system is quite visible. As for earlier photographs, the shoal evident in this photograph does not appear to be prominent. The river cut through the bar is directed to the south.

Figure D-6 presents an oblique aerial photograph in which two wave systems are evident. Of relevance is that the long wave crests are not modified significantly in the vicinity of the river mouth. In this photograph, the river cut through the bar does not appear to be deflected.

Figure D-5. Aerial photograph of area of interest, 1994. Photograph taken during low tide conditions. Note relatively small bar system.

Figure D-6. Oblique aerial photograph taken October 3, 2004 at mid-to high-tide. Note two wave systems and no deflection of the river mouth is evident. Also alignment of longer wave crests are not modified significantly in vicinity of river mouth.

Figure D-7 presents an aerial photograph taken on June 27, 2005 at low tide. Three bars are present. Low tide conditions allow better visualization of the ETS. This photograph shows little effect of the ebb tidal shoal. The alignment of the waves breaking on the offshore bar are not modified significantly in the vicinity of the river mouth. The river cut through the bar is directly seaward.

As in other photographs, Figure D-8, taken in 2007, indicates a small ETS and as in most other aerial photographs, the river channel through the bar is deflected southerly.

Figure D-7. Aerial photograph taken on June 27, 2005 at low tide. There are three bars present. The ETS deposit is relatively small deflecting the low tide shoreline only a minor amount.

Figure D-8. Aerial photograph taken 2007. Note small expression of the ETS on the breaker line and the channel deflection to the south.

Summary

Examination of eight aerial photographs spanning the 56 year period 1951 through 2007 suggests: (1) Any effects of the river ebb tidal shoal on coastal processes are small and that the volume of material stored in this shoal is small, and (2) based on deflection of the river cut through the bars, the direction of net longshore sediment transport is to the south as found independently from modeling of coastal processes in this project independently through the application of available wave data.