APPENDIX C

HYDRAULIC DESIGN

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1.0 INTRODUCTION

1.1 Appendix Purpose

This appendix describes the hydraulic design of the Little Diomede Navigation Improvement Project. It provides the background for determining the Federal interest in the major construction features including breakwater construction dredging, and operation and maintenance.

1.2 Project Purpose

The purpose of this study is to identify a design to enable protected boat access to the shoreline. Improvements were screened to ensure the correct navigation improvement measures were evaluated in more detail for the National Economic Development (NED) and locally preferred plan.

1.3 Description of Project Area

Diomede is located on the west coast of Little Diomede Island in the Bering Straits, 135 miles northwest of Nome (Figure 1). It is only 2.5 miles from Big Diomede Island, Russia, and the international boundary lies between the two islands. It lies at approximately 65.76 North Latitude and 168.96 West Longitude. (Sec. 08, T004N, R049W, Kateel River Meridian.) Diomede is located in the Cape Nome Recording District. The area encompasses 2.8 sq. miles of land. Summer temperatures average 40 to 50 °F. Winter temperatures average from -10 to 6 °F. Annual precipitation averages 10 inches, and annual snowfall averages 30 inches. During summer months, cloudy skies and fog prevail. The Bering Strait is generally frozen between mid-December and mid-June.

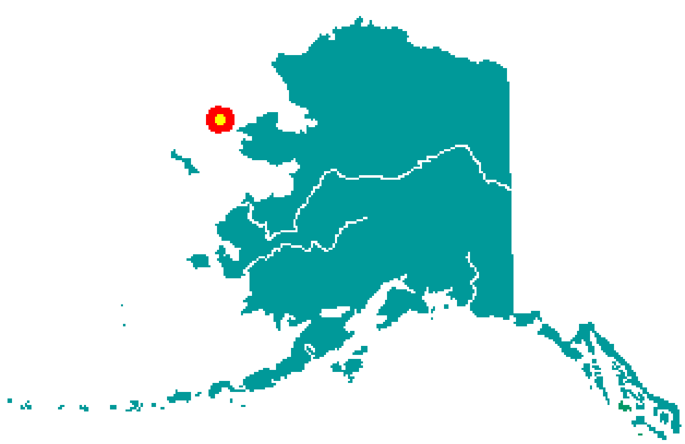


Figure 1 State of Alaska location map with location of Little Diomede.

1.4 Background

The community of Diomede is situated on a flat-topped, steep-sided island that is very isolated by its location (Figure 2 and Figure 3). Rough seas and persistent fog that shrouds the island characterizes the island during the summer months.

Little Diomede Island is believed to be a Tuya type mountain (distinctive, flat-topped, steep-sided volcano formed when lava erupts through a thick glacier or ice sheet). The community's location is the only area which does not have near-vertical cliffs to the water. Behind the town and around the entire island rocky slopes rise at about 40° up to the relatively flattened top. The island has very scant vegetation.

Diomede residents live a subsistence lifestyle, harvesting fish and crab, hunting whales, walrus, seals and polar bears. The limited terrain does not allow for a runway, so weekly mail delivery is made by helicopter. Float planes rarely risk landing on the rough seas in summer, but ski planes do occasionally land on an ice runway during the winter months. Most supplies and fuel come from an annual barge delivery.

Because of its location, Diomede is vulnerable to waves from the north, south, and west. This exposure limits the ability of the residents to launch their boats to subsistence hunt and fish during the open water season. The shore is rocky at the village and even small wave action can cause difficulties and damage when launching their boats or trying to return from hunting or fishing.

Figure 2 Left: Little Diomede Island with the community of Diomede circled.

Figure 3 Aerial view of Diomede

2.0 STUDY CONSTRAINTS

During the Navigation Improvement Study, a number of study constraints were identified. These included:

(1) Any in water work will need to be coordinated to not interfere with subsistence hunting of marine mammals.
(2) Work offshore is governed by ice formation.
(3) There is limited space to house a construction crew.
(4) Gravel sized material to build a construction pad or barge landing is not available locally
(5) Ice constrains the shipping season for the importation of construction materials and there are no offloading facilities other than the shore.
(6) There is no lay down area to store equipment or materials

3.0 CLIMATOLOGY, METEOROLOGY, HYDROLOGY

3.1 Temperature

Little Diomede is in an arctic environment. Summer temperatures average 40 to 50 °F. Winter temperatures average from -10 to 6 °F. Annual precipitation averages 10 inches, and annual snowfall averages 30 inches. During summer months, cloudy skies and fog prevail.

The nearest site to Little Diomede is Wales (Figure 4) where climate records were kept from 1949 to 1995. While not exact, the statistics from Wales can give an indication of the climate at Little Diomede (Table 1).

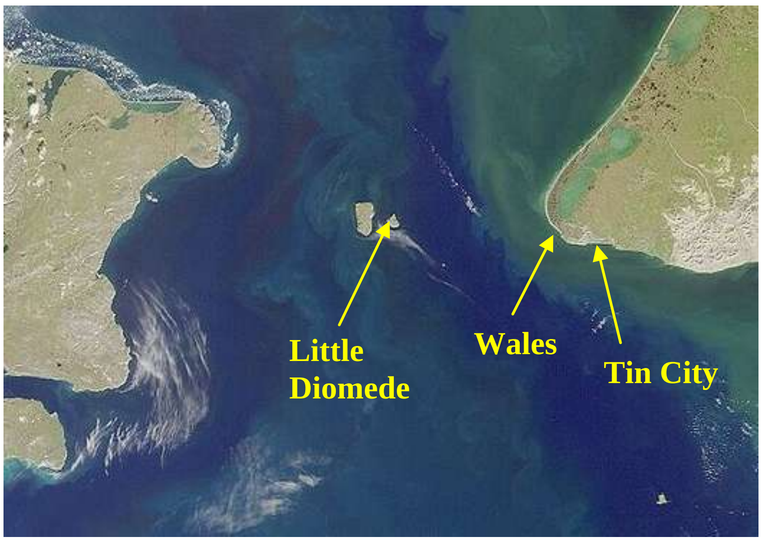


Figure 4 Little Diomede in relation to Wales and Tin City

Table 1 Period of Record Monthly Climate Summary

WALES, ALASKA (509739)

Period of Record : 9/ 1/1949 to 8/31/1995

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Average Max. Temperature (F)	8.4	2.8	5.8	16.4	32.1	43.3	51.0	50.7	43.8	32.7	22.3	10.1	26.6
Average Min. Temperature (F)	-5.9	-10.6	-8.3	3.5	22.9	33.3	41.7	42.4	36.4	24.7	11.0	-2.7	15.7
Average Total Precipitation (in.)	0.43	0.37	0.44	0.31	0.51	0.68	1.42	2.65	2.15	1.41	0.71	0.40	11.48
Average Total SnowFall (in.)	4.1	3.8	4.5	3.3	2.2	0.2	0.2	0.0	1.4	6.2	7.7	4.6	38.1
Average Snow Depth (in.)	9	11	13	14	10	1	0	0	0	1	5	8	6

3.2 Ice Conditions

At Little Diomede, the Bering Strait typically is frozen between mid-December and mid-June. Stability is achieved after one or more significant pack ice “shoves” deform and ground the ice. Once grounded and stabilized, the shore fast ice cover remains in place until the start of breakup in June to July.

3.3 Tides

Little Diomede is in an area of semi-diurnal tides with two high waters and two low waters each lunar day.

Tidal parameters at Little Diomede are similar to those at Tin City (Figure 4). The tidal parameters in Table 2 were determined using National Oceanic and Atmospheric Administration published data for Tin City. The Tin City tide data is based on observations made during the month of September 2007. There was no reported highest observed water level and no lowest observed water level.

Table 2 Tidal Parameters – Tin City

Parameter	**Elevation (ft)**
Mean Higher High Water (MHHW)	1.02
Mean Sea Level (MSL) *	0.47
Mean Tide Level (MTL) **	0.46
Mean Lower Low Water (MLLW)	0.00

*MSL The arithmetic mean of hourly heights observed over the National Tidal Datum Epoch. Shorter series are specified in the name; e.g. monthly mean sea level and yearly mean sea level.
**MTL The arithmetic mean of mean high water and mean low water.

3.4 Currents

The dominant flow through the Bering Straits is to the north. The current velocity has been reported to vary between 1to 3 knots. Flow at the surface is greatly influenced by winds. Flow to the north increases strongly with southerly winds and diminishes or completely reverses under the influence of northerly winds.

3.5 Water Level

The effect of an increase in water level needs to be evaluated when designing a navigation project. Water level increase is typically a result of wave set up, storm surge, and tide. Relative sea level rise is a longer term increase in water level and its effects on a project is an additional factor that needs to be considered in a breakwater design.

Wave Setup
Wave setup is the water level rise at the coast caused by breaking waves. The breakwaters evaluated for this project extend beyond the area of breaking waves so wave set up was not considered in the calculations for the Little Diomede Navigation Improvement project.

Storm Surge
Storm surge is an increase in water elevation caused by a combination of relatively low atmospheric pressure and wind driven transport of seawater over relatively shallow and large unobstructed waters. Friction at the air-sea interface is increased when the air is colder than the water, which causes more wind-driven transport. Storm induced surge can produce short term increases in water level, which can rise to an elevation considerably above tidal levels. Little Diomede experiences low pressure events that could contribute to storm surge, but the water is too deep to stack up and cause a significant surge. A rise in the water elevation due to surge has not been a problem reported at Little Diomede.

Tide
The mean higher high tide of 1.02 feet was used for the high water elevation. The basis for the high tide Tin City tide data previously discussed.

Sea Level Rise
In recent years evidence has suggested that the arctic environment is experiencing a warming trend. The magnitude, duration, and effect of a warming trend is not known; however the Office for Naval Research, the Naval Ice Center, the Oceanographer of the Navy, and the Arctic Research Commission held a conference in 2002 which discussed the shrinking polar ice cap. They even indicated that the polar ice pack is projected to retreat to the extent that a new shipping route may be opened. This would potentially increase frequency of the large storms experienced by Little Diomede.

The Corps of Engineers requires that planning studies and engineering designs over the project life cycle, for both existing and proposed projects consider alternatives that are formulated and evaluated for the entire range of possible future rates of sea-level change (SLC), represented by three scenarios of “low,” “intermediate,” and “high” sea-level change. According to the EC the SLC “low” rate is the historic SLC. The “intermediate” and “high” rates are computed using the following:

> Estimate the “intermediate” rate of local mean sea-level change using the modified NRC Curve I and the NRC equations. Add those to the local historic rate of vertical land movement.
>
> Estimate the “high” rate of local mean sea-level change using the modified NRC Curve III and NRC equations. Add those to the local rate of vertical land movement. This “high” rate exceeds the upper bounds of IPCC estimates from both 2001 and 2007 to accommodate potential rapid loss of ice from Antarctica and Greenland.

NRC Equations

The 1987 NRC described these three scenarios using the following equation:

$$E(t) = 0.0012t + bt^2$$

in which t represents years, starting in 1986, b is a constant, and $E(t)$ is the eustatic sea-level change, in meters, as a function of t. The NRC committee recommended “projections be updated approximately every decade to incorporate additional data.” At the time the NRC report was prepared, the estimate of global mean sea-level change was approximately 1.2 mm/year. Using the current estimate of 1.7 mm/year for GMSL change, as presented by the IPCC (IPCC 2007), results in this equation being modified to be:

$$E(t) = 0.0017t + bt^2$$

> The three scenarios proposed by the NRC result in global eustatic sea-level rise values, by the year 2100, of 0.5 meters, 1.0 meters, and 1.5 meters. Adjusting the equation to include the historic GMSL change rate of 1.7 mm/year and the start date of 1992 (which corresponds to the midpoint of the current National Tidal Datum Epoch of 1983-2001), results in updated values for the variable b being equal to 2.71E-5 for modified NRC Curve I, 7.00E-5 for modified NRC Curve II, and 1.13E-4 for modified NRC Curve III. The three GMSL rise scenarios are depicted in Figure 5.

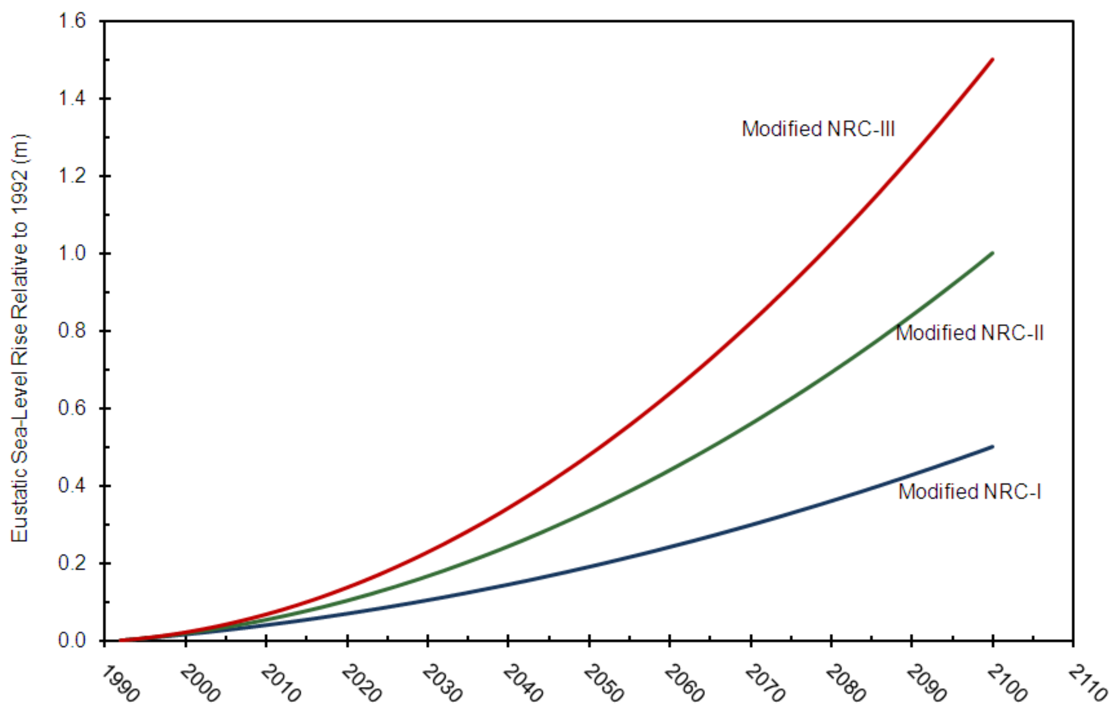


Figure 5 Scenarios for GMSL Rise (based on updates to NRC 1987 equation).

Manipulating the equation to account for the fact that it was developed for eustatic sea level rise starting in 1992, while projects will actually be constructed at some date after 1992, results in the following equation:

$$E(t_2) - E(t_1) = 0.0017(t_2 - t_1) + b(t_2^2 - t_1^2)$$

where t_1 is the time between the project's construction date and 1992 and t_2 is the time between a future date at which one wants an estimate for sea-level change and 1992 (or $t_2 = t_1$ + number of years after construction) . For the three scenarios proposed by the NRC, b is equal to 2.71E-5 for Curve 1, 7.00E-5 for Curve 2, and 1.13E-4 for curve 3.

This sea level rise was then added to a measured sea level trend for the Little Diomede area. There is no sea level trend data for Little Diomede or the area around Little Diomede. Guidance in Appendix C of EC 1165-2-212 recommends that the next closest long term gage be used. NOAA has sea level trends published for Providenia, Russia, which is the closest station to Little Diomede. The sea level trend for Providenia is +0.1299 inches/year which is 0.54 feet in 50 years. This value was added to the values obtained from the NRCS equation (Table 3).

Table 3 Sea Level Rise Prediction for a 50 Year Project Life.

Risk	Low	Intermediate	High
	0.54 feet	1.2 feet	2.5 feet

For a fifty year project life, a project at Little Diomede could see sea level rise as much as 2.5 feet (Table 3).

3.6 Soil Conditions

The slopes around the island of Little Diomede are comprised of loose boulders that can be unstable and result in slides. The boulders are also home to many species of birds. The potential to use rock from the island for the navigation project was evaluated but the presence of nesting birds, the lack of storage area to stockpile the boulders, the potential for slides to occur as the boulders were collected, and the possible need for blasting near the community made the use of the boulders from the site an impractical alternative.

A field investigation of subsurface conditions was conducted by Peratovich, Nottingham, and Drage (PN&D) in 2002. The purpose of the investigation was to explore the feasibility of the installation of a seawater intake for an Arctic Environmental Observatory. As part of the feasibility study, subsurface explorations north of the helipad were performed (Figure 6). Borings from the investigation indicate that the sea floor is comprised of boulders similar to the nearshore environment (Figure 7 though Figure 13). While these borings are not in the footprint of the proposed breakwaters, they give an initial indication of the seafloor conditions which appear stable, and indicate that dredging could possibly require blasting. These assumptions will need to be verified during when plans and specifications are being developed for construction.

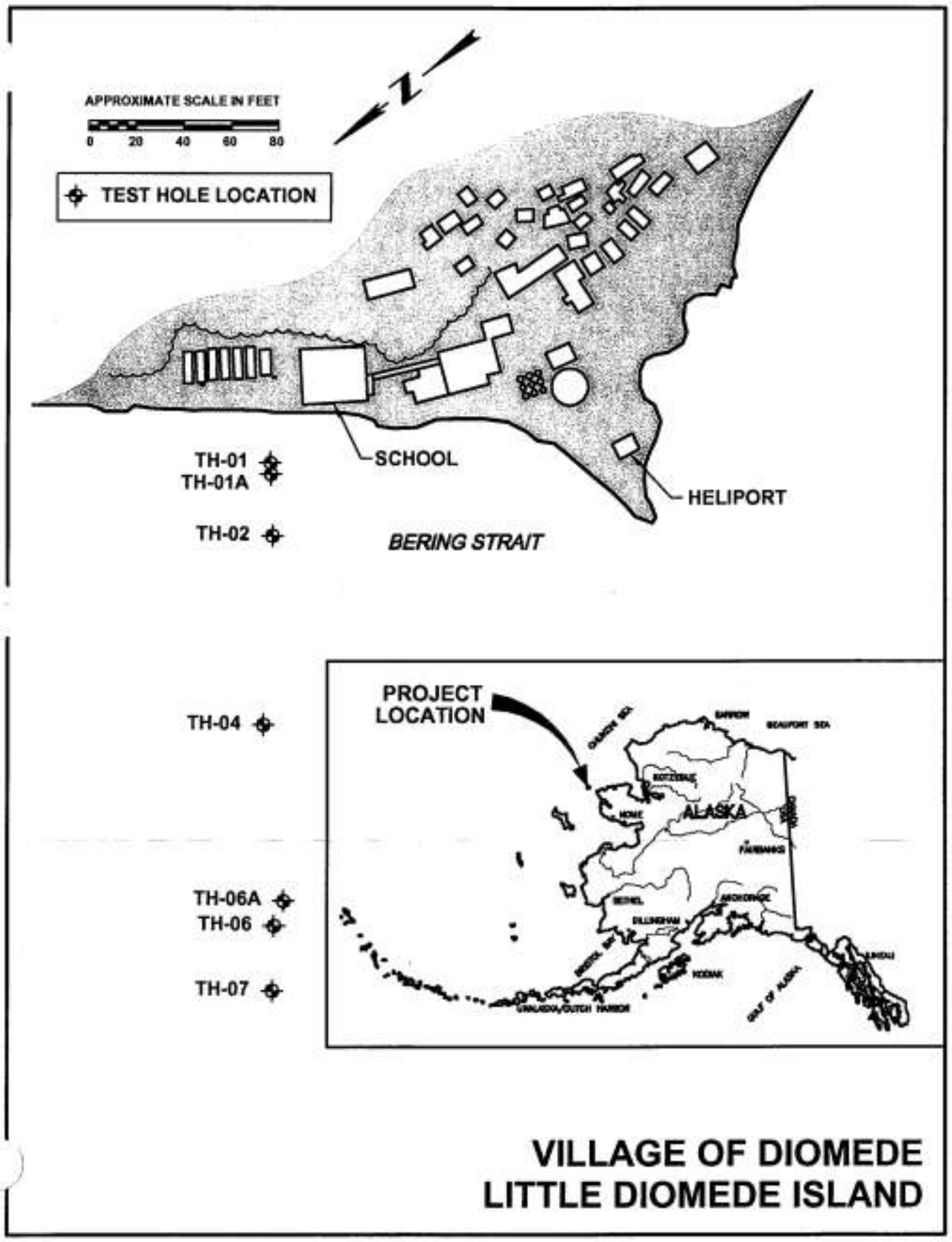


Figure 6 Location of offshore soil borings from the PN&D investigation.

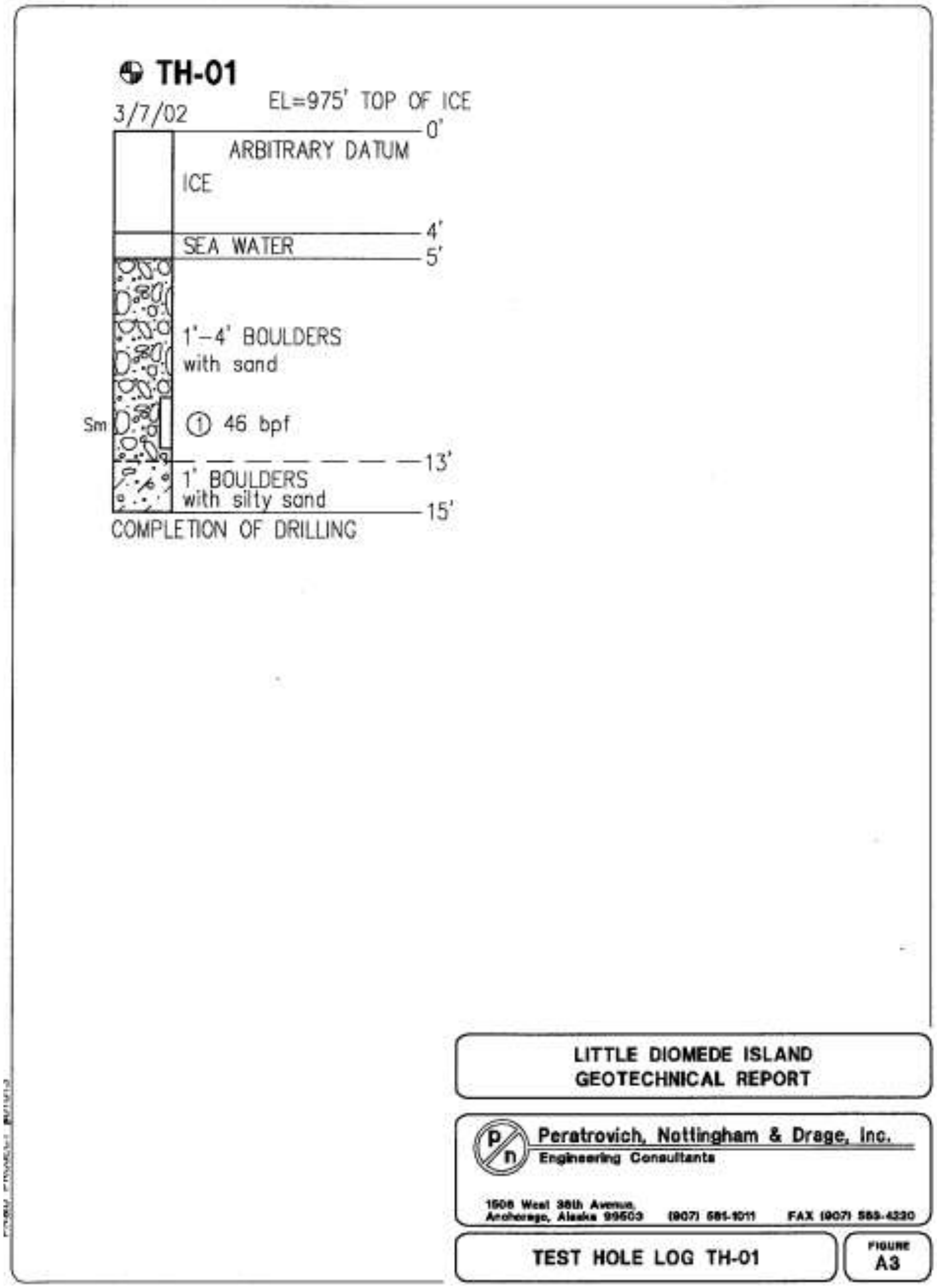


Figure 7 Test hole TH-01

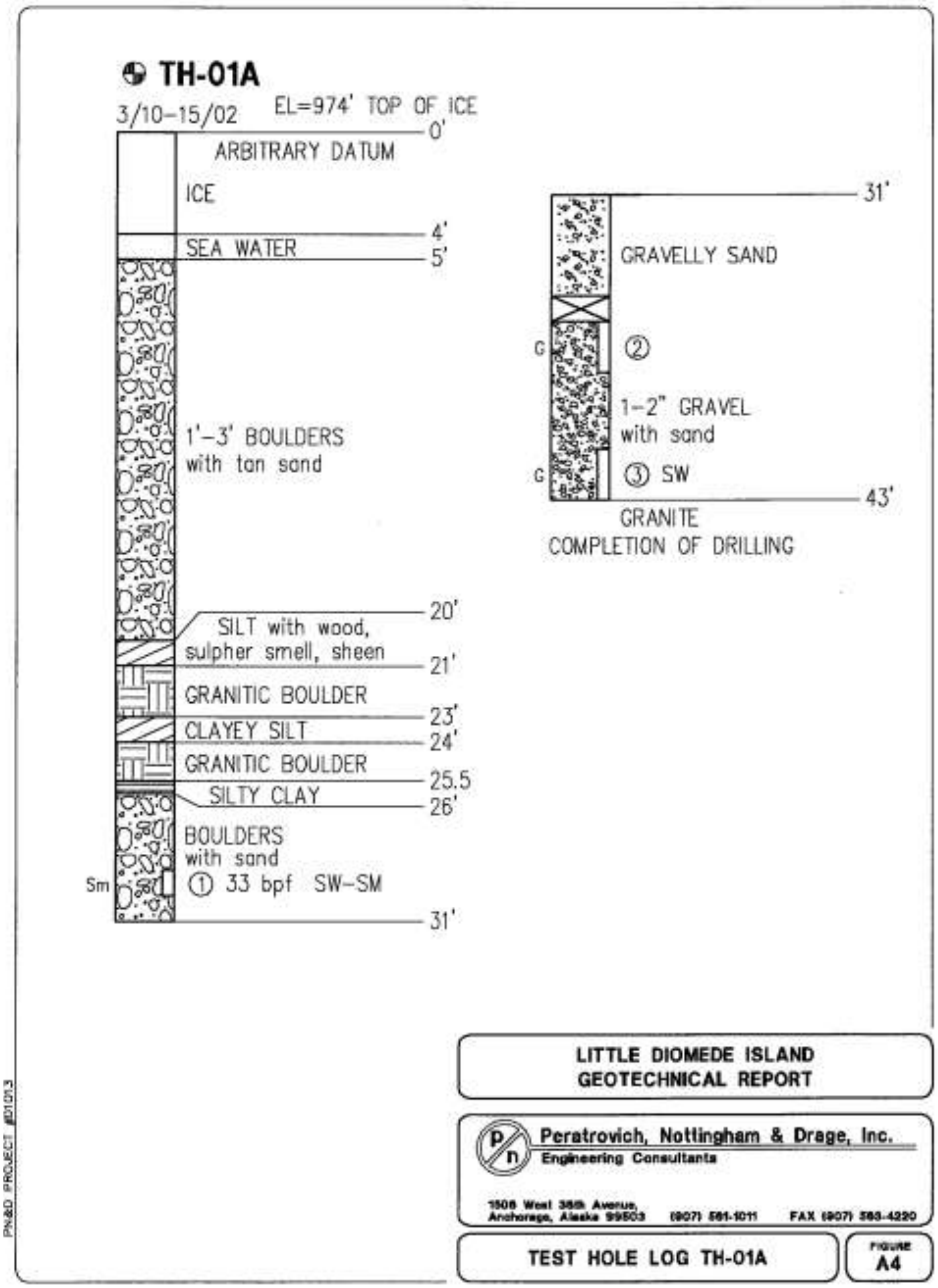


Figure 8 Test hole TH-01A

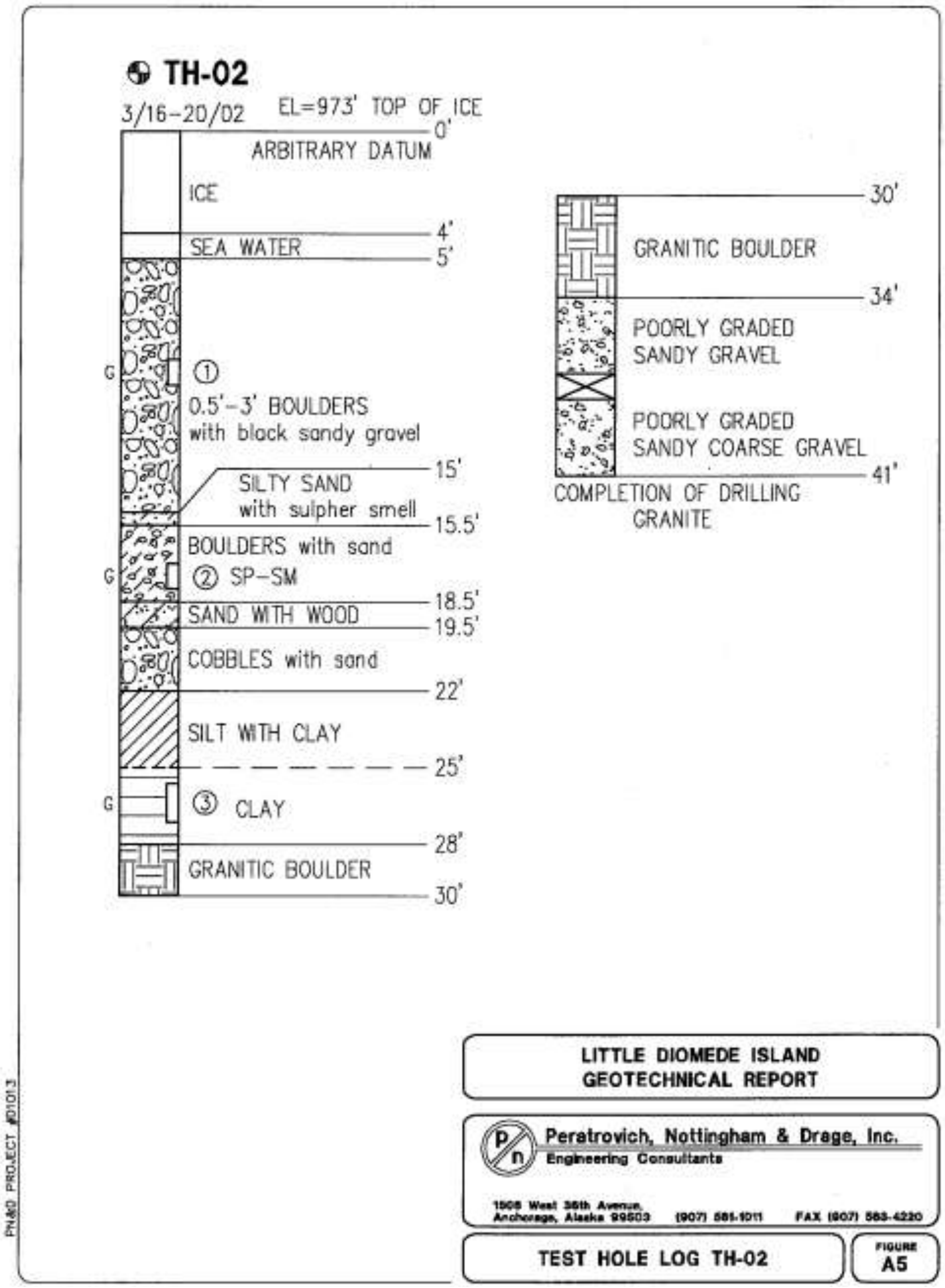


Figure 9 Test hole TH-02

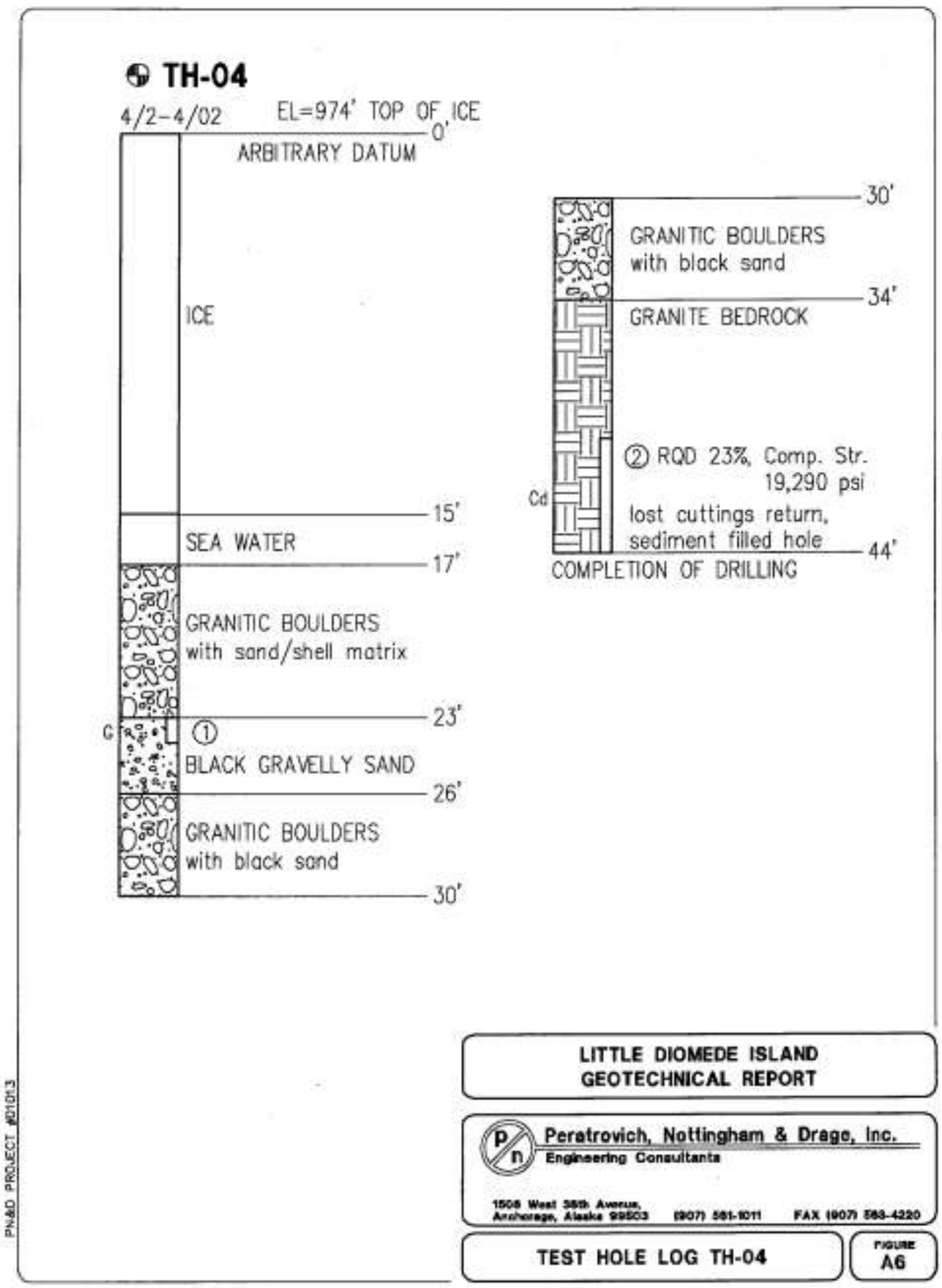


Figure 10 Test hole TH-04

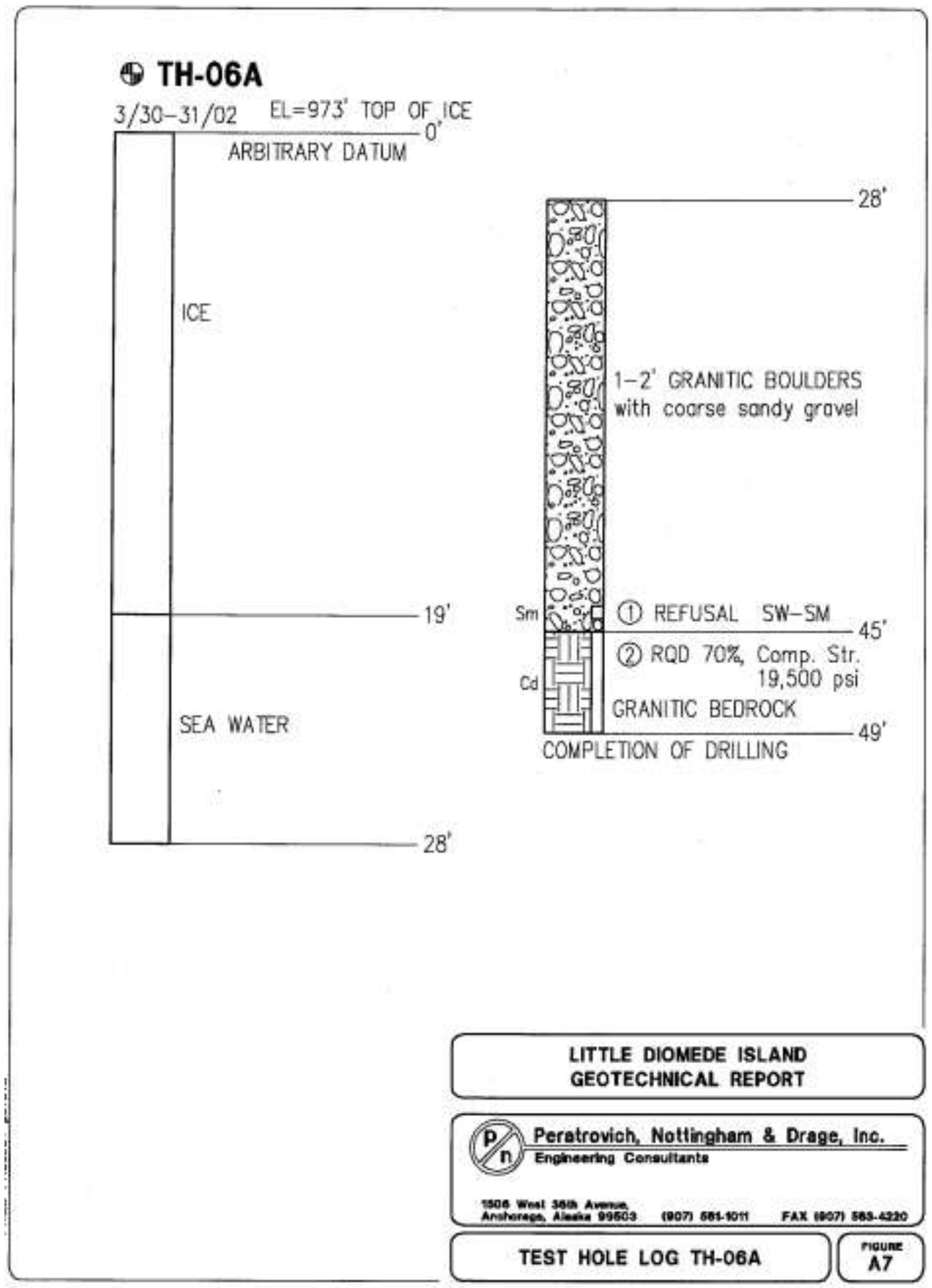


Figure 11 Test hole TH-06A

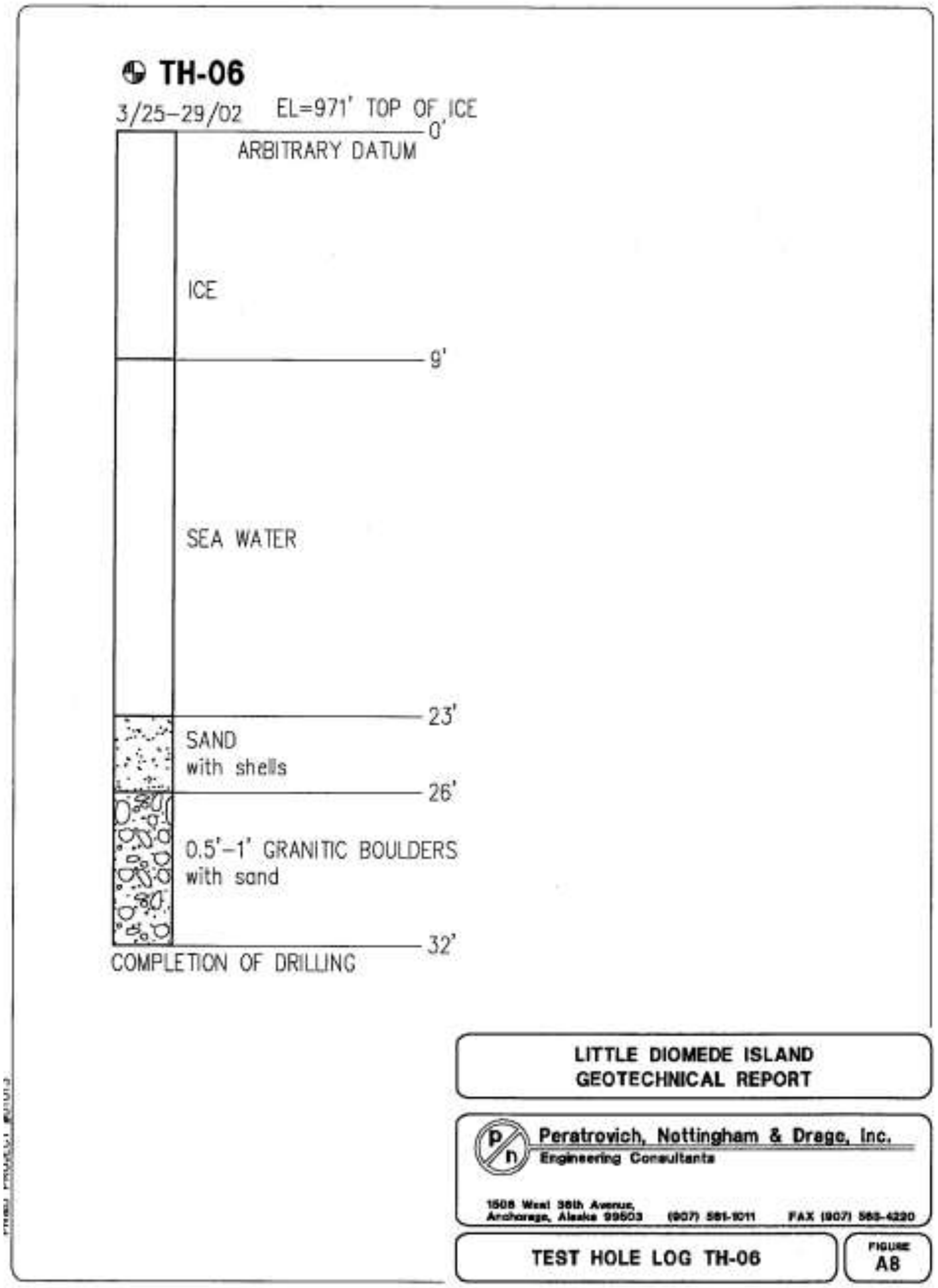


Figure 12 Test hole TH-06

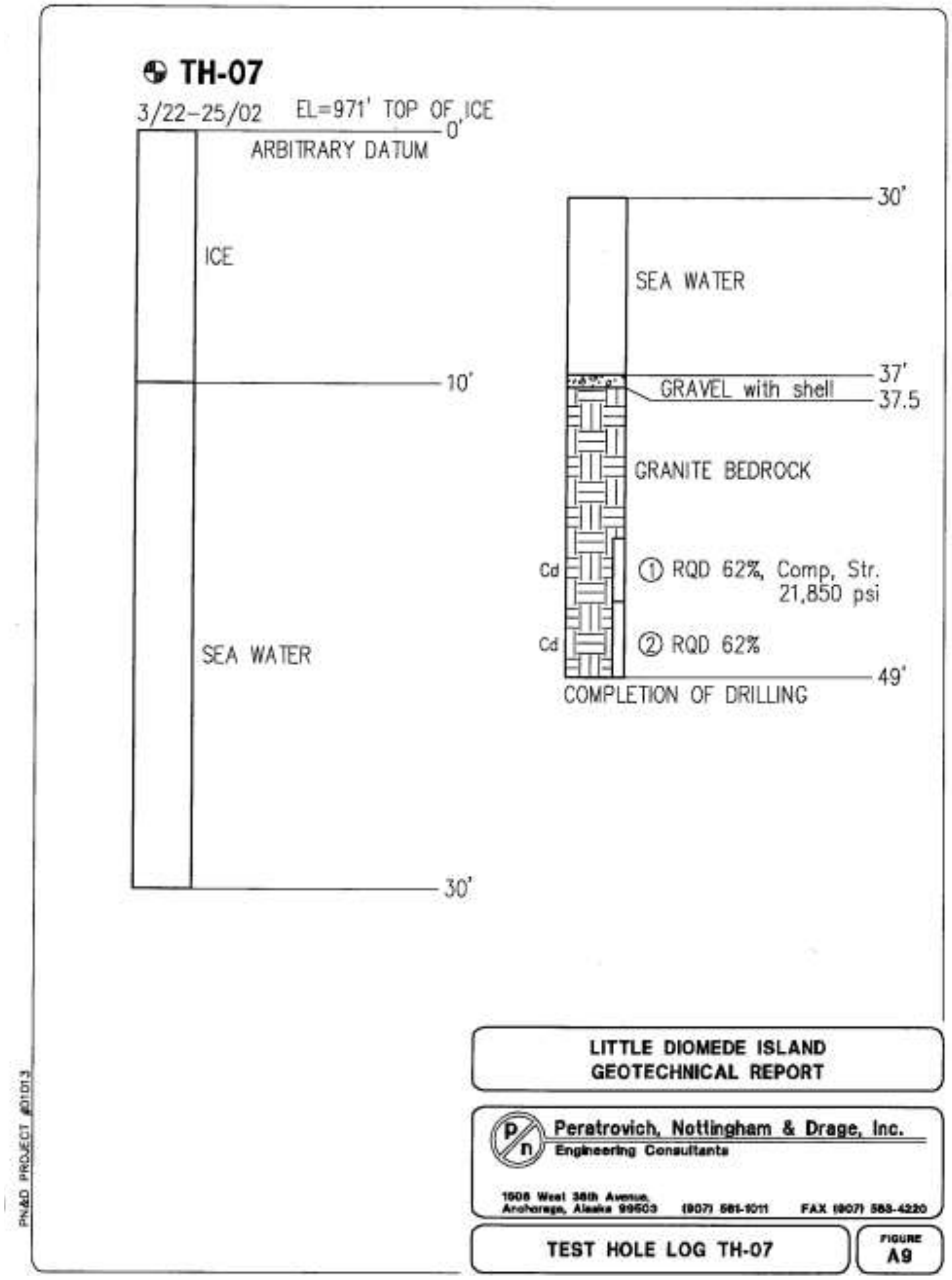


Figure 13 Test hole TH-07

4.0 WAVE CLIMATE

The Coastal and Hydraulics Laboratory (CHL) of the Engineer Research and Development Center (ERDC) developed a Western Alaskan deepwater wave hindcast for the years 1985-2009 using hindcast generated wind data, supplemented with selected storms from the early 1950's through 1984 for evaluation of the extreme wave condition to determine the 50 year return interval deep water wave height (Figure 14). Waves from the hindcast save points in the deep water off the coast of Little Diomede were then transformed into the area of interest on Little Diomede using STWAVE.

Unlike a forecast, a wave hindcast predicts past wave conditions using a computer model and observed wind fields. By using value-added wind fields, which combine ground and satellite wind observations, hindcasted wave information is generally of higher accuracy and is more representative of observed wave conditions.

In the case of Little Diomede area, the complexities increase because of its location and the ever-changing offshore ice coverage opening up the area for wind-wave development, or preventing it as the ice builds in the fall.

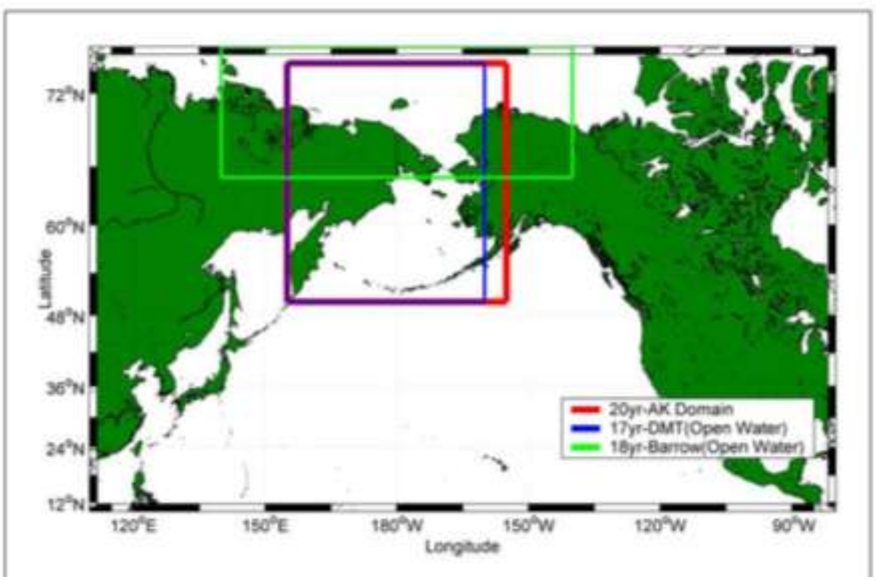


Figure 14. The Western Alaska model target domain in red.

The blue and green domains are from previous hindcast efforts.

4.1 Wind Hindcast[1]

The specification of the wind fields is critical to the generation of an accurate wave climate. A ten percent uncertainty in the wind speed estimate will lead to an approximate 20 percent uncertainty in the wave height. To accurately characterize the forcing mechanisms for the deep water wave, a hindcast was performed for the years 1985-2009 by Oceanweather Inc. (OWI), under contract to the Coastal Hydraulics Laboratory (CHL). The hindcast was supplemented with selected storms from the early 1950's through 1984.

Wind Field Description

The Interactive Optimum Kinematic Analysis (IOKA) System (Cox et al. 1995) was used to construct the wind fields. All wind field estimates were restricted to the target domain shown in Figure 33. Five critical elements are required for the IOKA system:

- Background wind fields
- Point source measurements (airport anemometer records, buoy data)
- Ship records (archived wind speed and direction)
- Scatterometer estimates of the wind speed
- Kinematic control points (KCPs).

These data sets (excluding the KCPs) must be adjusted for stability and brought to a common reference level. Stability accounts for the changes in the boundary layer due to differences between air and water temperatures. Considerations to the differences in boundary layer effects over the pack ice were neglected.

The background wind fields for Little Diomede were derived from the National Center for Environmental Prediction/National Center for Atmospheric Research (NCEP/NCAR) Reanalysis Project. These wind fields were spatially interpolated to a fixed spherical grid.

Point source measurements such as buoy data and airport records reflect wind speeds and directions based on short time burst averaging. These short term averages (1 to 10 minute averages) are temporally interpolated to hourly data. Land based wind measurements were also adjusted for boundary layer effects. Every land based, point source measured data set was individually investigated, and adjustments were made as needed. These adjustments depended not only on the wind direction, but also on the wind magnitude.

Scatterometer wind fields derived from satellites are not true wind speed measurements. They are derived from inversion techniques and are extremely useful because of the spatial coverage obtained during one satellite pass. The repeat cycle is 35 days (on a 12 hour orbit); therefore, temporally continuous data are not available as in the case of point source measurements. In addition, data from all satellite-based scatterometers do not

[1]Hindcast discussion excerpted from Jensen, et al. 2002, and U.S. Army Corps of Engineers 2008

span the entire hindcast period, or any of the pre-1982 extreme storms that were considered in the study. Including these data may produce a series of discontinuities in the development of the wind field climatology; however, use of these data adds considerable value to the final wind products, and outweighs concerns regarding the consistency of the climatological wind products.

Once all data sets were transformed to equivalently neutral, stable 33.3 feet (10 meter) winds, the IOKA system is used. Each input wind data product carries a specified weight which can be overridden by an OWI analyst at any time. Background wind fields are ingested into OWI's Graphical Wind Work Station, displaying all the available data sets (point source measurements, scatterometer data). The NCEP/NCAR Reanalysis wind fields are at a 6-hour time step, so all 1-hour point source wind measurements are repositioned via "moving centers relocation". This assures continuity between successive wind fields.

The most powerful tool of the IOKA system is the use of KCPs by the analyst. This tool can input and define ultra fine scale features such as frontal passages, maintain jet streaks, and control orographic effects near coastal boundaries. The analyst can use the KCPs to define data sparse areas using continuity analysis, satellite interpretation, climatology of developing systems, and other analysis tools. The IOKA system contains a looping mechanism that will continually update the new wind field based on revisions performed by the analyst.

The final step in the construction of the OWI regional wind fields was to spatially interpolate the winds to a target domain and resolution. The final wind fields were spatially interpolated to the target domain at a longitudinal resolution of 0.50°, a latitudinal resolution of 0.25° at a time step of 6-hours. This was done because the NCEP/NCAR Reanalysis wind fields are resolved at 6-hour time steps.

A sample of a wind rose that was produced as a result of the wind hindcast is shown in Figure 15

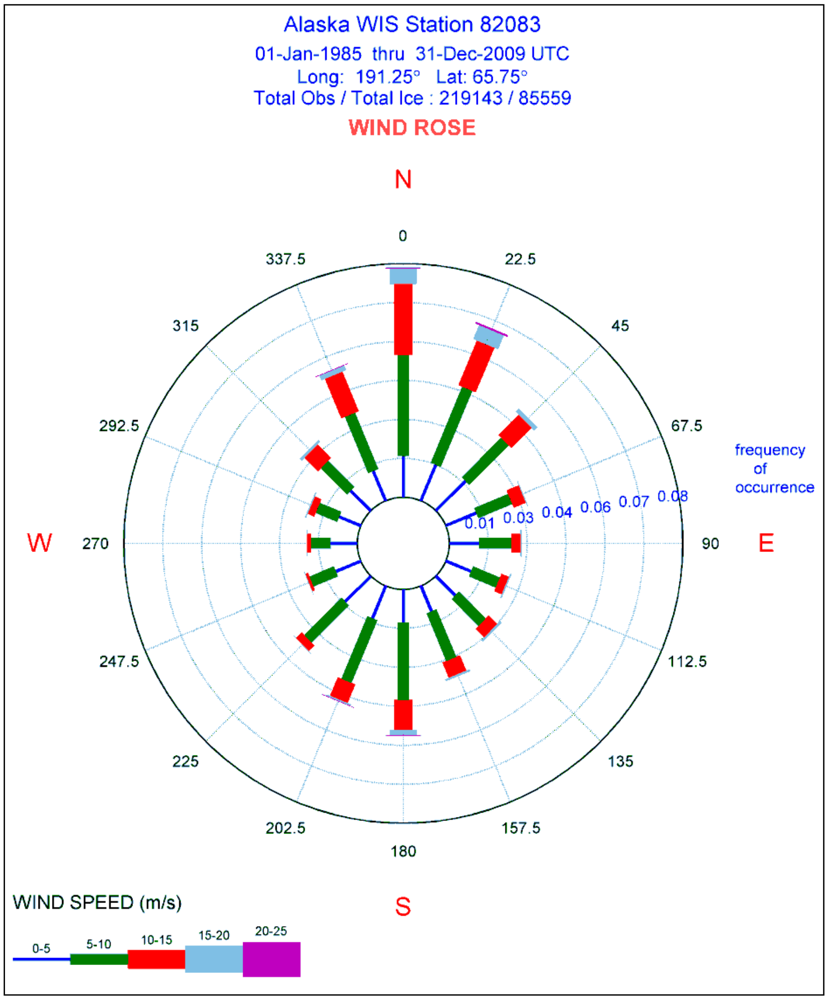


Figure 15 Wind rose from hindcast for all years all months.

4.2 Ice Field Specification[2]

The specification of the ice edge quantifying the open water capable of wind-wave growth is one of the major controlling variables in the specification of the wave climatology.

Ice Field Methodology

Mean weekly ice maps were used for the modeling effort. An example of the final ice map for week 31 (30 July through 5 August) in 1998 is presented in Figure 16. Digital ice field maps are derived from remote sensing techniques using visible and infrared imagery from the polar orbiting satellites that have been used since 1972 (VanWoert, M. 2002). Algorithms have been built to estimate the sea ice concentration and more recently sea ice thickness. Once established, these images are then translated to gridded information, and archived at the National Oceanic and Atmospheric Administration

[2] Ice Field discussion excerpted from Jensen, et al. 2002 and U.S. Army Corps of Engineers 2008

(NOAA), National Environmental Satellite Data Information Services (NESDIS). The approximate resolution is 25 km. Weekly estimates of the ice concentration were generated for the western Alaska hindcast. Ice maps for selected storm events prior to the 1972 digital database were constructed by Oceanweather, Inc.

A predetermined concentration level of the ice field must be set to either open water or land. This study used a concentration level of 70-percent or greater to switch the water point to land. This concentration was chosen based on previous wave hindcast experience at the Delong Mountain Terminal. Examples of sea ice differences are shown in Figure 17 and are derived from NOAA's Observers Guide to Sea Ice (prepared by Dr. O. Smith, University of Alaska, Anchorage, http://response.restoration.noaa.gov).

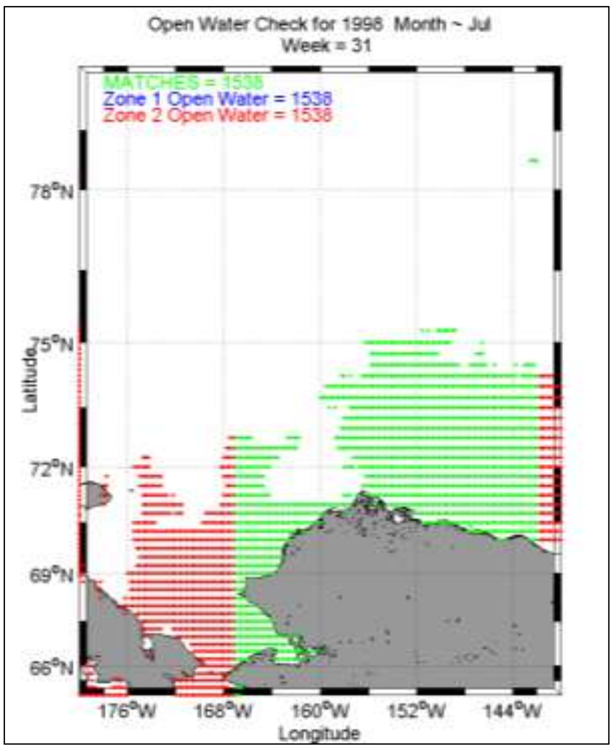
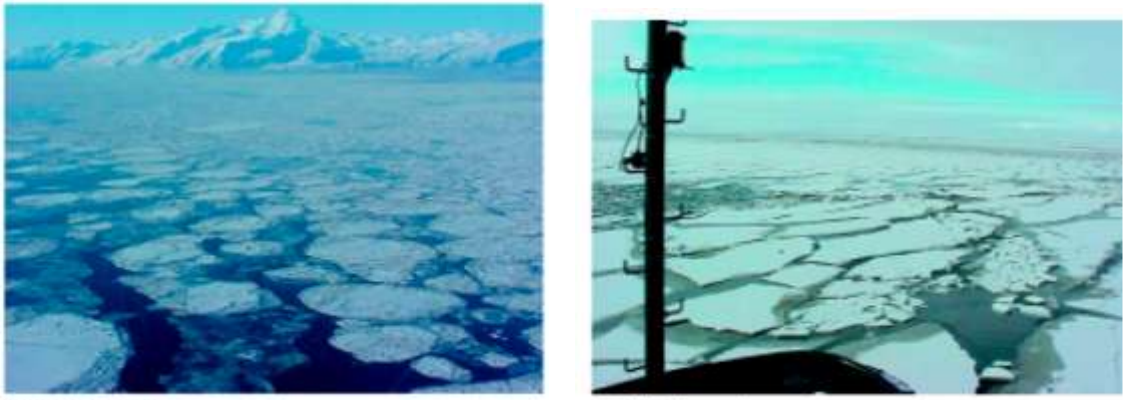


Figure 16. Example of the final ice mask used in wave model simulation.

Note the symbols identify the open water area. The zones refer to the level of grid refinement.



5 - 6 tenths "open drift" 7 - 8 tenths "close pack"

Left 50 to 60 percent, right panel 70 to 80 percent concentration.

Figure 17 Examples of sea ice concentration.

4.3 Deepwater Wave Hindcast[3]

The deepwater waves were analyzed using the **WA**ve prediction **M**odel (WAM)**.** WAM is a third generation wave model which predicts directional spectra as well as wave properties such as significant wave height, mean wave direction and frequency, swell wave height and mean direction. All source terms (wind input, wave-wave interaction, whitcapping, wave bottom effects, and wave breaking) are specified with the same degree of freedom in WAM with which the resulting directional wave spectra are specified. There is no a priori assumption governing the shape of the frequency or directional wave spectrum. WAM has been used extensively at weather prediction centers with the option to include ice coverage.

Model Assumptions for WAM are:

- Time dependent wave action balance equation.
- Wave growth based on sea surface roughness and wind characteristics.
- Nonlinear wave and wave interaction by Discrete Interaction Approximation (DIA).
- Free form of spectral shape.
- High dissipation rate to short waves.

Verification of Deepwater Wave Model

Little Diomede is impacted by storm events from the south and from the north. This required model verification for the north hindcast storms in the Chukchi Sea and the south hindcast storms in the Bering Sea.

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[3] Deepwater Wave Hindcast discussion excerpted from Jensen, et al. 2002 and U.S. Army Corps of Engineers 2008

South Hindcast Verification

Bering Sea Buoy
The nondirectional NDBC buoy 46035 provided the means for long term analysis of the wave model's performance, since the buoy has been deployed for many years, much longer than any other wave measurement platform in the region. Despite the distance between Little Diomede and buoy 46035, comparisons between the model and these measurements are very relevant to the assessment of the hindcast quality (Figure 18). They add credibility to the WAM results in the far field, and validate the basin scale winds in terms of capturing synoptic scale meteorological events and meso scale tropical energy. Comparisons also verify the OWI regional wind field generation. An example of the comparison of the WAM output and buoy 46035 are shown in Figure 19.

Figure 18 Location of buoy 46035

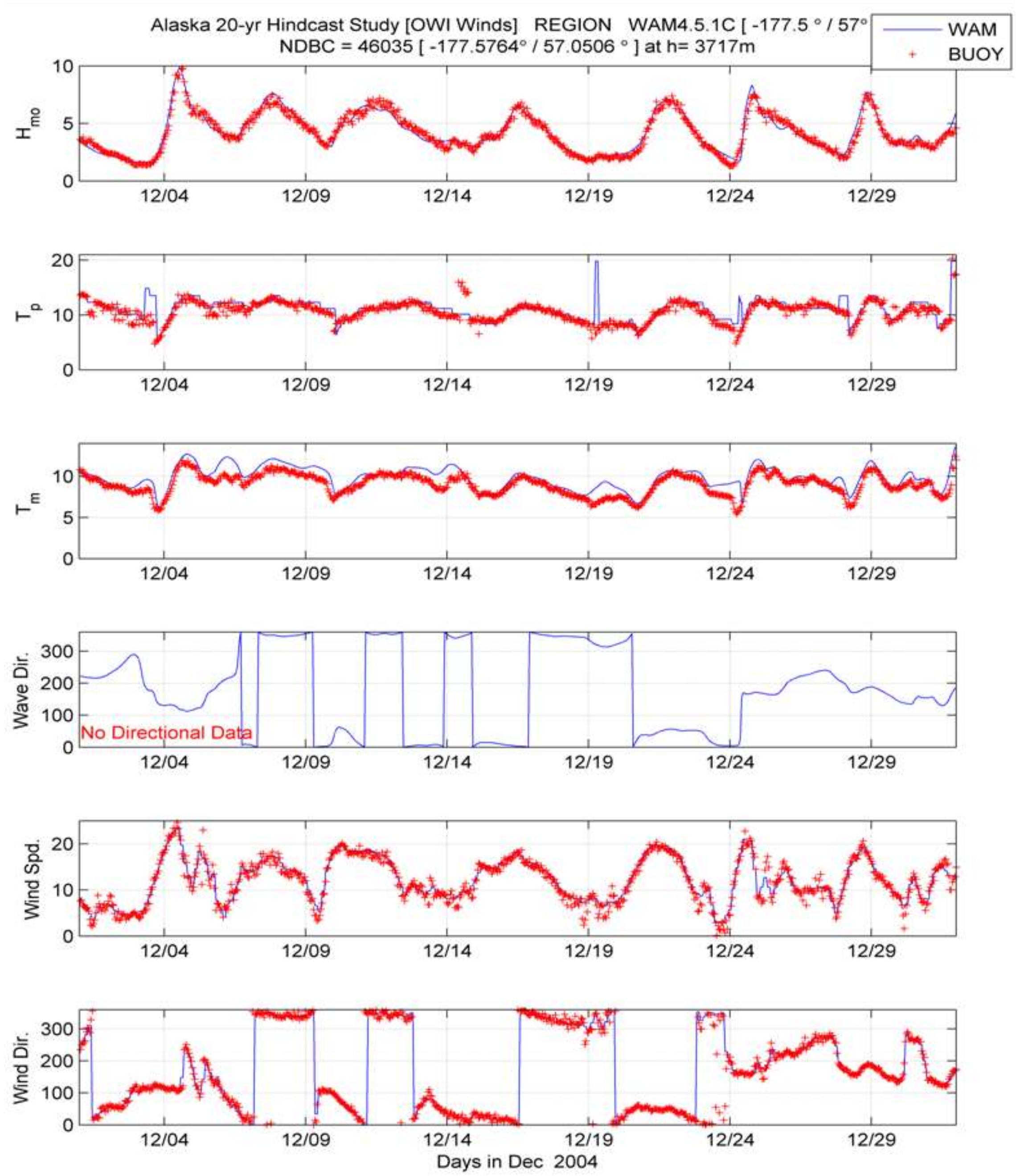


Figure 19 Example comparison of WAM Cycle 4.5 (solid blue line) to NDBC buoy 46035 .

S4ADW Gage

In addition to the Bering Sea buoy a second buoy located in the Chukchi Sea near the Delong Mountain Terminal was used for hindcast comparison (Figure 20). Directional wave measurements were available for the 1998 open water season with the S4ADW gage. The location of the S4ADW gage and the nearest hindcast output point were not coincident and water depth was different; however, hindcast quality issues were examined using the data. An example of the comparisons of the WAM output and S4ADW gage data is shown in Figure 21.

Figure 20 Location of S4ADW buoy

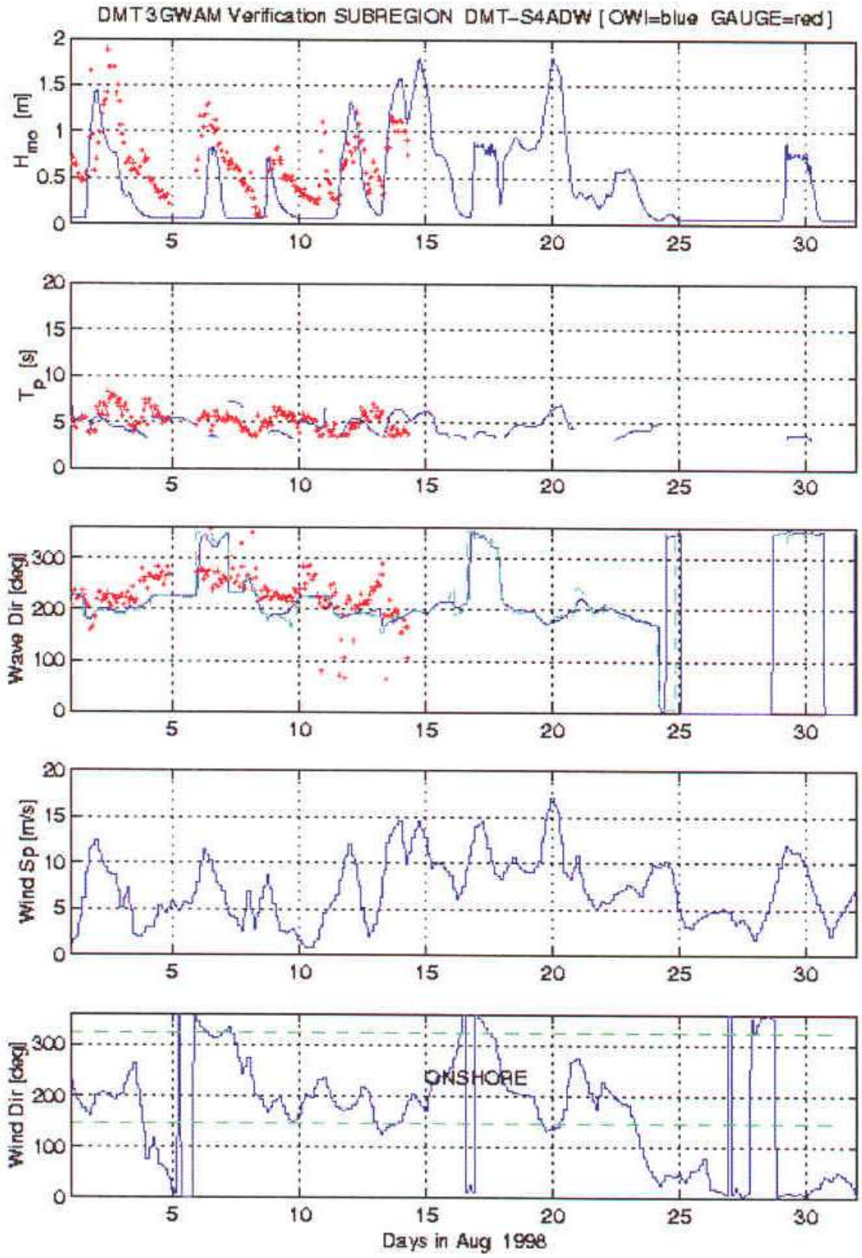


Figure 21 August S4ADW and WAM comparison S4 data in red, hindcast data in blue.

North Hindcast Verification

There is not a regularly maintained wave buoy in the Chukchi Sea against which the model could be compared. In the absence of long term continuous data, point-source measurements were obtained from Shell Oil Company, for two non-directional wave buoys deployed in 1983 and 1984. The general location of these sites is shown in Figure 22 and despite their distance from the Little Diomede Site; they can strongly suggest the overall quality in the wave model's performance. All data representing the measurements were hand-digitized from time plot records. These results should not be construed as ground-truth as in the case of digital wave records. Note the direction convention for all time plots of the θ_{mean} wave, and the wind direction are in a meteorological coordinate system (e.g. 0° from the north, 90° from the east).

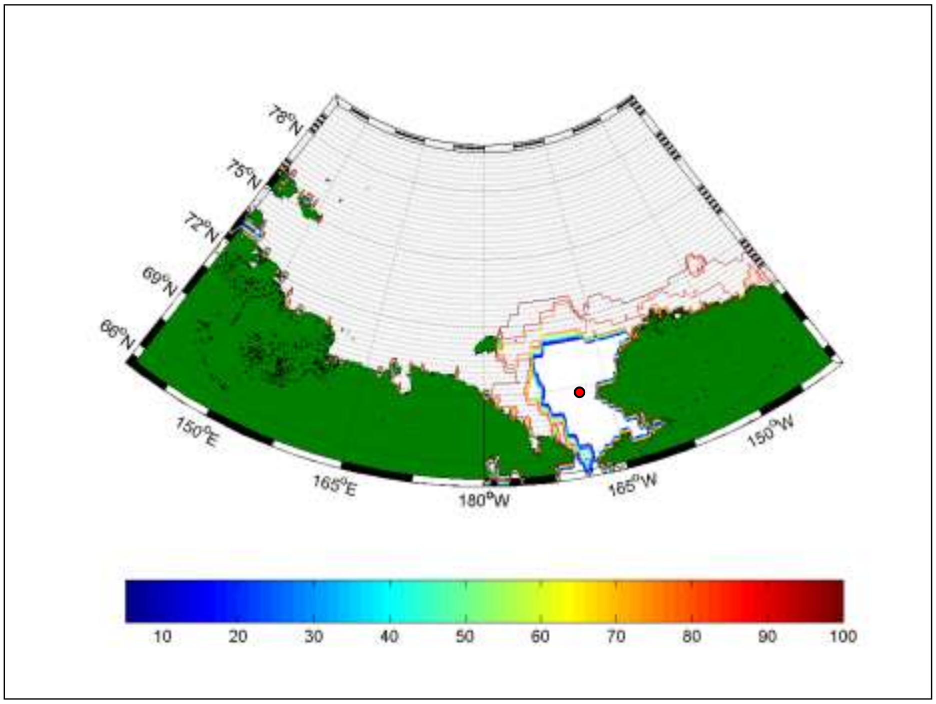


Figure 22 Location (red symbol) of the Shell Oil wave measurements

Location shown for Stations A and B during two deployment cycles of 1983 and 1984. Ice concentrations are color contoured, and grey area signifies the ice pack.

All verification WAM runs were made with wind and ice fields identical to that of the climatology simulations. These tests were made to assure quality in the overall performance of the winds, ice coverage, and ultimately the wave model. Time and scatter plots as well as statistical tests were generated, however because of the paucity of data, the statistical results will be biased and regarded as an approximation to the true performance of the wave model.

Estimates of the significant wave height (Hmo), and mean wave period, (Tmean) for 1983 are presented in Figure 23 and Figure 24 for Site A and B. The WAM Hmo, and Tm estimates for the first deployment period shows remarkable similarity to the measurements. The storm peaks are well represented in all but one case (21 September), and are slightly low. There is one storm that is completely missed in the model results occurring at about 30 September. The maximum wave height measured during this missed event was on the order of 1-meter (3.3 feet). The winds are in a decaying mode, and the wind directions are rapidly turning from a northeasterly direction to a southerly direction. The winds for this case may be slightly low for this case or the direction slightly off. It could also be the wave model, its grid and/or spectral directional resolutions. If the errors found at Site A, under similar meteorological conditions persist, then it would be reasonable to conclude the wave model is in error. However, in general the model emulates the measurements quite well in height and mean wave period.

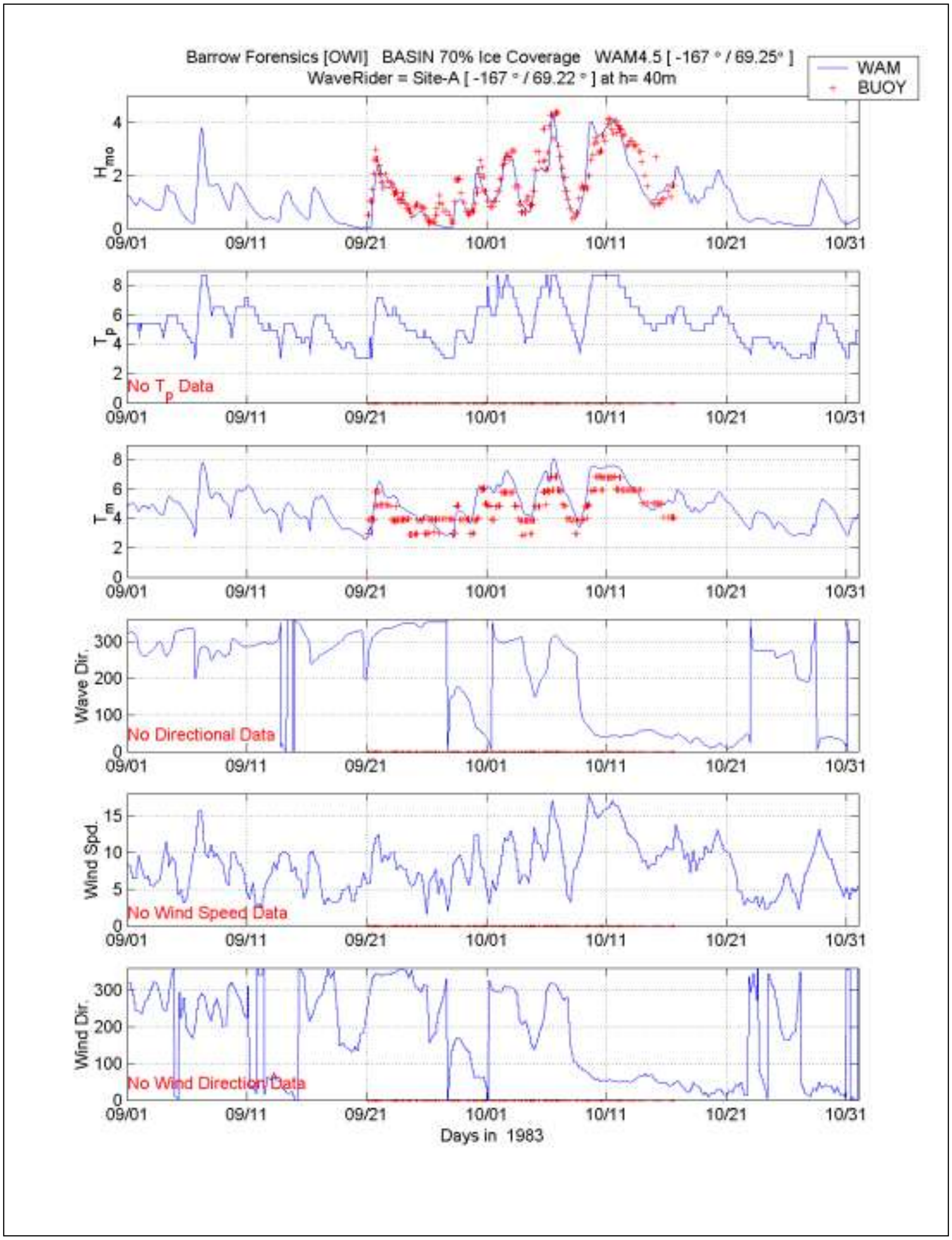


Figure 23 Comparison of WAM Cycle 4.5 (solid blue line) to Shell Oil Co. buoy data.

Comparison for deployment 1 at Site A.

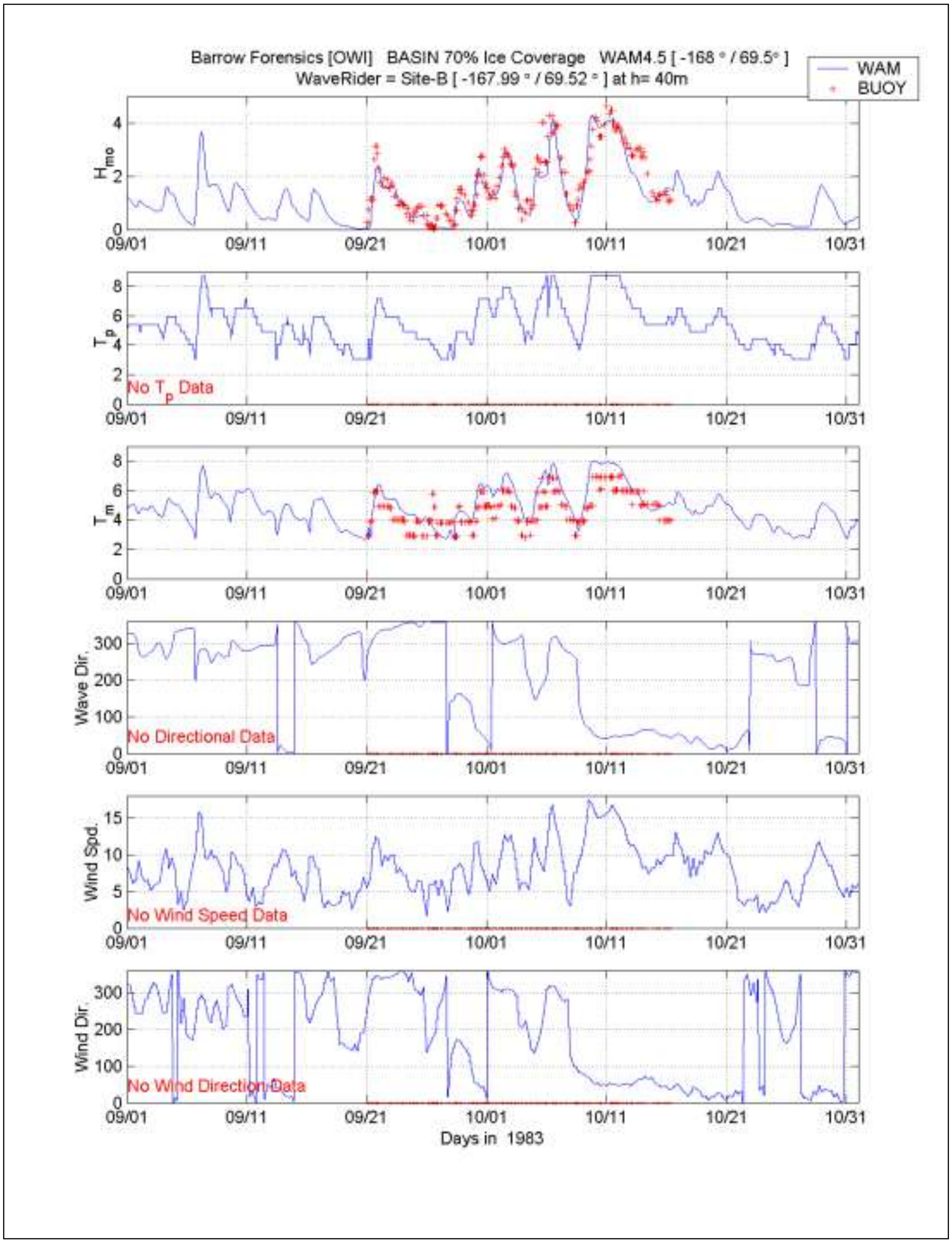


Figure 24 Comparison of WAM Cycle 4.5 (solid blue line) to Shell Oil Co. buoy data.

Comparison for deployment 1 at Site B.

Wave Climate Analysis

There are two distinct and separate parts in the development of the offshore wave climate for the points around Little Diomede. A continuous portion was run and encompassed the years 1985 through 2009. The length of each simulation period varied because of the weekly changes in the ice maps, and the monthly changes in the wind fields. However, to retain continuity between each simulation period, a RESTART (or warm start) file was retrieved from the previous simulation. Hence, consistency was maintained throughout each year that was processed. For each year WAM Cycle 4.5 was started from a cold start, preconditioning the wave field with fetch limited wave estimates derived from the input wind fields, operating on the open water dictated by the ice coverage.

The second portion was developed from a series of individual storm simulations that had documented evidence producing large water levels and/or elevated wave conditions in the area of the Bering Straits.

A series of special output locations were saved along the land/water boundary. These output locations and how they were used in this study are shown in Figure 25.

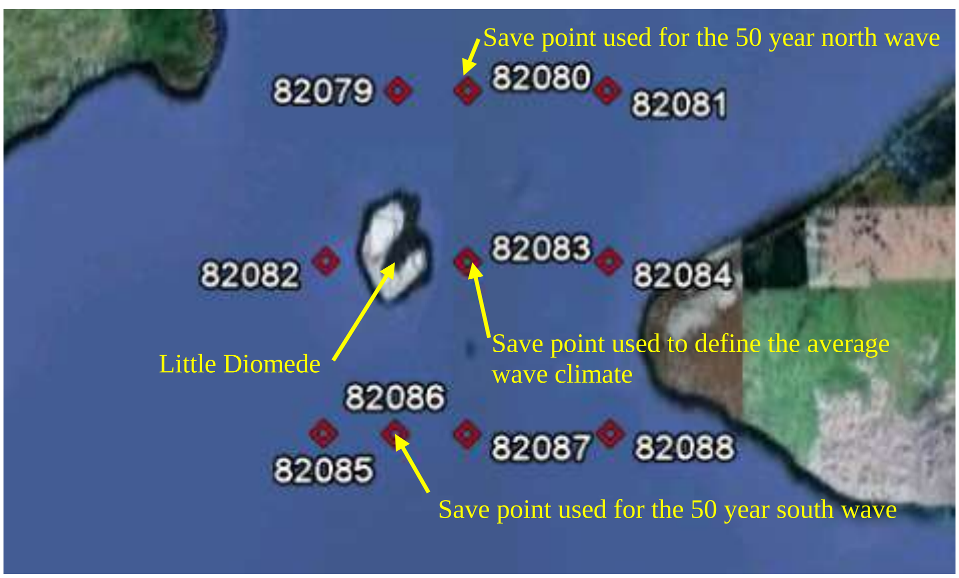


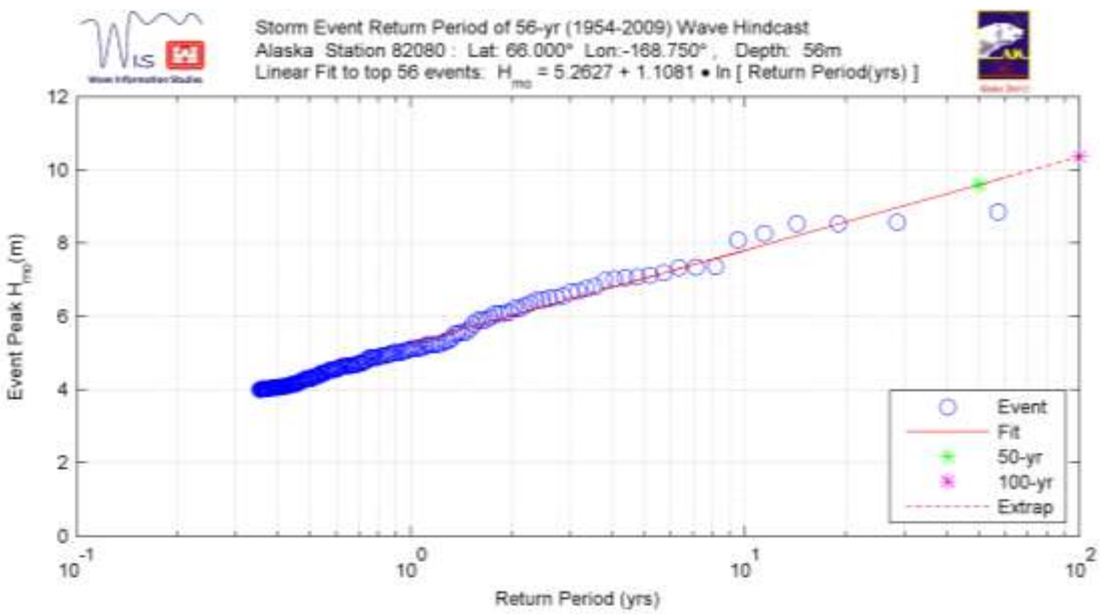
Figure 25 Special output locations (red)

4.4 Extreme and Average Wave Climate

Extreme Storms

Severe historic storms dating back to 1954, which were thought to have a significant influence on wave conditions at Little Diomede, were included in the hindcast. Inclusion of the additional storms provided higher confidence in the extreme wave estimates (those representing 50-year return-period events) that are critical for design of any storm damage reduction project.

North Storms
The largest storm of record from the north in the extremal wave analysis occurred in November 1989. The peak significant wave height was 28 feet with an 11.2-second period. The return period predicted for this storm by the extremal analysis is 20 years. A plot of the deep-water significant wave height and the return period for the north save point is shown in Figure 26. Significant wave heights for the top 10 storms from 1954 to 2009 for the north save point are shown below the plot along with their ranking. Note that the top ten storms occur equally from the north and the south. From the plot, the 50 year return period wave is 9.6 meters or 31.5 feet.



Top 10 events based on Peak H_{mo}

Event	Date/Time(UTC)	H_{mo}	T_p	θ_{mean}	Event	Date/Time(UTC)	H_{mo}	T_p	θ_{mean}
1	1976/10/27 13:00	8.86	12.28	181.0	6	1992/11/24 13:00	8.08	11.17	3.0
2	1989/11/23 13:00	8.58	11.17	17.0	7	1994/10/06 13:00	7.36	11.17	359.0
3	1963/10/07 13:00	8.53	12.28	168.0	8	2005/11/10 13:00	7.35	11.17	188.0
4	1963/10/07 13:00	8.53	12.28	168.0	9	1973/10/02 13:00	7.33	12.28	153.0
5	1966/11/16 13:00	8.27	11.17	348.0	10	1993/11/12 13:00	7.20	10.15	8.0

An event is defined as any period when H_{mo} > 4.00m θ_{mean} is direction that waves are arriving from

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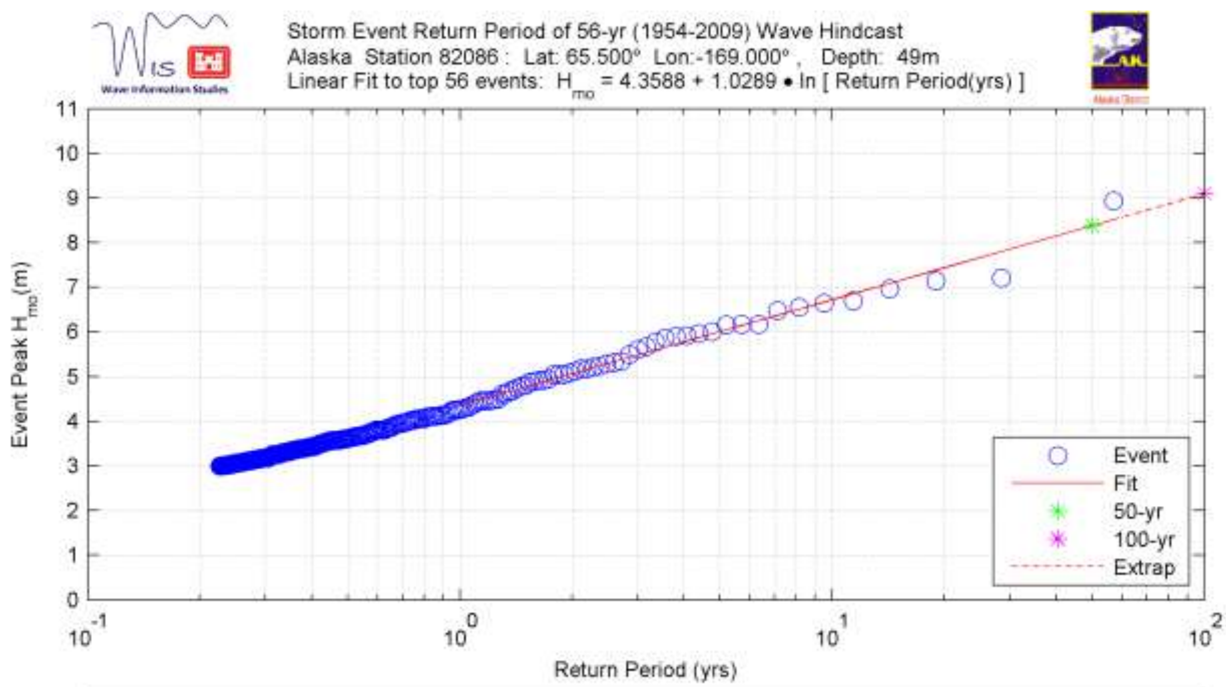
Figure 26 Deep water wave height return period for save point north of Little Diomede. The storm direction associated with the top 10 events has been updated on the Wave Information Study web site (http://wis.usace.army.mil/hindcasts.shtml?dmn=alaskaWIS)

South Storms

The largest storm of record from the south in the extremal wave analysis occurred in October 1996. The peak significant wave height was 24 feet with a 11.2-second period. The return period predicted for this storm by the extremal analysis is 16 years. A plot of the deep-water significant wave heights and the return period for the south save point is shown in Figure 27. Significant wave heights for the top 10 storms from 1954 to 2009 for the south save point are shown below the plot along with their ranking. Note that the top ten storms occur equally from the north and the south. From the plot, the 50 year return period wave is 8.4 meters or 27.6 feet.



Top 10 events based on Peak H_{mo}

Event	Date/Time(UTC)	H_{mo}	T_p	θ_{mean}	Event	Date/Time(UTC)	H_{mo}	T_p	θ_{mean}
1	1966/11/16 13:00	8.94	11.17	345.0	6	1989/11/23 13:00	6.64	11.17	20.0
2	1996/10/28 13:00	7.21	11.17	204.0	7	1976/10/27 13:00	6.55	12.28	179.0
3	1970/11/27 13:00	7.14	11.17	34.0	8	1978/11/09 13:00	6.48	10.15	333.0
4	1974/11/12 13:00	6.96	11.17	356.0	9	1963/10/07 13:00	6.17	10.15	156.0
5	2004/10/19 13:00	6.70	10.15	181.0	10	1963/10/07 13:00	6.17	10.15	156.0

An event is defined as any period when H_{mo} > 3.00m θ_{mean} is direction that waves are arriving from

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Figure 27 Deep water wave height return period for save point south of Little Diomede. The storm direction associated with the top 10 events has been updated on the Wave Information Study web site (http://wis.usace.army.mil/hindcasts.shtml?dmn=alaskaWIS)

Average Wave Climate

The average wave climate in the area of the Diomede Islands is dominated by waves from the north and south as shown in the Figure 28 wave rose. Wave heights between 0.3 to 3.2 feet dominate the wave climate in June and July. By August the climate is fairly evenly split between the north and south for all wave heights evaluated, and by September and October the wave dominance has switched to the north along with an increase the percentage of occurrence of the larger waves (3.3 to 6.6 feet). Table 4 illustrates the percentage of occurrence of waves from the north and south broken out into waves 0.3 to 1.6 feet, 1.7 to 3.2 feet, and waves 3.3 to 6.6 feet. The remaining percentages not shown are either wave heights greater than 6.6 feet or calms.

0.3 to 1.6 foot Waves
Waves from 0.3 to 1.6 feet were out of the south 34-38 percent of the time during June and July. Waves up to 1.6 feet were out of the north 13-14 percent of the time for the June and July. In August, the waves from the south are still the majority for the 0.3 to 1.6 foot range, but are almost half as much. The 0.3 foot waves out of the north decrease slightly in August to 10 percent. By September and October, the majority of the 0.3 to 1.6 foot waves are out of the north between 5 to 8 percent of the time while the percentage of waves between 0.3 to 1.6 feet reduced to 3 to 5 percent of the time.

1.7 to3.2 foot Waves
Waves 1.7 to 3.2 feet were at a maximum in July at 17 percent of the time (range between 5 to 17 percent), while the waves out of the north stayed fairly consistent and ranged between 11 to 17 percent to the time.

3.3 to 6.6 foot Waves
Larger waves between three and six feet occurred much less of the time in June and July, but significantly increased from the north in August, September, and October. The increase in frequency of the 3.3 to 6.6 foot waves also coincides with an increase in storm waves that are not shown in the table below, namely the six foot to thirteen foot waves, which are also predominantly from the north.

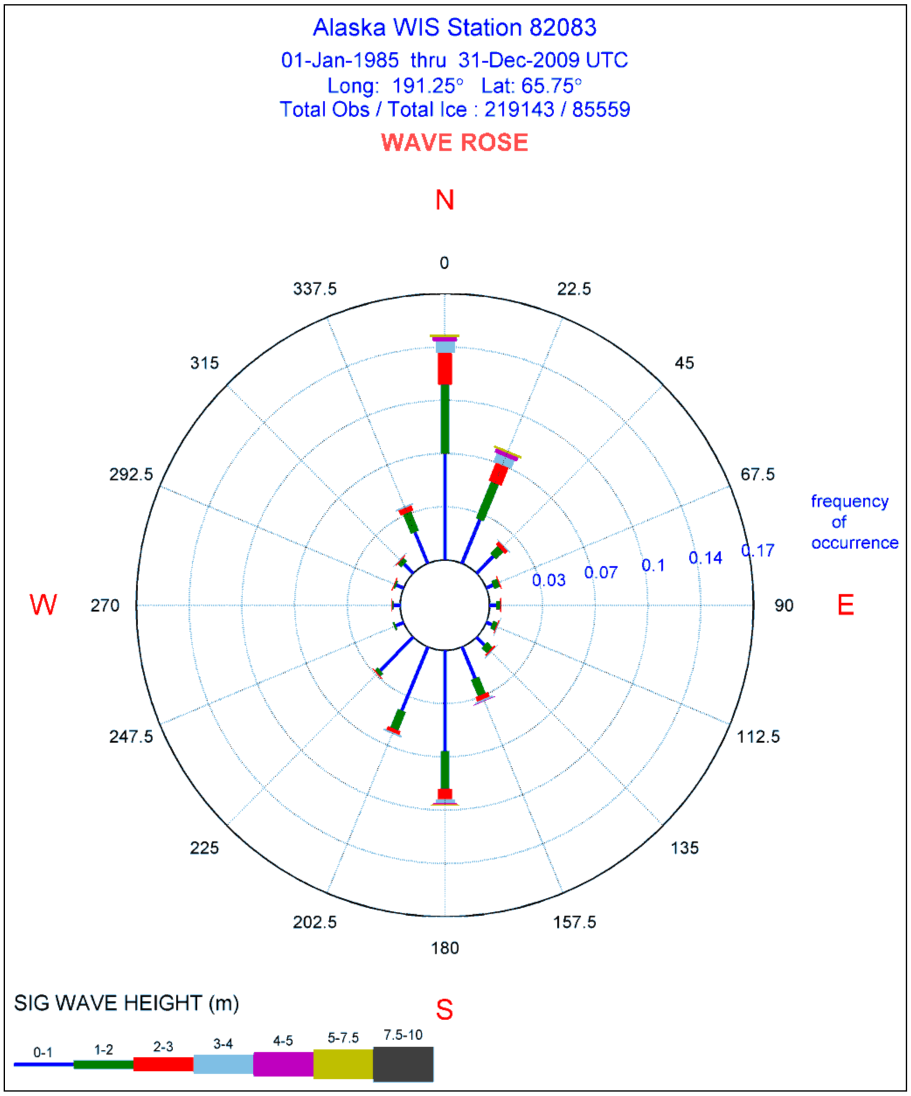

Figure 28 Wave rose for all hindcast years, January through December

Table 4 Percent of occurrence of wave heights from the north and the south 1985-2009 (save point 82083)

	Wave Direction Degrees [0 = wave from the north, 90 = wave from the east]	Wave Height			
		Calms 0-0.2 feet No direction	0.3-1.7 feet	1.7-3.3 feet	3.3-6.6 feet
June	North [326.25-56.25]	7.1	14.4	11.5	7.5
	South [236.25-146.25]		37.6	12.0	3.4
July	North [326.25-56.25]	1.1	12.6	10.8	7.6
	South [236.25-146.25]		34.0	17.3	6.9
August	North [326.25-56.25]	0.8	9.5	14.3	14.8
	South [236.25-146.25]		15.6	14.0	11.4
September	North [326.25-56.25]	0.1	8.2	17.0	25.3
	South [236.25-146.25]		4.6	8.4	4.8
October	North [326.25-56.25]	0.0	4.5	15.5	26.6
	South [236.25-146.25]		2.9	5.4	5.8

4.5 Shallow Water Wave Transformation

The shallow water wave analysis consisted of numerically modeling the transformation of the deep water wave. The deep-water 50 year return interval wave was transformed to the nearshore using the Steady-State Spectral Wave (STWAVE) model in order to size armor stone for a breakwater.

STWAVE is a steady state finite difference model based on the wave action balance equation. It simulates depth-induced wave refraction and shoaling, current-induced refraction and shoaling, depth- and steepness-induced wave breaking, wind-wave growth, and wave-wave interaction and white capping that redistribute and dissipate energy in a growing wave field.

Bathymetry

Figure 29 shows a contour plot of the bathymetry for the Little Diomede STWAVE grid. The grid was developed by merging digital bathymetry from a 2010 NOAA survey, a 2007 Terrasond survey, and hand input bathymetry from NOAA bathymetric charts for the area. The grid orientation is 0 deg meaning that the x-axis points toward Little Diomede in the cross-shore direction. The offshore boundary of the grid is in a water depth of approximately 164 ft.

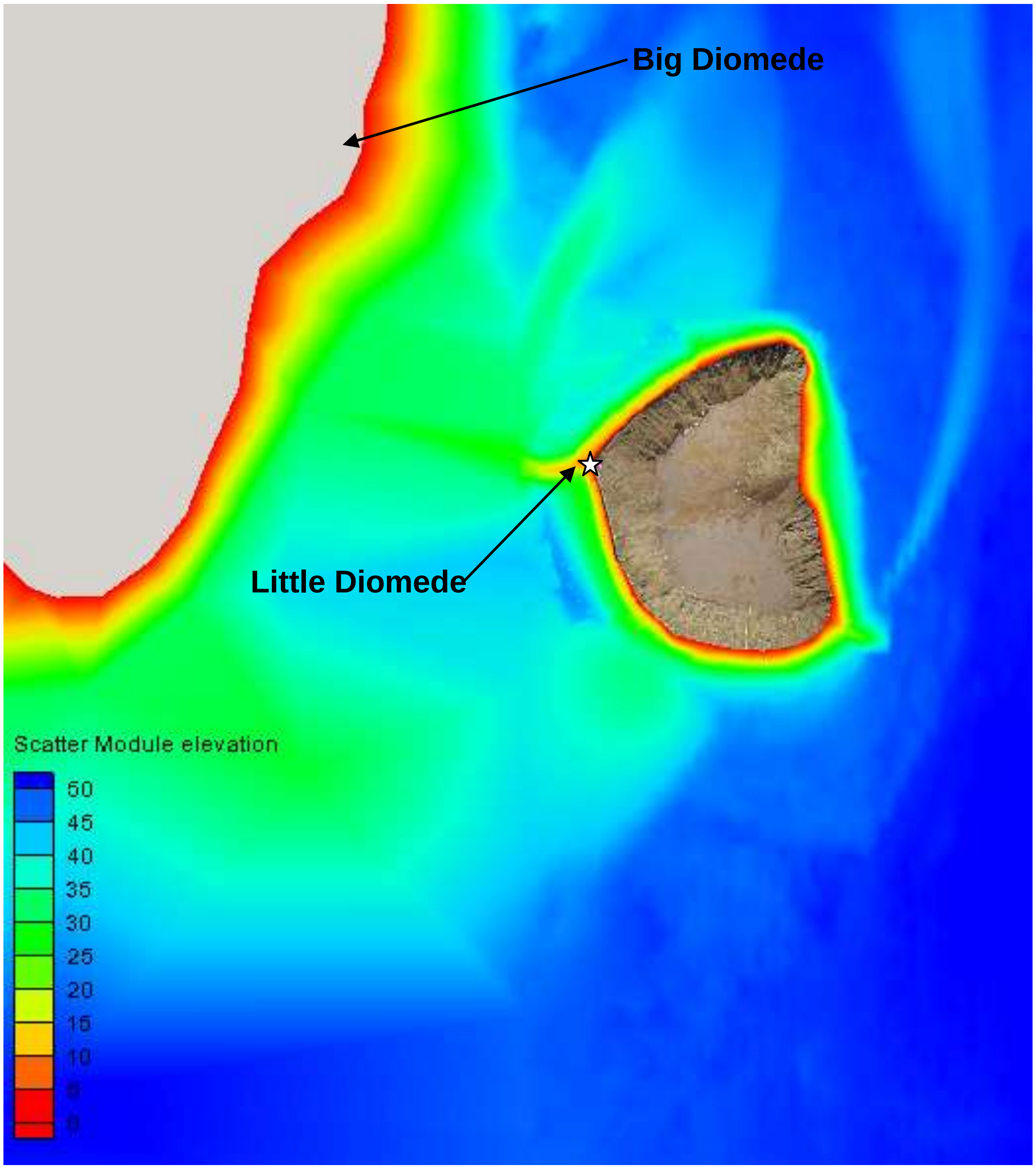

Figure 29 STWAVE bathymetry for Little Diomede, AK (depths in meters).

Water level and wind.

Water level is applied in STWAVE as constant water depth increase, relative to MLLW, over the entire grid. Water levels for typical wave condition simulations were specified as mean higher high water.

Wind input in STWAVE simulates wave growth across the grid domain. Local wind input was not included for the typical wave simulations since the waves were already developed for the 50 year storm event.

Sample output

Figure 30 shows example output from STWAVE. The color contours represent wave height. The waves can be seen refracting around the shoal off of the helipad. The incident wave condition for this case is a wave height of 27.5 feet with a period of 12 sec, directed to the north. Note that the breakwaters are shown to illustrate outer limits of the project. They were not included in the STWAVE model runs.

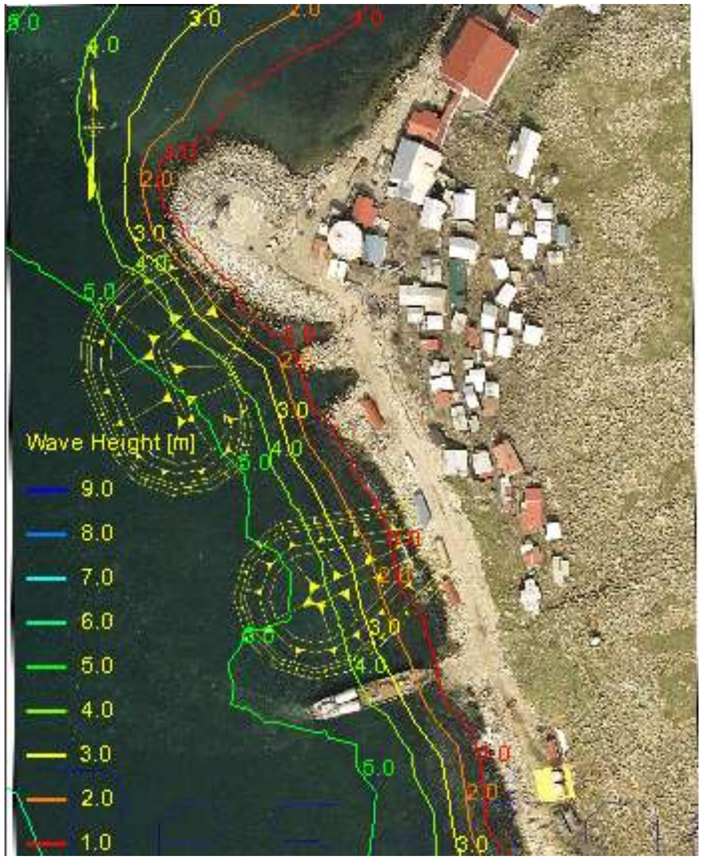

Figure 30 Sample STWAVE transformed wave height field.

Model Validation

There was no data available to validate the results of the STWAVE model so instead, a check on the model output was performed by evaluating the transformed wave heights on an existing structure at the site. The construction of the heliport at Little Diomede was completed in 1993. This structure has not needed major rehabilitation since construction. As built drawings of the helipad indicate that the armor stone around the helipad is 6 tons. Hudson's equation for armor stone sizing was used to determine if the stone size that is at the heliport is appropriate for the transformed wave height. Using a K_d of 2, and a transformed wave height of 9.9 feet, the armor stone size would be 6.8 tons. The transformed wave heights predicted by the model were compared to the armor stone size around the helipad. When used in Hudson's equation, the wave height predicted by the model resulted in an oversized the armor stone by 0.8 tons. This indicates that the STWAVE model for the Little Diomede project is producing wave heights that are in a reasonable range when transformed. Although this results in a larger stone size being used, it adds a factor of safety for an area with a severe wave climate.

Summary of Results

The wave transformation model STWAVE was used to transform waves from the deepwater wave hindcast boundary output points located north and south of Little Diomede to the nearshore at Little Diomede. The modeling simulations included the 50 year return interval extreme storm events from the north and south. The model was checked by examining the wave height experienced at the heliport pad to determine if the armor stone on the pad could survive the modeled wave climate. The check shows good agreement between the model and the existing armor stone size, indicating the deepwater hindcast and nearshore transformation model methodologies are sufficiently skilled to provide design input.

5.0 DESIGN CRITERIA

5.1 Design Vessel and Fleet

The characteristics of the fleet proposed to occupy the various alternatives are shown in Table 5. Proposed plans were laid out to accommodate vessels that need to access the shore at Little Diomede. The subsistence boat dimensions listed below reflect boat sizes that the community indicated they would consider investing in if they had a protected launch/take out area. The rescue/emergency boat is the largest boat that has been suggested for use.

Table 5 Fleet Characteristics

Vessel	Vessel Length [ft]	Design Beam [ft]	Design Draft [ft]	Height [ft]
Subsistence boat	20	7.5	3	5
Rescue/Emergency boat	54	17	5.25	35

It should be noted that the rescue boat will not be home ported at Little Diomede. There is no moorage area for the boat and no means to remove it from the water at the end of the season. The boat will likely be docked at Nome. Service to Little Diomede will likely be on an "as needed" basis.

5.2 Entrance Channel and Mooring Area.

The entrance channel is 4 to 5 times the beam of a boat used for subsistence hunting and fishing. This will provide adequate clearance for the subsistence boats to exit and return. The entrance channel width is also two times the beam of the emergency ship which would allow it to use the landing during calmer weather.

5.3 Launch Depth

The shore at Little Diomede is comprised of cobbles and boulders. The launch area would need to be smoothed and widened to provide an area to take boats out. The subsistence boat was used to calculate the required depth at the site during operational periods (Table 6). Based on conversations with residents of Little Diomede, the maximum wave height for boating is approximately 4 feet. Because of the lack of shelter, the required depth for the rescue boat was also calculated for use during operational periods. This added two feet to the depth.

Table 6 Launch Depth Allowances

	Subsistence Boat [ft]	Rescue Boat [ft]
Draft [ft]	3	5
Pitch, Roll, Heave [ft]	2	2
Safety Clearance [ft]	3	3
Total depth required [ft]	8	10

6.0 NAVIGATION IMPROVEMENT OPTIONS

There are two types of boats that could benefit from navigation improvements at Little Diomede:

- An emergency rescue vessel to allow residents to travel to the mainland for medical emergencies.
- Subsistence or commercial fishing boats.

Options considered for vessel protection during launching and landing include:

- Floating Breakwater
- Rubblemound breakwater

Floating Breakwater
A floating breakwater consists of a floating structure that can provide wave protection for short period waves with heights up to 4 feet. A floating breakwater is anchored with chain or piles. Because of the ice climate at Little Diomede, a floating breakwater would need to be removed and stored seasonally. There is no place to store a floating breakwater at Little Diomede. The topography at Little Diomede is a steep slope all around the island and there is no flat area to store a floating breakwater. Part of a floating breakwater project would be the construction of a flat area to store the breakwater in the winter. Because the waves at Little Diomede are regularly greater than the limits of protection (larger than 4 feet and periods between 4 to 12 seconds), the floating breakwater option was dropped from further consideration.

Rubble mound Breakwater
The use of a rubble mound breakwater to provide wave protection in an arctic environment that is susceptible to ice and severe wave action is a proven concept. Rubble mound breakwaters have been successfully used at Nome and Saint Paul Alaska. Rubble mound revetments have been successfully used at Kivalina and Shishmaref Alaska and a rubble mound revetment currently protects the Little Diomede helipad. Because rubble mound breakwaters have a proven history in similar environments, the decision was made to pursue a rubble mound breakwater option.

There are two options for the location of a rubble mound breakwater: north of the helipad or south of the helipad. Residents indicated that they preferred the breakwater to be located south of the helipad. This is where their current boat launch is located. It was also observed during a site visit that a shoal exists off of the helipad. A distinct current was observed over the shoal that would make an entrance channel dangerous if it were located in the area of the shoal.

7.0 DESIGN PARAMETERS

7.1 Design Wave

The armor stone was sized using the transformed wave height from STWAVE. The 50 year return interval wave from hindcast point 82080 from the north and 82086 from the south were transformed into the near shore at Little Diomede. The 50 year return interval design wave from the south of 27.6 feet transformed into a design wave of 16.4 feet using STWAVE. The 50 year return interval design wave from the north of 31.5 feet transformed into a design wave of 17.2 feet on the nose of the breakwater by the helipad and a 15 foot wave on the storage pad. Runs were made without wind forcing and with the mean higher high water level of 1.02 feet.

7.2 Armor Stone

Using Hudson's equation for a wave of 17.2 feet and a K_d of 4 results in armor stone size of 17.2 tons on the north side breakwater by the helipad. A design wave of 15 feet results in an armor stone size of 11.8 tons for the storage pad.

Using Hudson's equation for a wave of 16.4 feet and a K_d of 4 results in armor stone size of 15.7 tons on the south breakwaters, with the exception of Alternative S2. The K_d was increased to 6 for Alternative S2 and the sea side armor on the north breakwater increased to 23 tons. Using a Kd of 4 and 6 for the calculations indicates that the armor stone will require selective placement and will be critical in the construction of the breakwater. The Alaska District has successfully used selective placement for breakwater construction projects throughout Alaska.

In addition to wave forces, any structure placed along the coast at Little Diomede is also going to be subject to ice forces. Design work for a breakwater at Nome indicated that 8 ton stone was the minimum armor size to survive ice shoves. The armor stone size of 15.7 ton exceeds the minimum 8 ton requirement for Nome.

In the event that the armor stone size must be reduced due to availability or cost, a reduction in stone size is possible provided that a flume study is performed to determine the stone size reduction.

7.3 Crest Height

The crest height was set at 25 feet using ACES and equation VI-5-13 in the Coastal Engineering Manual. A still water level of 1.0 foot was used. Storm surge was not included in the calculations since storm surge in not typically an issue at Little Diomede and the structure was designed for overtopping. A 10% exceedence level for the number

of waves was used for the CEM equation. Because of the 10% exceedence level, the structure is designed to be a periodic overtopping structure. Since the structure is not designed to protect fixed harbor facilities or moored boats from a 50 year wave this is a reasonable approach. The intention of the breakwater is to allow safe launching and removal of boats in the typical wave climate, not during a 50 year event. The local boats would need to be removed from the water when a large storm event is forecast. The crest width was set at 20 feet based on armor stone size.
The structure is being designed as a periodic overtopping structure so it will be able to accommodate higher run up that would associated with increased sea level elevation. According to CEM calculations a structure set at an elevation of 25 feet would be over topped by 33% of the waves under the high risk water level rise scenario.

7.4 Water Quality and Circulation

Water quality and circulation criteria were applied to the alternative designs to minimize environmental degradation associated with harbor improvements. Nece, et al. 1979 "Effects of Planform Geometry on Tidal Flushing and Mixing in Marinas" is adopted as standard practice for estimating harbor basin flushing by use of an average exchange coefficient for one tidal cycle. This work is based on physical model studies of harbor basins of varying geometry and tidal range typical of Puget Sound in the State of Washington. It is noted that the mean tidal range for the project site at Little Diomede is less than that for the Puget Sound area of 6 feet.

The aspect ratio is a measure of the length divided by the width of the basin. Generally aspect ratios of greater than 0.3 and less than 3.0 are desirable. Such geometry will minimize possible zones of stagnation and short-circuiting of circulation cells within the basin. Additionally, the ratio of the basin planform area (A) to the entrance cross sectional area (a) is recommended to be less than 400 for an optimal basin configuration for flushing.

All alternatives considered in detail for this study used the above criteria for design and evaluation.

7.5 Dredge Material Disposal

Material dredged for this project will be incorporated into the breakwater to the maximum extent possible. It is anticipated that the dredge material will be in the form of boulders and cobbles which could be incorporated into the core or B rock layer depending on dredge material size.

8.0 ALTERNATIVES CONSIDERED IN DETAIL

Breakwaters for the proposed alternatives were positioned to reduce the wave climate for launching and taking boats out. Three alternatives were positioned south of the helipad to reduce the wave climate associated with waves from the north. These three alternatives would not provide protection from south waves. One alternative was positioned north of the helipad to reduce waves from the south. This alternative would not reduce waves from the north.

None of the alternatives provide protection from wave events from all directions. None of the alternatives are designed to provide a safe harbor for mooring. The intent of the breakwater is to provide a more sheltered nearshore environment to prevent boat damage at the shore during launching and landing.

8.1 No Action

This alternative would leave the community without a safe place to launch or take out their boats or rescue vessels to land. Vessels will continue to sustain damages as they try to launch or take out and opportunities to subsistence hunt or fish will be lost.

8.2 North of Helipad

Alternatives located on the north side of the helipad were not preferred by the residents because there was little room available to take out and store their boats. Only one alternative was looked at north of the helipad and it was designed to provide adequate take out area and boat storage. This alternative would need a road built to the pad in order to access the storage area.

Alternative N1

This plan consists of two rubble mound breakwaters that would provide shelter from south storms and prevent shore side boulders from being transported into the landing area. The north breakwater was widened to provide an area for boat storage once removed from the water and an area was dredged and filled to provide an adequate take out area. This alternative would require improvements to the north shoreline to provide vehicle access to the storage area (Figure 31).

Dredging. In this option a small area nearshore would be dredged to -10 feet MLLW to provide boats a rock free approach to shore and room to turn around once launched. It is assumed that the dredging would include boulders and could possibly need blasting. Approximately 2,000 cubic yards would need to be removed for this alternative.

Breakwaters. The two breakwaters would require approximately 20,600 cubic yards of core rock, 24,400 cubic yards of B rock, and 28,600 cubic yards of armor stone (Figure 32).

Wave Reduction. The output from the STWAVE model runs were used with a diffraction diagram to determine the wave height reduction achieved by this alternative. This alternative would provide protection from waves with periods of 8 second or lower from the south, but would offer minimal or no protection from waves with longer periods. The 50 year storm wave was not evaluated since it was assumed to have a period equal to or greater than the top 5 storms of the hindcast which were 11 to 12 seconds. The breakwater was not designed to provide protection from storm waves, rather; it was designed to make launching and retrieval safer in the average wave climate, not during storm events. This breakwater configuration would reduce waves, that are 8 seconds or less, from the dominant south direction (168.75^{o} - 191.25^{o}) to 2.5/10 of the wave height at the boat launch area (Figure 33).

Shoaling. No shoaling in the entrance is anticipated due to the highly energetic environment and the lack of fine sediment for deposition.

Construction Dredging. Dredging quantities were developed using a hydrographic survey performed in 2007. Drilling will be performed during the development of plans and specifications for this project. Until project specific drilling is accomplished, boring logs from drilling in front of the school can provide a general description of the soil conditions that are anticipated. The results of that drilling indicate that boulders and sand can be expected.

Work inside the breakwaters can be accomplished with land based equipment. Depending on the size of the boulders, blasting may be required. Dredging equipment and methods would be left as an option for the contractor.

Side slopes for the basin would be dredged to 1V:3H transitioning to a 1V:10H ramp. It is anticipated that these side slope will hold because of the rocky nature of the dredge material.

Maintenance Dredging. Maintenance dredging is not expected for any of the proposed plans. The wave climate at the site is highly energetic. Sediment for deposition is not found in the area around the site so no maintenance dredging is anticipated.

Dredge Material Disposal. The dredged material will be used in the breakwater construction to the maximum extent possible

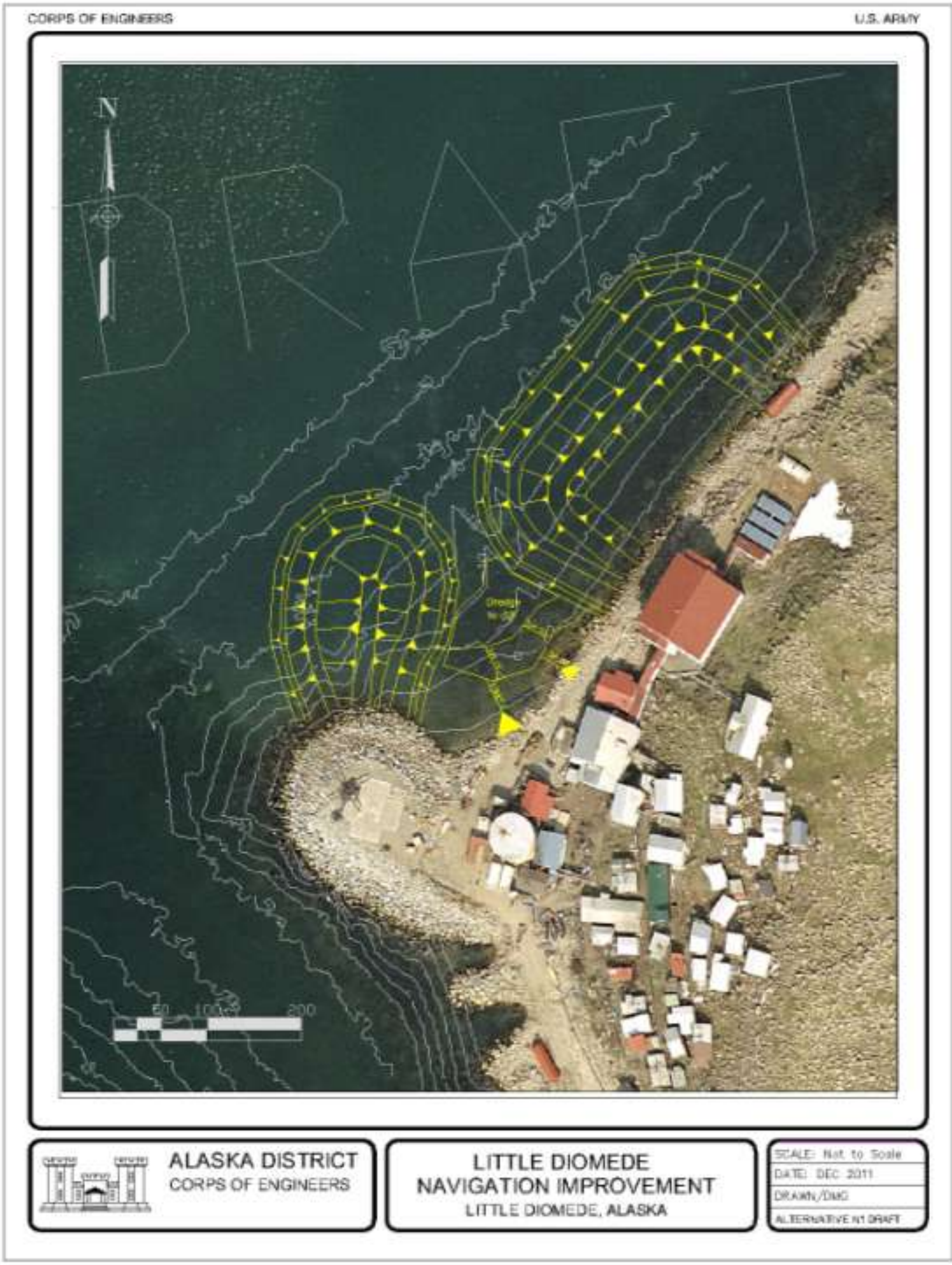

Figure 31 Plan view of alternative N1

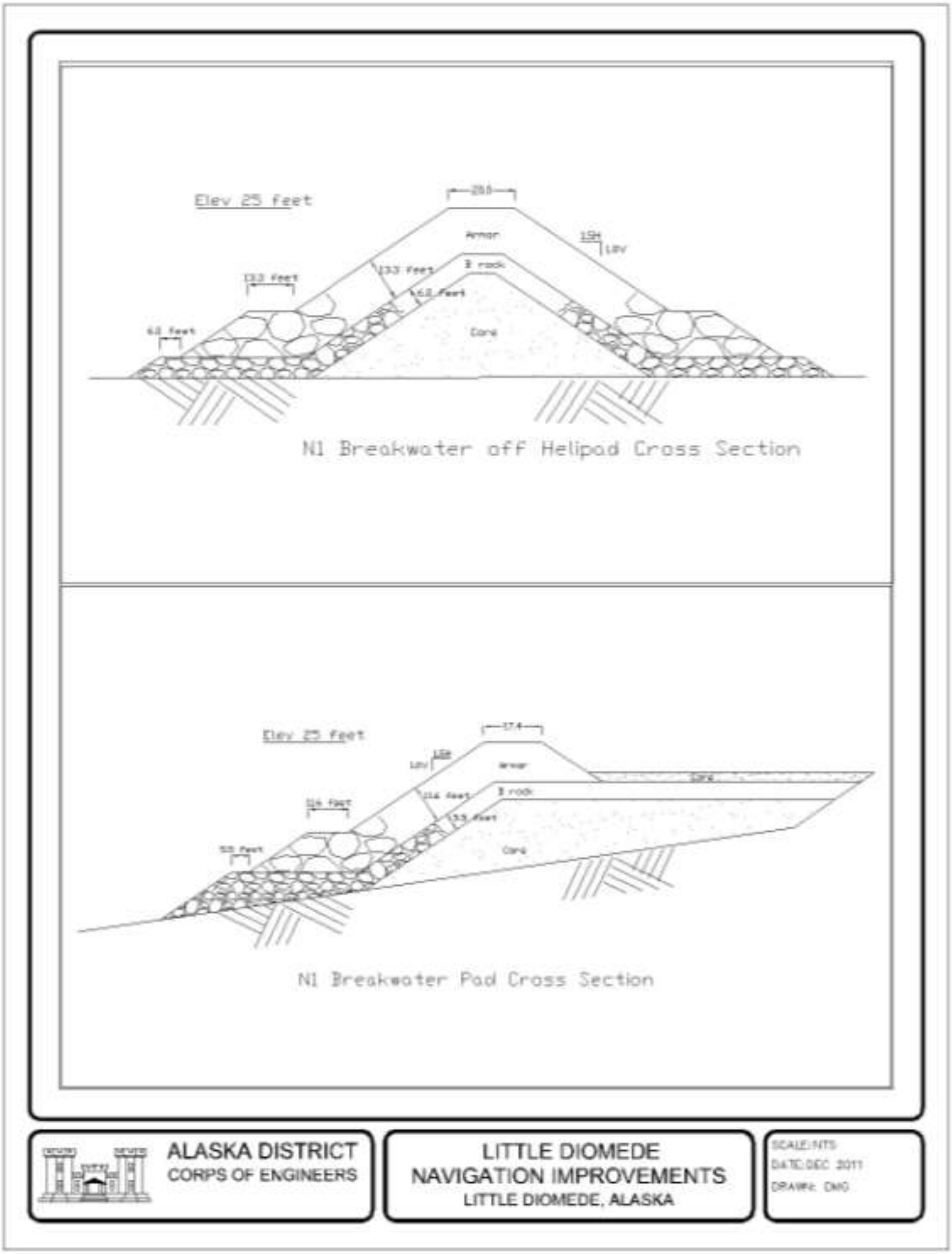

Figure 32 Typical cross sections for alternative N1

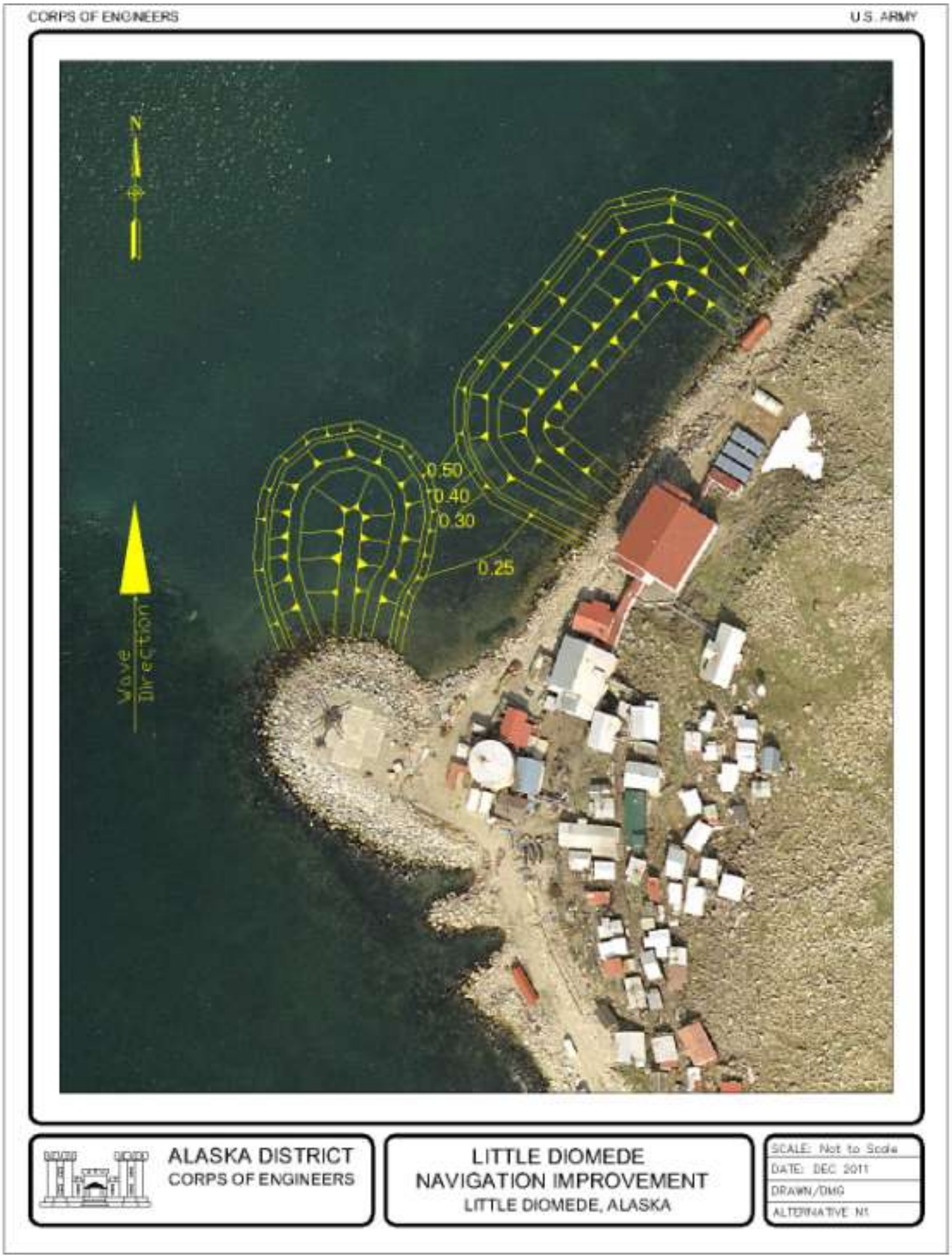

Figure 33 Wave diffraction for alternative N1 showing K' coefficients (multiply the coefficient shown by the incident wave height to determine the diffracted wave height in the launch area).

8.3 South of the Helipad

Alternatives where the entrance channel forced boats to travel over the shoal were eliminated from consideration during alternative evaluation. Observation of the current travelling over the shoal extending from the helipad indicated that an entrance channel over the shoal would create a hazardous situation.

Three alternatives were looked at in detail on the south side of the helipad.

Alternative S1

This plan consists of two rubble mound breakwaters that would provide shelter from north storms and prevent shore side boulders from being transported into the landing area. The south breakwater was widened where it tied into shore to provide an area for boat storage once removed from the water. The size of the armor stone took up the majority of space that could be used as a storage area, making the alternative impractical (Figure 34).

Dredging. In this option a small area nearshore would be dredged to -10 feet MLLW to provide boats a rock free approach to shore and room to turn around once launched. It is assumed that the dredging would include boulders and could possibly need blasting. Approximately 3,000 cubic yards would need to be removed for this alternative.

Breakwaters. The two breakwaters would require approximately 12,600 cubic yards of core rock, 24,800 cubic yards of B rock, and 25,500 cubic yards of armor stone (Figure 35).

Wave Reduction. The output from the STWAVE model runs were used with a diffraction diagram to determine the wave height reduction achieved by this alternative. This alternative would provide protection from waves with periods of 8 second or lower from the south, but would offer minimal or no protection from waves with longer periods. The 50 year storm wave was not evaluated since it was assumed to have a period equal to or greater than the top 5 storms of the hindcast which were 11 to 12 seconds. The breakwater was not designed to provide protection from storm waves, rather; it was designed to make launching and retrieval safer in the average wave climate, not during storm events. This breakwater configuration would reduce waves, that are 8 seconds or less, from the dominant north wave direction (348.75^{o} - 11.25^{o}) to 2.5/10 of the wave height at the boat launch area (Figure 36).

Shoaling. No shoaling in the entrance is anticipated due to the highly energetic environment and the lack of fine sediment for deposition.

Construction Dredging. Dredging quantities were developed using a hydrographic survey performed in 2007. Drilling will be performed during the development of plans and specifications for this project. Until project specific drilling is accomplished, boring logs from drilling in front of the school can provide a general description of the soil conditions that are anticipated. The results of that drilling indicate that boulders and sand can be expected.

Work inside the breakwaters can be accomplished with land based equipment. Depending on the size of the boulders, blasting may be required. Dredging equipment and methods would be left as an option for the contractor.

Side slopes for the basin would be dredged to 1V:3 H transitioning to a 1V:10H ramp. It is anticipated that these side slope will hold because of the rocky nature of the dredge material.

Maintenance Dredging. Maintenance dredging is not expected for any of the proposed plans. The wave climate at the site is highly energetic. Sediment for deposition is not found in the area around the site so no maintenance dredging is anticipated.

Dredge Material Disposal. The dredged material will be used in the breakwater construction to the maximum extent possible.

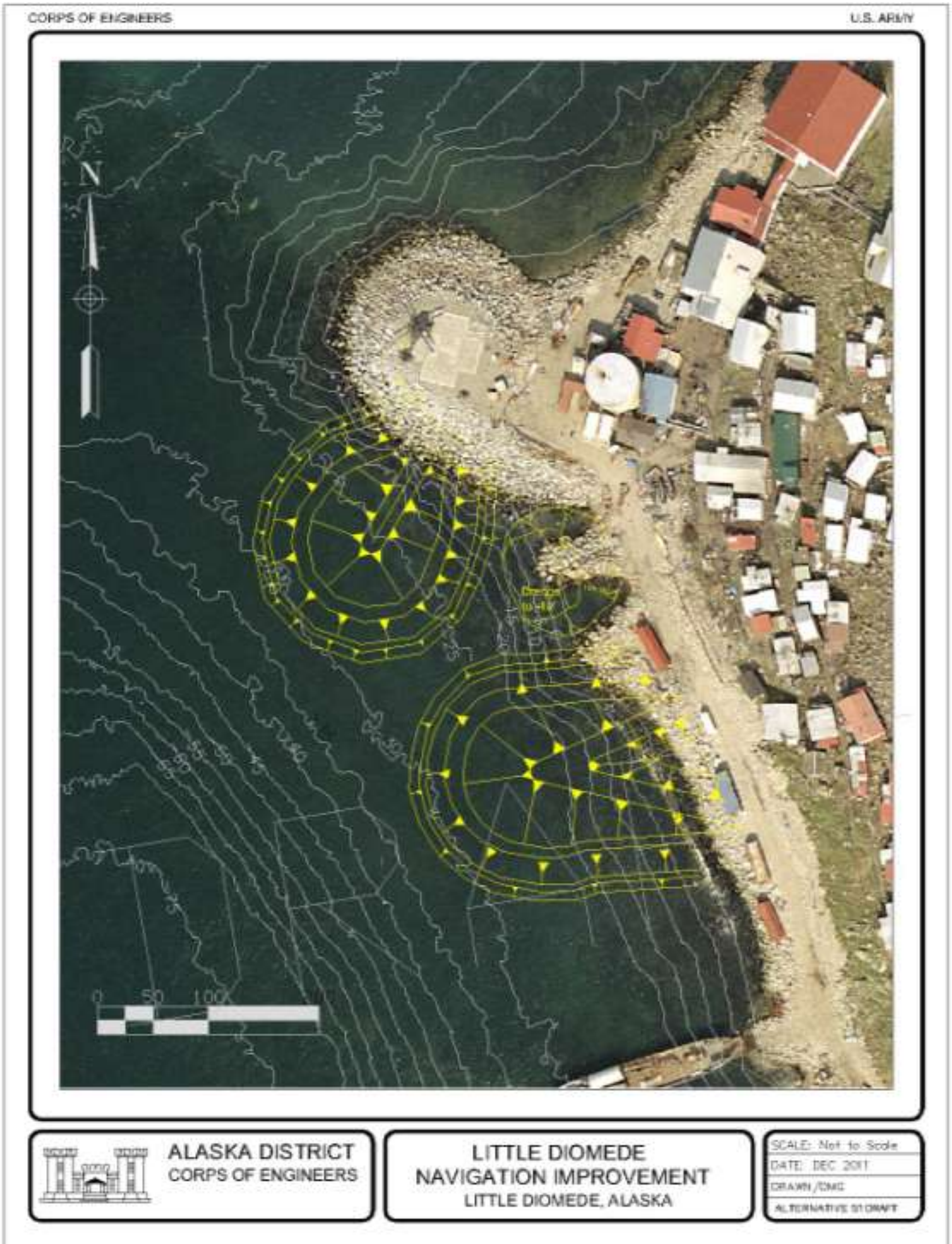

Figure 34 Plan view of alternative S1

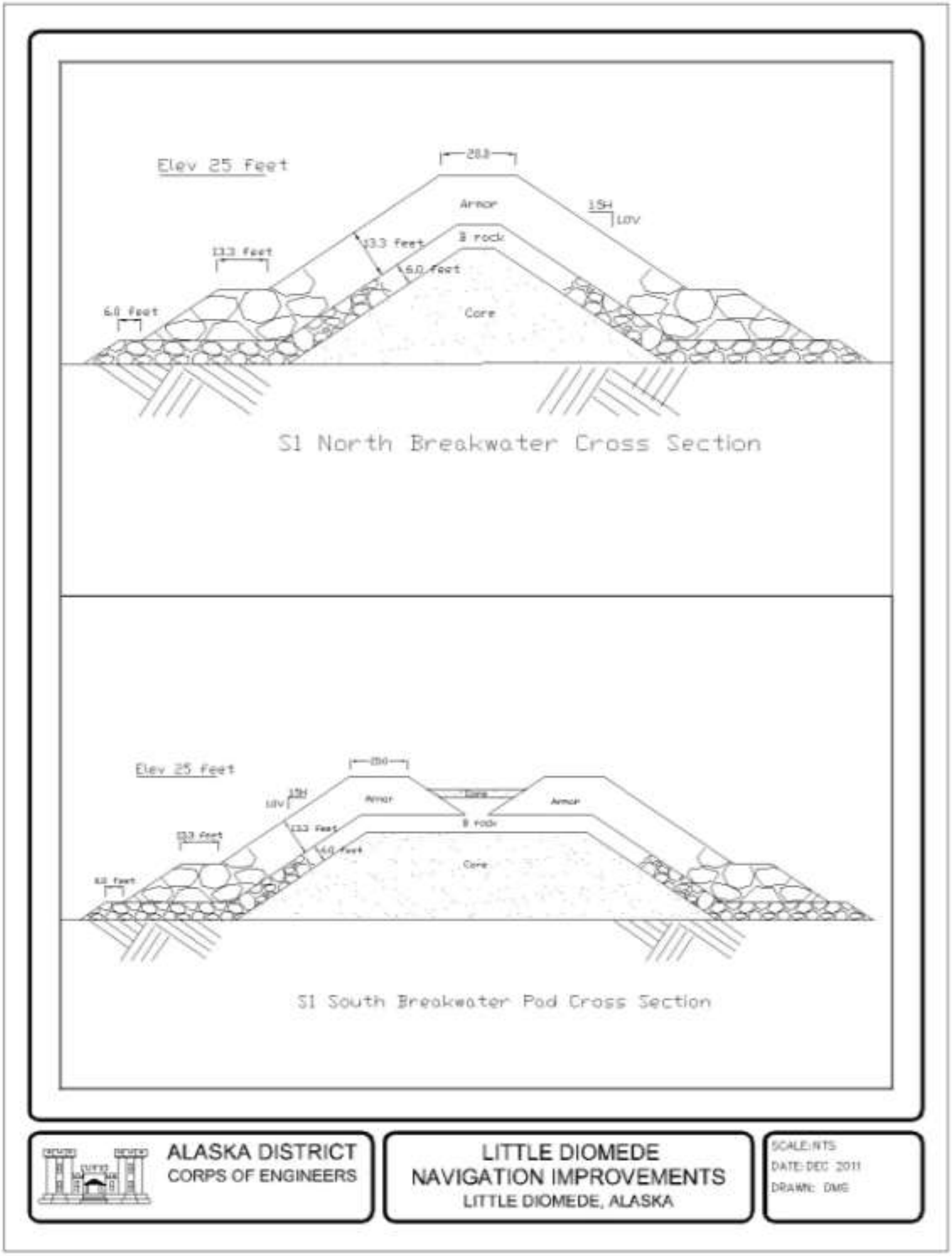

Figure 35 Typical cross sections for alternative S1

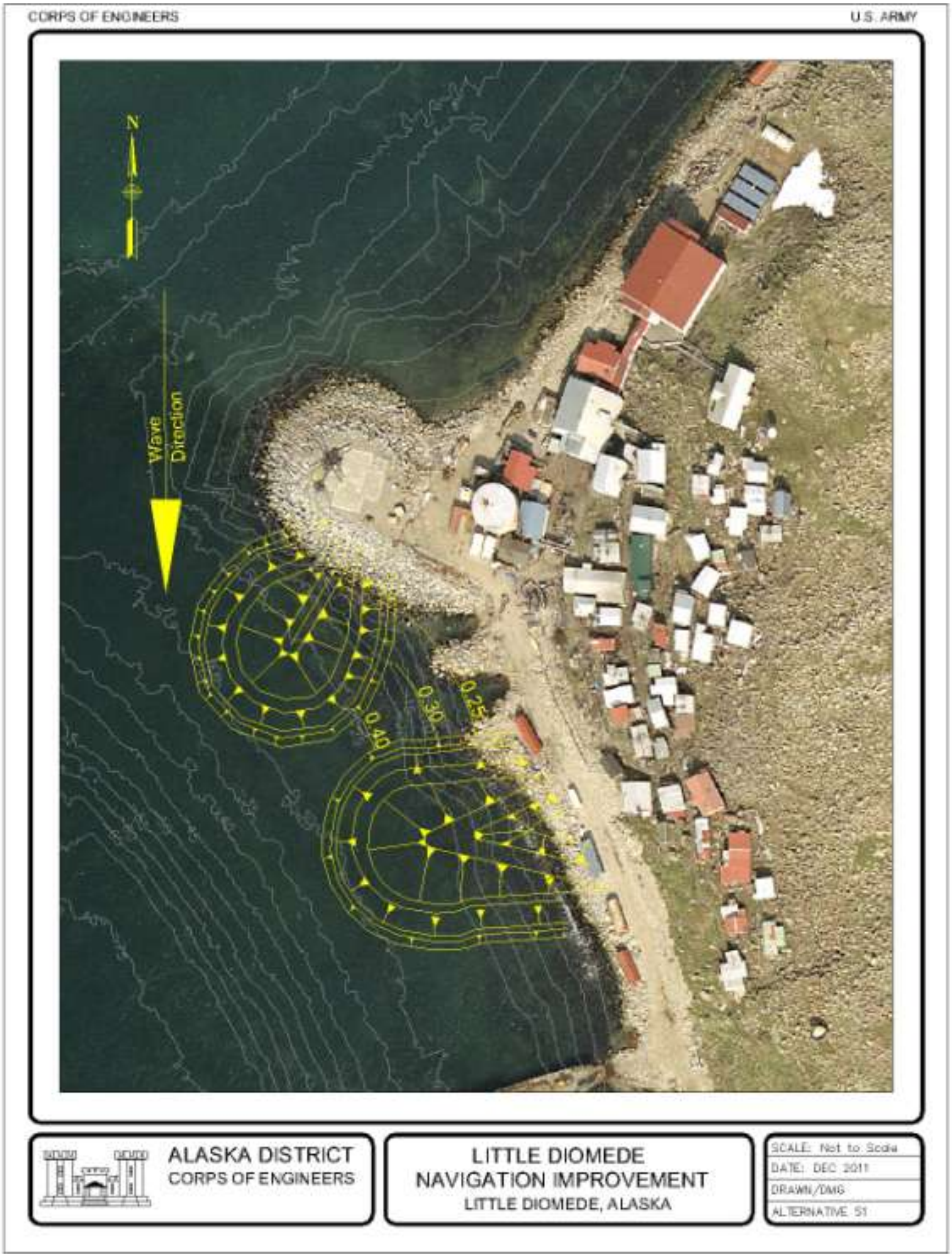

Figure 36 Wave diffraction for alternative S1 showing K' coefficients (multiply the coefficient shown by the incident wave height to determine the diffracted wave height in the launch area).

Alternative S2

This plan consists of two rubble mound breakwaters. One breakwater is perpendicular to the shore and the other is hooked off of the helipad. This alternative would provide shelter from north waves and give a little more protection from waves from the west. This alternative would also prevent shore side boulders from being transported into the landing area. This alternative provides no area to store boats taken from the water (Figure 37).

Dredging. In this option a small area nearshore would be dredged to -10 feet MLLW to provide boats a rock free approach to shore and room to turn around once launched. It is assumed that the dredging would include boulders and could possibly need blasting. Approximately 3,000 cubic yards would need to be removed for this alternative.

Breakwaters. The two breakwaters would require approximately 23,400 cubic yards of core rock, 24,200 cubic yards of B rock, and 32,900 cubic yards of armor stone. Armor stones on the sea side of the north breakwater are 23 tons and would need to be specially placed in order to achieve a tight interlock between armor stones (Figure 38).

Wave Reduction. The output from the STWAVE model runs were used with a diffraction diagram to determine the wave height reduction achieved by this alternative. This alternative would provide protection from waves with periods of 8 second or lower from the south, but would offer minimal or no protection from waves with longer periods. The 50 year storm wave was not evaluated since it was assumed to have a period equal to or greater than the top 5 storms of the hindcast which were 11 to 12 seconds. The breakwater was not designed to provide protection from storm waves, rather; it was designed to make launching and retrieval safer in the average wave climate, not during storm events. This breakwater configuration would reduce waves, that are 8 seconds or less, from the dominant north wave direction (348.75^o - 11.25^o) to 2/10 of the wave height at the boat launch area (Figure 39).

Shoaling. No shoaling in the entrance is anticipated due to the highly energetic environment and the lack of fine sediment for deposition.

Construction Dredging. Dredging quantities were developed using a hydrographic survey performed in 2007. Drilling will be performed during the development of plans and specifications for this project. Until project specific drilling is accomplished, boring logs from drilling in front of the school can provide a general description of the soil conditions that are anticipated. The results of that drilling indicate that boulders and sand can be expected.

Work inside the breakwaters can be accomplished with land based equipment. Depending on the size of the boulders, blasting may be required. Dredging equipment and methods would be left as an option for the contractor.

Side slopes for the basin would be dredged to 1V:3H transitioning to a 1V:10H ramp. It is anticipated that these side slope will hold because of the rocky nature of the dredge material.

Maintenance Dredging. Maintenance dredging is not expected for any of the proposed plans. The wave climate at the site is highly energetic. Sediment for deposition is not found in the area around the site so no maintenance dredging is anticipated.

Dredge Material Disposal. The dredged material will be used in the breakwater construction to the maximum extent possible

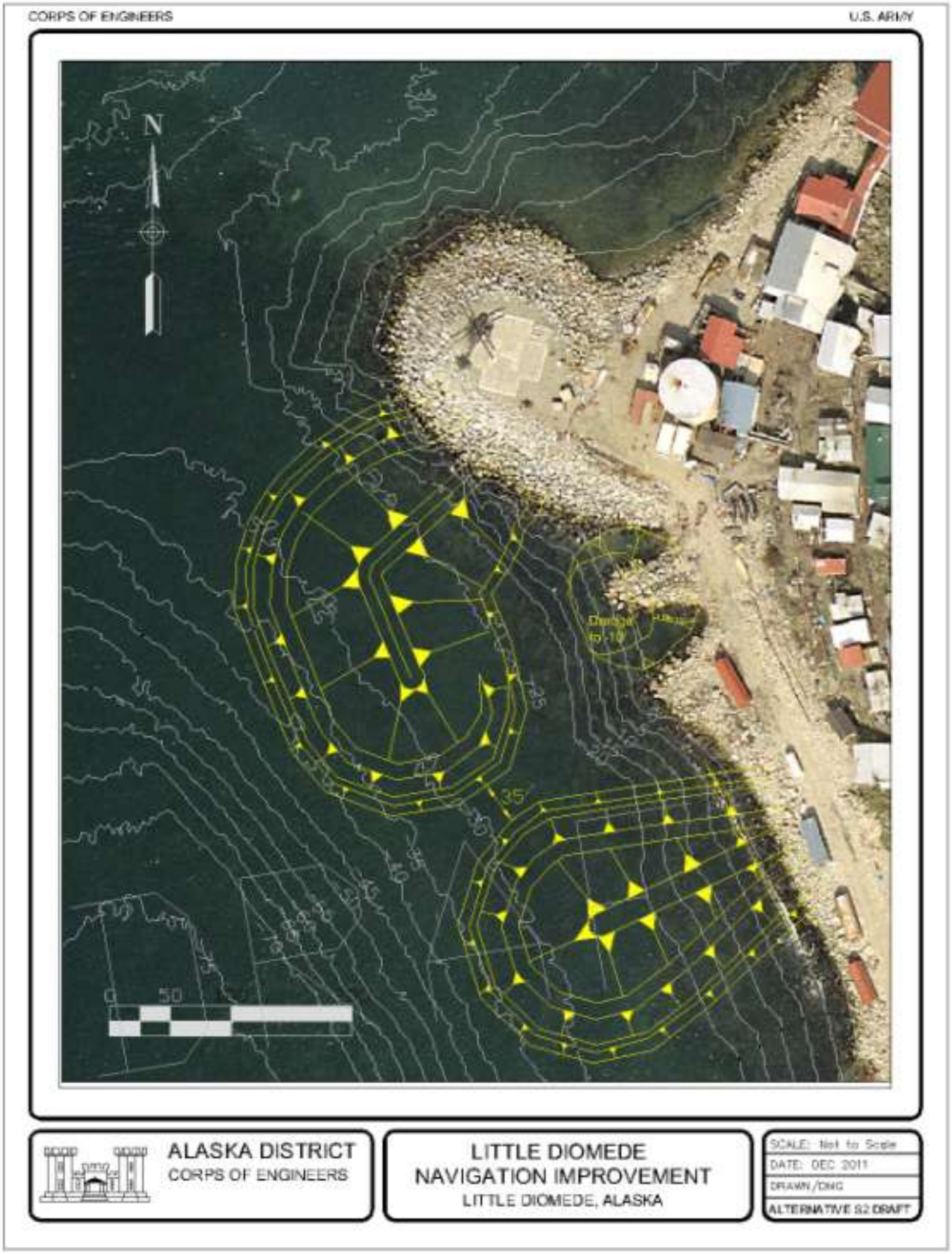

Figure 37 Plan view of alternative S2

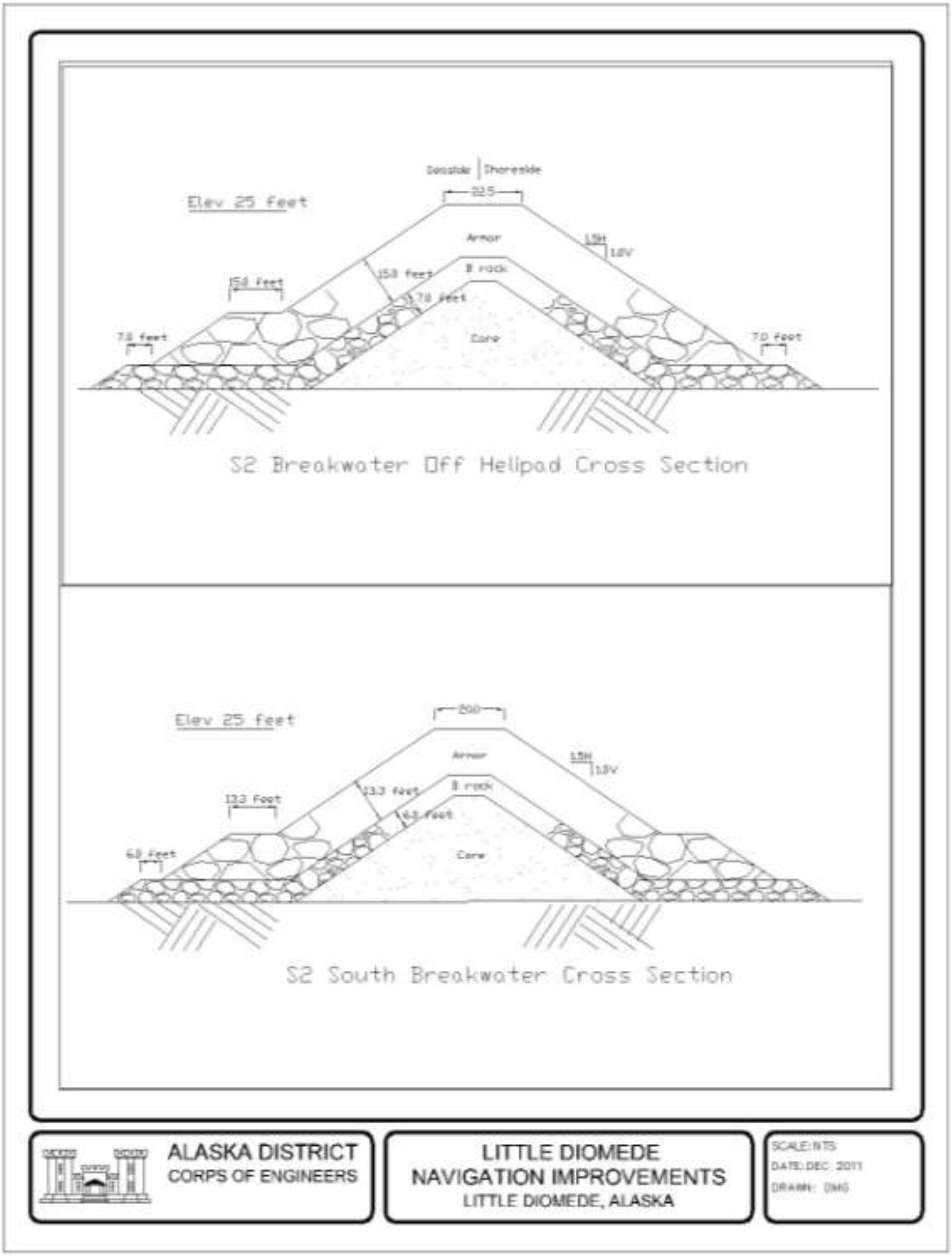

Figure 38 Alternative S2 cross sections

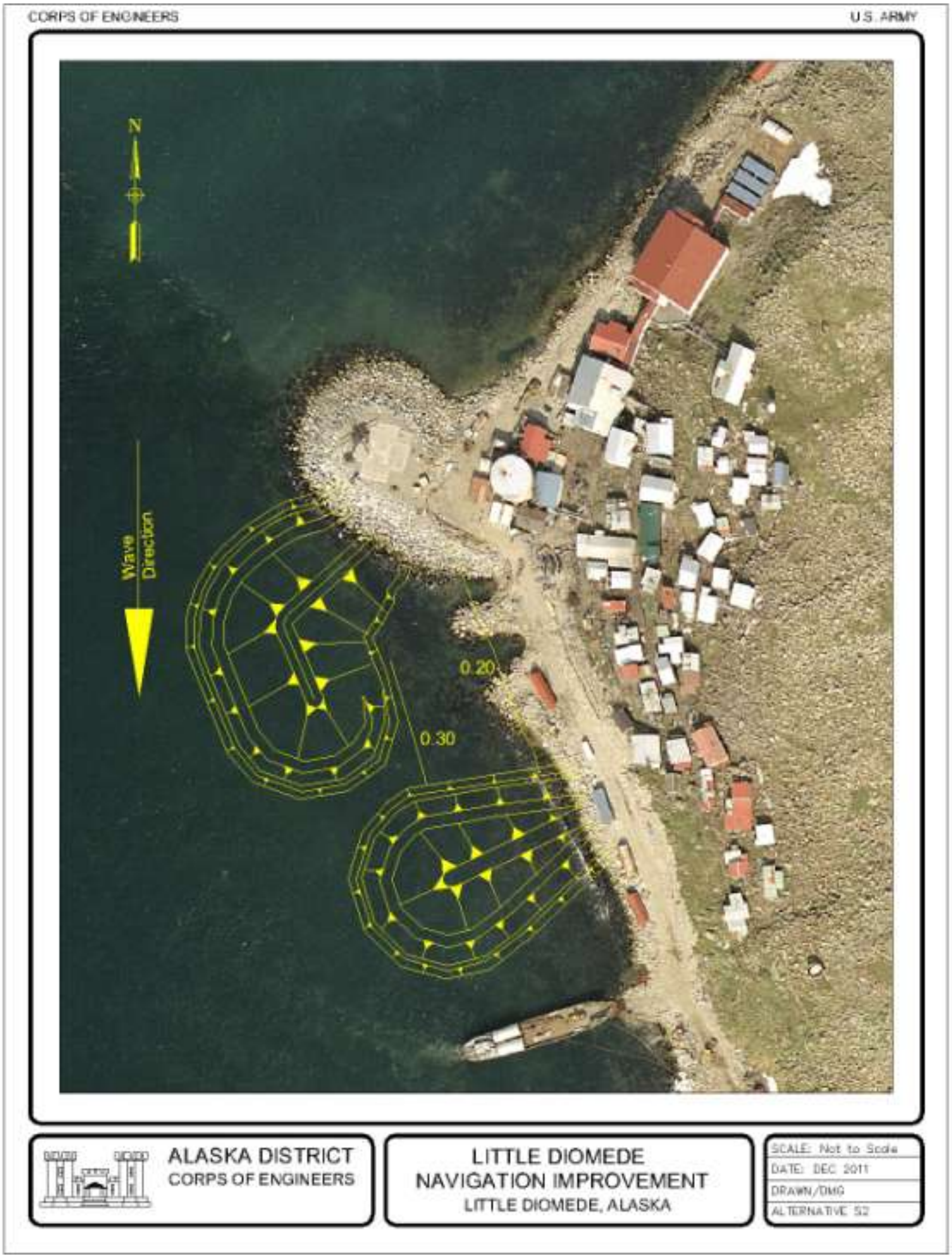

Figure 39 Wave diffraction for alternative S2 showing K' coefficients (multiply the coefficient shown by the incident wave height to determine the diffracted wave height in the launch area).

Alternative S3

This plan consists of two rubble mound breakwaters that would provide shelter from north storms and prevent shore side boulders from being transported into the landing area. The south breakwater was widened to provide an area for boat storage once removed from the water (Figure 40).

Dredging. In this option a small area nearshore would be dredged to -10 feet MLLW to provide boats a rock free approach to shore and room to turn around once launched. It is assumed that the dredging would include boulders and could possibly need blasting. Approximately 2,500 cubic yards would need to be removed for this alternative.

Breakwaters. The two breakwaters would require approximately 19,000 cubic yards of core rock, 23,100 cubic yards of B rock, and 36,400 cubic yards of armor stone (Figure 41).

Wave Reduction. The output from the STWAVE model runs were used with a diffraction diagram to determine the wave height reduction achieved by this alternative. This alternative would provide protection from waves with periods of 8 second or lower from the south, but would offer minimal or no protection from waves with longer periods. The 50 year storm wave was not evaluated since it was assumed to have a period equal to or greater than the top 5 storms of the hindcast which were 11 to 12 seconds. The breakwater was not designed to provide protection from storm waves, rather; it was designed to make launching and retrieval safer in the average wave climate, not during storm events. This breakwater configuration would reduce waves, that are 8 seconds or less, from the dominant north wave direction (348.75^o - 11.25^o) to 2.5/10 of the wave height at the boat launch area (Figure 42).

Shoaling. No shoaling in the entrance is anticipated due to the highly energetic environment and the lack of fine sediment for deposition.

Construction Dredging. Dredging quantities were developed using a hydrographic survey performed in 2007. Drilling will be performed during the development of plans and specifications for this project. Until project specific drilling is accomplished, boring logs from drilling in front of the school can provide a general description of the soil conditions that are anticipated. The results of that drilling indicate that boulders and sand can be expected.

Work inside the breakwaters can be accomplished with land based equipment. Depending on the size of the boulders, blasting may be required. Dredging equipment and methods would be left as an option for the contractor.

Side slopes for the basin would be dredged to 1V:3 H transitioning to a 1V:10H ramp. It is anticipated that these side slope will hold because of the rocky nature of the dredge material.

Maintenance Dredging. Maintenance dredging is not expected for any of the proposed plans. The wave climate at the site is highly energetic. Sediment for deposition is not found in the area around the site so no maintenance dredging is anticipated.

Dredge Material Disposal. The dredged material will be used in the breakwater construction to the maximum extent possible

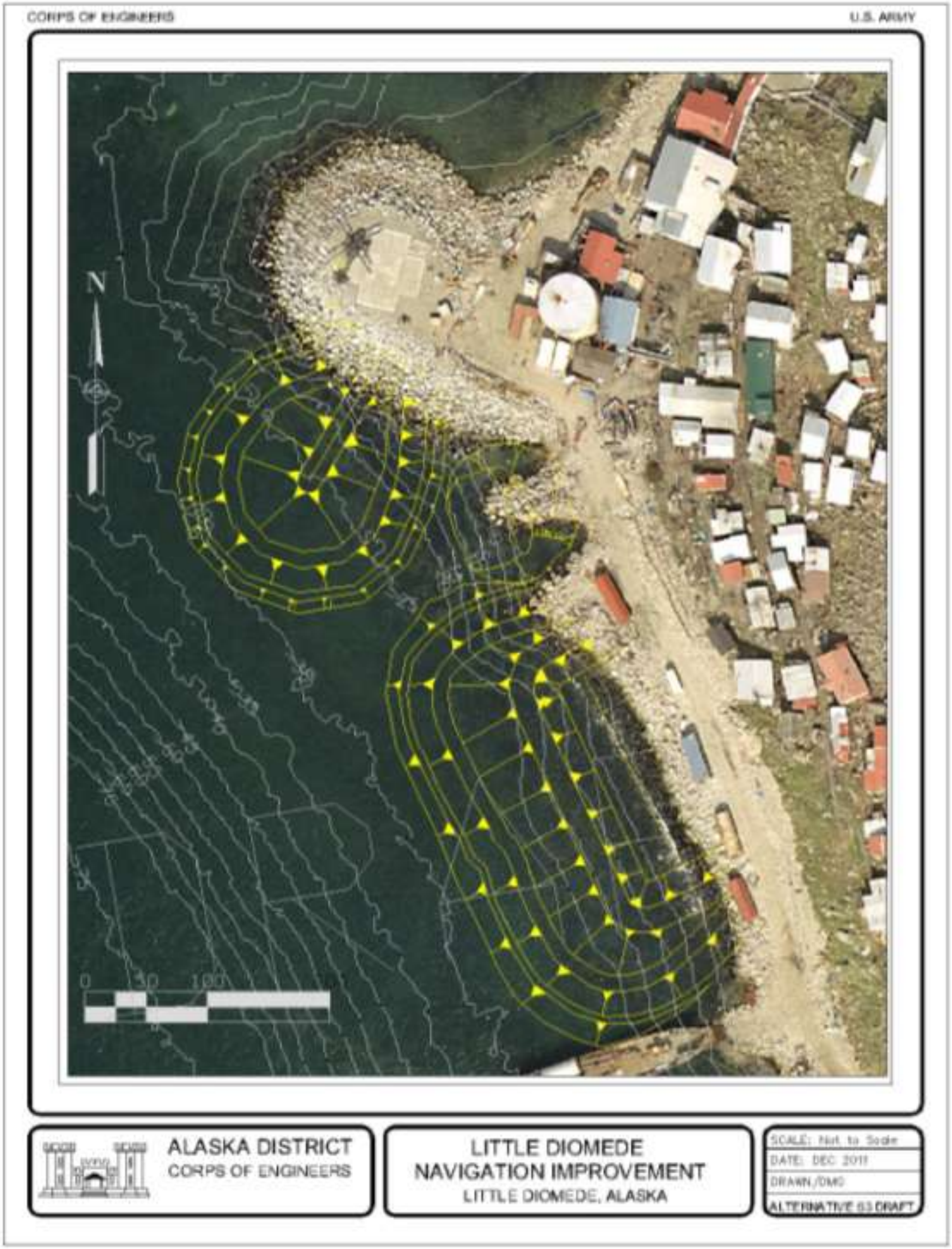

Figure 40 Plan view for alternative S3

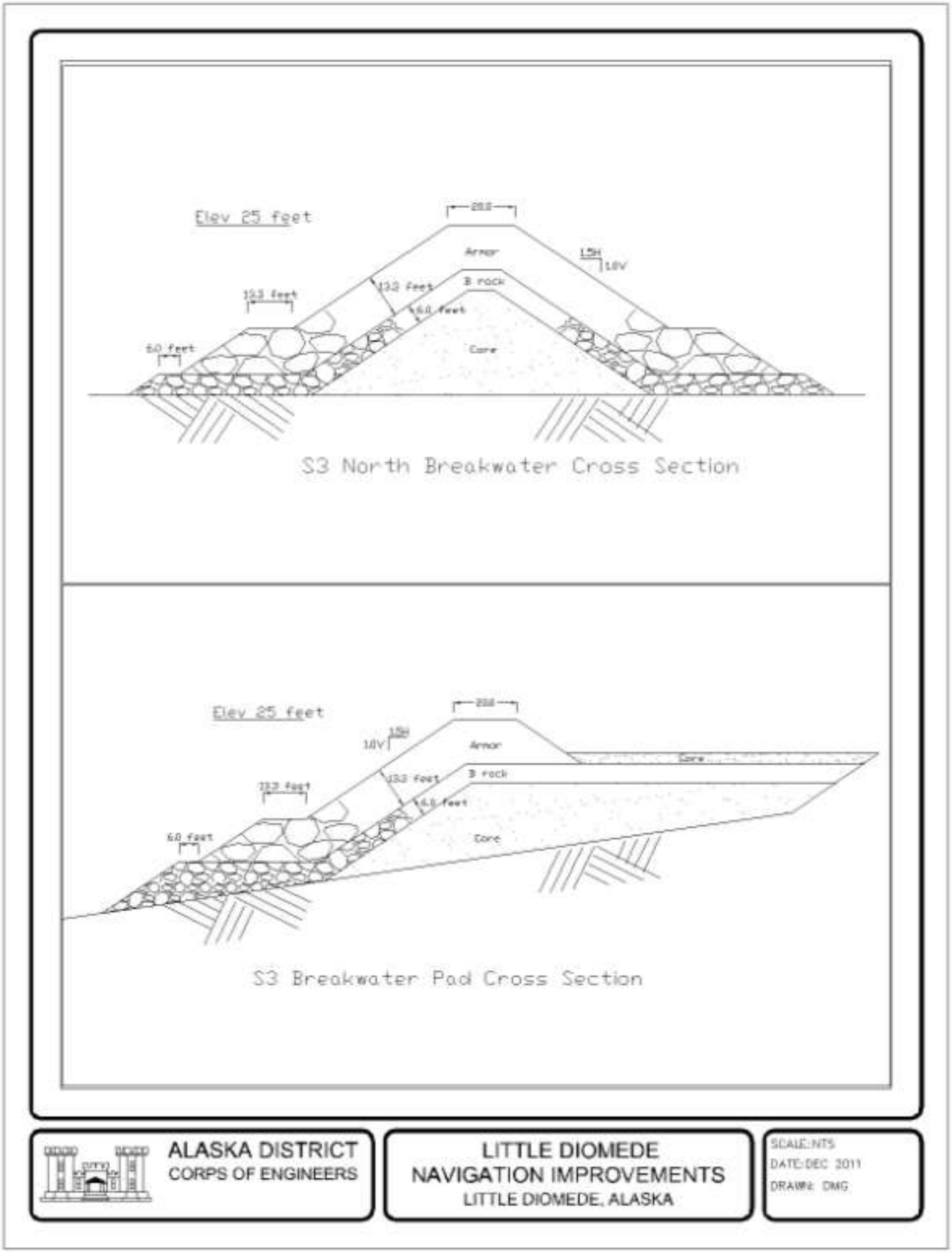

Figure 41 Typical cross sections for alternative S3

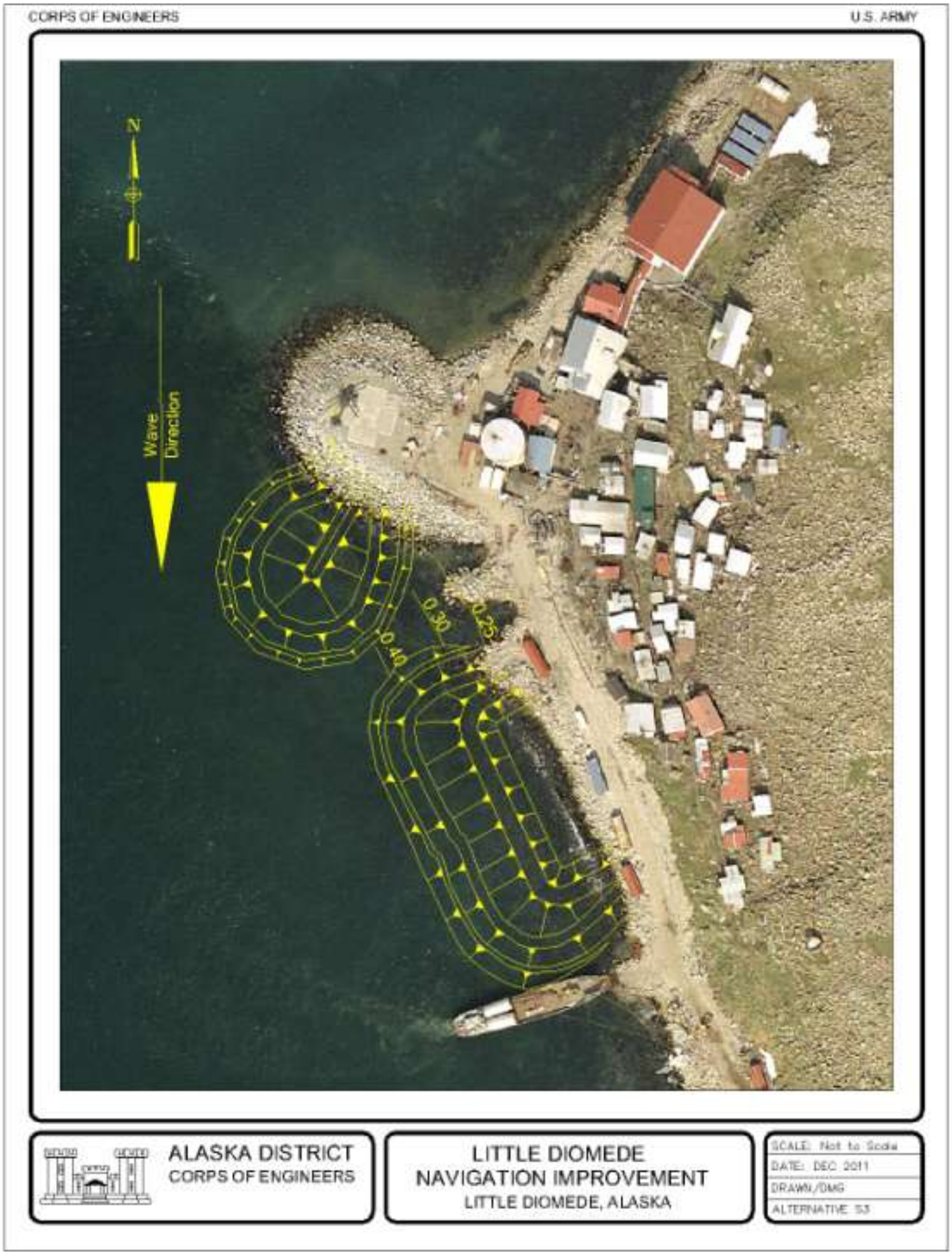

Figure 42 Wave diffraction for alternative S3 showing K' coefficients (multiply the coefficient shown by the incident wave height to determine the diffracted wave height in the launch area).

9.0 NAVIGATION AIDS

The Coast Guard may require a fixed navigation aid for the breakwater. During development of plans and specifications the Coast Guard will be contacted to determine the navigation aid requirements. Any navigation aid other than the Coast Guard required aid would be a local cost and maintenance responsibility.

10.0 CONSTRUCTION CONSIDERATIONS

The breakwater construction is anticipated to take two years to complete, assuming a contract award in the fall. In order to attract a number of bidders, it is recommended that the project be advertised early to interest contractors to bid on this project. The contract should be awarded in the fall to allow the contractor the winter to prepare the logistics for the upcoming open water season.

The work season length, remote site location, wave climate, lack of local protection from wind and/or wave events are just some of the conditions that a contractor will need to consider when proposing on this contract. It is anticipated that there will be approximately 100 days available for work before ice formation and storms prevent work being performed at the site. Equipment needs to be demobilized from the site before the Bering Sea ices and prevents travel to or from the site.

Storms at the site move through the area very rapidly and there is no place to run for shelter. Generally storms occur in the fall months.

Little Diomede is a remote location so crew members will need to be flown to the site in a helicopter or ship up with the construction equipment. Once on site the crew that will work on the project will need to have room and board provided. It may be possible for the contractor to put his crew up at the school. It anticipated that the contractor will work two shifts, 10 hours a day, 7 days a week.

The contractor will need to make sure that there is fuel available for him at the site. He could bring up his own fuel barge. Purchase of fuel would need to be coordinated early in the year so that arrangements could be made to have additional fuel delivered to the site.

It is expected that the stone for the breakwater will come from Nome. There is no place to offload and stockpile the stone. At the end of the construction season, the breakwater will need to be finished with armor stone.

11.0 MAINTENANCE

The breakwater stone was sized to withstand the 50 year wave so it is not anticipated that there will be a significant loss of stone from the structure over the life of the project. It is estimated that a worst case of 5% of the armor stone will need to be replaced every 10 years. Stone quality will be strictly specified in the contract specifications so that little to no armor degradation is anticipated.

12.0 REFERENCES

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