# Barrow Alaska Coastal Erosion Feasibility Study

## Appendix F: Geotechnical


## Barrow, Alaska

US Army Corps of Engineers
Alaska District

GEOTECHNICAL APPENDIX
BARROW ALASKA COASTAL EROSION FEASIBILITY STUDY
BARROW, ALASKA

# 1. INTRODUCTION

**1.1** This geotechnical appendix supports the on-going coastal erosion feasibility study for Barrow, Alaska, being prepared by the Alaska District, U.S. Army Corps of Engineers. Geotechnical investigations performed for the study consisted of site reconnaissance and evaluating available information on site conditions and potential rock and gravel material sources in the region, relevant to the proposed flooding and erosion mitigation alternatives. A more intensive geotechnical site investigation involving soil borings and/or test pits will be conducted during the Preconstruction Engineering and Design (PED) phase, tailored to the Tentatively Selected Plan (TSP). Topographic (LIDAR), bathymetric, and tidal surveys were completed in August-September 2018 for use in Hydraulics and Hydrology analyses for the study.

**1.2** The problem being addressed by the feasibility study is the occurrence of frequent and severe coastal storms in Barrow, resulting in coastal erosion and flooding which threaten public health and safety and the community's economy. The study's intent is to identify a safe and functional method of coastal storm damage protection, with objectives to (1) reduce risk to public health, life, and safety, (2) reduce damage caused by flooding and shoreline erosion to residential and commercial structures and critical public infrastructure, and (3) reduce or mitigate damage to tangible cultural heritage. The coastal erosion and flooding problem is detailed in the main report summary and is not elaborated within this appendix. The geotechnical contribution to the feasibility study is to provide input on geotechnical site conditions that impact and influence the selection of measures to mitigate the coastal erosion and flooding problem.

**1.3** Barrow is located approximately 750 miles north of Anchorage and 320 miles north of the Arctic Circle (Figure 1). The coastal city of Barrow has a population of approximately 5,000 and is positioned where the Chukchi Sea meets the Beaufort Sea. Some of the main geographic and cultural features of the immediate Barrow study area are shown in Figure 2. As shown in Figure 2, the extent of coastline currently being studied is approximately 25,300 feet in length.

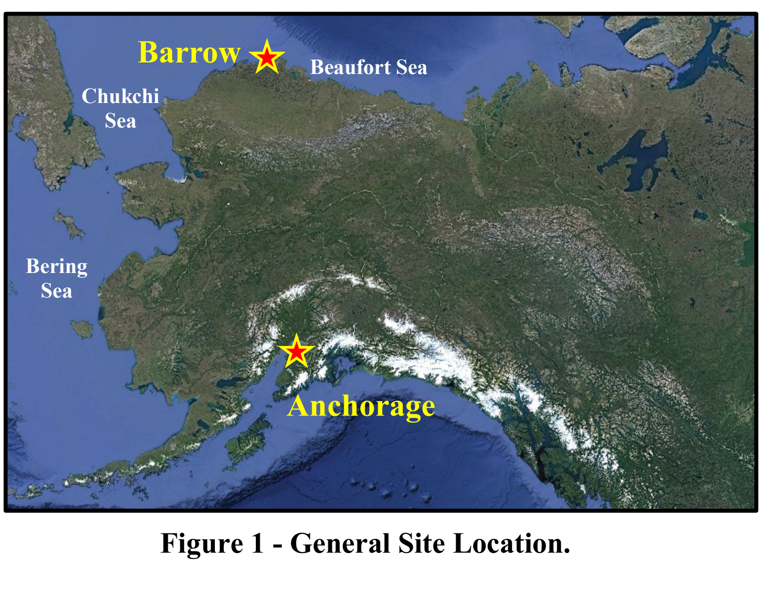



**Figure 1 - General Site Location.**

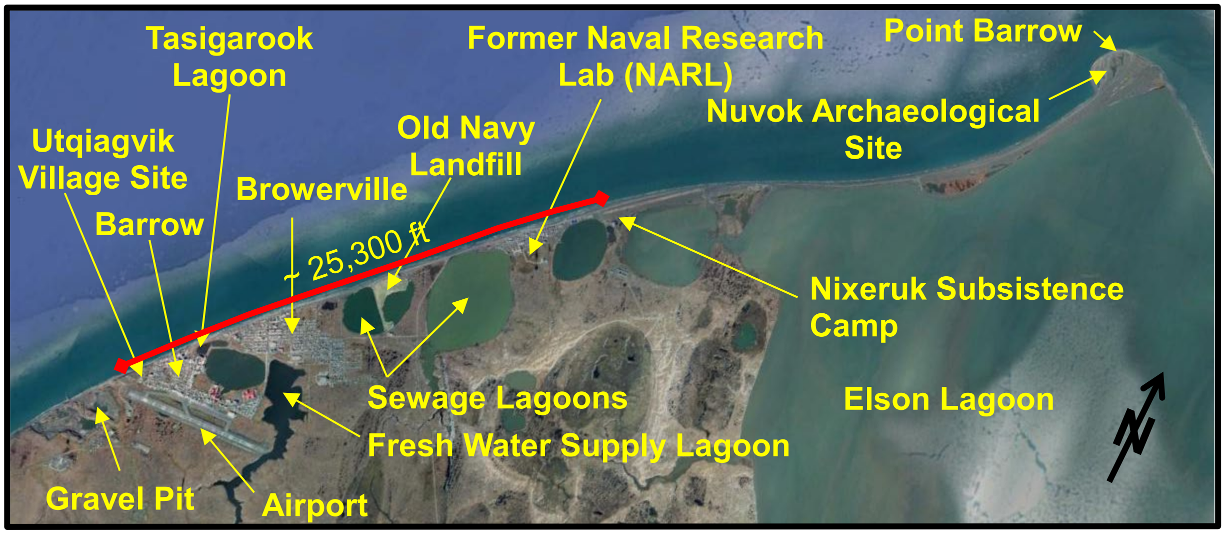



**Figure 2 - Features within Study Area.**

## 2. ALTERNATIVES AND TENTATIVELY SELECTED PLAN

**2.1** The study team evaluated eight (8) mitigation alternatives (Alternatives A through H) in the process of recommending a TS). Alternative H was selected as the recommended TSP. A description of these eight (8) alternatives is given below. Individual reaches (i.e. discrete sections along the coastline with specific mitigation measures identified) were developed based on a consideration of geomorphic conditions (e.g. bluff versus beach) and features to be protected (e.g. major infrastructure). Reaches associated with each of the mitigation alternatives are shown in Figure 3.

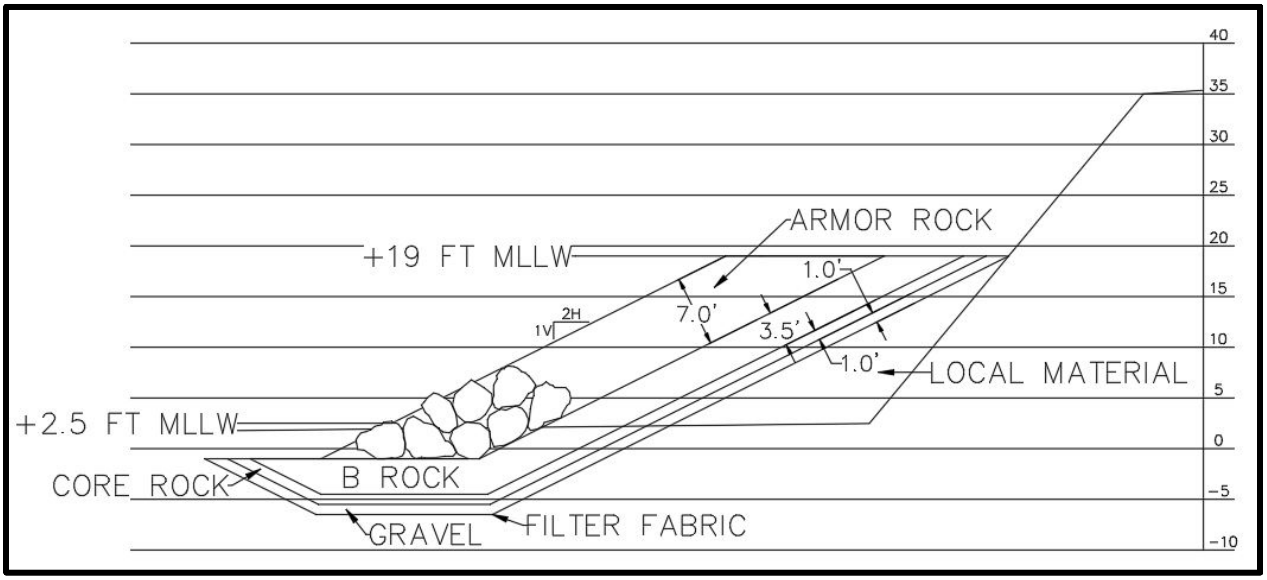
- **No Action.**
- **Alternative A: Barrow and Lagoon.** Rock revetment constructed against the natural bluff in the area marked "Barrow" in Figure 3. Revetted berm in front of Tasigarook Lagoon to reduce the risk of saltwater inundation to the community's freshwater source.
- **Alternative B: Barrow, Lagoon, and Bluff.** Same as Alternative A, with addition of a rock revetment against the natural bluff in the area marked "Bluff" in Figure 3.
- **Alternative C: Barrow, Lagoon, Bluff, and Browerville.** Same as Alternative C, with addition of raising and revetting Stevenson Street in the area marked "Browerville" in Figure 3 to reduce the risk of flooding in the low-lying Browerville neighborhood.
- **Alternative D: Barrow, Lagoon, and South and Middle Salt.** Same as Alternative A, with addition of raising and revetting Stevenson Street in the area marked "South and Middle Salt" in Figure 3 to reduce over topping of the road with flooding and erosion to the landfill and sewage lagoons.
- **Alternative E: Barrow, Lagoon, Bluff, and South and Middle Salt.** Same as Alterative B, with addition of raising and revetting Stevenson Street in the area marked "South and Middle Salt" in Figure 3 to reduce over topping of the road with flooding and erosion to the landfill and sewage lagoons.
- **Alternative F: Barrow, Lagoon, Bluff, Browerville, and South and Middle Salt.** Same as Alternative E, with addition of raising and revetting Stevenson Street in the area

marked “Browerville” in Figure 3 to reduce the risk of flooding in the low-lying Browerville neighborhood.

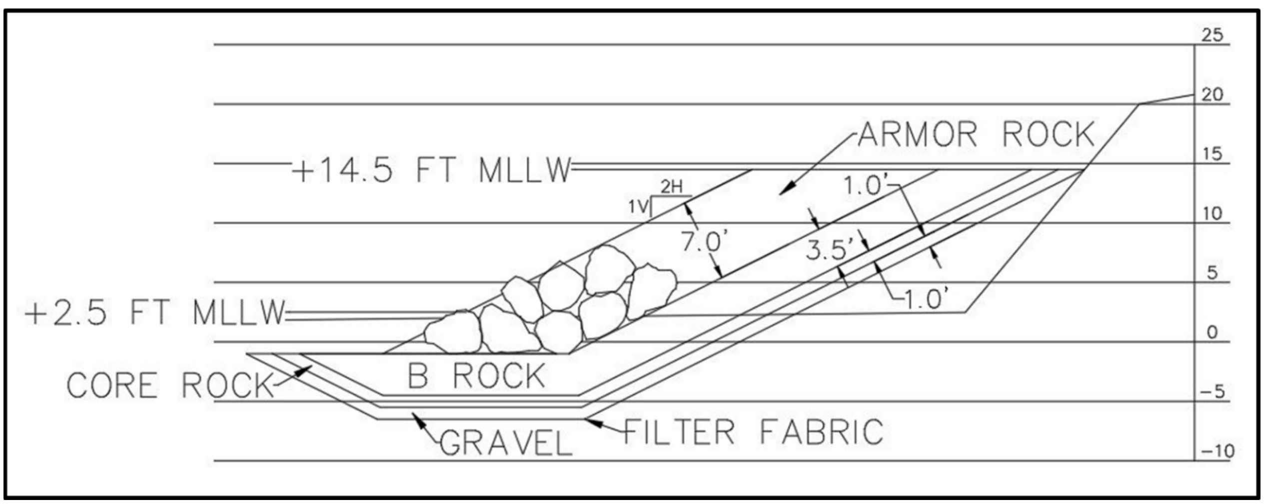
- **Alternative G: Barrow, Lagoon, Bluff, South and Middle Salt, and NARL.** Same as Alternative E, with addition of raising and revetting Stevenson Street in the area marked “NARL” (Naval Arctic Research Laboratory) in Figure 3 to reduce the risk of flooding and over topping of the road during strong weather events.
- **Alternative H: Barrow, Lagoon, Bluff, Browerville, South and Middle Salt, and NARL.** This alternative reduces flooding and erosion impacts to the entire 5-mile study area. A rock revetment is constructed against the natural bluff in the areas marked “Bluff” and “Barrow” in Figure 3. The Lagoon area has a revetted berm to reduce the risk of saltwater inundation to the community’s freshwater source. The areas of Browerville, South and Middle Salt, and NARL have a raised and revetted Stevenson Street to reduce the risk of flooding and over topping of the road during strong weather events.


**Figure 3 – Alternative Plans by Reach.**

**2.2** For Alternative H, the recommended TSP, preliminary design cross sections are given in Figures 4 and 5 for the revetted bluff, revetted berm, and raised and revetted Stevenson Street. Revetments along the bluff would range from a maximum height of +19 feet mean lower low water (MLLW) at the extreme west end of the study area where the bluffs are highest, reducing to a minimum height of +14.5 feet MLLW in front of Barrow as the bluff height gradually decreases. Moving eastward, the revetted berm in front of the Lagoon would have a height of +14.5 feet MLLW. The revetted berm would then transition to a raised and revetted Stevenson Street from the intersection of Tahak Street and Stevenson Street, extending to the intersection of Stevenson Street with Dewline Road, just past NARL.

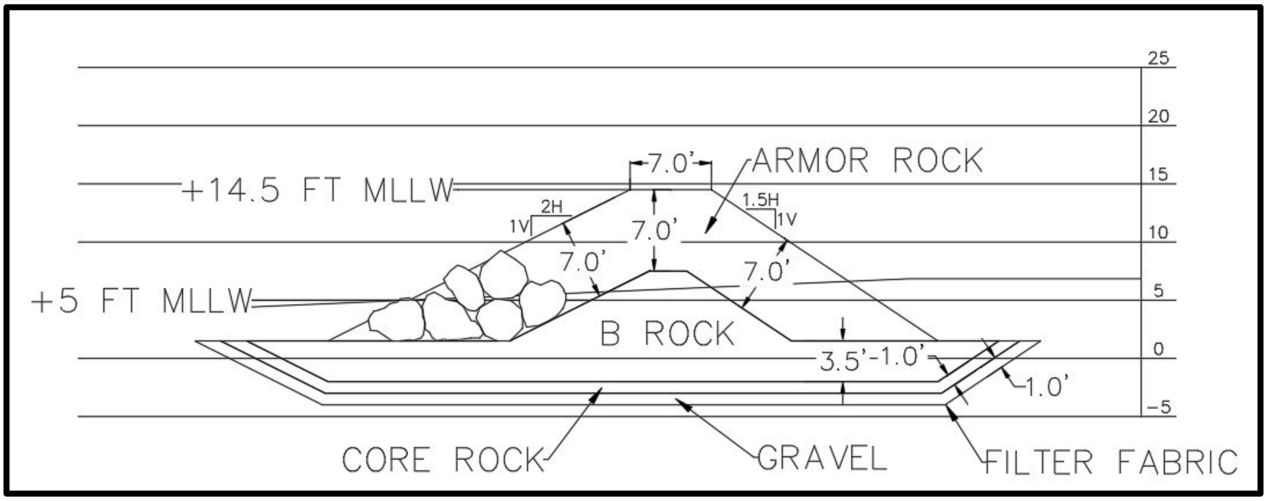



Rock Revetment along Bluffs built to +19 feet MLLW (Reach "V" in Figure 3).

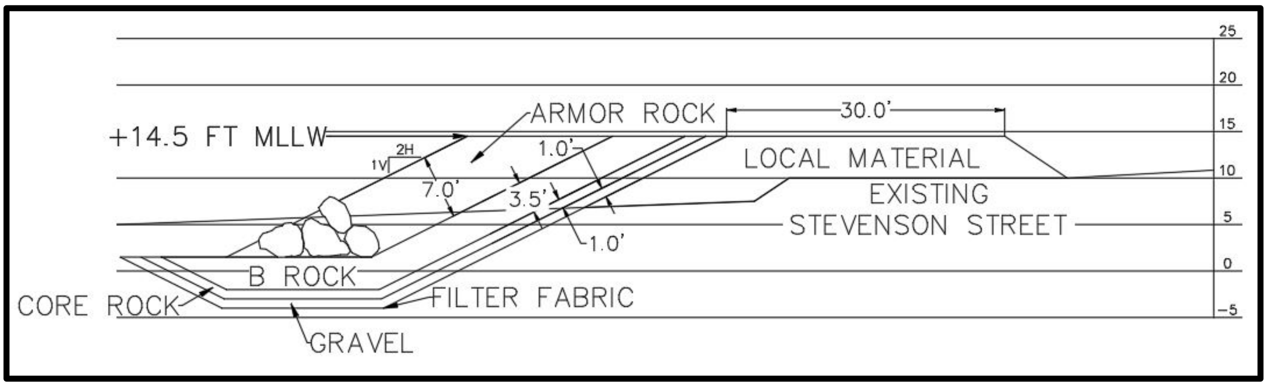



Rock Revetment along Bluffs built to +14.5 feet MLLW (Reach "V" in Figure 3).

**Figure 4 – Alternative H Preliminary Design Cross Sections.**




Revetted Berm along low lying areas built to +14.5 feet MLLW (Reach "B" in Figure 3).




Raised and Revetted Stevenson Street built to +14.5 feet MLLW (Reach "R" in Figure 3).

**Figure 5 – Alternative H Preliminary Design Cross Sections.**

**2.3 <u>Past and On-Going Erosion Mitigation Measures</u>.** Various measures have been used in the past at Barrow to provide some degree of localized protection from coastal erosion and flooding, generally considered to be temporary and/or expedient. These measures are more fully discussed in other project-related reports, with photos provided in Figure 6. The current local practice is to build soil berms along the seaside edge of the beach road extending from Barrow to NARL. During storm events, dozers operate in the surf zone, reforming the berms that storm waves are washing away. Soil for these emergency berms is provided by local borrow pits operated by UIC (Ukpeagvik Iñupiat Corporation) and ASRC SKW (Arctic Slope Regional Corporation, Smith-Kilber-Wheeler). Photos of the emergency berm activities conducted during the storm of September 2017 are shown in Figure 7.




**Gabions** **HESCO Concertainers** **Utilidor Wall** **Longard Tubes**



**Supersack Revetment** **Angled Tar Barrels** **Beach Nourishment w/Dredge Material**

**Figure 6 - Past Erosion Mitigation Measures.**

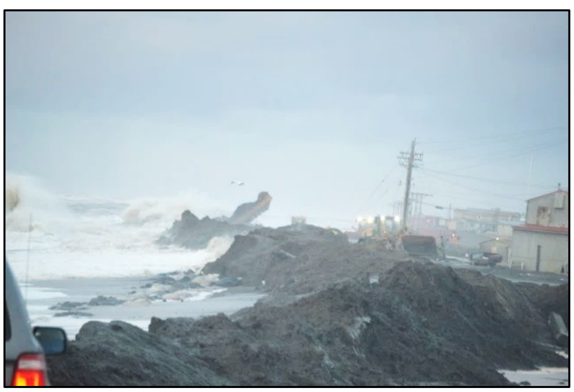



**Figure 7 - Berm Protection during Storm Events.**

## 3. GEOTECHNICAL SITE CONDITIONS

**3.1 Geomorphology.** Coastline photos were taken by the United States Geological Survey (USGS) in August 2006 for the North Slope area, including Barrow. Photo locations within the Barrow study area are plotted on Figure 8, with the photos given in Figures 9 through 25. Geomorphology combined with the nature of the subsurface materials across the study area have had a significant influence on the area's susceptibility to erosion and flooding, which will be discussed further in this appendix. The southwest portion of the study area (Figures 9 through 15) is characterized by high bluffs which gradually reduce to relatively low relief beaches abutting a slightly elevated Stevenson Street for the remainder of the study area (Figures 16 through 26). The bluffs are highest between the SKW gravel pit (Figure 9) and the Utqiagvik Village Site (Figure 12), ranging up to approximately 30 feet in height. Through storm wave action, the bluffs have been eroding and receding, and the low relief beaches have also been susceptible to erosion while presenting pathways for flooding of low-lying inland property. Field work to be performed in PED will better define material characteristics of the bluffs and beach that have made them continuously susceptible to erosion.


**Figure 8 - Photograph Locations.**


**Figure 9 - SKW (City) Gravel Pit.**


**Figure 10 - SKW and ADOT (Alaska Department of Transportation) Gravel Pits.**


**Figure 11 - Airport Runway.**


**Figure 12 - Utqiagvik Village Site.**


**Figure 13 - Barrow Neighborhood.**


**Figure 14 - Barrow Neighborhood.**


**Figure 15 - Barrow Neighborhood.**


**Figure 16 - Tasigarook Lagoon.**


**Figure 17 - In Front of Tasigarook Lagoon.**

**Figure 18 - Browerville Neighborhood.**


**Figure 19 - Browerville Neighborhood.**


**Figure 20 - Browerville Neighborhood.**


**Figure 21 - Edge of Browerville Neighborhood.**


**Figure 22 - Old Navy Landfill.**


**Figure 23 - Stevenson Street before NARL.**


**Figure 24 – NARL.**


**Figure 25 - Barge Unloading at Edge of NARL.**


**Figure 26 - Emergency Runway at End of Study Area.**

## 3.2 Geologic Setting

**3.2.1** The geology of Alaska is complex in its tectonic history, lithology, seismicity, structural geology (e.g. faults and folds), and stratigraphic characteristics. Geologic conditions relevant to the feasibility study are fairly straight forward and relate to shallow soil conditions and relatively recent geologic factors (e.g. glaciation and sea level changes) across the site. A geologic map of the Alaskan North Slope area is given in Figure 27. Geologic provinces within northern Alaska are identified in Figure 28. The Barrow study area falls within the Arctic Coastal Plain, bound on the north by the Beaufort Sea, on the south by foothills of the Brooks Range, and on the west by the Chukchi Sea. Referring to Figure 27, the entire North Slope area is underlain by unconsolidated to poorly consolidated surficial deposits of Quaternary, Pleistocene and upper Tertiary age (QTs). Sediment characteristics vary with location, but generally range from silt to coarse gravel, originating as fluvial, glaciofluvial, colluvial, eolian, and shallow marine deposits. Bedrock below the North Slope area mainly consists of Cretaceous sedimentary rock (Ks) occurring at varying depths in an unconformable contact (i.e. age gap due to erosion or geologic structure) below these surficial deposits.

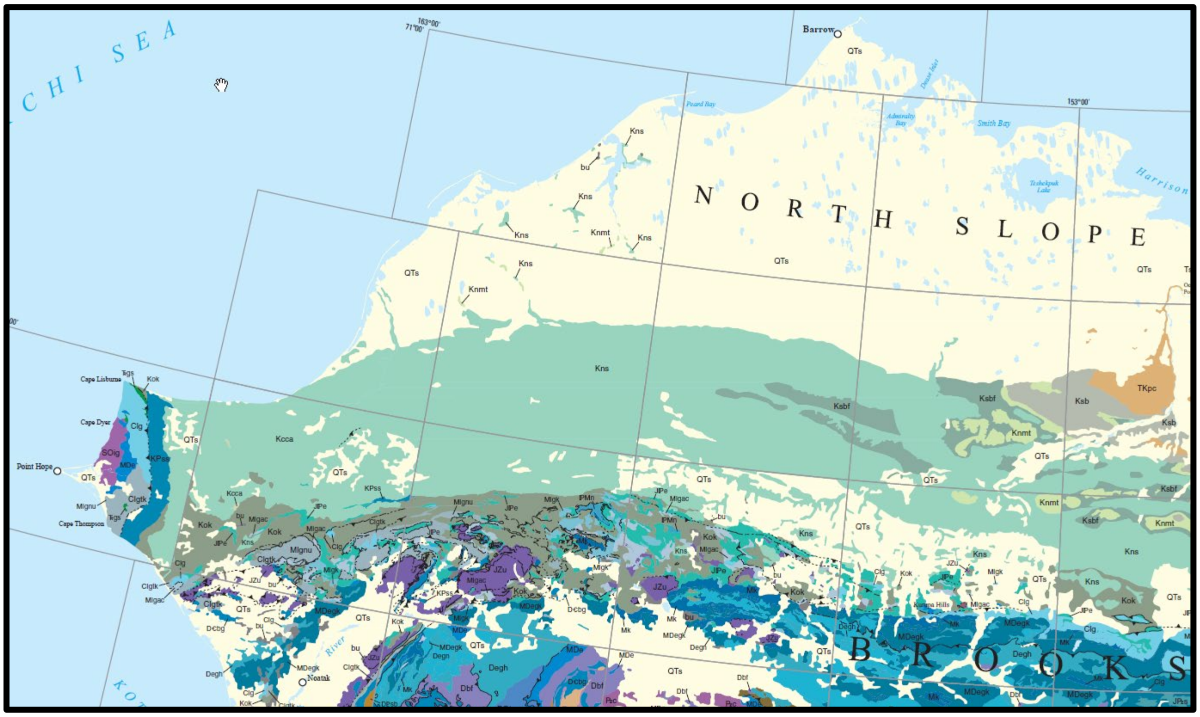



**Figure 27 - Geologic Map of Alaska.**
**(USGS, Geologic Map of Alaska, 2015. See https://pubs.usgs.gov/sim/3340/sim3340_sheet2.pdf for explanation of geologic map units)**

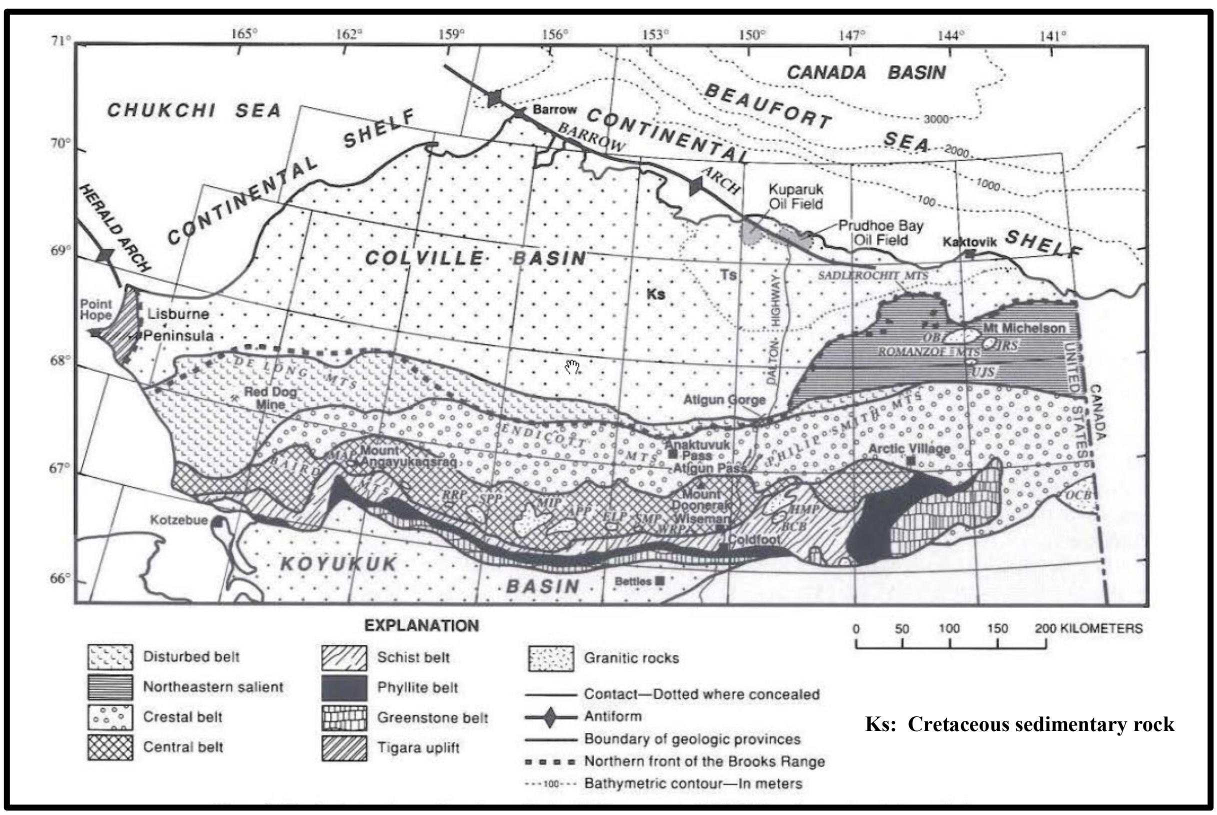



**Figure 28 - Geologic Provinces within Northern Alaska.**
**(Geological Society of America, Geology of Northern Alaska, 1994)**

**3.2.2** Unconsolidated surficial deposits underlying the northern part of the Arctic Coastal Plain belong to the Quaternary Gubik Formation, generally consisting of marine and fluvial deposits characterizing a shallow near-shore shelf environment with periods of uplift and erosion and frequent shifting of the shoreline. The Gubik Formation is composed of three units, given in order of oldest to youngest: Skull Cliff Unit; Meade River Unit; and Barrow Unit. Figure 29 shows the distribution of these units, with the Barrow Unit most represented within the study area. The Barrow Unit consists of poorly-graded to well-graded mixtures of clay, silt, sand, and gravel, generally of marine origin near its base and lacustrine and fluvial in origin within its uppermost layers. Part of the Barrow Unit may be glacially derived, ice locally constitutes more than half its volume, and organic matter is abundant in its upper part. Previous investigations indicate that the Barrow Unit is generally 25 to 50 feet thick and is underlain by the Skull Cliff Unit which is mainly composed of silt and clay. The Gubik Formation within the immediate Barrow area is underlain by Cretaceous sedimentary rock (sandstone, conglomerate, shale, and coal) at depths below ground surface ranging from approximately 50 to 100 feet, based on a number of deep core borings conducted in the 1940s and 1950s.

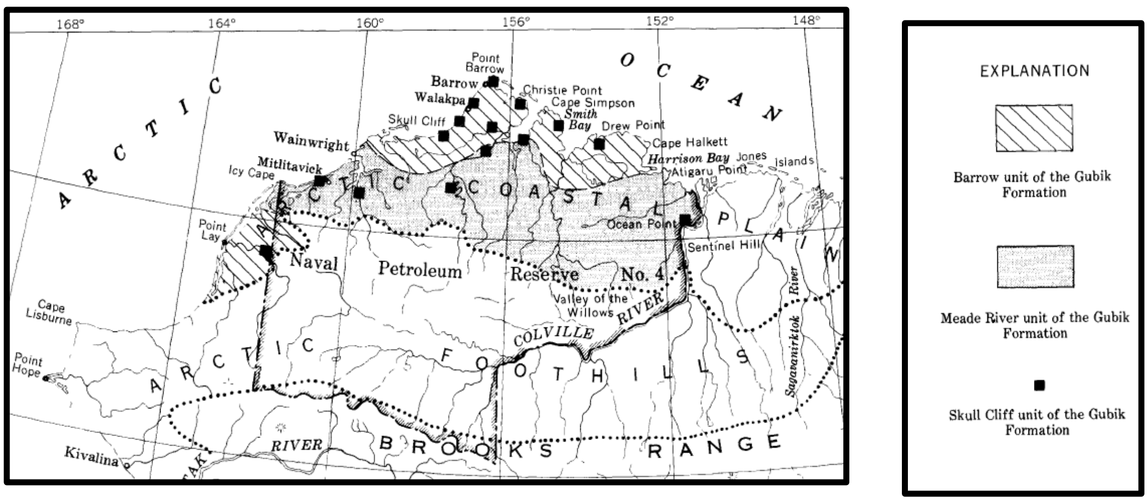



**Figure 29 - Distribution of Gubik Formation within Arctic Coastal Plain.**
**(U.S. Geological Survey Professional Paper 302-C, Quaternary Age In Northern Alaska, 1964)**

## 3.3 Permafrost

**3.3.1** The study area is underlain by continuous permafrost, defined as ground that maintains a temperature at or below 32° Fahrenheit (F) for at least two consecutive years. Available information indicates that permafrost in the Barrow area may extend as much as 1,300 feet below the surface. The depth of the active layer below the surface (i.e. the zone that is subject to seasonal freeze-thaw cycles) typically varies between 1.5 and 3.0 feet. The presence of permafrost has resulted in characteristic surface features exhibited in the general study area, as illustrated in Figures 30 (ice wedges), 31 (polygon pattern), and 32 (thermokarst lakes).

**3.3.2** Ice wedges are produced by the formation of thermal contraction cracks in winter and subsequent filling of the cracks with hoar frost, snow, and meltwater. Repeated cracking and filling of the vertical to near-vertical cracks results in wedges that can be as large as several meters across at the top, tapering downwards to apices that can be as deep as 30 feet. Wedges intersect across the landscape to form networks of enclosed polygons ranging in diameter from approximately 15 to 100 feet in diameter. Ice wedges can be exposed along coastal bluffs, such as shown in Figure 30, where exposure to wind and wave action can dramatically accelerate thawing and erosion of the bluff.

**3.3.3** Thermokarst lakes develop by water collecting within ice wedge polygons, forming a surface pool. These pools deepen and expand laterally by thawing near-surface ice-rich permafrost along the pool edges and beneath the water. As seen in Figure 32, these thermokarst lakes are oriented with their long axes normal to the prevailing east-northeast and west-southeast winds as a result of wind-induced waves and currents which build protective banks on the downwind shores and concentrate erosion on the north-northwest and south-southeast shores.

**Figure 30 - Ice Wedges along Coastline Bluff (Cape Blossom, Alaska).**


**Figure 31 - Polygon Pattern (Barrow, Alaska).**


**Figure 32 - Thermokarst Lakes (Barrow, Alaska).**

**3.3.4** A unique aspect of coastal permafrost is that the permafrost contains dissolved salts in its pore water. Saline permafrost, also referred to as unbonded permafrost, freezes at lower sub-zero temperatures because of freezing-point depression of the dissolved salts, resulting in the permafrost only being partially frozen. The mechanical properties of saline permafrost have been well researched and documented in construction practice. Saline permafrost is mechanically weaker than non-saline permafrost, has reduced allowable strength and bearing capacity in foundation applications (e.g. spread footings and piles), has reduced stability in open trenches and excavations, and exhibits prolonged deformation under load (creep). In this relatively weak state, saline permafrost exposed along coastal bluffs such as in Barrow would be particularly susceptible to thaw and erosion.

**3.4 <u>Previous Geotechnical Site Investigations</u>.** There have been several geological and geotechnical site investigations conducted in the past within the Barrow area that provide information of value to this feasibility study - primarily regarding subsurface conditions and the search for local gravel materials to support potential coastal erosion mitigation measures. Relevant details of these investigations are summarized in Table 1, with approximate site investigation locations shown in Figures 33 through 35 (ID numbers in Table 1 are linked to site location). There have also been material source investigations conducted outside of the general Barrow area, with findings applicable to this study. Relevant details of these broader material source investigations are summarized in Table 2, with approximate source locations given in Figure 36 and photos of some of the material sources shown in Figure 37. A further assessment of available material sources which support the TSP will be made during the PED phase.


**Figure 33 - Previous Geotechnical Site Investigation Locations.**

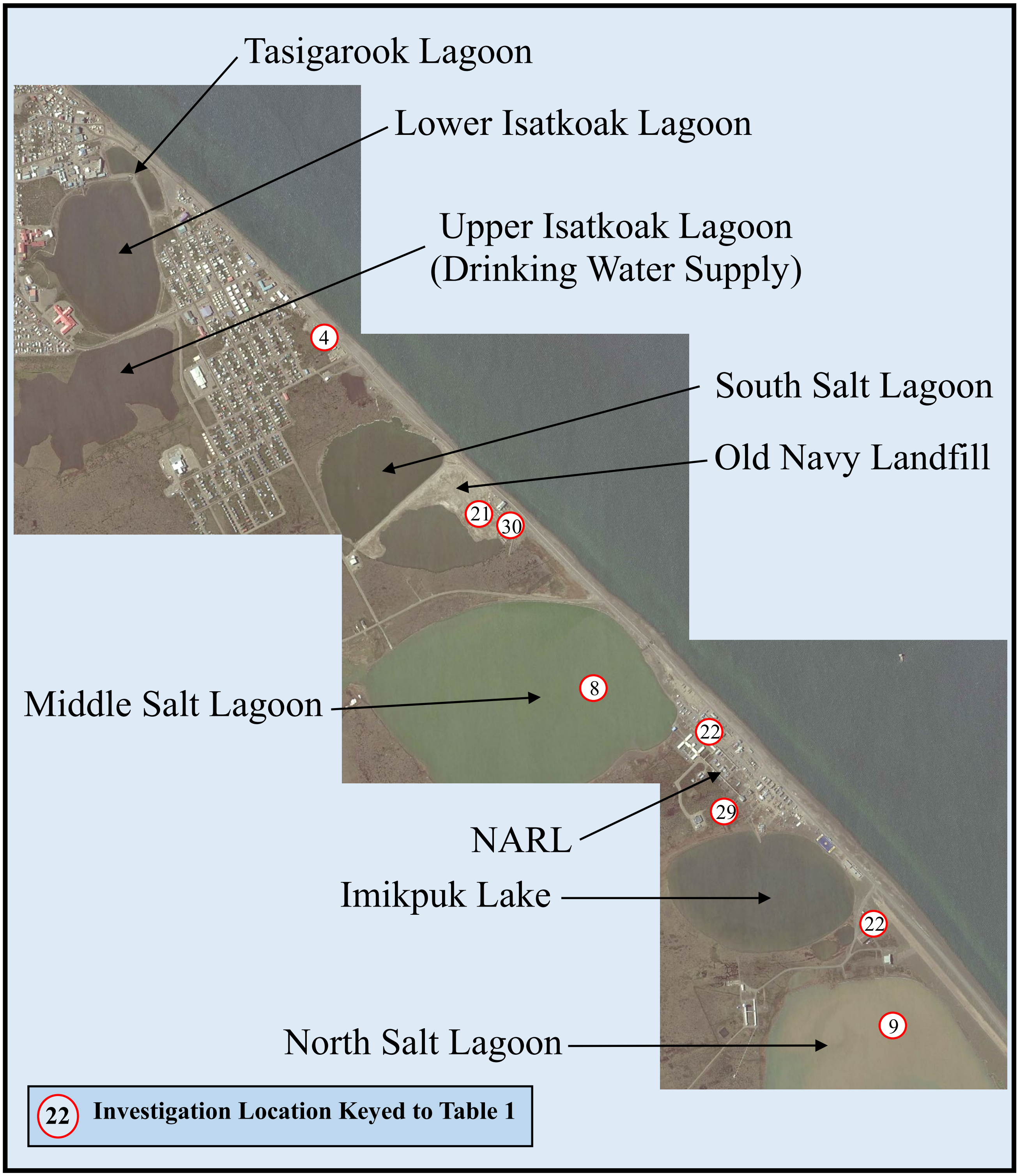



**Figure 34 - Previous Geotechnical Site Investigation Locations.**

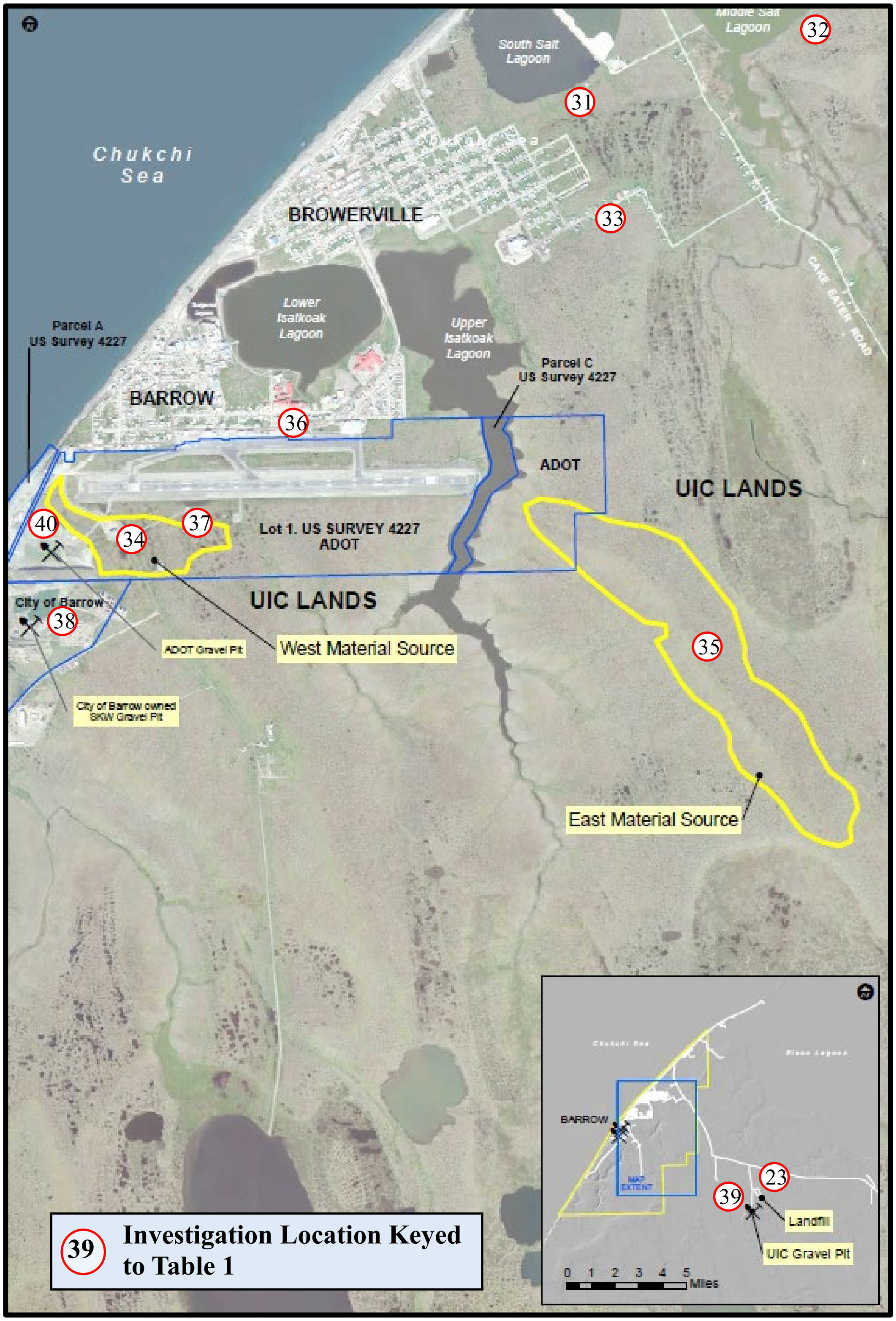



Figure 35 - Previous Geotechnical Site Investigation Locations.

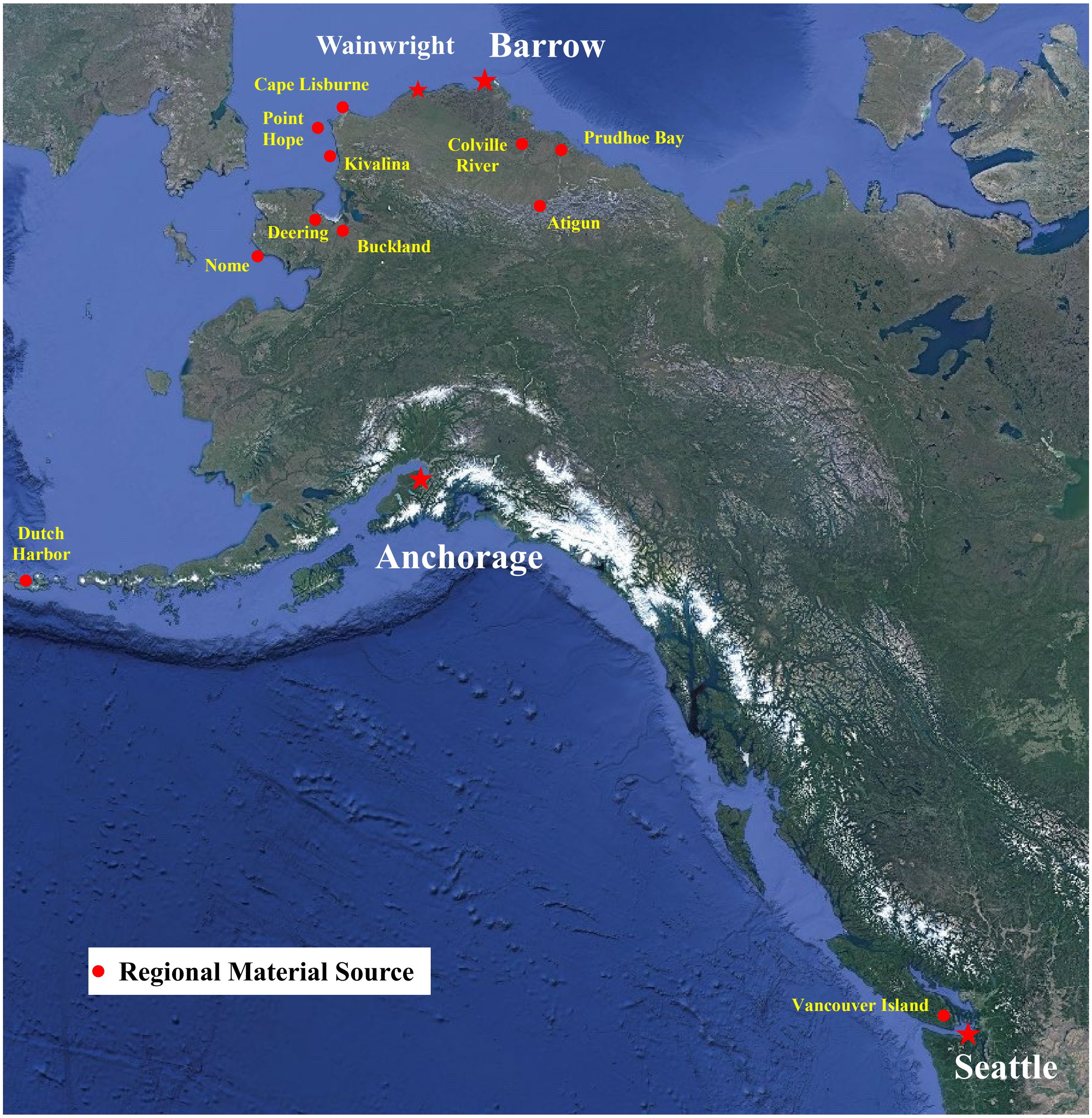



**Figure 36 – Location of Regional Material Sources**

**Table 1 - Summary of Site Investigations within Barrow Area.**

| ID No. | Title/Author | Date | Comment |
|---|---|---|---|
| 1 | Fill Materials and Aggregate Near Barrow Naval Petroleum Reserve No. 4, Arctic Institute of North America | Jan 1973 | Regional Exploration. Investigated possible gravel and coarse sand deposits within 25 mile radius of Barrow. Reported about 25 million cubic yards ($yd^3$) of gravel and sand, about 4 million $yd^3$ readily exploitable-without severe environmental damage. Identified these potential borrow sources: Barrier Islands (e.g. Cooper Island); western coast line and bluffs southwest of Barrow; southwest side of Point Barrow spit; uplifted beach ridges (e.g. Central Marsh Ridge); and isolated deposits south of Nunavak Bay. |
| 2 | Geotech Investigations for Barrow Utilities, Harding-Lawson Associates | Feb 1979 | Barrow Neighborhood. 80 borings drilled to a maximum depth of 20 feet (ft). Below a surficial layer of peat (average thickness 1.5 ft), soil generally consists of sandy silt and silty sand. Upper 5 ft has an organic content. Silt is more common in 5 to 10 ft range; silt decreases and sand becomes more predominant below 10 ft. Occasional stratum of gray to black silty clayey soil. Massive ice is greatest in 5 to 10 ft depth range, thickness up to 13 ft. Active layer in undisturbed areas 8 to 12 inches below surface. Unbonded permafrost in some borings due to saline content, with salinity increasing significantly below 10 ft. Fill material is locally present. |
| 3 | Same as above | Feb 1979 | Browerville Neighborhood. 25 borings drilled to a maximum depth of 20 ft. Below a surficial layer of peat (average thickness 1 ft), soil generally consists of sandy silt and silty sand. Upper 5 ft has an organic content. Silt is more common in 5 to 10 ft range; silt decreases and sand becomes more predominant below 10 ft. Occasional stratum of gray to black silty clayey soil. Massive ice is greatest in 5 to 10 ft depth range, thickness up to 13 ft. Active layer in undisturbed areas 8 to 12 inches below surface. Unbonded permafrost in some borings due to saline content, with salinity increasing significantly below 10 ft. Fill material is locally present. |
| 4 | Same as above | Feb 1979 | Sewer Outfall Alignment (Stevenson Street). 11 borings drilled to a maximum depth of 20.5 ft. Upper zone of peat or organic sandy silt to maximum 4-ft depth, typically underlain by ice-rich silty sand or sandy silt to bottom of borings. Some borings encountered 9 to 10 ft of massive ice directly below the peat. Zones of unbonded permafrost were encountered in five borings. Silty sand, gravelly sand, and sandy gravel found in four borings near South Salt Lagoon. |

| ID No. | Title/Author | Date | Comment |
|---|---|---|---|
| 5 | Same as above | Feb 1979 | Block A. Six borings drilled to a maximum depth of 20 ft. Upper zone of sandy silty organic material (peat) to a maximum 3.5-ft depth, underlain by massive ice and ice-rich sandy silt to a depth of 15 to 18 ft, underlain by sandy silt and silty sand to the depth explored. |
| 6 | Preliminary Report - Barrow Winter Granular Borrow Source Study, RZA Inc. Geotech Consultants | Jun 1982 | Elson Lagoon. Forty-six borings drilled within lagoon near Point Barrow spit. Identified two areas immediately against the spit with fine to coarse gravelly sand (25% gravel and 3% silt) with no significant overburden. Searching for final report with borehole details. |
| 7 | Same as above | Jun 1982 | Emaiksoun Lake. Forty-nine borings drilled to maximum depth of 40 ft. Soil consists of clayey silt to silty fine sand. |
| 8 | Same as above | Jun 1982 | Middle Salt Lagoon. Thirty-eight borings drilled to maximum depth of 35 ft. Northern shoreline consists of medium to coarse gravelly sand (12% gravel and 10% silt) with no significant overburden. Fine-grained soil elsewhere in the lagoon. |
| 9 | Same as above | Jun 1982 | North Salt Lagoon. Three borings drilled along northern shoreline of lagoon. Soil consists of icy, silty fine sand. |
| 10 | Same as above | Jun 1982 | Nunavak Bay. One hundred fifteen borings drilled in the northern and southern portion of the bay and upland area. Sandy gravel to gravelly sand (15% gravel and 5% silt) found along upper 9 ft of a barrier bar at mouth of Nunavak Bay. Elsewhere in the bay, material consists of silt to silty fine sand with occasional minor lenses of gravelly sand. Within upland area, a 6-ft thick deposit of silty gravel interlayered with gravelly silt is overlain by at least 20 ft of overburden consisting of icy silty soil. |
| 11 | Same as above | Jun 1982 | Footprint Lake. Six borings were drilled across the lake, with the soil consisting of sandy silt and clayey silt. |
| 12 | Upland Barrow Borrow Source Reconnaissance, RZA Inc. Geotech Consultants | Oct 1982 | Fresh Water Lake Road Beach Strand. Thirteen borings drilled along a 3-mile long relic beach strand to a maximum depth of 30.0 ft. A tundra mat covers the area to a maximum depth of 1.5 ft. Below the tundra, silty ice and icy silt with random pockets of icy silty sand and sandy silt to depths of 2 to 18 ft, underlain by icy gravelly sand and sandy gravel in strata 6 to 10 ft thick, underlain by icy silty sand and sandy silt to the depth explored. |

| ID No. | Title/Author | Date | Comment |
|---|---|---|---|
| 13 | Same as above | Oct 1982 | Upper Isatkoak Lagoon Beach Strand. Five borings drilled along a 2.7-mile long relic beach strand to a maximum depth of 30 ft. A tundra mat covers the area to a maximum depth of 1.5 ft. Below the tundra, the soil primarily consists of icy silty sand, sandy silt, and silt to the depth explored. There are some intervening horizons of icy gravelly sand, sandy gravel, and sand. |
| 14 | Same as above | Oct 1982 | Gas Well Road Beach Strand. Six borings drilled along and adjacent to a 4.5-mile long relic beach strand to depths of 15 to 30 ft. Below a 1.5-ft thick tundra mat, three borings within the beach ridge found icy silty sand and sandy silt with no significant gravel component. Below a 1.5-ft thick tundra mat, three borings drilled within a dry lake bed found icy sandy silt in upper 5 to 7 ft, underlain by icy gravelly sand and sandy gravel to depths of 6 to 16 ft, underlain by icy sandy silt and silty sand to the depth explored. |
| 15 | Barrow Borrow Source Study, RZA Inc. Geotech Consultants | Jul 1983 | Upper Isatkoak Lagoon Area. Forty-four borings drilled to a maximum depth of 35 ft. Top 5 to 25 ft consist of non-usable overburden materials (sod mat; silt; ice; icy silty sand; icy silty, fine gravelly sand), underlain by fine gravelly sand and sand (non-continuous gravel content) with a thickness ranging from 1 to 30.5 ft. |
| 16 | Same as above | Jul 1983 | Fresh Water Lake Road Area. Sixty-three borings drilled to a maximum depth of 35 ft. Top 5 to 15 ft consist of non-usable overburden materials (sod mat; silt; ice; icy silty sand; icy silty, fine gravelly sand), locally as thick as 20 ft, underlain by fine gravelly sand and sand (discontinuous horizons) with thicknesses ranging from 5 to 10 ft for the fine gravelly sand and 5 to 15 ft for the sand. |
| 17 | Same as above | Jul 1983 | Gas Well Road Area. Twenty borings drilled to a maximum depth of 34 ft. Upper tundra mat and icy, organic silt and sandy silt layer from 3 to 17 ft, underlain by fine-grained icy materials (silt, silty sand, sand) with only sparsely scattered lobes of granular material. Not a viable gravel source. |
| 18 | Same as above | Jul 1983 | Elson Lagoon. Six borings drilled to a maximum depth of 42 ft. Relatively uniform subsurface conditions consisting primarily of interbedded fine sandy silt and silty fine sand below lagoon water and ice. Not a viable gravel source. |

| ID No. | Title/Author | Date | Comment |
|---|---|---|---|
| 19 | Barrow Offshore Exploration, BTS/LCMF Limited | Sep 1988 | Offshore Exploration. Fifty-four vibracores taken offshore from City gravel pit area up to Browerville. Vibracores up to 20 ft in length, taken in water depths from 7 to 40 ft. Sediment mainly silt and sand with little gravel content. Subsequent dredging in 1999 produced material high in silt with very little gravel content. |
| 20 | Foundation Investigation - Staff Housing, IHS Hospital, Duane Miller & Associates | Feb 1991 | Foundation Investigation. Eleven borings drilled to maximum depth of 25 ft. Subsurface consists of upper sand layer underlain by silt, sandy silt, silty clay and silty sand. Site is underlain by permafrost, some being ice-rich. Pore fluid has high salinity, with much of the soil marginally bonded to unbonded. Poorly bonded soil typically found between depths of approximately 8 to 23 ft. Salinity ranges from 2 to 73 parts per thousand (ppt), increasing with depth. |
| 21 | Geotech Investigation - Sanitation Facility, Duane Miller & Associates | Nov 1993 | Foundation Investigation. Four borings drilled to maximum depth of 20 ft in a coastal beach environment. Stratigraphy from top to bottom consists of: sandy gravel and gravelly sand fill material to a depth of about 2 ft; then poorly-graded sand with occasional coarse gravel component to the depth explored. Continuous bonded permafrost below active layer, with salinity values less than 7 ppt. |
| 22 | Geotech Exploration, Naval Arctic Research Laboratory, Duane Miller & Associates | Aug 1994 | Environmental-Related Investigation. Eight borings drilled to depths of 8 to 20 ft along alignment of proposed berm and contaminant recovery trench on NARL facility. Stratigraphy from top to bottom consists of: poorly-graded sand, silty sand and gravelly sand fill material, with occasional peat layer below the fill; then sandy silt, silty sand, and sand to the depth explored (beach deposits). Continuous bonded permafrost below active layer, with salinity values generally less than 8 ppt except for two borings with salinities up to 46 ppt. |
| 23 | UIC Gravel Investigation, Harding Lawson Associates | May 1998 | Borrow Source Investigation. Thirteen borings drilled within an expansion area of the UIC borrow pit in Barrow. Borings were a maximum 14 ft deep (incomplete boring information). Also includes logs for nine borings drilled in Dec 1987 within the existing pit. Overburden material to a maximum depth of 6 ft is described in some borings as peat with segregated ice throughout, and ice and silty sand. Below the overburden, soil consists of these materials: sandy silt and silty sand (predominant soil type); silt; and sand with fine gravel within some borings. Continuous permafrost with both bonded and unbonded zones. |

| ID No. | Title/Author | Date | Comment |
|---|---|---|---|
| 24 | Geotech Investigation - Samuel Simmons Hospital Site, Duane Miller & Associates | Jun 2004 | Foundation Investigation. Twelve borings drilled to maximum depth of 25 ft. Stratigraphy from top to bottom consists of: tundra mat followed by organic silt and peat to depth of about 2 ft; silt and ice to depths as great as 13 ft; then beach and marine deposits (silt and sandy silt) underlie the icy soils and contain high salt levels. Continuous permafrost, with unfrozen soil found in lower levels of three borings due to high salt content. Salinity ranges from near zero to more than 120 ppt, increasing with depth. |
| 25 | Coastal Storm Damage Reduction Gravel Exploration, USACE Alaska District | Mar 2005 | Offshore Exploration. Four borings drilled 100 to 400 ft offshore of Barrow to maximum sampled depth of 25.5 ft. Fine sand with variable silt content, with only about 10% gravel content. Silt increases with distance from surf zone. |
| 26 | Same as above | Mar 2005 | Cooper Island. Ten borings drilled Cooper Island over distance of 4 miles to a maximum sampled depth of 41.5 ft. Eleven feet of relatively clean sand overlies silt and clay than composes the seafloor. Average 10 to 20% gravel and 5% silt within sand. |
| 27 | Same as above | Mar 2005 | BIA Tract. Thirty-one borings drilled within Bureau of Indian Affairs (BIA) tract to a maximum sampled depth of 41 ft. Upper 10 to 20 ft consists of frozen silt and silty sand. Sand with variable gravel content underlies upper silt/silty sand layer. |
| 28 | Same as above | Mar 2005 | Offshore Exploration. Six borings drilled 2 to 6 miles offshore from Point Barrow spit to a maximum sampled depth of 33 ft. Sediment consists of fine silty sand and sand silt, with insignificant gravel content. |
| 29 | Geotech Exploration, Global Climate Change Research Facility, Duane Miller & Associates | Apr 2005 | Foundation Investigation. Seven borings drilled to a depth of 23 ft in a coastal beach environment. Stratigraphy from top to bottom consists of: tundra mat with underlying peat and organic silt to depths of 3 to 12 ft; silt; sand, silty sand, and sandy silt to the depth explored. Massive ground ice found in several borings as thick as 6 ft and as deep as 9 ft. Continuous ice-rich permafrost below active layer, with salinity values generally less than 8 ppt. |
| 30 | Geotech Exploration, Naval Arctic Research Laboratory, Duane Miller & Associates | Jul 2005 | Foundation Investigation. Five borings drilled for a Transfer Station Addition to the Thermal Operating System facility. Borings were a maximum 24.5 ft deep. Stratigraphy from top to bottom consists of: silty gravelly sand and sand fill with some debris to maximum 11-ft depth; then poorly-graded sand and silty sand with minor gravel component to the depth explored. Continuous well-bonded permafrost. |

| ID No. | Title/Author | Date | Comment |
|---|---|---|---|
| 31 | Geotechnical Report - Barrow Roads, HDL Consultants | Jun 2009 | Laura Madison Road Extension. Four borings drilled to a maximum depth of 21.5 ft. Stratigraphy from top to bottom consists of: thin vegetative mat of a few inches; frozen organic silt to 2-ft depth; ice with silt to 3.5-ft depth; sandy silt, silt, and silty clay to 15-ft depth, with 2.5 to 5-ft thick massive ice sections in some two of the borings; then silty sand, sand, and gravelly sand to the depth explored. Pore water salinity varied from 0 to 19.3 ppt. |
| 32 | Same as above | Jun 2009 | Proposed Uivaqsaagiaq Road. Nine borings drilled to a maximum depth of 21 ft. Stratigraphy from top to bottom consists of: thin vegetative mat of a few inches; frozen organic silt to 2-ft depth; ice with silt to 3.5-ft depth; sandy silt, silt, and silty clay to 15-ft depth, with 2.5 to 5-ft thick massive ice sections in some two of the borings; then silty sand, sand, and gravelly sand to the depth explored. Pore water salinity varied from 0 to 19.3 ppt. |
| 33 | Ahgeak Street Water and Sewer Extension, Geotech Report, Golder Associates | Oct 2010 | Geotechnical Report. Nine borings drilled to a maximum depth of 30.5 ft. Stratigraphy from top to bottom consists of: fill to a depth of 2 to 5 ft, poorly-graded sand with gravel and trace fines; 2-ft layer of peat and organic silt; 2 to 5.5-ft layer of massive ice or silty massive ice; then various layers of silt, sandy silt, sand and silty sand to the depth explored. Unbonded permafrost zones encountered in three borings, generally below 22-ft depth. Pore water salinity varied from 0.4 to 44 ppt, increasing with depth. |
| 34 | Barrow Airport Apron Expansion Material Site Investigation, Alaska DOT | Mar 2014 | West Material Source Area. Thirty-two borings drilled to a maximum depth of 47 ft. Top 4 to 19 ft consist of ice-rich and organic-rich silt and sandy silt, underlain by 2 to 10 ft of sand with silt to silty sand, underlain by sand and gravel with low silt content ranging in thickness from 5 to 36 ft. Contains layers of massive ice from 3 to 7-ft thick. |
| 35 | Same as above | Mar 2014 | East Material Source Area. Sixty-three borings drilled to a maximum depth of 37 ft. Top 3 to 18 ft consist of ice-rich and organic-rich silt and sandy silt, underlain by 1 to 12 ft of sand with silt to silty sand, underlain by sand and gravel with low silt content ranging in thickness from 2 to 20 ft. Contains layers of massive ice from 4.5 to 7-ft thick. Most borings terminated in silt or clay-rich soil. |

| ID No. | Title/Author | Date | Comment |
|---|---|---|---|
| 36 | Barrow Airport Building Sites and Apron Expansion Project, Alaska DOT-PF | Sep 2014 | Ahkovak Street. Thirteen borings drilled to depths ranging from 14 to 22 feet along and nearby Ahkovak Street. Stratigraphy from top to bottom consists of: 2.5 to 6.5 ft of embankment fill, composed of sand and gravel, with scattered zones of silty soil; ice-rich and organic-rich silt to silty sand with layers of massive ice, from 2.5 to 6.5 ft below ground to depth explored. Massive ice ranged from 5.5 to 9 feet in thickness in some borings. |
| 37 | Same as above | Sep 2014 | Proposed Building Sites and Apron Extension. Eight borings drilled to depths ranging from 21 to 42 feet at three alternative building sites and the apron extension. Stratigraphy from top to bottom consists of: 2.5 to 6.5 ft of embankment fill, composed of sand and gravel, with scattered zones of silty soil; ice-rich and organic-rich silt to silty sand with layers of massive ice, from 2.5 to 6.5 ft below ground to depth explored. |
| 38 | Barrow Comprehensive Plan 2015-2035 | Mar 2015 | SKW Borrow Pit. The ASRC SKW operates a borrow pit on land owned by the City of Barrow. Material produced is classified as sandy gravel and gravelly sand, with a considerable amount of overburden fines (sand and silt) required to be processed to generate granular material. Generally produces 30,000 to 50,000 $yd^3$ of granular material annually, with an estimated 10 years useful life remaining. |
| 39 | Same as above | Mar 2015 | UIC Borrow Pit. The UIC operated pit has material which is generally finer grained (sand and silt) than the SKW pit, typically producing poorly- graded silty sand with gravel. UIC applying for large pit expansion through the Alaska District. |
| 40 | Same as above | Mar 2015 | Alaska DOT Borrow Pit. The ADOT has a borrow pit on State property adjacent to the airport, and is operated by SKW on behalf of ADOT. Material generated is for exclusive State use (e.g. Federal Aviation Administration projects). Expansion of the pit is limited within State property. Material produced is similar to the SKW borrow pit. |
| 41 | Barrow-Pt. Hope Coastal Erosion Mitigation Report - Geotech Investigation, PND Engineers | Apr 2015 | Pump Station 3. One boring drilled to a depth of 45 ft. Stratigraphy from top down consists of: 5-ft fill layer of poorly graded sandy silt fill; 1-ft layer of peat; 11 ft of mass ice; then, poorly-graded sand with silt and silty (fine) sand to depth explored. Salinity ranged from 2 to 80 ppt (average salinity of seawater is 35 ppt). |

| ID No. | Title/Author | Date | Comment |
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| 42 | Same as above | Apr 2015 | Pump Station 4. Five borings drilled to a maximum depth of 46 ft. Stratigraphy from top down consists of: 15-ft layer of unbonded poorly-graded sand with silt; from depth of 15 to 24 ft, bonded to unbonded lean clay; then, poorly- graded sand with silt to depth explored. Salinity ranged from 8 to 143 ppt. |
| 43 | Same as above | Apr 2015 | Shoreline Borings. Three borings drilled along seaside edge of Egasak Street, by Pump Station 4, to a depth of 46 ft. Material consisted of sandy soils to 46 ft (poorly-graded sand with silt and gravel, silty sand, well-graded sand with gravel) with an interbedded 5 to 10-ft thick silt layer starting at about 15 ft in depth. Contained bonded and unbonded permafrost sections, with salinity ranging from 8 to 113 ppt (generally increasing with depth). |

**Table 2 - Summary of Regional Borrow Sources.**

| No. | Source Location | Type of Borrow Material - Comments |
|---|---|---|
| 1 | Nome Quarry, AK | **Aggregate and Rock (granite).** Well established quarry supplying high quality rock, including riprap and armor stone, for civil works projects in Alaska. Stone has been barged to Barrow for upcoming road construction project by UIC. Reference: May 18 discussion with UIC. |
| 2 | Atigun Quarry, AK | **Aggregate and Rock (conglomerate).** Established quarry 150 miles south of Prudhoe Bay, Mile Post 261 on Dalton Highway, supplies aggregate and quality rock, including riprap and armor stone, for AKDOT and Prudhoe Bay oil industry. Bureau of Land Management (BLM) property. Reference: Jan 18 discussion with AKDOT with accompanying documents. |
| 3 | Cape Lisburne Quarry, AK | **Aggregate and Rock (dolomite and limestone).** Established quarry for restricted, permitted use by the United States Air Force (USAF) through the U.S. Fish and Wildlife Service in maintaining facilities at the Cape Lisburne USAF facility, including the construction of a coastal revetment by Corps of Engineers. Access to rock and aggregate from this location is doubtful due to federal military and wildlife refuge jurisdictions. |
| 4 | Point Hope, AK | **Aggregate and Rock (arkose and limestone).** Two potential material sources inland from Point Hope have been investigated for aggregate and rock. Further investigation and material testing is needed to determine the viability of establishing quarry operations in this area. Reference: North Slope Borough Erosion Protection, PND Engineers, Jul 2015; Point Hope Materials Source Reconnaissance, HDL Engineering, Mar 2011; Point Hope Materials Source Evaluation, UMIAQ Project #10-038, Apr 2011. |
| 5 | Kivalina, AK | **Aggregate and Rock (dolomite and limestone).** Several potential material sites inland from Kivalina have been investigated with borings by AKDOT for possible sand and gravel aggregate and armor stone. Further investigation and material testing is needed to determine the viability of establishing quarry operations in this area. References: University of Alaska Anchorage (UAA) Coastal Erosion Workshop, NANA Regional Corporation, Jan 2010; Jan 2018 discussion with AKDOT; Kivalina Replacement School Geotechnical Data Report, Golder Associates, Dec 2015. |
| 6 | Buckland, AK | **Aggregate and Rock (monzonite).** Existing material sources at the Kanik Creek quarry, but appears to be a small operation for local material use. Reference: UAA Coastal Erosion Workshop, NANA Regional Corporation, Jan 2010. |
| 7 | Deering, AK | **Aggregate and Rock (dolomite and andesite).** Existing material sources at the Kugruk and Inmachuk quarries, but appears to be a small operation for local material use. Reference: UAA Coastal Erosion Workshop, NANA Regional Corporation, Jan 2010. |

| No. | Source Location | Type of Borrow Material - Comments |
|---|---|---|
| 8 | Dutch Harbor, AK and BC, Canada | **Rock Quarries External to Mainland Alaska.** Rock revetment seawall was constructed at Wainwright, Alaska, for coastal erosion protection, using 30,000 tons of rock barged from the Bering Shai quarry at Dutch Harbor (B rock and filter rock) and the Stebbings Road quarry in Shawnigan Lake, British Columbia (armor stone). Project completed in Nov 2013. According to the NSB client, this combination of borrow sources proved more economical at the time than Nome. Reference: May 18 discussion with NSB with accompanying project documents. |
| 9 | Colville River, AK | **Aggregate.** The ASRC Colville Consolidated Use Gravel Pit is a large out-of-bank sand and gravel mining operation in the Colville River, Nuiqsut area. The current Phase 3 mining area contains about 430 acres of mineable quantities of sand and gravel, estimated at about 15 million $yd^3$. Reference: Permit modification letter to CEPOA-RD-N, 23 Jan 17. |
| 10 | Prudhoe Bay Area | **Aggregate.** There are multiple developed sand and gravel borrow pits within alluvial deposits formed by rivers flowing into Prudhoe Bay, including the Sagavanirktok River. The North Slope Borough owns three material sites in the Prudhoe Bay and Kuparuk area, identified as Mine Site F (7.0 million $yd^3$), Mine Site 3 (10.5 million $yd^3$), and Deadhorse South (10.5 million $yd^3$), with estimated sand and gravel marketable-quantities indicated in parentheses. References: May 18 discussion with the North Slope Borough (NSB); Feasibility Study for NSB - Development of Three Gravel Sources in the Prudhoe Bay Area, UMIAQ, Jun 2014. |

Nome Quarry (Granite)

Atigun Quarry (Conglomerate)


Cape Lisburne (Dolomite/Limestone)

Kivalina (Dolomite)

Buckland (Monzonite)

Point Hope (Limestone)

Dutch Harbor (Diorite)

Vancouver Island (Diorite)

**Figure 37 - Photos of Some Regional Material Sources.**

**3.5 Subsurface Ground Conditions of Significance to TSP (Alternative H).** The prior geotechnical investigations and available information on local borrow material sources as summarized in Table 1 provide a reasonable understanding regarding geotechnical site conditions of significance to the ongoing feasibility study. A preliminary discussion of geotechnical site conditions relevant to the TSP is given below, to be updated subsequent to further geotechnical site investigations during PED.

**3.5.1 Bluffs.** The bluffs and ground immediately inland from the bluffs and beach area are typically underlain by the following deposits:

- For ground in its undisturbed condition, there is a thin vegetative tundra mat at the surface, underlain by peat and silt, sandy silt or silty sand with organic content to depths ranging from about 1.5 to 5 feet. For areas that have been filled over original or excavated ground, the fill material likely consists of poorly-graded sand, silty sand, gravelly sand, and gravelly sand as provided by the local UIC or SKW borrow pits.

- Below the upper organic layer, the soil consists predominantly of silty sand to sandy silt, with a minor component of fine gravel within certain strata, to the base of the bluffs. The proportion of silt typically decreases and sand becomes more prevalent below approximately 10 feet in depth. This soil is well representative of the Gubik Formation.

- There is continuous permafrost below an active layer that extends to a depth of about 1.5 to 3 feet. There are both bonded and unbonded zones within the permafrost, with unbonded zones appearing to increase below a depth of about 10 feet along with an associated increase in pore water salinity. Massive zones of ice and ice-rich silt are common to a depth of about 18 feet, with recorded thicknesses of massive ice ranging from 2.5 to 13 feet in the Barrow area. Ice wedges associated with polygon formation may be present behind the bluffs, which adds to the potential instability of the bluffs as advanced thawing and erosion occurs along the exposed slopes.

**3.5.2 Beach.** The beach and ground immediately adjacent to the beach are typically underlain by the following deposits:

- The beach deposits appear to be predominantly silty sand, poorly-graded sand with silt and gravel, well-graded sand with gravel, and gravelly sand. The gravel component appears to increase towards the northeast end of the study area, continuing along the Point Barrow spit to Point Barrow. These deposits belong to the Gubik Formation, extending to depths of at least 46.5 feet (maximum depth explored) based on a few borings performed along the beach.

- For the three borings drilled near Pump Station #4 (Figure 31), along the seaside edge of Egasak Street, the soil was unbonded and thawed to a maximum depth of 10 feet, with pore water salinity increasing with depth (maximum 113 ppt). It is expected that beach deposits along the study area will exhibit increased depths of thawing compared to ground beyond the beach and above the bluffs.

**3.5.3 Bedrock.** There are a few older references which document deeper borings that reached bedrock in the general Barrow area, primarily related to gas well exploration. There have been no borings drilled to bedrock within the immediate study area where Alternative H would be constructed. Bedrock depths ranging from 56 to 137 feet were recorded within these deep borings, located within a distance of 5 miles from the shoreline, with depths being most typical in the range of 56 to 85 feet. Bedrock below the general area consists of Cretaceous sedimentary rock of the Torok Formation (shale, mudstone, and siltstone) and the Nanushuk Formation (lithic arenite, conglomerate, carboniferous shale, and coal).

## 3.6 Foundation and Earthwork Considerations of Significance to TSP (Alternative H).

Detailed geotechnical design input will be developed during PED, specific to Alternative H. Preliminary foundation and earthwork considerations for Alternative H are provided below.

### 3.6.1 Foundation Engineering.

**3.6.1.1** Coastal engineering design will account for the shore environment at Barrow (wind, waves, topography/bathymetry, subsurface condition, and seasonal ice), to be analyzed by the hydraulics/hydrology design team as discussed in Appendix F. Site-specific geotechnical information (e.g. soil borings and material testing) will be obtained during PED, focused on constructing stable and resilient embankments and protecting adjacent ground and structures. With respect to aspects of bearing capacity, settlement, and slope stability, no major foundation engineering impediments are foreseen to construct a rock revetment, revetted berm, or revetted and raised Stevenson Street at this location.

**3.6.1.2** Construction of the erosion mitigation measures will totally be a land-based operation, with required rock and gravel materials stockpiled at nearby staging areas. The preliminary design concept is for the revetted bluff and revetted berm structures to be embedded approximately 5 feet below natural beach grade, accommodating filter fabric, gravel, core rock, and B stone layers above excavation bottom. High water levels from surf conditions may be encountered along a stretch of revetted bluff construction where the beach is particularly narrow. In this circumstance, construction may need to be paused until the high water level dissipates or will be conducted from the surf zone. Potential revetment/berm construction below the water line needs to be reflected in contract plans and specifications but is not seen as an insurmountable construction operation. Construction areas vulnerable to high water levels and impacts on design will be further evaluated during PED. This includes consideration of using a marine mattress base layer where rock revetment construction may encounter high water in the excavation.

**3.6.2 Construction Duration.** It is estimated that it will take up to 5 years to complete construction of Alternative H, based on considerations of seasonal arctic weather conditions and associated challenges in acquiring rock, gravel, and general fill materials needed for construction. As discussed below, rock and select gravel materials will probably be obtained from the Nome quarry, transported to the project site by barge. Ice-free sea conditions typically allow barge deliveries to Barrow only from mid-June through September, although weather and ice conditions can vary from year to year. The ability to sustain construction operations at the project site for an extended period of perhaps May through December depends to some extent on the ability of regional quarries to produce and transport sufficient rock and gravel materials for each season's placement. The ability of local borrow pits to provide a sufficient quantity of general fill material for less critical portions of embankment construction will also be important factor in achieving material placement each work season and on overall construction duration.

### 3.6.3 Rock Borrow Sources.

**3.6.3.1** There are unique challenges on the availability of gravel and rock borrow materials to support properly engineered embankment construction. There are no local sources of rock within the Barrow area and there are very few rock quarries in operation within the entire North Slope Borough region (see Figure 36). The largest rock quarry operation within the North Slope Borough region are the Nome and Atigun quarries, approximately 700 miles and 350 miles from Barrow, respectively. There are a number of smaller rock quarries in operation (e.g. Buckland and Deering), and a number of locations that have been investigated by others as potential rock quarries (e.g. Kivalina and Point Hope). It is doubtful that these smaller rock quarries produce stone that would meet material specifications required for this project. Cape Lisburne has a rock quarry that is currently active, but stone generated from the quarry has been limited to use only for the local USAF installation. For planning purposes, it should be assumed that armor rock for revetment construction will come from the Nome quarry. However, as seen from a non-Corps seawall construction project completed at Wainwright (see Figure 36 for location), it may be possible that quarries outside of mainland Alaska, in this case Dutch Harbor, may turn out to be economically competitive at the time of construction bidding.

**3.6.3.2** Rock for the revetments will need to be barged from Nome to Barrow. The rock would be offloaded at a landing site and transported to a designated staging area. There are three tentative staging areas, two with adjacent landing sites, which are being considered for this project (see Figures 38 to 40 for locations). Landing sites in the Chukchi Sea/Beaufort Sea region generally consist of non-designated sandy gravel beach landings, where the barges nose in and power up to the beach to maintain position during loading/offloading. This is the typical landing procedure for supply barges at Barrow, with an example of a beach landing shown in Figure 41 for nearby Point Hope. Depending on the draft of the incoming barges, the contractor may extend a temporary gravel/rock ramp into the water to facilitate offloading the rock. Ice-free sea conditions typically allow for barge deliveries to Barrow from mid-June through September, although weather and ice conditions can vary from year to year.


**Figure 38 – Tentative Rock Staging Area #1 with Potential Barge Landing Area.**


**Figure 39 – Tentative Rock Staging Area #2 with Potential Barge Landing Area.**


**Figure 40 – Tentative Rock Staging Area #3 with Potential Barge Landing Area.**

**Figure 41 – Typical Barge Landing on Beach (Point Hope).**

### 3.6.4 <u>Sand and Gravel Borrow Sources</u>.

**3.6.4.1** With regard to gravel borrow materials, there are local borrow pits within the Barrow area, being the UIC and SKW (City of Barrow) operations, with the AKDOT borrow pit operating exclusively for State of Alaska projects. Annual gravel production from each of the UIC and SKW pits ranges from 30,000 to 50,000 $yd^3$. Quarry managers indicate a potential for each providing up to 100,000 $yd^3$ of gravel a year, which needs to be confirmed. The SKW pit is limited in its ability to expand laterally due to property ownership boundaries, and their management indicates that gravel deposits will diminish in approximately 10 years. The UIC pit has room to expand laterally and was recently permitted for a phase of expansion.

**3.6.4.2** From review of gradation tests performed on the material from the pits, an understanding of subsurface conditions in the area, and discussions with the quarry operators, it is expected that what is being referred to as gravel is most often a fine gravelly sand or sandy fine gravel. This material is used, for example, for local road maintenance and construction, with the North Slope Borough reporting an average 1,000 $yd^3$ of material used for annual road maintenance. The local road construction practice is to place up to 5 feet of gravel with underlying insulation and geotextile fabric, over natural subgrade to protect underlying permafrost from seasonal thawing. This road bed material is obtained from the local borrow pits. While the local road construction practice calls for free-draining gravel, the material most likely consists of sandy fine gravel.

**3.6.4.3** Deposits within the UIC and SKW borrow pits consist predominantly of some combination of sand and silt, with less frequent layers of gravelly sand and sandy gravel being the most valued material being produced. Very similar stratigraphic conditions exist for the undeveloped West and East Material Source Areas (see Figure 35 and ID #34 and #35 in Table 1). As was the case for initial development of the UIC and SKW borrow pits, development of these two potential borrow sources will require a considerable effort to first remove thick deposits of ice-rich and organic-rich silt and sandy silt, followed by layers of sand with silt and silty sand, before reaching deposits containing the desired gravel component.

**3.6.4.4** The UIC and SKW borrow pits may be able to provide non-frost-susceptible fill material (sand with low silt content) and to a lesser extent, sandy fine gravel and gravelly fine sand, to support construction of certain coastal erosion elements such as raising Stevenson Street and general fill for the berms, depending on fill material specifications to be developed during PED. Granular fill involved in road, berm, or revetment construction would have specific gradation limits that require processing with screens. It was noted in a May 2018 site visit that the SKW borrow pit has some screens for processing material. The UIC borrow pit did not have screens at their operation, but staff stated that screens could be obtained if needed. The ability of local borrow material to meet quantity and gradation requirements for use in beach nourishment is no longer being evaluated since beach nourishment is not a measure included in Alternative H.

**3.6.4.5** The total quantity of locally available borrow material that could actually be dedicated to coastal erosion mitigation is uncertain at this time, requiring further discussions with the local controlling agencies, and knowing that the community has other continuing needs for gravel material as expressed in their Barrow Comprehensive Plan 2015-2035 report. Operation of the gravel pits is based on the specific amount of material that has been contracted for. One or more annual quarry blasts are performed to begin the process for providing the planned quantity of material to be delivered to customers. There is no mass stockpiling of gravel material at the quarries for possible advance use. Therefore, use of local borrow sources requires considerable advance planning and coordination, particularly if borrow site expansion is required or a new borrow source would be developed.

**3.6.4.6** Granular material with very specific gradation limits and critical performance requirements may have to be provided by a quarry external to the Barrow area. This may include the gravel course used in revetment and berm construction, to be clarified during PED. Large quarry operations at Coleville, Prudhoe Bay, and Nome would be able to provide select gravel material, but at very high transportation costs. Possible acquisition of gravel waste from the Cape Lisburne quarry operation has been informally discussed but not confirmed as a material source. The current assumption is that select gravel material will come from the Nome quarry.

**3.6.5 Ground Contamination and Artifacts.** During drilling of four borings at Pump Station #3 (see Figure 33 and ID #42 in Table 1), soil was found to be contaminated with diesel range organics that exceed Alaska Department of Environmental Conservation (DEC) cleanup levels. Ground contaminated with fuel product is also present within the NARL facility area. The potential for encountering fuel-contaminated soil in excavations for revetment and berm construction needs to be reflected in the project plans and specifications. In addition, there are archaeological artifacts including human remains within the study area, at known locations such as the Utqiagvik Village Site (Figure 10) and probably at other locations not as yet uncovered. In recognition of one of the study's objectives (reduce or mitigate damage to tangible cultural heritage), the presence of archaeological artifacts within the study area will need to be considered in designing and executing the erosion mitigation work.

## 4. GEOTECHNICAL FIELD INVESTIGATIONS DURING PED

**4.1** Geotechnical field investigations initially planned for the feasibility study are postponed until the PED phase based on approved, risk-informed decision making by the study team. With Alternative H being chosen as the TSP, a geotechnical field investigation will then be executed during PED to support design of the bluff revetment, revetted berm, and a raised and revetted Stevenson Street. The investigation scope will be finalized after Alternative H design features have been more fully defined, to include the location of beach access points and other discrete locations where sheet piles may be a design consideration.

**4.2** It is expected that the geotechnical field investigation will include both soil borings and test pits to characterize foundation conditions along the Alternative H alignment. The test pits will be excavated to characterize the beach sediments for hydraulic/hydrology analyses of beach erosion and any influence the material may have on the planned revetment/berm construction. The test pits will be positioned midway between the waterline and toe of bluff or seaside edge of the beach perimeter road. The pits will be spaced roughly 1500 feet apart and will be approximately 5 feet deep. A maximum of three sediment samples will be retrieved from each test pit for laboratory soil classification.

**4.3** Soil borings will be performed along the footprint of the planned rock revetments and berms to evaluate the competency of the subgrade to support the embankment construction. This evaluation will include considerations of bearing capacity, settlement, and embankment filter criteria, and will characterize subgrade permafrost conditions (depth, bonded/unbonded, saline content). The soil borings will likely be drilled to a maximum 50-foot depth unless a deeper soil characterization is determined to be required (for example, supporting sheet pile design for certain locations). The number of required soil borings is estimated to be about 15, to be updated after further development of the Alternative H design.

**4.4** In addition to soil borings and test pits, a number of shallow grab samples will be taken from the bluff face to characterize the in-situ material that will be behind and above the revetted bluff. Grab samples will also be obtained from the temporary berm materials currently in place along the seaward flank of Stevenson Street to determine the acceptability of using this material for general fill requirements for Alternative H construction. It is expected that the geotechnical field investigation during PED will continue to evaluate the availability and suitability of local and regional soil, gravel, and rock borrow materials, updating the borrow source findings contained in this feasibility study appendix.