SHAKTOOLIK COASTAL FLOODING ANALYSIS

October 2011

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EXECUTIVE SUMMARY

The community of Shaktoolik, Alaska is on a narrow spit composed of sand and gravel, bounded by Norton Sound and the Togoomenik River. It lies 125 miles east of Nome and 33 miles north of Unalakleet. The area encompasses 1.1 square miles of land. Shaktoolik's current location leaves the community vulnerable to erosion and coastal damages from storm surge. No protection measures have been installed to date to protect Shaktoolik from erosion or coastal damages.

The community of Shaktoolik, through an agreement with the Denali Commission and Kawerak, Inc., has asked the U.S. Army Corps of Engineers (USACE), Alaska District and the Coastal and Hydraulics Laboratory (CHL) to perform an analysis to identify the likelihood and severity of coastal flooding in Shaktoolik. For the purposes of this study, coastal flooding is inundation caused by a combination of storm surge, waves, and wave runup. Bathymetry, existing ground elevations, and first floor elevations were surveyed and referenced to Mean Lower Low Water (MLLW). Historic wind, wave, and storm surge water level data were modeled and a deep-water wave transformation to beach analysis was completed. Sea level rise and tsunamis were not analyzed. The Alaska District was also asked to update the erosion rates determined in the 2009 Alaska Baseline Erosion Study.

Identifying coastal flooding involves the use of historical wind, wave, and storm water level data coupled with computer modeling to replicate previous storm events. The data obtained for the events included 56 storms from 1954 to 2009. The modeled events were then compared with Shaktoolik resident accounts of coastal flooding to verify the accuracy of the modeled events, specifically the significant events of October 1960, September 2005, and November 2009. The frequency of coastal flooding was estimated for 5-, 10-, 15-, 20-, 25-, 50-, and 100-year recurrence intervals.

The events of 2005 and 2009, where residents reported damages to the community, were each slightly less than a 10-year event or had a slightly more than a 10% chance of occurring in any given year. The largest coastal flooding event experienced at the old site was the October 1960 event, where residents recalled water overwashing the old site runway and sea-water infiltrating the fresh-water of the Tagoomenik River. Extremely large debris was also carried into the old town site by this storm. The October 1960 event is estimated to be a 72-year return period event for Shaktoolik. The old site also sat at a higher elevation than the current community site. Coastal flooding of this magnitude has not been seen at the current community site.

Through the analyses presented in this study, coastal flooding with approximately a 50-year or higher recurrence interval would significantly affect the road and community structures. Events of this magnitude would inundate the entire community with approximately 1-3 feet of water flowing over the top of the road along with the additional damaging effect of debris laden waves. Smaller events without complete inundation would have less potential for damages as waves would break and run up the beach. Flooding is expected to occur from the coastal side of the community. Increased water levels in the Tagoomenik River are a concern, but are not expected to cause the primary flooding. This study establishes the probability of coastal flooding and corresponding water elevations for the community of Shaktoolik. The serious nature of coastal flooding brings safety concerns that need to be addressed. Additional investigations that could help Shaktoolik address safety issues are, but not limited to, the design analysis of structural flood control measures and flood proofing community infrastructure. Structural flood control measures may include a revetment for wave protection or relocation of structures. Flood proofing measures may include elevating buildings and mechanical and electrical units.

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1.0 INTRODUCTION

1.1 PURPOSE OF STUDY

The purpose of this report is to identify the likelihood and severity of coastal flooding, and to update the erosion map presented in the 2009 Alaska Baseline Erosion Study for the community of Shaktoolik, Alaska. Coastal flooding results from the combination of wave, surge, and runup. The “old site,” approximately 3 miles south of the current community site, endured several storms that resulted in flooding and damage to the community. The extent of erosion at the “old site” was one of the factors that prompted the community to relocate to its current site in 1974. This report has been prepared to assist the community of Shaktoolik in future planning, studies, and projects.

1.2 COORDINATION

The results of this report were reviewed by the U.S. Army Corps of Engineers, Alaska District, Coastal and Hydraulics Laboratory (CHL), residents of Shaktoolik, Kawerak Corporation, and the Denali Commission.

2.0 AREA STUDIED

2.1 SCOPE OF STUDY

Through an agreement with the Denali Commission and Kawerak, Inc., the community of Shaktoolik has asked the U.S. Army Corps of Engineers (USACE), Alaska District and the Coastal Hydraulics Laboratory (CHL) to conduct a combined wave, surge, and runup analysis to determine the likelihood and severity of coastal flooding in the community. The erosion rates determined in the 2009 Alaska Baseline Erosion Study were also updated.

2.2 COMMUNITY DESCRIPTION

The community of Shaktoolik is on the east shore of Norton Sound 125 air miles east of Nome and 33 air miles north of Unalakleet. Shaktoolik is sited on a spit that separates the Tagoomenik River from Norton Sound. This spit is a berm of sand and gravel formed by littoral transport of sediment from the southeast.

Shaktoolik covers approximately 1.1 square miles and has a population of approximately 230. The local economy is based mainly on subsistence food harvest supplemented by part-time wage earnings and commercial fishing.

Shaktoolik has a subarctic climate with maritime influences when Norton Sound is ice-free, usually from May to October. The mean annual temperature is 26°F, with approximately 77 frost-free days per year. The community was originally located 6 miles up the Shaktoolik River and moved to the mouth of the river in 1933 (“old site”). This “old site” was prone to erosion and coastal flooding and the community was relocated to its present location in 1974. The present community site is shown in Figure 1 (date of aerial photograph, June 2004).

The topography of the Shaktoolik area consists of a gravel and sand spit. Tundra is the characteristic vegetation cover. Trees are virtually absent, and plant life is largely confined to lichens and shrubs, mosses, low berry bushes, and grasses. Bird and aquatic life is relatively plentiful.

Figure 1 – Location and Vicinity of Shaktoolik

2.3 PRINCIPAL FLOOD PROBLEMS

Residents have stated that fall storms with a southwest wind typically have the largest waves and cause the most damage (damage by movement of woody debris) and erosion. Coastal flooding is a major concern for this community, and there is no accessible high ground in the vicinity of the town site. Typical debris left from a storm event is shown in Figure 2.

Figure 2 – View of Shaktoolik Beach in June 2008

Severe storms occurred in October 1960 and 1965; November 1966, 1970, 1974, 1975, and 1978; October 2004, September 2005, and November 2009. In October 1960, water reportedly carried woody debris that overtopped the “old site” airport runway. The 1965 storm resulted in the complete loss of one dwelling and several outhouses at the “old site.” Residents reported 1.5 feet of water in the community after the 1960 storm at the old site (see Appendix B for resident accounts).

During the 2005 storm, runup from waves caused damage to several fences and gravel to be washed away from the foundation of buildings (See Figure 3). The 2009 storm produced runup from waves that carried woody debris up the beach and onto the airport runway (Figure 4). Several fences were also damaged by the push up of woody debris (See Figure 5).

Figure 3 - Waves and Damaged Fence in 2005

Figure 4 – Debris near Airport Apron

Figure 5 – Damaged Fence in front of School

There are no documented high water marks in the community from either coastal or riverine flooding. Most of the sustained damages have resulted from the washout of gravel and debris pileup from coastal storm surge and wave runup (Figures 6 and 7).

Figure 6 – Debris Pileup near Road to Airport – Note debris on River side (Right Photo)

Figure 7 – Debris Pileup near Tank Farm

2.4 Coastal Flood Protection Measures

There are no coastal flood protection measures or floodplain ordinances for the community of Shaktoolik.

3.0 ENGINEERING METHODS

Identifying inundation caused by coastal storms involves the use of historical wind, wave, and water level data coupled with computer modeling to replicate previous storm events. The modeled events are then compared with resident accounts of particular storms to verify the accuracy of the modeled events: specifically, the significant events of October 1960, September 2005, and November 2009. Statistical techniques, through frequency analysis, are used to estimate the probability of the occurrence of any given storm event. The recurrence interval is based on the probability that the given event will be equaled or exceeded in any given year. Ten or more years of data are required to perform a frequency analysis for the determination of recurrence intervals. The analysis for Shaktoolik includes 56 years of wind, wave, and surge model estimates. A description of recurrence intervals and probabilities is shown in Table 1.

Table 1 – Recurrence Intervals and Probabilities of Occurrences

Recurrence Interval, in years	Probability of Occurrence in any given year	Percent Chance of Occurrence in any given year
100	1 in 100	1
50	1 in 50	2
25	1 in 25	4
10	1 in 10	10
5	1 in 5	20
2	1 in 2	50

It is important to note that since the 100-year flood level is statistically computed using existing data, as more data becomes available, the level of the 100-year flood will change (especially if a huge storm hits in the current year). As more data are collected, the frequency of flooding is re-evaluated.

The Ranked Plotting Method (Makkonen, 2005) was applied to generate frequency of occurrence relationships for waves, surge, and runup. The frequency of occurrence relationships for extreme surge were also obtained using the Empirical Simulation Technique (EST) (Scheffner and Borgman, 1999). Both methods assume that future events will be statistically similar in magnitude and frequency to past events. The results of the extremal analyses are presented in the following sections.

The analyses reported here reflect flooding potential based on conditions existing in the community at the time of completion of this study. Maps and flood elevations should be amended periodically to reflect future changes.

3.1 WAVE EFFECTS

Damage from storms in coastal areas is the result of coastal flooding. The storm water level is composed of astronomical tide, caused by gravitational effects of the sun and moon; storm surge, the rise in water level due to wind stress and low atmospheric pressure; and wave setup, the increase in water level due to shoreward mass transport of water. The runup of breaking waves, or the maximum of wave uprush on a beach above the storm water lever, can cause flooding and structural damage at elevations above the storm water level of the flood. A schematic illustration of these wave processes is shown in Figure 8.

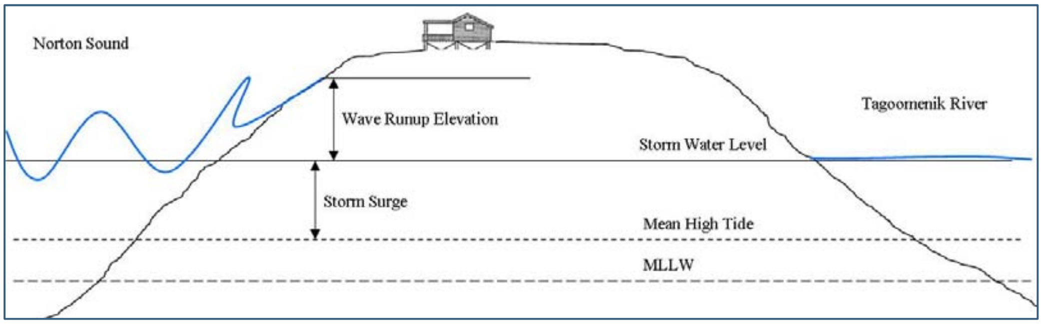

Figure 8 – Schematic Illustration of Wave Effects

Wave characteristics are initially estimated in deep water, then are analytically propagated shoreward to the beach and structures. Wave height parameters used in this analysis are energy and statistically based. The energy-based wave height is commonly referred to as H_{m0}. Statistically based waves are developed using the statistics of the heights of individual waves in a record. These terms are commonly referred to as H_s, significant wave height or the average height of the one-third highest waves; and H_1, the average of the highest one-percent of all waves.

The analysis tools used to estimate the storm surge, wave height, and wave runup elevation for Shaktoolik included the WAve prediction Model (WAM, Gunther et al. 2005), the ADvanced CIRCulation Model (ADCIRC, Luettich et al. 1992), and the Storm-induced BEAch Change Model (SBEACH) (Larson and Kraus 1989) developed by the USACE Coastal and Hydraulics Laboratory (CHL).

3.2 WAVE MODEL (WAM)

The WAM numerical model was applied for estimating deep and intermediate depth wave conditions that occurred during the storm events. WAM solves the action balance equation for the spatial and temporal changes in two-dimensional wave spectra on a fixed grid system. Wave growth is based on the sea surface roughness and the wind characteristics. Initially, a 20-year wave hindcast was developed for the Western Alaska Coast (1985-2004). Through a Tribal Partnership, the hindcast effort was funded to extend the hindcast record to 56 years for Alaska (1954 – 2009). A continuous climatology 1985-2009 was developed by Oceanweather, Inc (2006, 2010). Extreme storm events were selected (by Oceanweather, Inc.) for the pre-1985 to 1954 period. This extends the storm climatology to 56-years and provides consistency in the wind and pressure forcing required in the wave and surge modeling efforts.

The waves were evaluated at an 8-meter (~27 ft) depth off shore. Regional wind fields and regional sea level pressures were gathered in 3-hour time steps. Regional ice concentration data were applied in a percentage-of-coverage format. The WAM numerical model determines the significant wave height, wave period, and wave direction for each historical event. The domain for the wave model used in the analysis is shown in Figure 9.

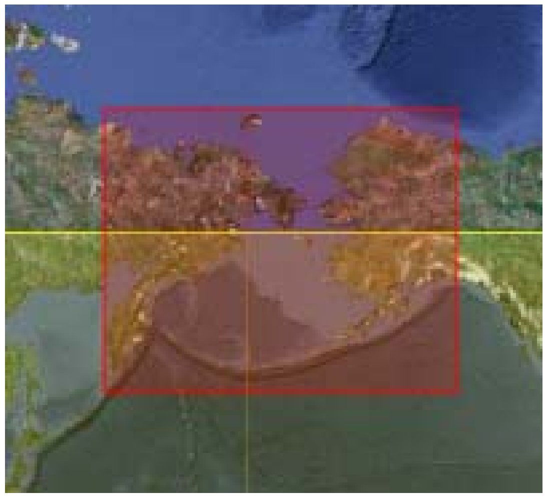

Figure 9 – Wave Hindcast Domain for Alaska

The information developed in the wave model is gathered in the Wave Information Studies (WIS). Save points, or stations, were created for data extraction. These save points were selected just offshore of the land/water boundary, separated by at least one active water point. Water depths were targeted to be between 8- to 15-meter depths. Shallow mechanisms were active with exception to depth induced refraction effects. Technically wave-refraction would be ill-posed for the grid resolutions used in the Alaska Hindcast (0.25-deg). The WIS is available through a Google application. A screen capture of the website is shown in Figure 10. The closest wave information station sites to Shaktoolik are 82108 and 82109 (also shown in Figure 10).

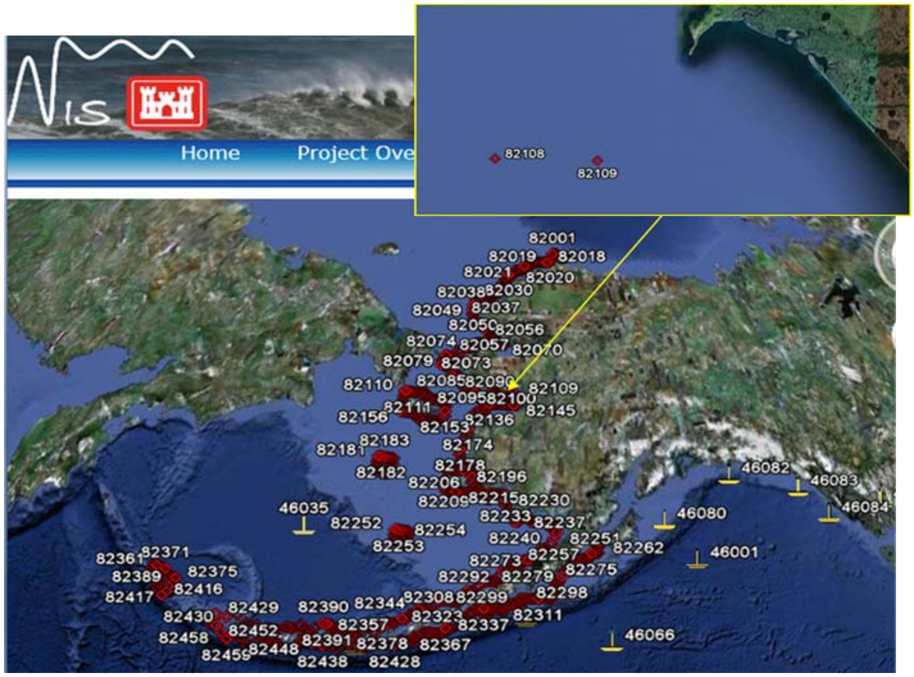

Figure 10 – Screen Capture of WIS Locations along Alaska Coast

Information obtained from the WIS website is varied based on the type of data (e.g, yearly wave height, wave roses, wind roses, and return period for the records). Station 82109 had 56 years of record. The top 10 waves from the H_{m0} (energy-generated wave height) extreme analysis for the 56-year record at Station 82109 and the significant events (shaded) are presented in Table 2.

Table 2 – Wave Heights of 56-year record at WIS Station 82109

Rank	Starting Date	H_{m0}, ft[1]	Return Period, yrs
1	4-Nov-78	11.52	59.5
2	3-Oct-60	11.19	47.5
3	15-Nov-65	10.20	24.2
4	15-Oct-85	8.99	10.5
5	16-Nov-66	8.92	10.1
6	12-Nov-65	8.86	9.6
7	9-Nov-03	8.79	9.2
8	16-Nov-89	8.69	8.6
9	26-Aug-75	8.69	8.6
10	28-Nov-70	8.69	8.6
11	11-Nov-09	8.46	7.4
14	22-Sep-05	7.87	4.9

[1]Wave H_{m0} reported at Mean Sea Level (MSL)

The wave heights presented in Table 2 indicate that in the 56-year record of deep water waves; Station 82109 (nearest to Shaktoolik) had not recorded a wave with a return period greater than 60 years. And, within the top 10, seven of the storms produced deep water waves less than a 20-year return period (5% chance of exceedance in any given year). With the exception of the October 1985, November 1989 and 2003 storms, the largest waves were generated by storms occurring in the 1960s and 1970s. The storms that resulted in memorable damages to the community at its current location (September 2005 and November 2009) rank less than a 10-year return period, or 10 percent chance of exceedance in any year.

3.3 ADVANCED CIRCULATION MODEL (ADCIRC)

The ADCIRC model simulates the long-wave hydrodynamic processes in the study area. When applying wind and atmospheric pressure forcing, the ADCIRC model can be calibrated to accurately predict storm-surge water levels and currents. A grid of the Alaska coast with local refinements to Norton Sound (Figure 11) was developed to simulate the storm event water levels.

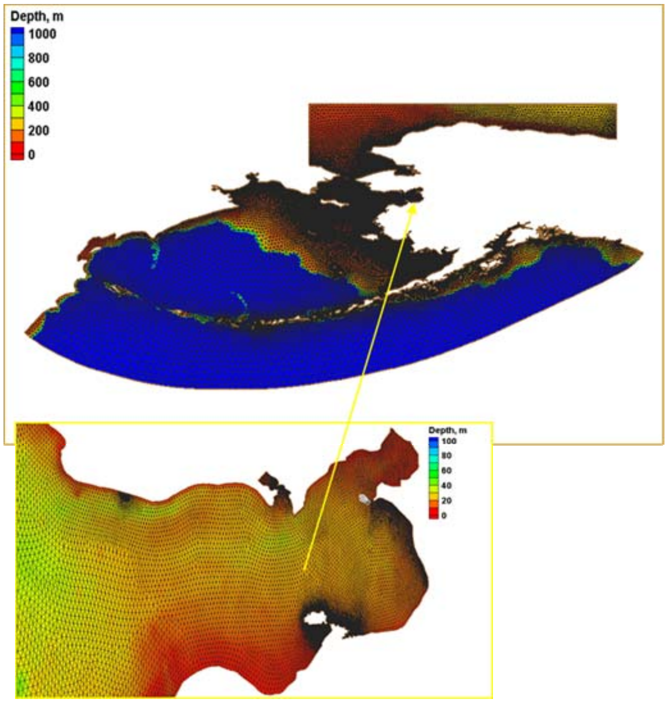

Figure 11 – ADCIRC Grid for Alaska Coast and Refined for Norton Sound

In order to increase the number of storms simulated, an analysis was undertaken to identify Shaktoolik-specific storm events that occurred during the 1985-2009 Oceanweather continuous climatology. The storm events were defined to have a 7-day duration centered about the peak wind speed. A review of the pre-1985 storm events developed by Oceanweather revealed that a number of the storms:(1) did not result in a water level setup in the study area; and (2) were of insufficient duration. As a consequence, the far offshore and easterly storm events were eliminated from the storm population, and the duration of the remaining events was lengthen to 7 days when necessary. The duration of the short duration storms were lengthened by repeating the first 3-hour wind and pressure field snapshot.

The presence of sea ice was evaluated in the ADCIRC model using a modified Garrett wind drag formulation method (Garratt 1977) to account for the additional roughness of free-floating ice (Chapman et al. 2005).

Fifty-six storms were identified between 1954 and 2009 by the methods described in Chapman et al. 2011. The top ten surge events and the significant events (shaded) are presented in Table 3.

Table 3 – Storm Surge Events of 56-year record (1954-2009)

Rank	Starting Date	Maximum Surge, ft MLLW	Max Wind Direction	Return Period, yrs
1	01-Oct-60	16.24	SW	58.2
2	10-Nov-74	14.44	SSE	48.1
3	26-Nov-70	12.70	SW	26.2
4	14-Nov-66	12.47	SSE	24.8
5	08-Nov-78	12.07	SSE	20.1
6	25-Aug-75	11.16	SSW	14.8
7	15-Oct-04	11.12	SSW	14.7
8	18-Sep-05	10.76	SSW	11.4
9	12-Nov-65	10.63	S	10.6
10	25-Oct-96	10.60	S	10.1
29	11-Nov-09	6.40	S	2.2

The surge elevations presented in Table 3 indicate that in the 56-year record of storm surge, the coast at Shaktoolik had not experienced a surge elevation with return period greater than 60 years. However, in contrast to the deep water waves, three of the significant events ranked in the top 10 for storm surge events. Even though ranking in the top ten, the September 2005 storm that resulted in recent memorable damages to the community at its current location has a return period of less than 15 years. Also similar to the deep water wave heights, the majority of the storms that produced the largest surge elevations occurred in the 1960s and 1970s.

3.4 Survey

The vertical datum provides a starting point against which flood, ground, and structure elevations can be referenced and compared. All flood elevations in this study are referenced to Mean Lower Low Water (MLLW). Structure and ground elevations in the community must, therefore, also be referenced to MLLW.

A tidal gauge and benchmarks to National Oceanic and Atmospheric Administration (NOAA) standards were set for the 2010 survey. The survey included beach and upland spot elevations, building and road locations, significant structures, and hydrographic survey at specified locations.

Horizontal Control: All positions were NAD83, Alaska State Plane, Zone 7, in U.S. feet. The basis of coordinates was Tide Station 9468691 Shaktoolik, Alaska.

Vertical Control: Elevations were determined at MLLW datum based on the 1983-2001 tidal epoch in U.S. feet. The basis of elevations was on NOAA/National Ocean Service (NOS) Tide Station 9468691.

Hydrographic Survey: The hydrographic survey was conducted July 21, 2010. Sounding data was collected using an ODOM Hydrotrac fathometer with a 200 kHz, 3-degree transducer. Positioning of the vessel and data collection was provided by GPS receiver.

The survey was finalized in February 2011. A 3D surface was generated from the survey points gathered, and beach profiles were extracted across the community at the four specified locations. The fifth profile, at the old town site, was estimated based on U.S. Geological Survey (USGS) topographic map, Norton Bay (B-5).

3.5 Runup Analysis

A wave runup analysis was conducted to determine the maximum coastal flooding elevation that could affect the community of Shaktoolik. By definition, wave runup is the maximum vertical extent of wave uprush on a beach or structure above the storm water level. The computer program SBEACH, developed by the USACE, was used to transform offshore storm conditions modeled by WAM and ADCIRC to the shoreface at Shaktoolik. Breaking waves and changing water levels are the major driving agents in SBEACH that produce sediment transport and beach profile change. While sediment transport and beach profile change are important to beach analysis, SBEACH also provides hydrodynamic results including estimates of maximum runup elevations. The elevations determined by SBEACH assume the wave will runup until it runs out of momentum.

The storms modeled in SBEACH were reduced from the 56 ADCIRC storms to 48 SBEACH storms. It was determined that five of the 56 events occurred during icing conditions, and thus, no waves and consequently no resulting SBEACH simulation for wave setup and runup could be developed. The storms were further reduced by three to 48 events because further analysis determined that these three events were secondary peaks of the already identified storms.

According to resident accounts, ice prevented wave runup from damaging the community in November 2009. Ice conditions were not modeled in SBEACH, thus the 2009 event was not ranked among the top modeled storms. The top 10 of the 48 SBEACH modeled storm events are presented in Table 4 (significant events are shaded).

Table 4 – SBEACH Top 10 Modeled Storms (1954-2009)

Date	Peak Wave Height[1], ft MLLW	Peak Wave Period, sec	Peak Water Elevation[2], ft MLLW
01-Oct-1960	18.65	11.17	18.13
10-Nov-1974	14.00	6.93	16.33
26-Nov-1970	14.48	10.15	14.58
14-Nov-1966	14.86	8.39	14.36
08-Nov-1978	13.07	7.63	13.97
25-Aug-1975	14.48	8.39	13.07
15-Oct-2004	10.60	8.39	13.01
18-Sep-2005	13.12	6.93	12.67
12-Nov-1965	17.00	10.15	12.52
11-Oct-1996	2.68	4.74	12.48

[1] The peak wave height represents the average of the highest one percent of waves for each event
[2] The peak water elevation represents the peak combined storm surge and mean high tide water level estimate

Four profiles were chosen for detailed analysis based on resident accounts of storm events for the SBEACH simulations. These profiles included: STA 6+25 (corporation building), STA 15+25 (tank farm), STA 28+50 (school fence), and STA 87+00 (airport apron). It was determined through comparisons of other locations along the coastline that these four profiles could be considered as representative beach profiles for the community. The available wave and water elevation information from WAM and ADCIRC simulations provided the environmental forcing input to SBEACH at each of these profiles. A median sediment grain size of 1.0 millimeters (mm) was specified as input to SBEACH due to the coarse nature of the beach at Shaktoolik, and an overwash transport parameter of 0.001 was input. Each profile extended at least 9,500 feet (1.8 miles) into Norton Sound. The locations of the Shaktoolik profiles are shown in Figure 12 (actual cross-section length is not shown for simplicity). The location of the old town site profile is shown in Figure 13.

The resident accounts at each profile location were compared with the estimated maximum runup elevations obtained from the SBEACH simulation for selected storm events. The model validation process is described in Section 3.6. See Appendix B for notes on personal communications with the residents of Shaktoolik.

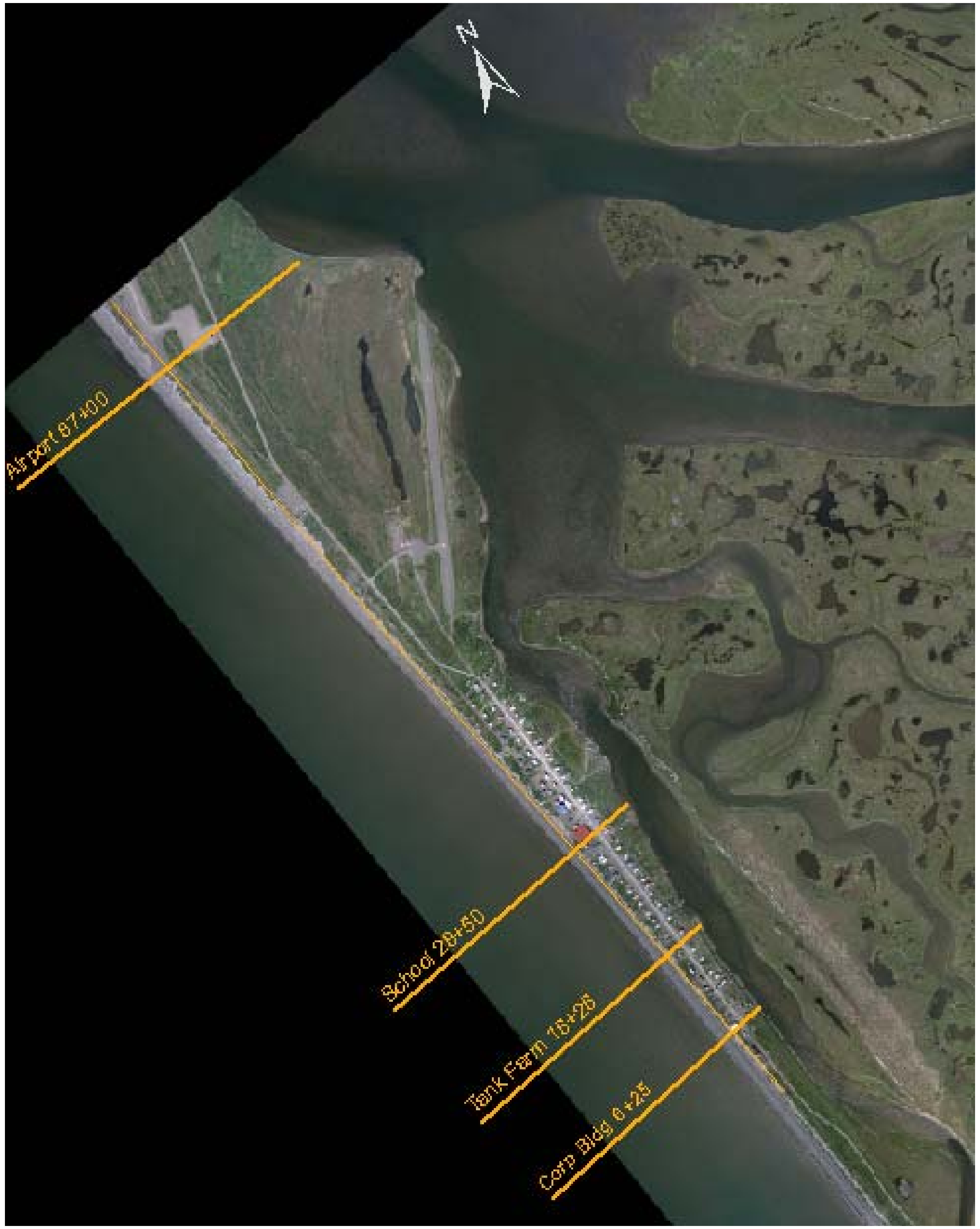

Figure 12 – SBEACH Profile Locations, Current Community Site

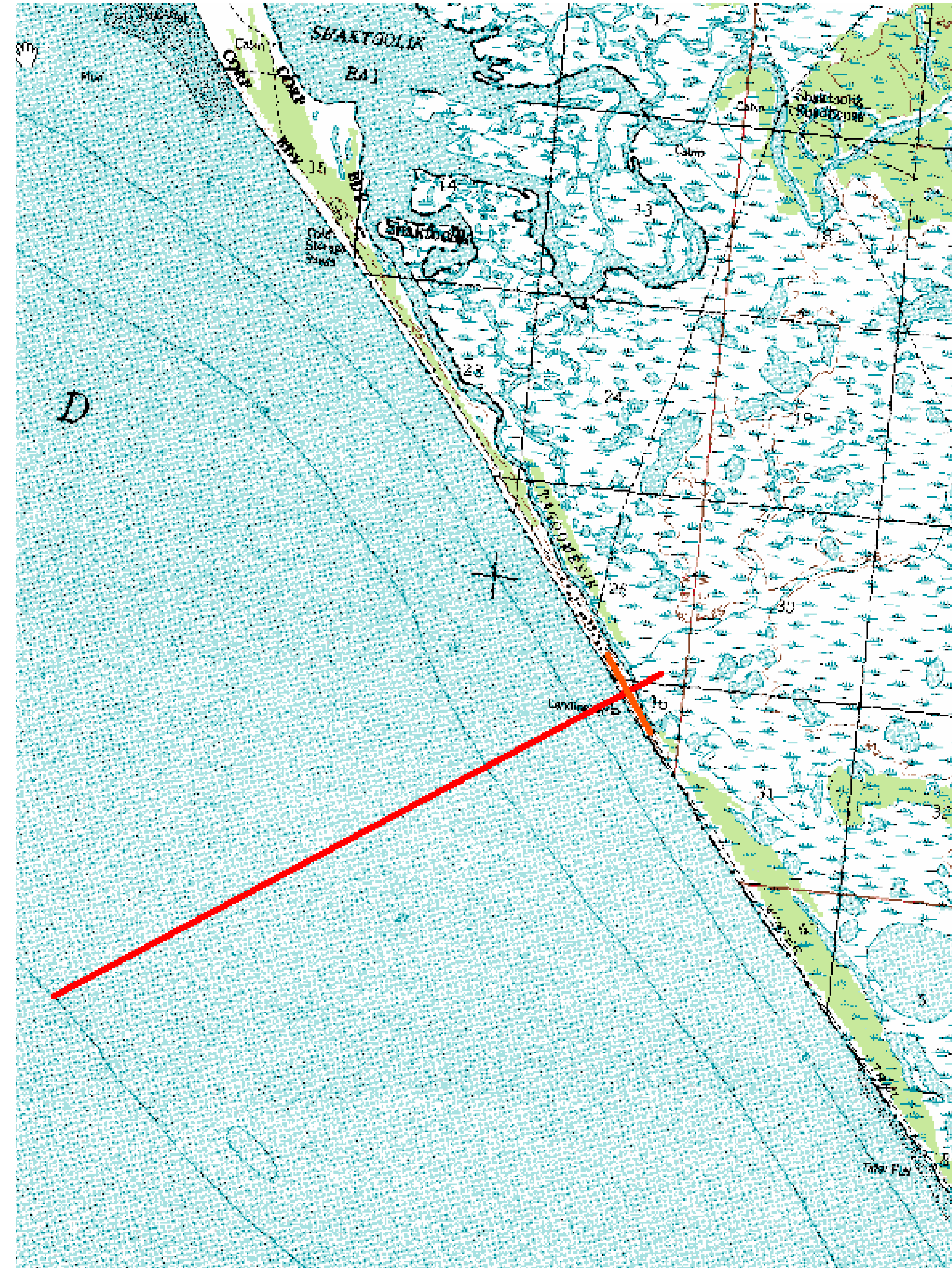

Figure 13 – SBEACH Profile Location, Old Town Site
(USGS Norton Bay, B-5, Rev. 1973)

3.6 SBEACH Model Validation

The SBEACH model simulations were validated using local resident accounts of modeled storm events. Data collected for the October 1960, September 2005, and November 2009 storms is presented in Table 5. Engineering judgment was used to determine the validity of the models as compared with the resident accounts of the storms. One beach profile was compared at Unalakleet (33 miles south) and four beach profiles at Shaktoolik. The H_1, or the highest one-percent of waves, was found to best match the "on the ground" accounts of each storm.

Table 5 – Validation Scenarios for the SBEACH Model

Date	Description	Elevation at Site, ft MLLW	SBEACH Max Run-up, ft MLLW
11/2009	Unalakleet: Ice and slush pushed up on top of airport runway	19.9	21.4
10/1960	Logs and debris washed up and over the Old Town Site airport	24.5[1]	27.5
09/2005	Gravel washed away at steps of Corporation Building	19.8	21.2
11/2009	Logs and debris washed up and damaged fence in front of school	19.2	20.6
11/2009	Logs and debris on corner of Airport apron	20.6	21.7

[1] Elevation at old town site airport estimated from USGS topographic maps. No survey was collected at the old site.

Maximum runup elevations indicate waves pushing debris up the beach slope and receding, not standing water at the location. The October 1960 storm event produced a wave runup elevation 3.0 feet higher than the estimated ground elevation. Three feet of moving water would be sufficient to move debris up and over the old town site airport runway as described by an Elder in Shaktoolik (see Figure 14). The September 2005 storm produced an estimated wave runup elevation 1.4 feet higher than the ground elevation at the corporation building. This amount of wave action is adequate to wash away the gravel described by the residents (see Figure 15). In November 2009, logs and debris were noted at two locations in Shaktoolik. The fence in front of the school was damaged by debris carried by waves 1.4 feet higher than the ground elevation (see Figure 16); and logs were pushed up onto the airport apron with 1.1 feet of wave runup (see Figure 17) . For additional validation of the model, one location was chosen in Unalakleet. The residents reported ice and slush pushed on top of the airport runway during the November 2009 storm event. The SBEACH simulation predicted a maximum runup elevation of 1.5 feet higher than the airport runway, validating the simulation.

To put these storm events into a runup frequency perspective, the October 1960 storm is considered a 72-year storm, the September 2005 storm an 8-year storm, and the November 2009 storm a 9-year storm. Although the community of Shaktoolik is no longer located where the 1960 storm information was gathered, it can be reasonably assumed that similar storm conditions would cause similar damage to the current community site. The maximum ground elevation at the old town site is estimated at 25 feet MLLW. This is 2.7 feet higher than the maximum ground elevation at the current community site.

Graphical representations of the wave runup elevations versus the ground elevations at the selected Shaktoolik profiles are shown in Figures 14 through 17.

Figure 14 - Old Site Profile Comparison of Runup to Storm Damage Report

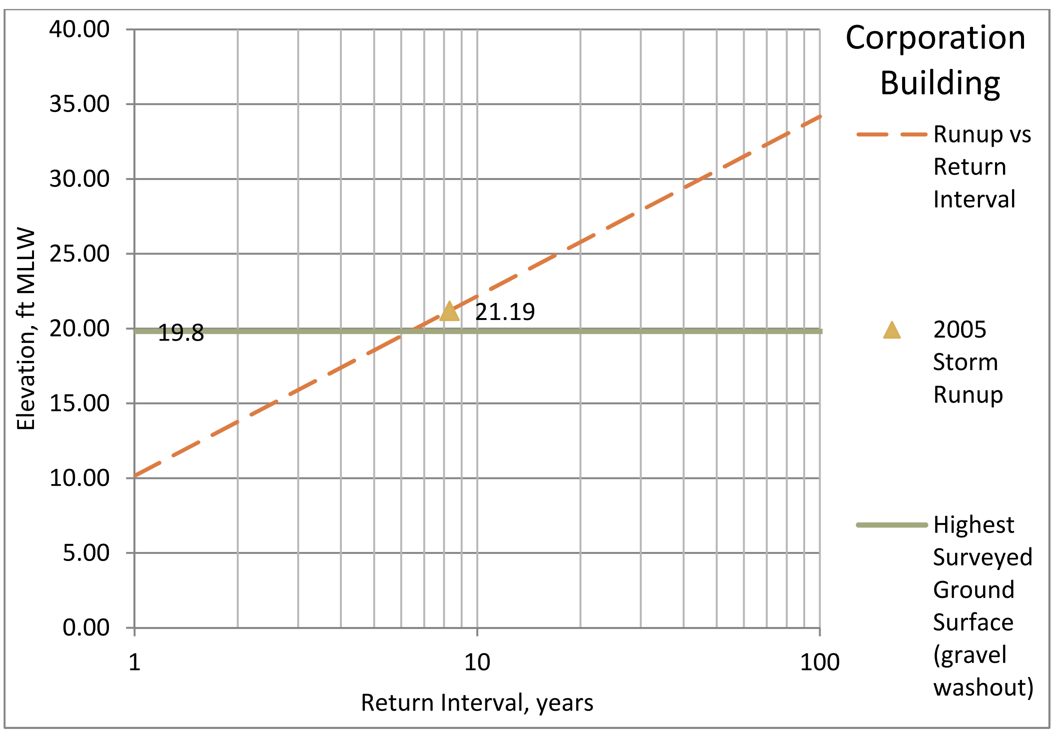

Figure 15 – Corporation Building Profile Comparison of Runup to Storm Damage Report

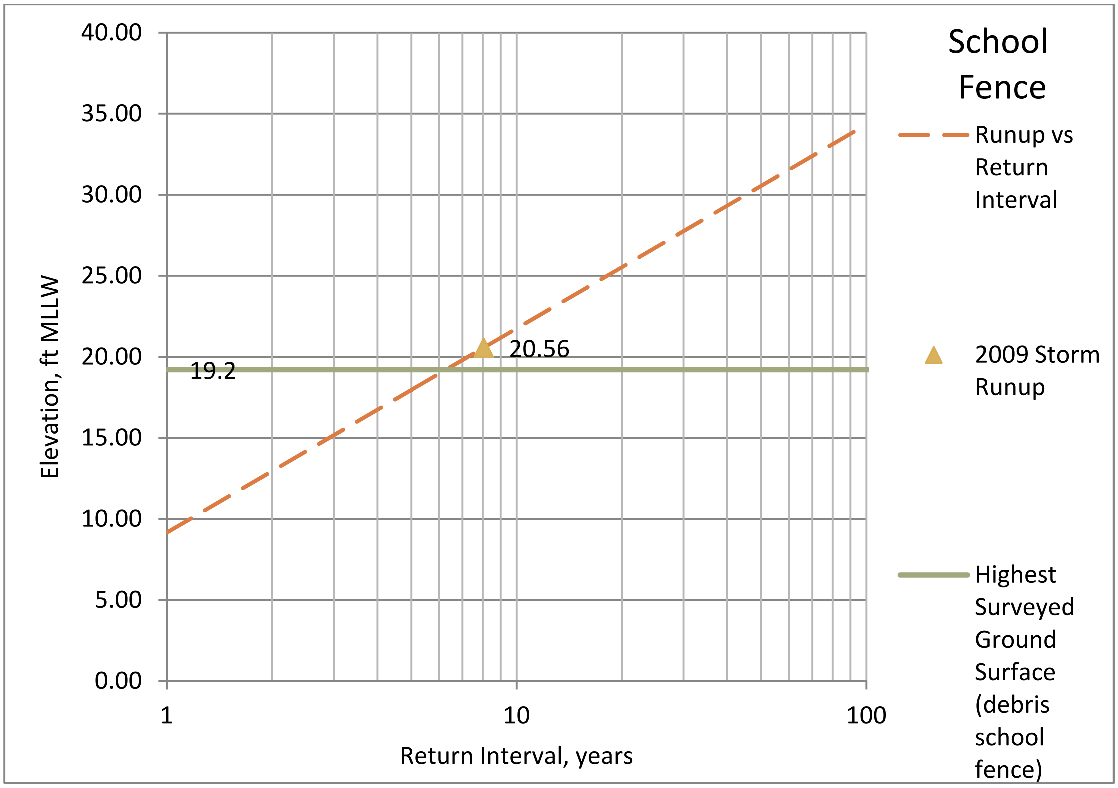

Figure 16 – School Building Profile Comparison of Runup to Storm Damage Report

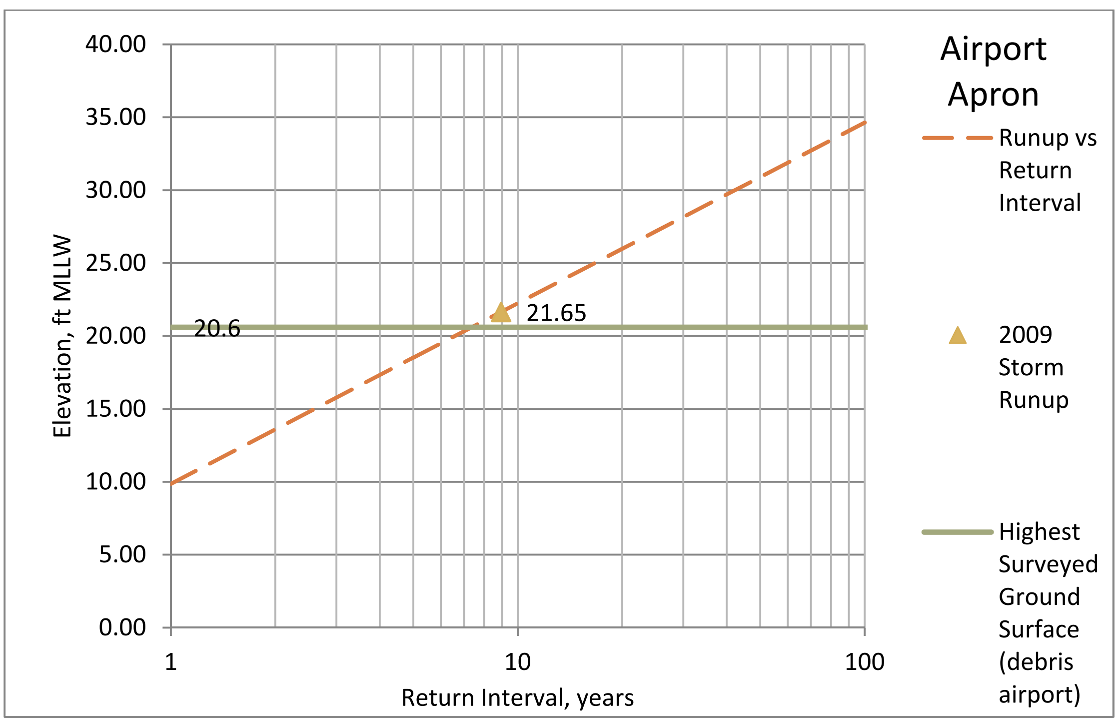

Figure 17 – Airport Apron Profile Comparison of Runup to Storm Damage Report

The maximum runup elevation was extracted from each SBEACH storm simulation, and a frequency analysis was conducted using Ranked Plotting Method. The storm events of 2005 and 2009, where residents reported damages to the community, were each slightly less than a 10-year event or had slightly more than a 10 percent chance of occurring in any given year. A storm event that produces a wave runup larger than a 15-year event is likely to push debris up into the community. The November 1974 storm was an approximately 15-year event. The results of the runup frequency analyses are presented in Table 6.

Table 6 – Maximum Runup Frequency of Occurrence

Location	Max. Ground Elev., ft MLLW	Maximum Runup, ft MLLW	
		5-yr	10-yr
Corp. Bldg, STA 6+25	22.31	18.5	22.2
Tank Farm, STA 15+25	21.24	18.7	22.4
School Fence, STA 28+50	22.11	17.9	21.7
Airport Apron, STA 87+00	21.53	18.5	22.2
Average	21.80	18.4	22.1

The maximum runup elevations for the 15-, 20-, 25-, 50- and 100-year return periods could not be extracted from SBEACH because the local ground elevation had been exceeded. Once an overtopping scenario occurred in the model, engineering judgment was applied to estimate the wave effects over land for these return periods (see Section 3.6.1).

Of the 48 storms modeled in SBEACH, the only storm that predicted runup elevations greater than the 20-year event was the October 1960 storm. This storm occurred before the community settled in its current location. The other 47 storms predicted runup elevations less than a 20-year (or 5% chance in any given year) event. Using the current community profiles, there has not been a storm that has reached elevations beyond that 20-year event at the present community site. This indicates that no one in the community has seen a 20-year or larger event at the present community site.

3.6.1 Coastal Flooding at the School Profile

The beach profile extracted at the school was used to graphically show the storm water levels for each of the recurrence intervals described in this report. The school was chosen because it would be the most likely structure where the residents of Shaktoolik would seek shelter should a large storm event occur. The profile distances are based on a top of beach line drawn based on the survey points taken. The storm water level for Norton Sound includes the mean high tide, storm surge, and wave setup. The runup elevation is the elevation that was simulated by the SBEACH model (see Table 6). Finished floor elevations of the school and the teacher housing were taken directly from the community survey completed in February 2011. The water level for the Tagoomenik River was determined using the mean high tide and the storm surge for each recurrence interval. The water levels and runup for the 5- and 10-year return periods are not graphically shown, but are represented by the lower and upper debris lines along the shoreline. The water levels and anticipated wave effects are shown in Figure 18 for the 15-, 20-, and 25-year return periods; and in Figure 19 for the 50- and 100-year return periods.

The runup for a 10-year event almost reaches the top of the beach. For runup by waves to reach an elevation higher than the Shaktoolik beach, a structure or piled up logs and debris must be present. The predicted runup elevations for the 15-, 20- and 25-year return intervals are shown in Figure 18.

The “unpredictable” areas shown for the 20- and 25-year events represent what is likely to happen to the elevation of the waves as they encounter the beach. Sea water would most likely inundate the coastal-side of the community with some flowing water and debris deposited well into the community. The natural variability in waves during a storm, their movement around structures and varying amounts of debris makes a precise estimate of surf zone action difficult to chart. The model used to estimate the maximum runup elevation predicts the elevation assuming there is runup onto a beach. Engineering judgment is used to estimate the wave action beyond the maximum beach elevation.

The storm water level, based on mean high tide plus surge plus wave setup, in Norton Sound is higher than the maximum beach elevation in Shaktoolik for the 50-year and 100-year events. This indicates that water levels before wave action would inundate the community. Additional water elevation due to wave action is shown as the dotted line in Figure 19. There is no runup plotted on the figure because the initial storm water level is overtopping the area before waves reach the beach. Model scenarios have shown that, for waves breaking at a shore, approximately 78 percent of the breaking wave height is above the storm water level (SPM, 1984).

A 50-year event is expected to overwash the land area of the community carrying debris from Norton Sound across the land to the Tagoomenik River, preventing overland travel during and after the storm. The debris would likely be piled up against building foundations. The storm water level for the 50-year event is 1.7 feet above the highest beach elevation at the school; 0.78 times 1.7 feet is 1.3 feet (calculation per SPM). So, the total water level expected to overwash the beach at the school during a 50-year event is 1.7 feet plus 1.3 feet, or 3.0 feet.

Based on the tide plus surge plus wave setup frequency response curves, a 100-year event could overtop the community with an estimated 4.6 feet of water from Norton Sound. This overtopping would likely include fast moving debris and make movement throughout the community extremely hazardous, if not impossible. The storm water level for the 100-year event at the school profile is estimated at 4.6 feet plus 3.6 feet, or 8.2 feet (calculation per SPM).

The “unpredictable” areas marked on Figure 19 represent what is likely to happen to the elevation of the waves as they encounter the beach. The natural variability in waves during a storm, their movement around structures and varying amounts of debris makes a precise estimate of surf zone action difficult to chart. The model used to estimate the maximum runup elevation predicts the elevation assuming there is something for the wave to runup on. Engineering judgment is used to estimate the wave action beyond the maximum beach elevation.

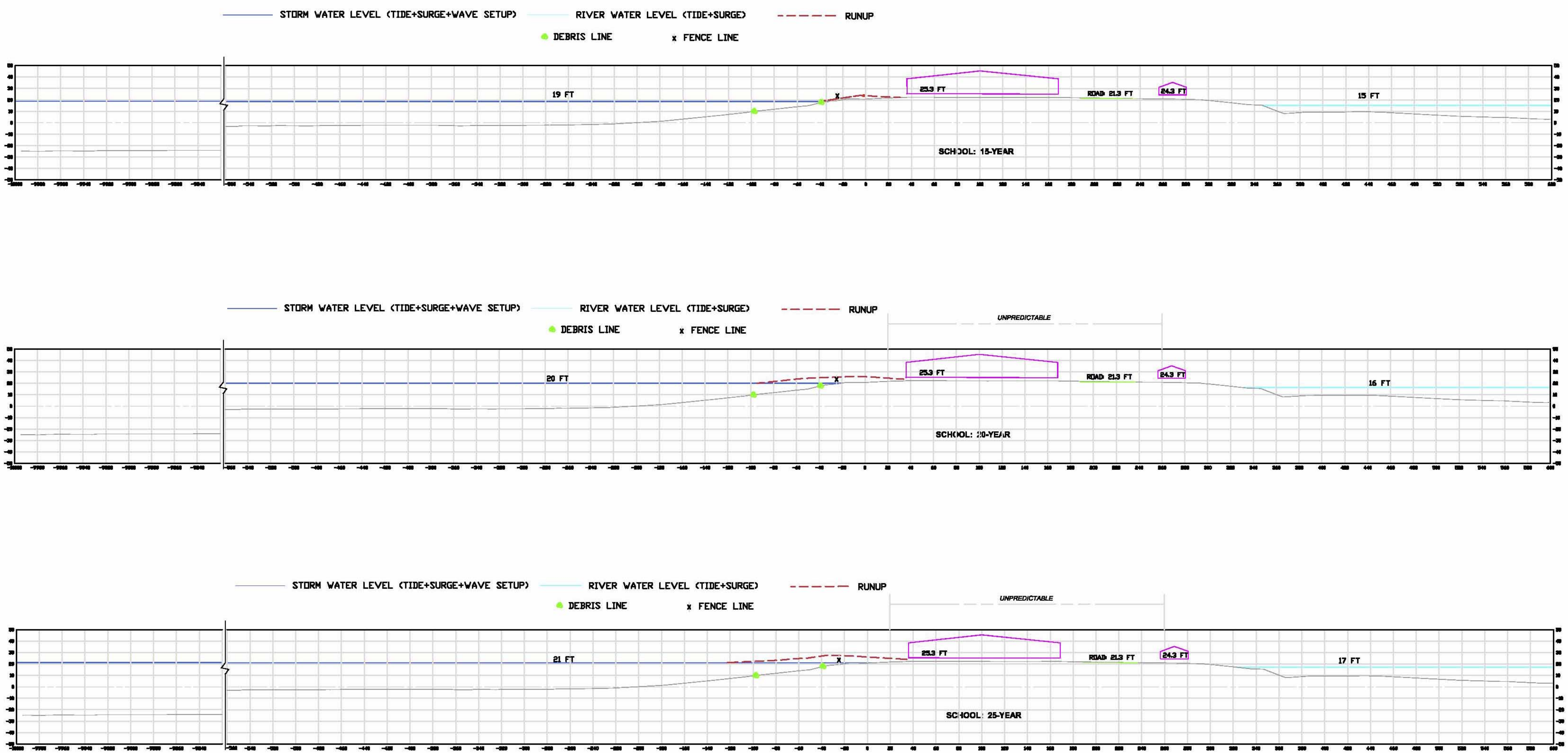

Figure 18 – 15-, 20-, and 25-year Water Levels

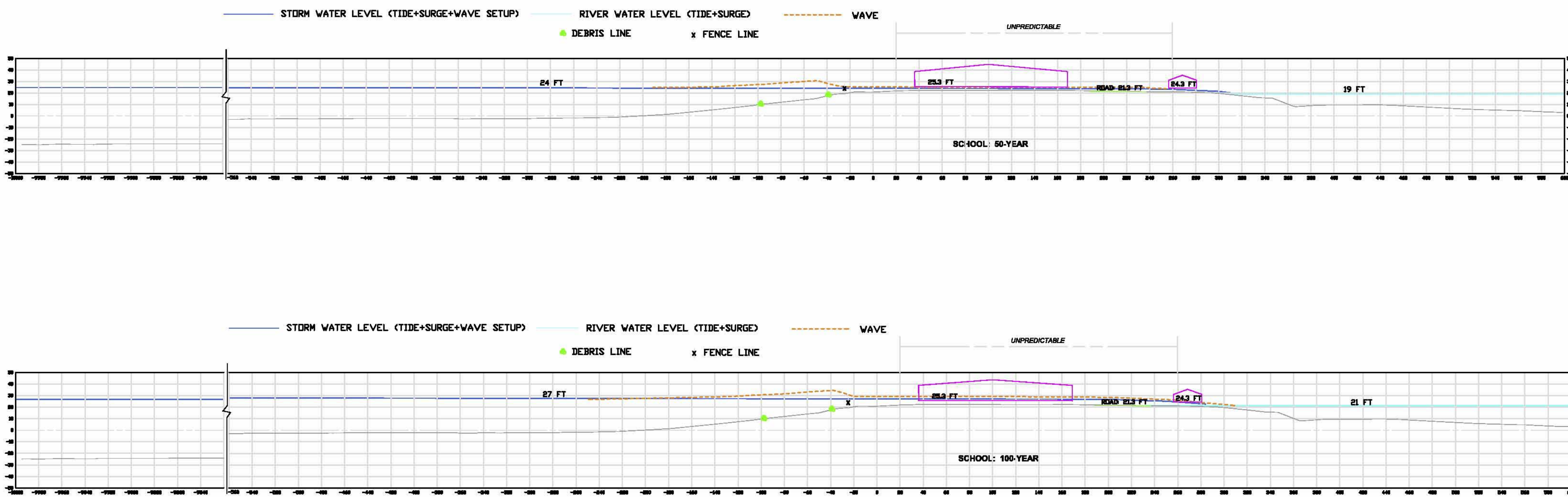

Figure 19 – 50-year and 100-year Water Levels

3.7 EXTENTS OF STORM WATER LEVEL INUNDATION

The landfill road is a gravel road that runs through the middle of the community (approximately 200 feet from the top of the beach facing Norton Sound). The highest elevation of this road is 23.56 feet at the southern limit of the community and the lowest is 18 feet near the abandoned runway. The highest ground elevation in Shaktoolik is 24.7 feet near the Public Safety Office. The highest finished floor (F.F.) elevation is 27.59 feet at a private residence approximately 600 feet northwest of the community water tank.

Some overwash of the beach is expected at the 25-year event, though it is not expected to overtop the landfill road nor have significant depths of water (refer to Figure 19). The 50-year event would overtop the beach with an average of 1.7 feet of water. This overtopping is before any waves are added. The additional wave height and associated water depths relative to the finished floor elevations are shown in Table 7.

Table 7 – Significant Structure Inundation

Location	Finished Floor Elevation, ft MLLW	Maximum Storm Water Level above Finished Floor(Depth, ft)	
		50-yr[1]	100-yr[2]
Corporation Bldg	23.19	2.0	7.1
National Guard Armory	26.36	-0.4	4.7
Tank Farm	21.24	4.7	9.8
Inupiat Assembly of God	24.25	1.1	6.2
Clinic	26.10	-0.8	4.3
School	25.32	0.0	5.1
Teacher Housing (near Library)	25.58	-0.3	4.8
Teacher Housing (across from School)	23.81	0.0	2.9
Public Safety Office	23.05	2.3	7.4
Airfield Hanger	21.57	4.2	9.3

[1] The storm water level overtops the beach an average of 1.7 feet at each location.
[2] The storm water level overtops the beach an average of 4.6 feet at each location

The highest finished floor elevation listed in Table 7 is at the National Guard Amory at 26.36 feet MLLW. For a 50-year storm event, it is unlikely that water would inundate the building, but waves would likely be breaking against the building and debris-laden water would be flowing under the building. The 100-year event could result in 4.7 feet of water over the finished floor of the Armory Building.

The Tank Farm is of particular interest to many in the community. The most recent storms that produced debris piles near the tank farm were the 2005 and 2009 storm events. These events had a recurrence frequency of less than a 10-year event. The tanks are essentially placed at ground level, and according to this analysis, it is possible that 4.7 feet of water could be surrounding the tanks in a 50-year storm. Additional debris would be carried by waves, likely damaging the tanks.

The information presented in Table 7 accounts for the storm water level only (mean high tide plus surge plus wave setup). For storms with a recurrence interval less than 50-years, wave runup would likely cause damages such as those reported by residents for the 2005 and 2009 storms. Coastal flooding becomes a concern when the storm water level overtops the community before waves are added. This scenario occurs at the 50-year and 100-year events. The structures listed in Table 7 are not a complete list of structures in the community, but chosen for their purpose and location within the community. Even though the finished floors of the National Guard Armory, clinic, and teacher housing are above the estimated 50-year storm water level, they are less than 1 foot from being overcome by the storm water level. And, these elevations do not account for waves that would be hitting the sides of the buildings and windows, and the debris that would likely be carried through the community during these events.

4.0 Coastal and River-side Flood Mapping

Federal Emergency Management Agency (FEMA) defines the coastal hazard area as the area of special flood hazard extending from offshore to the inland limit of a primary frontal dune along an open coast and any other area subject to high velocity wave action from storms or seismic sources. The primary frontal zone is a ridge of sand immediately landward and adjacent to the beach and subject to erosion and overtopping from high tides and waves during major coastal storms. For flood insurance rating purposes, the entire community of Shaktoolik would be classified in Zone V. Generally, this zone is the flood insurance risk zone that corresponds to the 1-percent-annual-chance (100-year) coastal floodplains that have additional hazards associated with storm waves.

For the purposes of this report, the coastal flooding boundaries are based on the storm water level (mean high tide plus storm surge plus wave setup). The wave effects on top of the storm water level are not mapped. Based on this analysis, almost every structure in the community would be affected by the 50-year coastal event. Overwash is expected to reach the buildings on the river-side of the landfill road. The Tagoomenik River is not expected to rise above the finished floor elevations of the buildings nearest its banks for the 50-year (mean high tide plus storm surge) event.

In the case of the 100-year event, or the 1 percent chance of occurrence in any given year, the storm water level (mean high tide plus storm surge plus wave setup) overtops the community well beyond the landfill road. There are no structures in Shaktoolik that have a finished flood elevation higher than the 100-year storm water level. The 100-year water level of the Tagoomenik River is expected to rise above the finished floor elevations of most buildings on the river-side of the community. It is likely that Shaktoolik would sustain significant damages to structures in a 100-year event.

Due to the anticipated overwash of the beach facing Norton Sound for the 50- and 100-year events, only the boundaries of the 5-, 10-, 15-, 20-, and 25-year events are shown in Figure 20. The boundaries were estimated based on the mean high tide plus surge plus wave setup. The estimated flooding by the Tagoomenik River is based on the mean high tide plus surge and is shown in Figure 21 for the 5-, 10-, 15-, 20-, 25-, 50-, and 100-year events.

The flood maps presented show the inundation lines from both the coastal and river-side of the community. Significant structures are clearly shown on the maps. A survey of the finished floor of each structure was also completed and by comparing the storm water elevations with the finished floor elevations, likely damages to structures may be determined.

Figure 20 – Coastal Flood Map (Elevations in MLLW); Close up of School Shown for Clarity

Figure 21 – River-side Inundation Map (Elevations in MLLW); Close up of School shown for Clarity

5.0 EROSION MAPPING

Shaktoolik is sited on a spit that separates the Tagoomenik River from Norton Sound. This spit is a berm of sand and gravel formed by littoral transport of sediment from the southeast. The seaward side of the berm is an active beach that responds dynamically to changes in sea conditions. Unlike the soils of a riverbank, the particles that form a beach are in motion. Wave action moves particles both parallel and perpendicular to the shoreline. The parallel component of motion is controlled by the direction of incident waves with sediment particles moving generally in the same direction as waves along the coast. The perpendicular component is controlled by the energy of the waves. During storms, waves transfer enough energy to the beach to suspend sediment particles in the water column and move them offshore. The sediment particles are typically deposited in an offshore bar where wave energy is insufficient to keep them in suspension. This process makes the beach slope steeper and the breadth narrower. From the perspective of the community, this is erosion. During relatively calmer periods, wave action pushes the sediment in the bar back onshore. This process makes the beach slope gentler and the breadth wider. At some locations, like Nome, Alaska, an offshore berm is not created as the beach responds to severe wave climate, but the beach slope is still steepened as beach material is moved offshore.

The Tagoomenik River generally runs to the northwest along the spit but meanders inland and away from the berm of sand and gravel formed by littoral drift. The land inland from the beach berm is about 10 feet below the elevation of the community of Shaktoolik. The Tagoomenik River meanders along the north side of the beach berm with some bends cutting into the berm itself. Where the river does run against the berm, it does not substantially cut into it. The most substantial impact of the river on the berm is at the first bend where the Tagoomenik River first meets the berm. This area is of particular concern to the community because if the berm is breached either by the sea or the river, the community's fresh water supply will be compromised. There have been no attempts to control erosion along the beach at Shaktoolik in the past. Currently, the best beach protection at the site is the large piles of woody debris that litter the top of the beach. While the debris is managed to some degree, this is for the purpose of maintaining beach access rather than for erosion control. At the first bend, oil drums filled with local material were used to prevent erosion of the road surface at the top of the bank. These drums do not protect the berm from toe erosion by the Tagoomenik River flow, but protect the road from loss of material due to surface runoff.

Erosion at Shaktoolik generally occurs in the fall, when storms from the Bering Sea generate high storm surges and waves. Storm surge is a change in sea level caused by high winds, usually during storm events. Onshore winds (winds that blow from the sea to the shore) cause sea level to rise while offshore winds cause sea level to fall. Norton Sound is prone to storm surge due to its shallow depth and shape. Fall storms typically produce winds that come from the southwest causing sea level to rise. The amount of storm surge is measured as the difference of the actual water level from predicted astronomical tides.

Analysis of a series of orthorectified photographs shows the occurrence of erosion along the Norton Sound coast and on outside of bends in the Tagoomenik River. Using the interpretation of the extent of vegetation along the beach, projected coast lines were estimated along the community. The process involved identifying erosion rates in specific stretches of the coast and then applying an offset to identify the 10-, 30- and 50-year erosion lines. Photo sets used to calculate the erosion rates at Shaktoolik were dated 1980, 1994, and 2004. A net erosion rate was determined for each of three sections:

- Section 1: 9,600 feet through main town with an average erosion rate of 2 feet/year
- Section 2: 3,900 feet along Tagoomenik River with an average erosion rate of 1.5 feet/year
- Section 3: 4,700 feet at old town site with an average erosion rate of 3 feet/year

Along the Tagoomenik River, the rate of erosion was not calculated, and erosion lines were not drawn because the amount of land lost over the period of record was less than a foot per year and the distance to the nearest buildings was more than 50 feet. Also, the land being lost is at a low elevation and not used for the construction of permanent structures such as housing and stores.

It should be noted, however, that determining erosion rates based solely on a vegetation line from aerial photography does not accurately predict beach erosion or accretion. The lines presented on the map in Figure 22 represent vegetation line movement only.

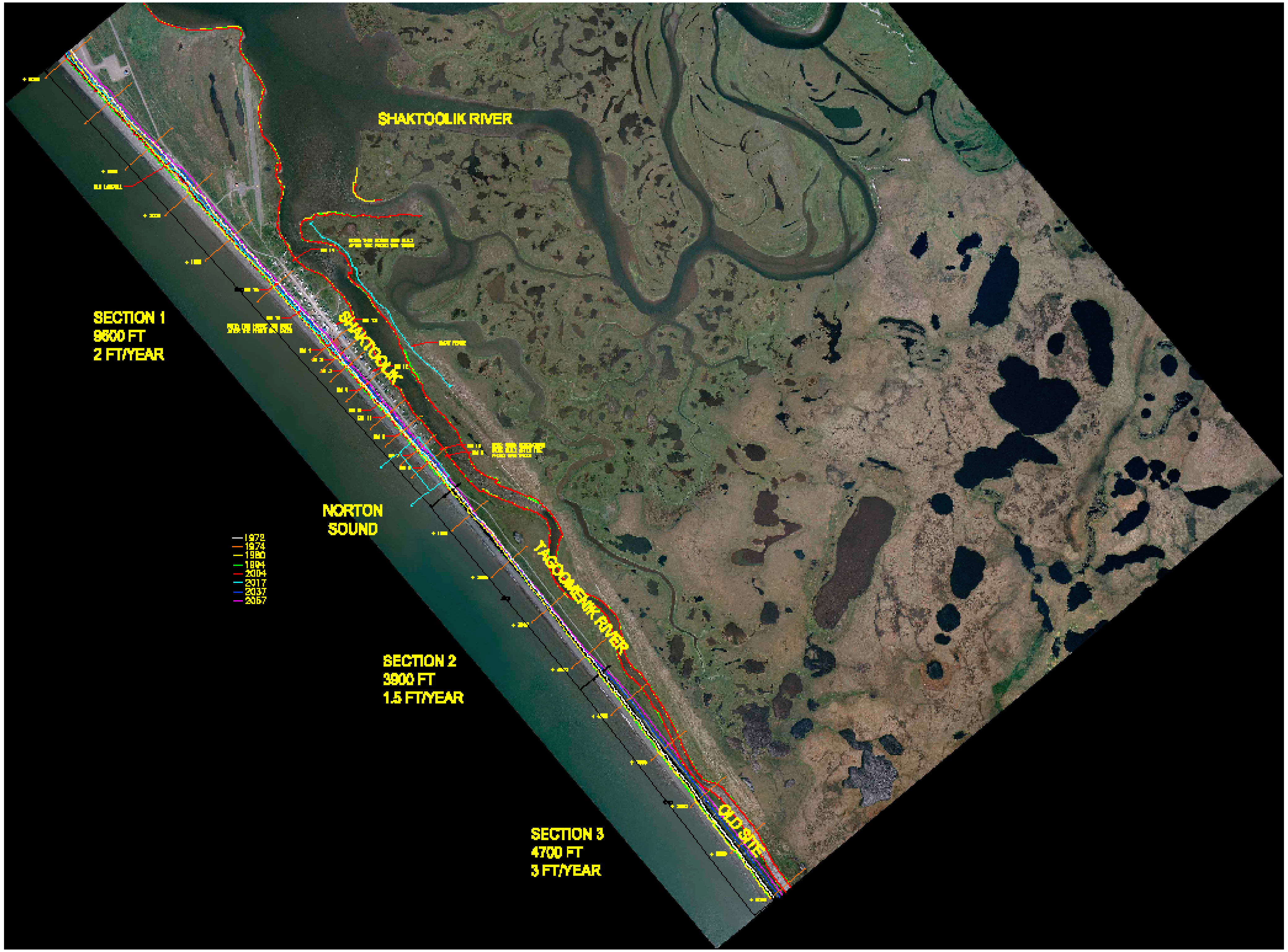

Figure 22 – Shaktoolik Vegetation Line Movement 1972 – 1994

6.0 COASTAL FLOOD ANALYSIS CONCLUSIONS

The community of Shaktoolik is susceptible to coastal flooding and erosion by coastal storms in Norton Sound. Residents have stated that fall storms with a southwest wind typically have the largest waves and cause the most damage (damage by movement of woody debris) and erosion. Residents of Shaktoolik recalled specific damages by the storms of October 1960, September 2005, and November 2009. The storm of October 1960 affected the "old site" and could be considered a 72-year event. The 2005 and 2009 storms affected the current community site, and could be considered 8-year and 9-year events, respectively. The majority of the storms that produced large waves, surge, and runup occurred in the 1960s and 1970s. The largest storm found in the 56-year record from 1954 to 2009 was the October 1960 storm. The residents of Shaktoolik occupied the "old site" from 1933 to 1974, and moved to the current site in 1974. The current community site has not experienced a storm of the magnitude of the October 1960 event.

Through the analyses presented in this study, it appears that at about the 50-year return period event, structures in the community would be affected by the storm water level from Norton Sound. This storm water level includes mean high tide, storm surge, and wave set up. Additional wave effects would be above the storm water level. Sea level rise and tsunami effects were not analyzed. The 50-year water level from the Tagoomenik River would likely not rise above the top of the landfill road. The 100-year storm water level from Norton Sound exceeds the finished floor elevation of all existing structures. The majority of storms in the Shaktoolik area bring debris to the shoreline. It is likely that higher return period events would carry this debris farther into the community causing roads to be blocked and possibly damaging structures.

Analysis of a series of orthorectified photographs shows the occurrence of erosion along the Norton Sound coast and on outside of bends in the Tagoomenik River. Using the interpretation of the extent of vegetation along the beach with photo sets dated 1980, 1994, and 2004, the average erosion rate was determined between 1.5 feet/year and 3 feet/year. The most erosion, based on the vegetation lines from the photographs, was near the "old site."

This study establishes the probability of coastal flooding and potential water elevations for the community of Shaktoolik. The serious nature of coastal flooding brings safety concerns that need to be addressed. Additional investigations that would help Shaktoolik address safety issues are the design analysis of structural flood control measures and flood proofing community infrastructure. Structural flood control measures may include a revetment for wave protection or relocation of structures. Flood proofing measures may include elevating buildings and mechanical and electrical units.

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APPENDIX A

SHAKTOOLIK SURGE REPORT,

COASTAL AND HYDRAULICS LABORATORY (CHL)

Storm-Induced Water Level Prediction Study for Shaktoolik Alaska

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Vicksburg, MS 39180-6199

Abstract: The U.S. Army Engineer District, Alaska (CEPOA) has a number of ongoing and potential projects located along the western coast of Alaska. At the request of CEPOA, the U.S. Army Engineer Research and Development Center, Coastal and Hydraulics Laboratory (ERDC/CHL) provided technical assistance in assessing storm-generated regional water levels and currents at selected sites. The purpose of this study was to add 2005 – 2009 events to the frequency-of-occurrence relationship of storm-generated water level database for Shaktoolik, AK.

Preface

The U.S. Army Engineer District, Alaska (CEPOA) has a number of ongoing and potential projects located along the western coast of Alaska. At the request of CEPOA, the U.S. Army Engineer Research and Development Center, Coastal and Hydraulics Laboratory (ERDC/CHL) provided technical assistance in assessing storm-generated regional water levels and currents at selected sites. The purpose of this study was to add 2005 – 2009 events to the frequency-of-occurrence relationship of storm-generated water level database for Shaktoolik, AK.

This study was conducted for the CEPOA. Ms. Mary T. Azelton served as the senior coastal engineer; Mr. Kenneth J. Eisses provided direct supervision as well as provided technical support and review for this study. Mr. David Williams served as the study program manager. Research and development activities for this study were conducted at the U.S. Army Engineer Research and Development Center (ERDC), Coastal and Hydraulics Laboratory (CHL), Vicksburg, MS. Drs. Raymond S. Chapman and Sung-Chan Kim, Coastal Processes Branch (HF-C), and Mr. David J. Mark, Estuarine Engineering Branch (HF-EL) performed the study.

This investigation was performed under the direct supervision of Mr. Ty Wamsley, Chief, HF-C, and Dr. Robert McAdory, Chief, HF-E. General supervision was provided by Mr. Bruce A. Ebersole, Chief, Flood and Storm Protection Division. In addition, Dr. William D. Martin served as Director, CHL, and Dr. Rose M. Kress served as acting Deputy Director. COL Gary E. Johnston was Commander and Executive Director of ERDC, and Dr. James R. Houston was Director.

Contents

Unit Conversion Factors

Multiply	By	To Obtain
Feet	0.3048	meters
Knots	0.5144444	meters per second
Miles (nautical)	1,852	meters
Miles (U.S. statute)	1,609.347	meters
Miles per hour	0.44704	meters per second

1 Introduction

The U.S. Army Engineer District, Alaska (CEPOA) has a number of ongoing and potential projects located along the western coast of Alaska. At the request of CEPOA, the U.S. Army Engineer Research and Development Center, Coastal and Hydraulics Laboratory (ERDC/CHL) provided technical assistance in assessing storm-generated regional water levels and currents at selected sites. The purpose of this study was to add 2005 – 2009 events to the frequency-of-occurrence relationship of storm-generated water level database for Shaktoolik, AK (Figure 1-1) , which is located at the eastern end of Norton Sound.

Figure 1-1 Shaktoolik AK study site

This study and report is an addition to the previous work of Chapman et al. 2005 and 2009, as such, the reader is directed to those publications for a detailed description of the data analysis and ADCIRC simulation procedure. The existing Western Alaska ADCIRC grid was refined and the bathymetry updated. Additional verification simulations were conducted to demonstrate model accuracy. A total of 74 ADCIRC storm event simulations have been performed and a data base of water levels verses return period was updated for Shaktoolik.

2 Selection of the 2005 – 2009 Events

The available data from the Nome gage in Norton Sound (NOAA gage 9468756, http://tidesandcurrents.noaa.gov/index.shtml) were examined to identify significant surge events that occurred during the 2005 – 2009 time period. To increase the number of storms simulated and emphasis events most affecting Shaktoolik, additional storm events were extracted from the continuous climatology data (1985 – 2009) when the local winds at Shaktoolik exceeded 15 m/s and prevailing direction was from the west to south. The storm events were defined to have a minimum 7-day duration centered about the peak wind speed. In cases where multiple events occurred within weeks of each other, a single simulation of a month long duration was performed. These storm events were included in the existing storm event population and are listed Table3-1.

3 Model Verification and Simulations

The numerical grid used in this study is that developed for the Storm-Induced Water Level Prediction Study for the Western Coast of Alaska (Chapman, et. al. 2009). The ADCIRC grid is shown in Figure 3-1.

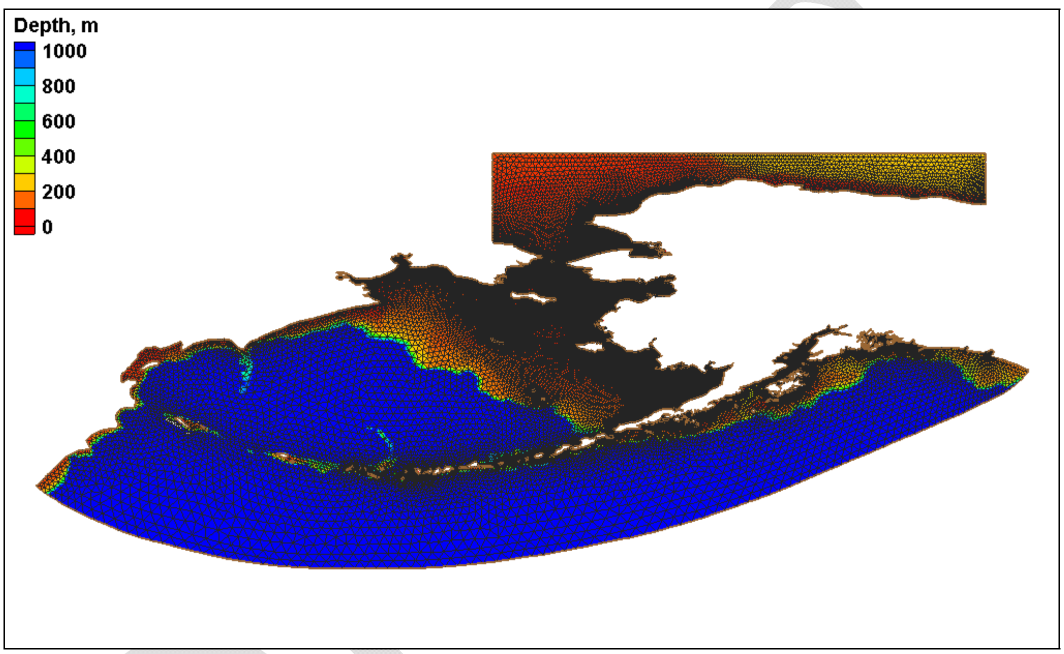

Figure 3-1. Numerical grid (Geographic projection).

Ice Concentration Correction

The ice correction adjustment to the surface wind stress drag coefficients utilized is that described in Chapman et. al. (2005, 2009) As an example, the ice-drag coefficient distribution for October 1992 is presented in Figure 3-2.

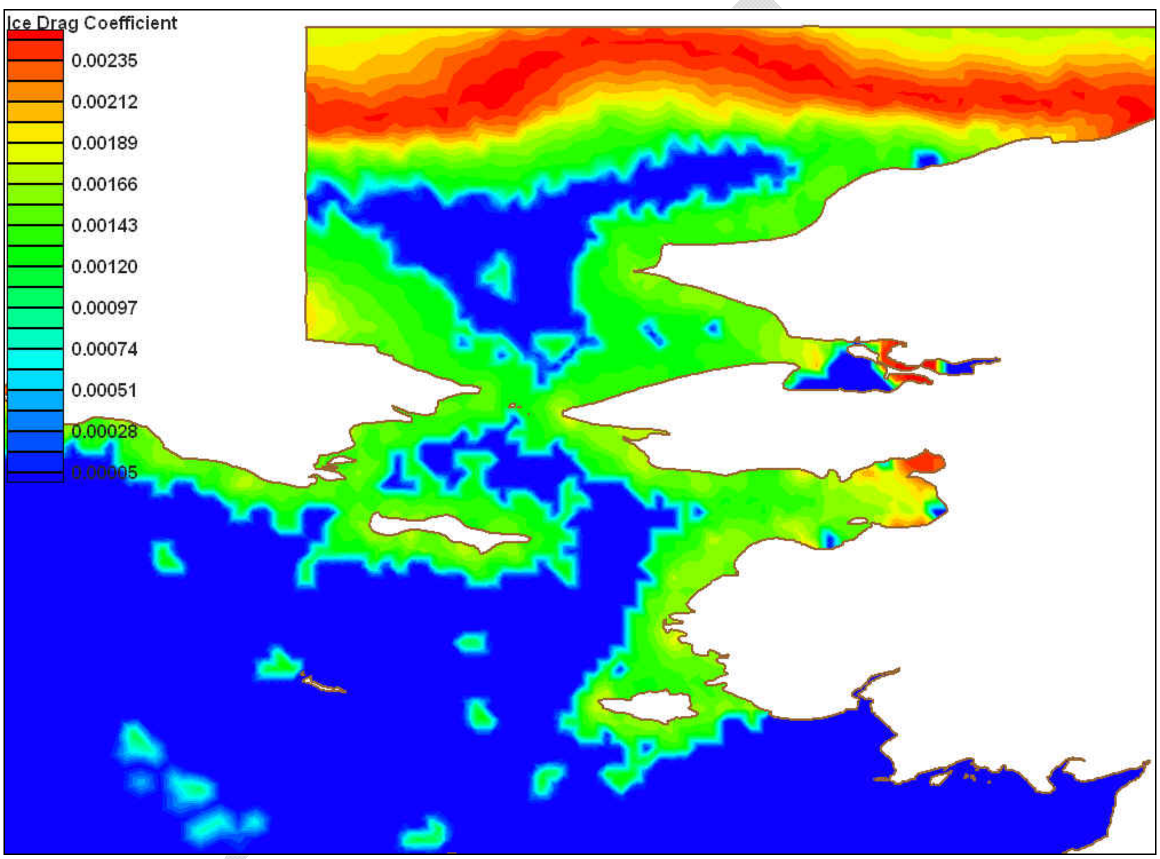

Figure 3-2. Ice-Drag Coefficient Distribution (Geographic projection).

Model Calibration and Additional Validation

Calibration and validation of the ADCIRC model was presented in Chapman et al. 2009. Satisfactory agreement between predicted and measured water levels during significant wind events provides confidence that the model can accurately replicate storm surges in the study area. As discussed in Chapter 2 of Chapman et al. 2009, the October 2004 storm was selected as the model calibration event at Nome and Red Dog Dock. The October 1992 storm chose as the original validation event as compared with Nome. The October 2004 calibration simulation (Figures 3-3 and 3-4), show good agreement between the model-predicted water-surface elevations and observed values at both Nome and Red Dog. The October 1992 predicted and observed water surface elevations at Nome, shown in Figure 3-5, again compare well. It should be noted that tidal forcing was not included in the model calibration and verification simulations.

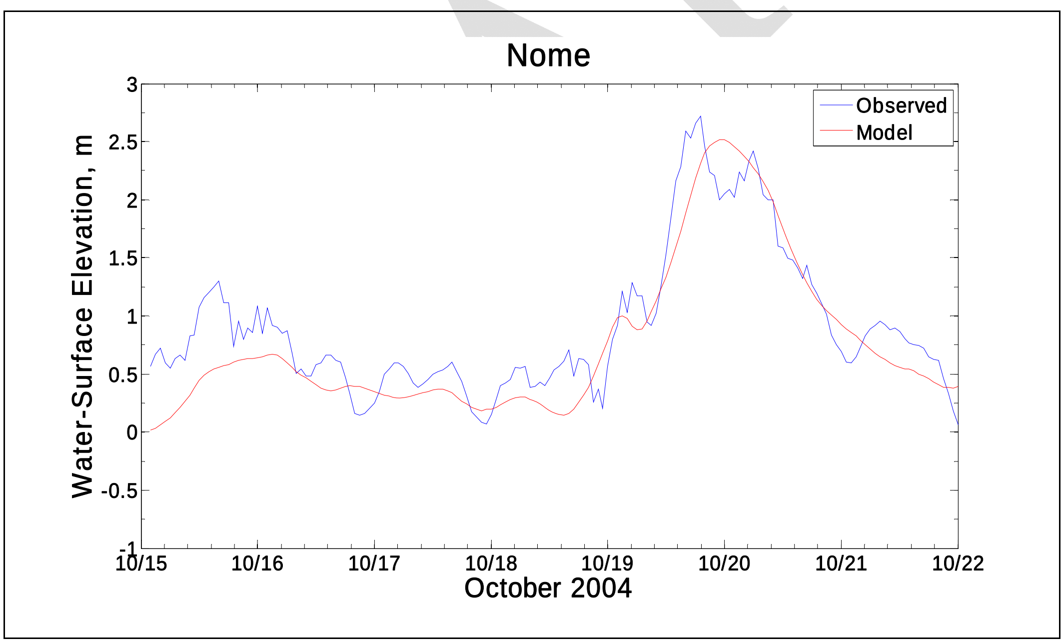

Figure 3-3. Comparison of observed and modeled water levels at Nome; October 2004.

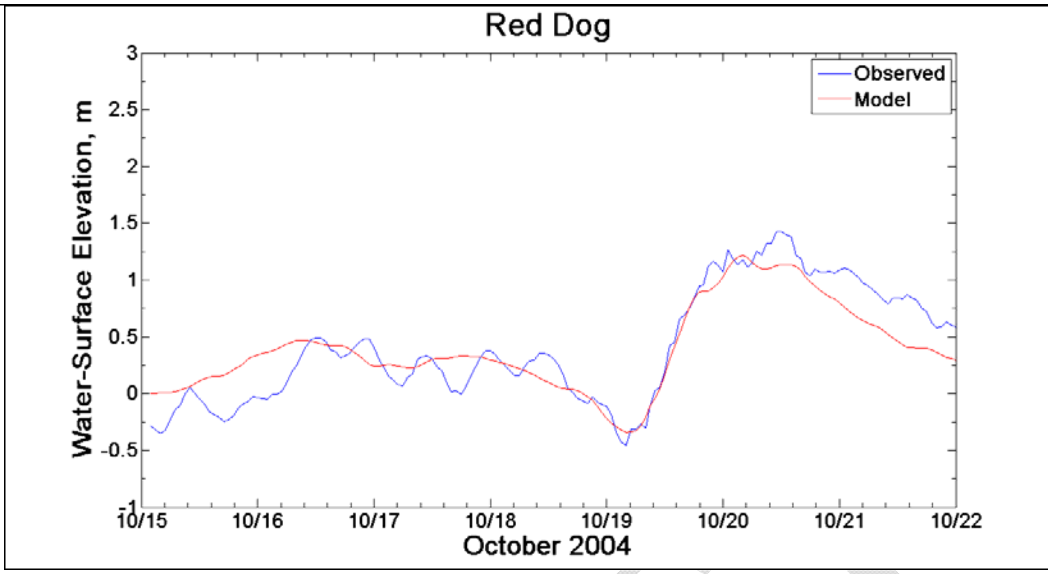

Figure 3-4. Comparison of observed and modeled water levels at Red Dog,; October 2004.

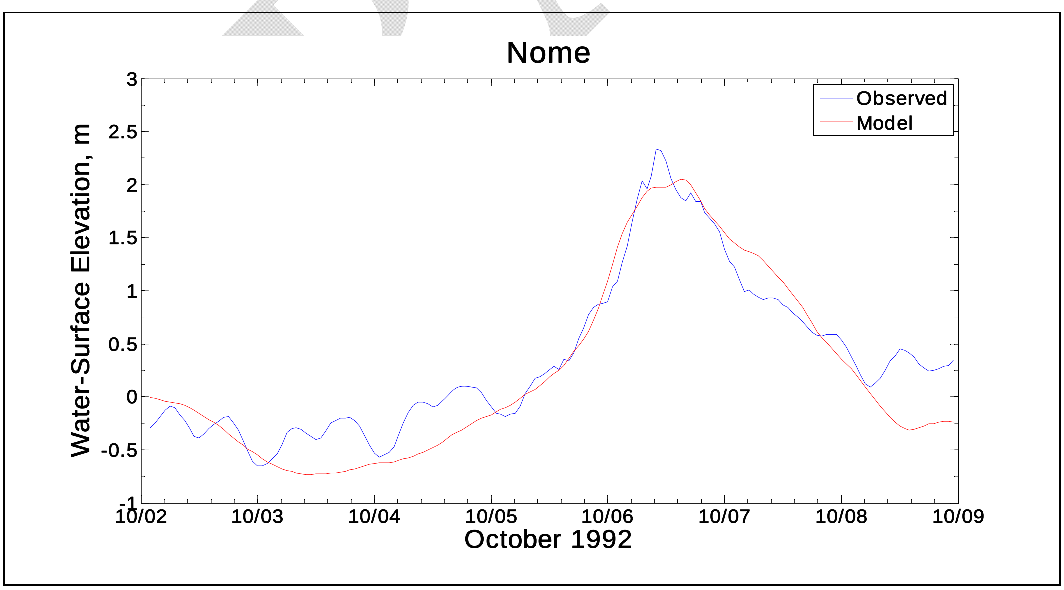

Figure 3-5. Comparison of observed and modeled water levels at Nome, AK; October 1992.

Additional verification simulations for this study for the September 2005 and November 2009 events were performed using the identical model set up of the Chapman et al. 2009 study. Figure 3-6 presents a comparison of the observed water surface elevation at Nome during the November 2003 event, along with those predicted at Nome and Shaktoolik. It is seen that the predicted water surface elevation estimates at both Nome and Shaktoolik compare well with the observations at Nome. In addition, the additional storm surge at Shaktoolik due to its location at the east end of Norton Sound and the prevailing direction of the wind is apparent.

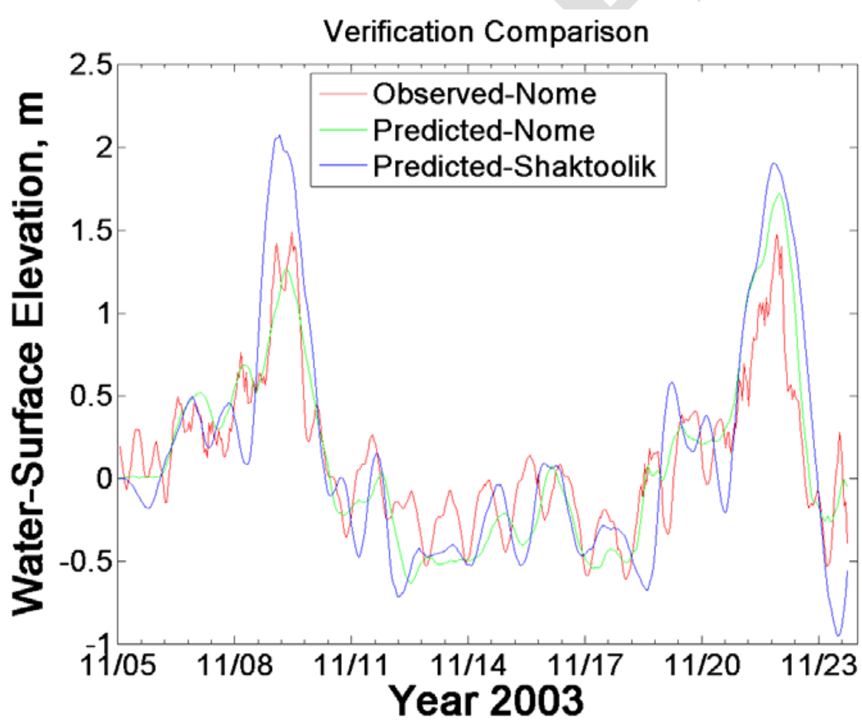

Figure 3-6. Comparison of observed and modeled water levels at Nome; November 2003.

Next, the verification simulation during the September 2005 events shows good agreement between observed and predicted water levels at Nome, however, the more south to southwest orientation of the wind direction does not result in an increase in storm surge at Shaktoolik (Figure 3-7).

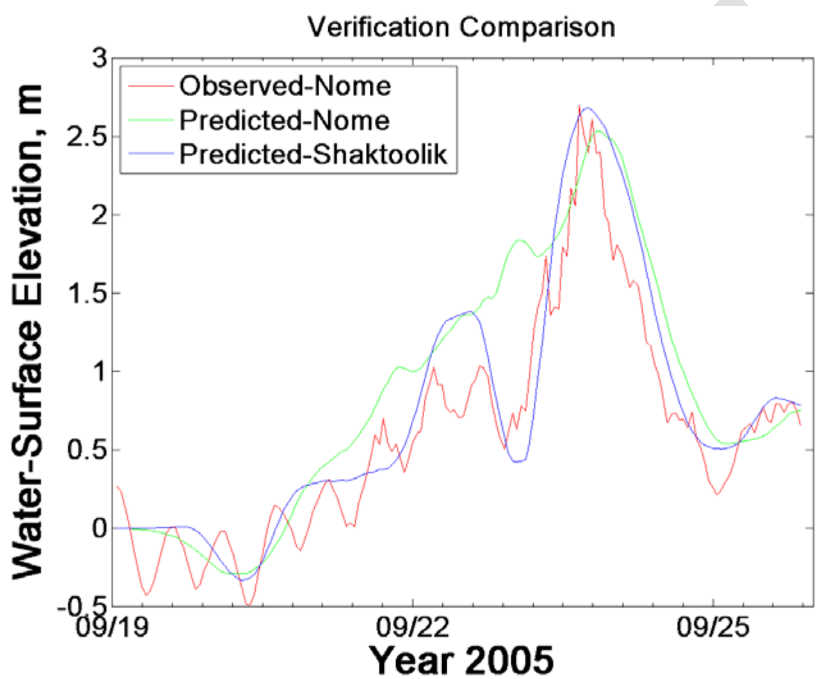

Figure 3-7. Comparison of observed water levels at Nome, AK with predicted at Nome and Shaktoolk during September 2005.

Finally, the comparison of observed and predicted water surface elevations at Nome during November 2009 (Figure 3-8) does not show good agreement, however, the increase in storm surge elevation in eastern Norton Sound is apparent.

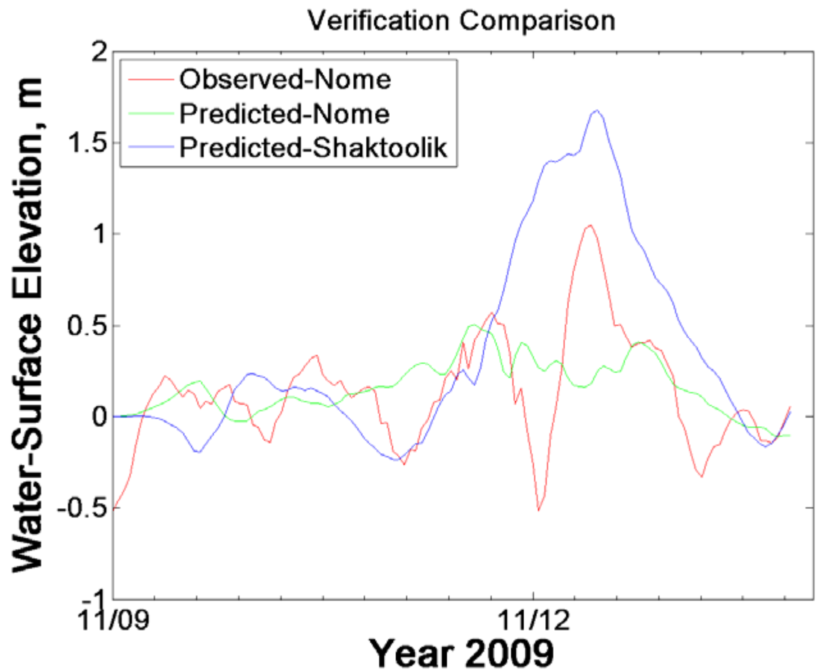

Figure 3-8. Comparison of observed water levels at Nome, AK with predicted at Nome and Shaktoolk during November 2009.

Storm Surge Production Simulations

Subsequent to model verification, additional Shaktoolik storm-event production simulations were performed. Table 3-1 presents the top fifty six surge events.

Table 3-1. Shaktoolik top 56 events (1954 – 2009)

RANK	START DATES (in UTC)				Max (m)	Duration (Days)
	Year	Month	Day	Hour		
1	1960	10	1	0	4.35	6.5
2	1974	11	10	0	3.8	6.5
3	1970	11	26	0	3.27	6.5
4	1966	11	14	0	3.2	6.5
5	1978	11	8	0	3.08	6.5
6	1975	8	21	15	2.8	6.5
7	2004	10	15	0	2.79	6.5
8	2005	9	18	0	2.68	7.5
9	1965	11	12	0	2.64	6.5

RANK	START DATES (in UTC)				Max	Duration (Days)
10	1996	10	25	0	2.63	6.5
11	2002	4	22	0	2.62	7
12	2006	2	4	0	2.47	22.75
13	1990	9	1	0	2.4	9.7
14	1991	10	18	0	2.2	6.5
15	2009	3	2	0	2.19	6.5
16	2006	2	4	0	2.17	22.75
17	1990	11	16	0	2.14	6.5
18	2001	2	5	0	2.11	9
19	2003	11	4	0	2.07	22.75
20	1985	11	6	0	2.07	6.5
21	2004	12	22	0	2.04	6.5
22	2003	12	4	0	1.9	22.75
23	2006	2	4	0	1.87	22.75
24	1983	10	3	0	1.84	8.5
25	1994	8	12	0	1.75	10
26	1960	9	21	0	1.73	6.5
27	1992	10	2	0	1.7	6.5
28	2009	12	3	0	1.69	7
29	2009	11	8	0	1.68	5.5
30	1998	4	6	0	1.67	23.5
31	1996	11	12	0	1.66	6.5
32	1997	8	1	0	1.61	5
33	1988	8	11	0	1.59	6.5
34	2002	1	13	0	1.56	8.5
35	1993	11	17	0	1.52	6.5
36	1998	8	16	0	1.47	6.5
37	1998	0	20	0	1.41	7.5
38	2004	11	19	0	1.4	6.5
49	1986	7	18	0	1.4	5
40	2000	8	26	0	1.32	6
41	1989	11	12	0	1.31	6.5
42	1962	8	29	0	1.29	6.5
43	1964	10	14	0	1.25	6.5
44	1999	7	27	0	1.22	7
45	1982	9	16	0	1.2	7
46	1986	9	8	0	1.19	5
47	1979	11	7	0	1.18	6.5
48	1961	6	12	12	1.16	6.5
49	1995	10	27	0	1.14	6.5
50	1989	10	19	0	1.13	6.5

RANK	START DATES (in UTC)				Max	Duration (Days)
51	2007	9	1	0	1.13	22.75
52	1963	8	17	0	1.11	6.5
53	1963	10	1	0	1.07	6.5
54	1978	10	30	21	1.0	5
55	2000	7	11	00	0.90	7.0
56	1987	10	11	0	0.85	7.7

These results were included in the storm event population at Shaktoolik and Ranked Method and EST extreme statistics generated. The Ranked Method results are summarized graphically in Figure 3-9.

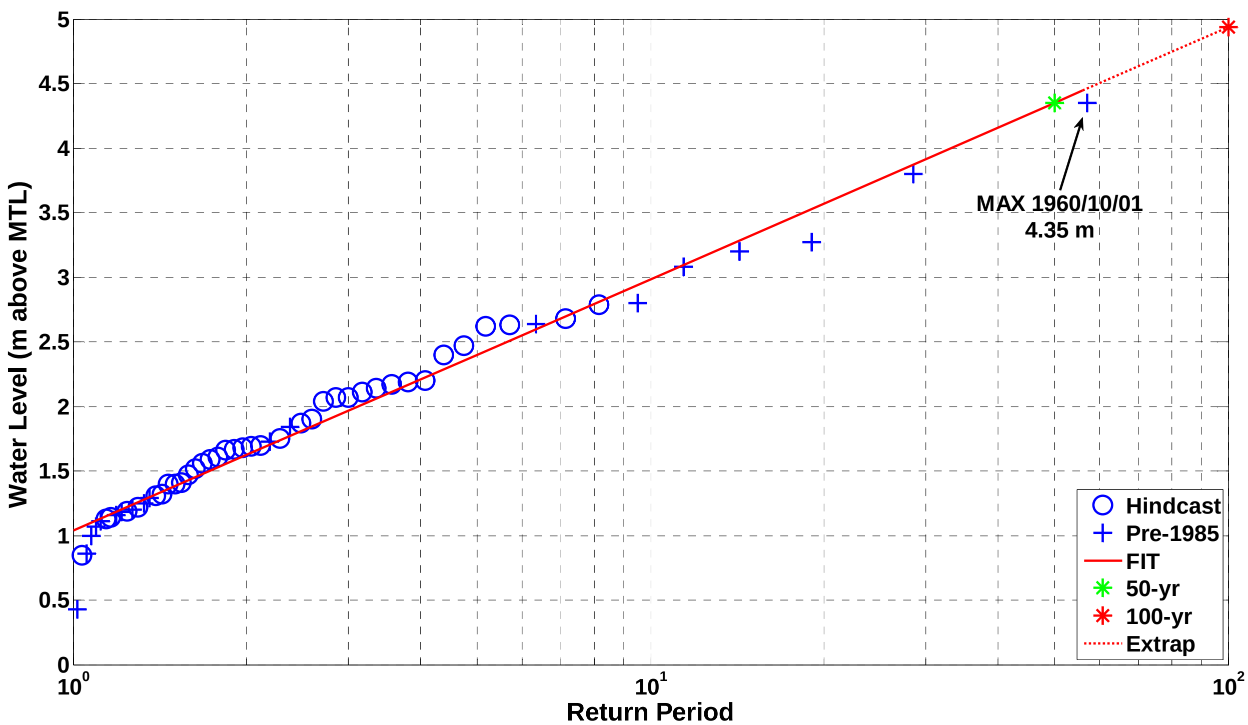

Figure 3-9. Ranked Method statistics Shaktoolik events (1954 – 2009)

Table 3-2 presents the updated top ten surge events and the EST based statistics. The September 2005 events generated a storm surge water level of 8.79 feet was included in the top ten list as the eighth rank event.

Table 3-1. Shaktoolik top ten events (1954 – 2009)

Shaktoolik
Location:
Longitude: 161.1500°W
Latitude: 64.3300°N
Exposure: SW
Top 10 surge events between 1954 and 2009

	Starting Date	Maximum Surge (ft MSL)	Minimum Surface Pressure (mb)	Maximum Wind	
				Speed (mph)	Direction
1	01-Oct-60	14.27	977.8	47.2	SW
2	10-Nov-74	12.47	981.6	40.0	SSE
3	26-Nov-70	10.73	1001.5	38.7	SW
4	14-Nov-66	10.50	1002.1	40.7	SSE
5	08-Nov-78	10.10	1001.9	37.8	SSE
6	25-Aug-75	9.19	1000.8	41.2	SSW
7	15-Oct-04	9.15	984.6	33.6	SSW
8	18-Sep-05	8.79	985.6	42.4	SSW
9	12-Nov-65	8.66	975.6	41.4	S
10	25-Oct-96	8.63	1008.7	25.9	S

Frequency of Occurrence

Return Period (years)	5	10	15	20	25	50	100
Surge Level (ft mllw)	8.67	10.57	11.39	12.04	12.61	14.87	17.26
Std. Deviation (ft)	0.56	0.59	0.75	0.98	1.21	2.10	2.92

It is seen in Table 3-2 that the increase in record length and replacing the eighth ranked storm event results in small decrease in the frequency of occurrence of storm water levels.   It should be noted that the original EST estimates for 1954-2004 used the tide range at Unalakleet (2.20 ft) to adjust the MTL simulation results to MLLW, whereas the more recent estimates used tide measurements at Shaktoolik, which established a preliminary adjustment of 1.95 ft.

Table 3-2. Shaktoolik events (1954 – 2004)

Frequency of Occurrence

Return Period (years)	5	10	15	20	25	50	100
Surge Level (ft mllw)	8.09	10.99	12.14	12.90	13.55	16.21	19.10
Std. Deviation (ft)	0.79	0.88	0.92	1.21	1.54	2.92	3.41

6 Summary

The purpose of this study was to add 2005 – 2009 events to the frequency-of-occurrence relationship of storm-generated water level database for Shaktoolik This study and report is an addition to the previous work of Chapman et al. 2005 and 2009, as such, the reader is directed to those publications for a detailed description of the data analysis and ADCIRC simulation procedure. Additional verification simulations were conducted to demonstrate model accuracy. A total of 74 ADCIRC storm event simulations have been performed and a data base of water levels verses return period was updated for Shaktoolik. The results of this study show that the increase in storm record time period and lack of additional maximum surge events suggest a slightly lower 50 and 100 year water surface elevation estimates than that reported in Chapman et al. 2009. Futhermore, the idea that the use of the nearest NOAA gage to estimate storm water extremes at specific and remote locations is not supported.

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APPENDIX B

COMMUNICATIONS – RESIDENT ACCOUNTS OF STORM DAMAGES

3/8/11: Spoke with Myron Savetilik; 955-2487, suggested talking to folks at IRA building.

Spoke with Michael Sookiayak (IRA office); 955-3701

- 2009, logs and debris washed up to airport apron
- 2009, logs broke chain-link fence in front of school septic
- 2009, logs pushed up against Corporation building

3/10/11: Spoke with Fred Sagoonick; 955-3241

- 2005, gravel under stairwell washed out from Corporation building
- 2005, wood debris pushed up to near the tank farm

3/28/11: Spoke with Edgar Jackson; 955-3501

- Edgar is a lifetime resident of Shaktoolik, he is 65 years old
- 1960, old town site airport covered in wood debris; does not think any of it came from the river; witnessed water overtopping from seaside to riverside

4/28/11: Sent memorandum to community residents, Kawerak, and Denali Commission showing initial modeling results for confirmation of validation points.

5/19/11: Met with Edgar Jackson in Anchorage. He reiterated his initial statement about the 1960 storm, and said that several people in the community remember that particular event at the old site location. Edgar also said that the debris was so large on the old site runway that they could not remove it by hand. Special equipment had to be moved in to assist in the removal of the debris. Edgar also told of spray and waves 3-4 feet high wetting the windows of the seaward buildings at the old site during the 1960 event. Due to the overwash from the waves in Norton Sound, saltwater entered the Tagoomenik River. Edgar remembered talking to his Elders at the time of the 1960 event, and he was told that storm was the worst of their memory as well.

Edgar also talked about the October 2010 storm. He said that a significant amount of ice had accumulated near shore and he and many others were sure that the ice had protected the community from severe waves. At the time of the 2010 event, the Tagoomenik River was iced over and no one would be able to pass over it. Edgar noted that if there had been large waves with runup, there would have been no safe place for evacuation.

Edgar graciously agreed to talk with the Shaktoolik Community when the Corps presents its findings later this summer.