APPENDIX E PTTL DESIGN CROSSING REPORT, SHAVIOVIK RIVER, KADLEROSHILIK RIVER, AND THE SAGAVANIRKTOK RIVER

PTTL CROSSING DESIGN REPORT

SHAVIOVIK RIVER, KADLEROSHILIK RIVER, AND SAGAVANIRKTOK RIVER CROSSINGS

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EXECUTIVE SUMMARY

The Point Thomson Transmission Line (PTTL) includes four major river crossings along its alignment from the Point Thomson facility just west of the Arctic National Wildlife Refuge to the Prudhoe Bay Facility. These are typical North Slope rivers, running south to north, draining the foothills and coastal plain to the Beaufort Sea. The discharge peaks during spring breakup, typically include ice jams, localized and intermittent flooding caused by such ice jams, aufeis, and ice floes of varying size. Spring breakup conditions typically form the basis for controlling design conditions for any river crossing on the North Slope. Crossing designs for the Shaviovik, Kadleroshilik, Sagavanirktok River, East Channel and West Channel, follow this pattern.

The initial river crossing designs for the conceptual design of PTTL included open-cut crossings of the Shaviovik, Kadleroshilik, and East Channel of the Sagavanirktok. For the West Channel of the Sagavanirktok, the design used the existing pipeline bridge to support the PTTL crossing.

This report discusses alternative crossing methods or crossing “modes,” for each of the four crossings. The crossing modes are 1) the open-cut method 2) Horizontal Directional Drill (HDD), and 3) a crossing utilizing a support system to carry the pipeline above the river, i.e. an “aerial” crossing. All of the alternative crossing methods have been used for pipeline crossings in past North Slope developments. Each has advantages and disadvantages, with associated costs and potential schedule and regulatory risk and operational concerns, which are dependent on the site specific details of the waterway and approach conditions and must be carefully weighed for comparison. While not evaluated as part of this study, other trenchless technologies (e.g., directional microtunneling) should be considered in future phases as alternates to HDD.

The approach was to gather available data for each of the planned crossing locations, and identify the prime design parameters required for each alternative analysis – at least sufficient to define comparative analyses on an equitable basis. For an open-cut crossing and HDD methods, the scour potential was of prime importance; it governed the minimum required burial depth and the profile of the crossing. Bank migration potential was important for all modes since it directed the boundary limits of the crossing. The length of the crossing governed the type of aerial crossing which was feasible.

As expected, there is lack of sufficient data at this early phase of design, therefore general experience gained from other North Slope surface hydrology tasks was used to supplement the design analyses. Where applicable, recommendations for acquiring the required data for future design are made.

Generally, the open-cut method construction technique is familiar to most contractors and does not require specialty crews or equipment and therefore is preferred for pipeline crossings. A major consideration however is the expected condition of the ditch and the difficulty in keeping the instream trench open to the required burial depth. Often, winter construction will mitigate this concern due to low flow, and frozen soil conditions, minimizing dewatering requirements.

The HDD method requires a specialty contractor, specialty equipment for the drilling operations, and considerable on-site support conditions for construction. A principal advantage of the HDD method is limited disturbance of the stream especially for stream crossings with fishery resources.

There is no single aerial method, as site conditions of the crossing will govern design considerations. Large instream ice forces will result in relatively high costs for instream piers, pushing the design for longer unsupported spans. However, longer spans require additional support hardware and consequent cost increases. For each of the crossings considered,

evaluation of feasible alternative aerial crossing designs forms an additional subtask in the comparative analysis.

The study details each crossing investigation. No critical items were found which would preclude any of the alternatives considered, except for the crossing of the West Channel of the Sag River where the open-cut alternative was not considered feasible because of the relatively deep water at the current proposed crossing location. It should be noted that shallower water is likely present both upstream and downstream of the current crossing location though the distance is unknown and could be significant. For the West Channel of the Sag, the existing bridge appears capable of supporting the new gas pipeline based on the limited data available to the project and remains the most viable option, although there is no certainty the permissions to use the bridge could be obtained. In that case, an HDD crossing would then be the technically feasible alternative.

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1.0 INTRODUCTION

The Point Thomson Transmission Line (PTTL) will transport natural gas from the Point Thomson Unit to the Gas Treatment Plant in Prudhoe Bay. There are four major river crossings located between Point Thomson and Prudhoe Bay (Figure 1). The approximate locations based on Route Revision C and current Alaska LNG (AKLNG) pre-FEED design concepts are:

- Shaviovik River, milepost (MP) 25.5, open-cut.
- Kadleroshilik River, MP 35.5, open-cut.
- Sagavanirktok River East Channel, MP 44, open-cut.
- Sagavanirktok River, West Channel, MP 53.5, attach to existing pipe bridge.

The objective of the PTTL crossing design report is to review the design approaches made in the conceptual design study at each of these crossings. Alternative crossing modes to be considered include the open-cut, horizontal directional drilling (HDD), and aerial options (i.e. crossing utilizing a support system to carry the pipeline above the river). Each alternative will be considered using the available data at each of the four crossings, in order to complete engineering and cost evaluation of the alternatives. Data gaps are identified appropriately as requirements to complete the crossing designs.

Figure 1: River Crossing Location Map

2.0 CROSSING MODE DESCRIPTIONS

The four major river crossings on the proposed PTTL pipeline alignment all have technically feasible alternative crossing methods or "crossing modes". Each crossing mode has advantages and disadvantages dependent on the specific crossing locations and site-specific details at those locations.

The base case crossing mode is open-cut (to match the existing Badami Sales Oil Pipeline (BSOP) crossing mode), except for the West Channel of the Sagavanirktok River crossing. This mode is often the most cost effective crossing mode, absent site-specific design requirements which need additional construction and/or operational considerations. For example, the BSOP crossing of the East Channel of the Sagavanirktok River caused breaching of adjacent small lake drainage, resulting in multiyear remediation requirements (see Figure 2). Regulatory approval for open-cut crossings is expected to be more difficult today than it was for Badami, in part because of this incident. Design considerations in any case would be to avoid potential long-term, and costly seasonal remediation for maintenance of the banks at the ditch excavation used for the open-cut crossing.

Figure 2: Badami Weir

Reference: SPCO 2007 Annual Report, p.53: "The Badami Weir was built to prevent erosion of the pipeline backfill at west bank of the pipelines' Sagavanirktok River crossing. This photo from July 13, 2007 shows the weir after interim corrective action temporarily stabilized the site. BPTA is currently working on a long-term solution."

HDD of the major river crossings is expected to be a favored option by oversight regulatory groups. For this study, HDD crossings were considered technically feasible for all of these crossings, and could in turn benefit the long term maintainability of the pipeline, even though initial installation costs for the HDD crossings would be greater than the open-cut and cover method. However, there is risk an HDD installation could not be completed in single winter construction season.

Another alternative to open-cut is aerial, which may be preferable to HDDs due to lower construction risk. The initial concept would be to employ a steel support structure for the pipeline, such as a girder bridge (twin plate girders or a single box girder) or lighter steel truss options. The girders or trusses can be modularly fabricated and field spliced to accommodate transportation to remote sites. Similar to the HDD option, bridges would be higher in cost than the basic installation cost of the open-cut river crossings, but may increase savings in life-cycle costs for maintenance and remediation.

In certain circumstances, especially in relatively stable waterways with a shallow water depth, an aerial crossing may simply include the use of long-span pipeline crossings on pier supports without additional structural components. The current aboveground cross-country mode for the PTTL includes a nominal span of 110 feet between supports. A moderate increase in span beyond 110 feet (up to 140 feet) is considered reasonable on PTTL characteristics. An increase to the basic PTTL wall thickness would generally lengthen the maximum span beyond the 140 feet considered in this evaluation.

2.1 OPEN-CUT CROSSING MODE

An open-cut crossing involves excavation of a trench to a design depth across the watercourse, laying the pipe in the trench, possibly with buoyancy control, and then backfilling the trench with suitable materials to restore the watercourse. Whenever possible, a river or stream crossing is aligned as near as perpendicular to the direction of flow. This orientation prevents channeling along the pipeline, minimizing the length of the crossing. Where it is necessary to cross a river or stream at less than a 90-degree angle to the flow, the need for mitigation will be evaluated and implemented where appropriate.

A trench may be "dry" or "wet" depending on the amount of water infiltration during construction. Pipeline construction in a dry trench does not vary significantly from normal cross-country below grade construction, while construction in a wet trench may require special techniques including dewatering, fluming, diversion, etc. Once the excavations are completed, the crossing sections are put into place and tied in, and trenches will be backfilled with materials equal to or better than the materials excavated. This will minimize the change in channel characteristics with respect to scour and erosion. Use of riprap or other bank protection techniques may be required at the river bank cuts.

Cathodic protection must be provided for the buried section of the pipe. For the open-cut installation method, a sacrificial anode (typically a magnesium or zinc ribbon cable) can be installed with the pipe.

The depth of a buried crossing is primarily driven by the need to ensure the pipe is not exposed to hydraulic forces of water flow and abrasive forces of sediment movement. Detailed design must evaluate the potential for pipe exposure on the river or stream bed due to the possibility of degradation and/or local scour or bank erosion. The occurrence of degradation, scour, or erosion is site dependent, and can be mitigated by site-specific designs.

It is understood blasting was required on part of the BSOP crossing of the East Cannel of the Sagavanirktok River. No evaluation of the effects or requirements for potential blasting associated with installation of the PTTL was conducted for this study.

2.2 HDD CROSSING MODE

HDD entails boring beneath a channel and pulling the pipe back through the borehole. The angle of inclination is between 10 and 16 degrees from horizontal at the entry and exit locations. The desired depth of installation beneath the channel is typically well below the design scour elevation. To achieve this, the crossing bore must begin and end a significant distance away from the channel bank due to the need for long radius (typically 1200 times the nominal pipe diameter or 3,200 feet for the PTTL) sweeps. Anticipated bank migration must also be considered in the crossing design.

A crossing installed by HDD has advantages over other river crossing techniques with regards to overall environmental impact: less surface disturbance, little to no increase in turbidity of the waterway, and no significant impact to waterway activities.

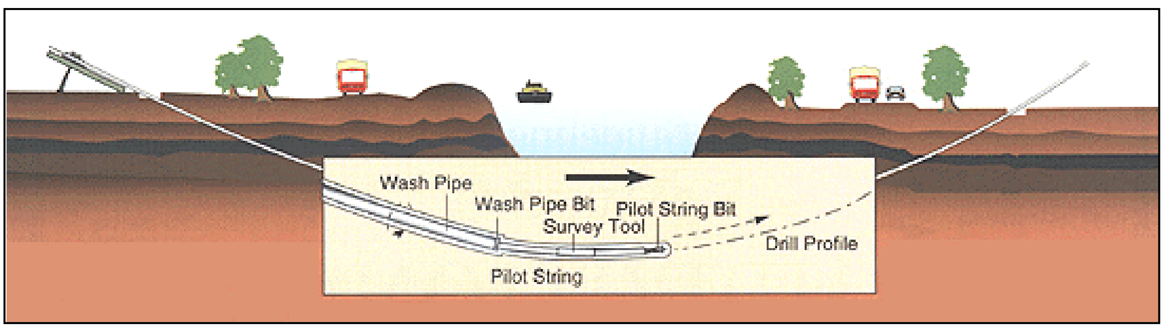
As envisioned, HDD operations, including pipe string preparation, would be conducted off ice/snow pads. The portions of the HDD traversing near surface thaw unstable soils would be excavated and backfill with gravel resulting in a relatively small (~20 feet wide by ~80 feet long by ~12-15 feet thick) permanent pad at the entry and exit locations.

The approaches may have the visual obstruction caused by thermosyphons, should they be required to mitigate potential thaw subsidence. However, the construction disturbance, when conducted during the winter from a properly constructed ice pad, is minimal.

Installation of a cathodic protection system will be required and will likely require a parallel installation of a sacrificial anode.

HDD begins with the boring of a small pilot hole along the desired profile. Drilling fluid is pumped to the drill motor through the drill stem and then returns to the entry point through the drilled annulus carrying the cuttings in suspension with it. Excess drilling fluids and cuttings would be transported to a permitted disposal site. A schematic of the initial pilot hole is presented in Figure 3.

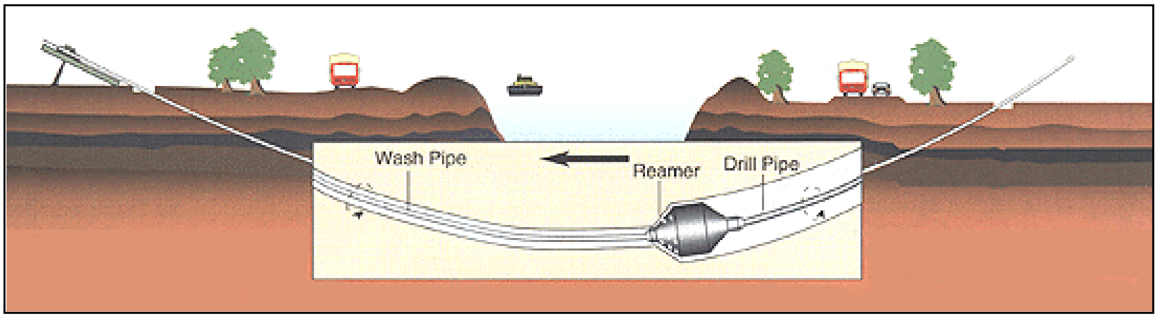
Figure 3: HDD Bore of the Pilot Hole



The area between the point where the pipeline enters the ground and achieves full depth is commonly referred to as the “transition zone.” Since the transition zones at the PTTL crossings will include permafrost soils, these areas may be subject to thaw settlement if pipeline operations melt ice inclusions. Special design considerations within the transition zones may be required to mitigate the concern.

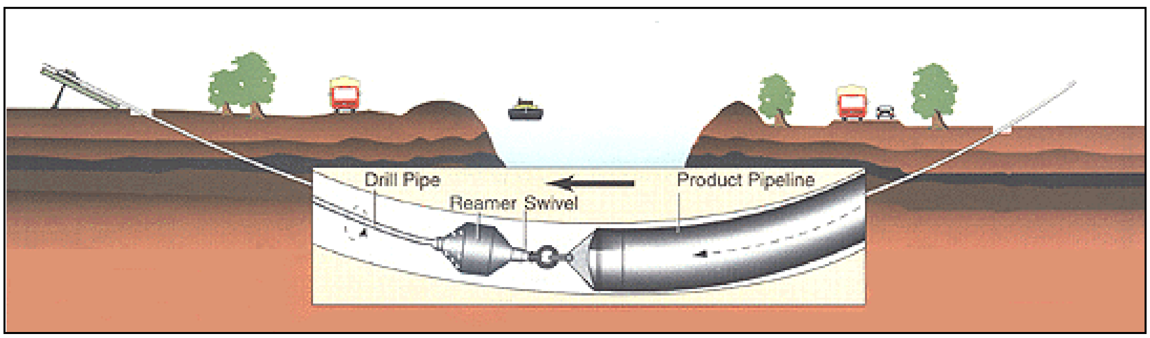
Once the pilot hole is complete, the hole is enlarged using a reamer (see Figure 4). Based on the diameter of the PTTL this procedure will require several passes with subsequently larger reamers. Reaming does not necessarily remove the cuttings produced during boring; rather, the cuttings are suspended in the drilling fluid circulated through the hole.

Figure 4: HDD Reaming Operation



After the hole has been enlarged sufficiently, a segment of pre-welded and pre-tested pipe is pulled through (see Figure 5). The force required to pull the pipe segment through the hole can be substantial, and vary based on overall length, pipe diameter and wall thickness, and soil conditions. The required pipe wall thickness is often governed by this installation consideration.

Figure 5: HDD Pipeline Pull Operation



Excess drilling fluid is pushed out of the bored hole or into the surrounding soils during the pull-back process. The drilling fluids used for HDD are typically acceptable for drilling potable water wells. Consequently, in the event of loss of drilling fluids into the surrounding soils, little to no environmental impact would be expected.

Data needs for the evaluation and design of HDD generally consist of obtaining information to evaluate the requirements for the drill equipment and anticipated drilling characteristics. The delineation of thawbulbs under the channel is a key component to the program. Ideally, the HDD would remain in frozen ground from entrance to egress, as the drill may have difficulty transitioning between thawed and frozen soils. In addition, the potential for fluid loss into the subsurface formation, mud blowouts, and difficulties maintaining hole stability are increased in subsurface materials such as clean, thawed gravel. If a strata of fine-grained soil of adequate thickness is observed, the design profile of the HDD may traverse this relatively conducive subsurface feature. In any case, the HDD design profile should detail the potential presence of cobbles and coarse gravel (particularly if frozen) that could be encountered during drilling.

Boreholes at planned HDD crossings are recommended to be drilled at approximately 500 foot intervals. The boreholes should be drilled to a minimum depth of 20 feet below the anticipated depth of the pipeline. The minimum recommended sample interval in the borehole is 10 feet. The sample interval should be decreased to 5 feet for a minimum of 20 feet above and below the planned pipe installation depth.

At least one borehole is recommended to be drilled to a minimum depth of 20 feet at the proposed location of each gravel pad as thaw stability in this area is important both for the drilling process and post-installation. The minimum sample interval for these boreholes is 5 feet.

2.3 AERIAL OPTIONS

There are a variety of options available to consider for crossing the rivers above the waterway. Generally, the major design consideration is the trade-off between the complexity and cost of the superstructure and that of the support substructures (piers). High ice forces for in-stream piers will require resistant piers resulting in the need for increased span lengths so as to minimize in-stream construction. However, longer spans require additional superstructure costs. These trade-offs are evident in the discussions of this section. If there is an existing aerial structure in the vicinity of the alignment, as at the West Channel of the Sagavanirktok, it is often economical to use this as a support structure, minimizing both cost and additional footprint.

2.3.1 Bridge Options

Descriptions of typical pipeline bridges for water crossings are described within this section. All bridge types have been constructed for past pipeline construction. For example, the 13 river crossings of the Trans-Alaska Pipeline System (TAPS) include pipeline suspension bridges and plate girder bridges. The box girder highway bridge at the Yukon River also supports the TAPS pipeline. The unique and award-winning arch bridge for the Gulkana River crossing, shown in Figure 6, was not part of the original design but was found necessary during construction requiring expedited design, logistics, and construction using available project materials.

Figure 6: TAPS Crossing of the Gulkana River

The characteristics, material types, and span ranges for the bridge descriptions discussed are guidelines only. Each individual bridge site should be carefully studied before determining a final bridge type and span configuration.

Typical pipeline bridges for water crossings will be evaluated for each river crossing site. The optimal bridge type depends on the site-specific requirements of each crossing and the characteristics, material types, and span ranges of the bridge type.

Each bridge type was designed for a general span length and summarized specifically for each crossing in subsequent sections of this document. Further analysis will be required to optimize the span lengths and member sizes by individual crossing. The conceptual aerial crossing evaluations are described below.

2.3.1.1 Steel Girder Bridges

Span lengths up to 350 feet can be technically obtained with this type of bridge, although the supporting steel structure becomes increasingly large, with corresponding high deflections, at longer spans. Since the typical bridges have relatively light live loads and relaxed deflection criteria, the use of high strength structural steels, such as HPS70W, for the main girders may prove to be economical and should be investigated in the preliminary design phase. Steel fracture toughness must meet the specification requirements for low temperature service.

A steel girder bridge with span lengths over 150 feet requires bearings for the thermal movement of the structure.

Field splices for the girders should be carefully laid out to accommodate hauling length and weight restrictions to the crossing sites.

Steel girder bridges are typically heavier than truss type bridges, but require less complicated field splicing.

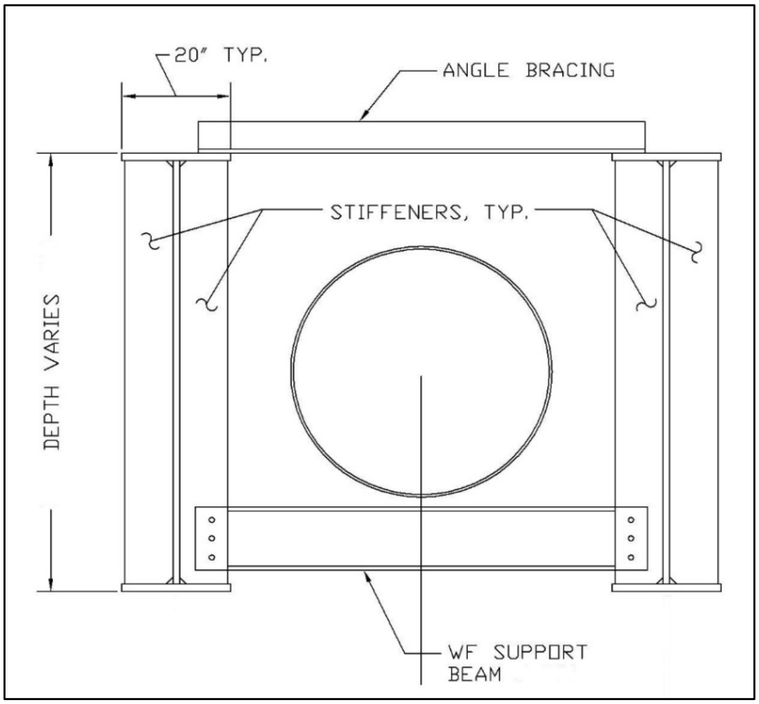
Due to the high self-weight of the girder type bridges, large deflections will occur mid-span. To allow the pipe to be supported by all bridge pipe supports, pre-camber of the girders should be a design consideration.

Two types of steel girder type bridges are explored herein: plate girder style, or box beam style.

- Plate Girder:

A plate girder bridge is comprised of two large built-up welded steel plate I-girders with intermediate diaphragms to provide girder lateral support through the spans (Figure 7). A span length of 250 feet was considered appropriate for this analysis.

Figure 7: Cross section of Plate Girder Pipeline Bridge



A girder spacing of 6 feet was selected to limit lateral bridge movement. The built-up steel two girder system would have an estimated depth of 54 inches which could vary for smaller spans. This depth can be more appropriately sized in detailed analysis. Due to the limiting slenderness ratio for a compact web, a minimum web thickness of 9/16 inches was used for this analysis. An analysis of the pipeline loads and girder system self-weight, and using a minimum deflection criterion of L / 80, concluded a girder flange width of 20 inches and thickness of 1.5 inches was required. The two-girder system requires lateral bracing and crossbeams to reduce the unbraced length of the top flange and provide attachment points for pipe saddles; these were assumed W12x35 members. All steel used in the analysis was assumed to be ASTM A572 Grade 50.

To resist lateral wind pressure and torsional buckling the girder system would also require cross bracing consisting of angles (L8x8x1/2). Bracing points for this analysis were assumed at 25 feet.

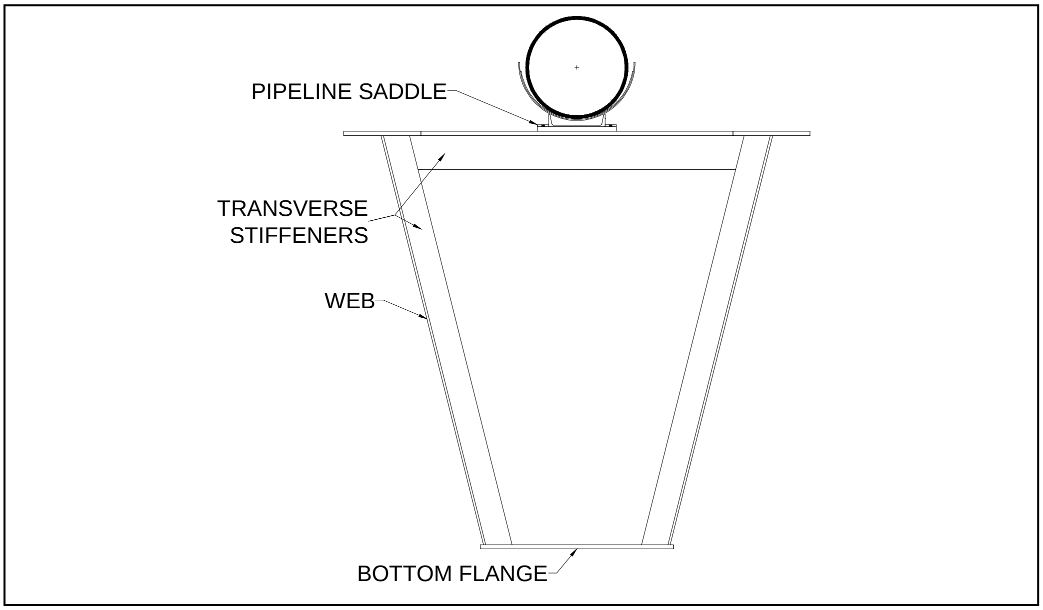
As stated earlier, this bridge type will have large deflections approaching 30.5 inches at mid-span under self-weight. When loaded with the pipeline an additional 5.5 inches of deflection would occur. Pre-camber of 36 inches at mid-span will result in the bridge and pipeline being nearly level after installation.

The two-girder system as described above results in a self-weight of 750 pounds per linear foot (plf).

- Box Girder:

A single plate box girder with intermediate diaphragms providing lateral support through the spans is another steel girder bridge option. The girder webs may be inclined or vertical as long as the inclination to the web plates to a plane normal to the bottom flange does not exceed 1 to 4. Inclined webs are advantageous to reducing the width of the bottom flange. A cross section of a pipeline box girder bridge with an inclined web is shown in Figure 8.

Figure 8: Cross Section of Pipeline Box Girder Bridge



A steel box girder system with a span length of 150 feet or more requires bearings for the thermal movement of the structure.

A box girder system can span greater lengths because of its intrinsic additional strength when compared to plate girder bridges. For this report, the bridge analyzed consisted of a built-up welded steel member with vertical webs, with a span length of 300 feet. Internal diaphragms were spaced at regular 25 foot intervals. The box girder section analyzed in this report has a depth of 66 inches, a width of 48 inches, a web thickness of 0.75 inches and a flange thickness of 1.5 inches. The material was assumed to be of ASTM A572 Grade 50 steel.

At each pier the box girder requires an end diaphragm plate with thickness of approximately ½ inch. Internal diaphragms are also assumed at ½ inch thickness.

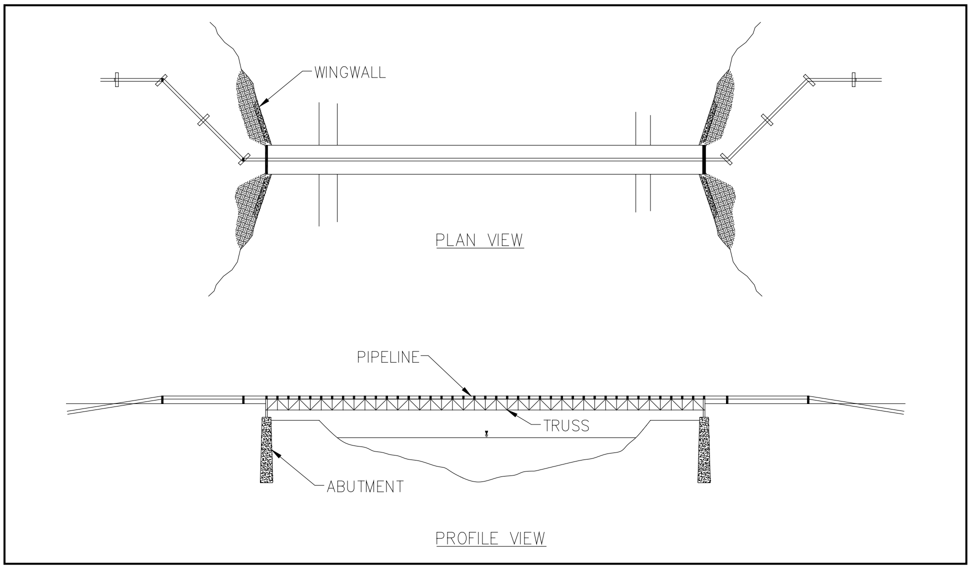
This bridge type will have large deflections approaching 39 inches at mid-span under self-weight. When loaded with the pipeline an additional 4.5 inches of deflection would occur. Pre-camber of this anticipated deflection at mid-span will result in the bridge and pipeline being nearly level after installation.

The box girder system as described results in a self-weight of 900 pounds plf.

2.3.1.2 Steel Truss Bridge Options

Truss bridges consist of smaller members, generally fabricated from rolled steel shapes. Span lengths from 300 to 1,000 feet can easily be accomplished. Actual truss configurations need to be addressed on a site by site basis. A schematic of a pipeline truss crossing is shown in Figure 9, while Figure 10 shows a picture of a pipeline truss bridge.

Figure 9: Schematic of Pipeline Truss Bridge



Generally, a Warren type truss configuration will be the most effective truss type. The most economical truss type may be an off-the-shelf vendor truss that is mass produced. Otherwise, fabricated trusses will be made up of steel rolled shapes, usually wide flanges, structural tubes, or pipe made from a variety of grades of steel.

The trusses will be designed to be field spliced to accommodate hauling to the remote sites.

Figure 10: Pipeline Truss Bridge

For this analysis, a simple span steel triangular truss consisting of a combination of pipe and wide flanged beam steel members having a span length of 300 feet was selected. The truss would have bays between connections spaced at 20 feet. The materials selected were API 5L X65 steel for pipe elements and ASTM A572 Grade 50 for the wide flanged beams.

The cross section of the bridge superstructure analyzed uses two upper chords consisting of pipe with 12.75-inch diameter by 0.406 inch wall thickness members along the ridge line of the structure. The lower chord consists of pipe with 14-inch diameter by 0.500 inch wall thickness. Vertical members used nominal pipe size (NPS) 4 pipe extending from the lower to upper chord. Diagonal bracing carrying predominately tension due to the Pratt truss shape would also consist of NPS 4 pipe members. Lateral bracing to resist wind loading were NPS 6 pipe. Cross bracing and sway bracing require members consisting of NPS 6 pipe as well. Crossbeam members would consist of a W12x35 where pipeline support saddles are located.

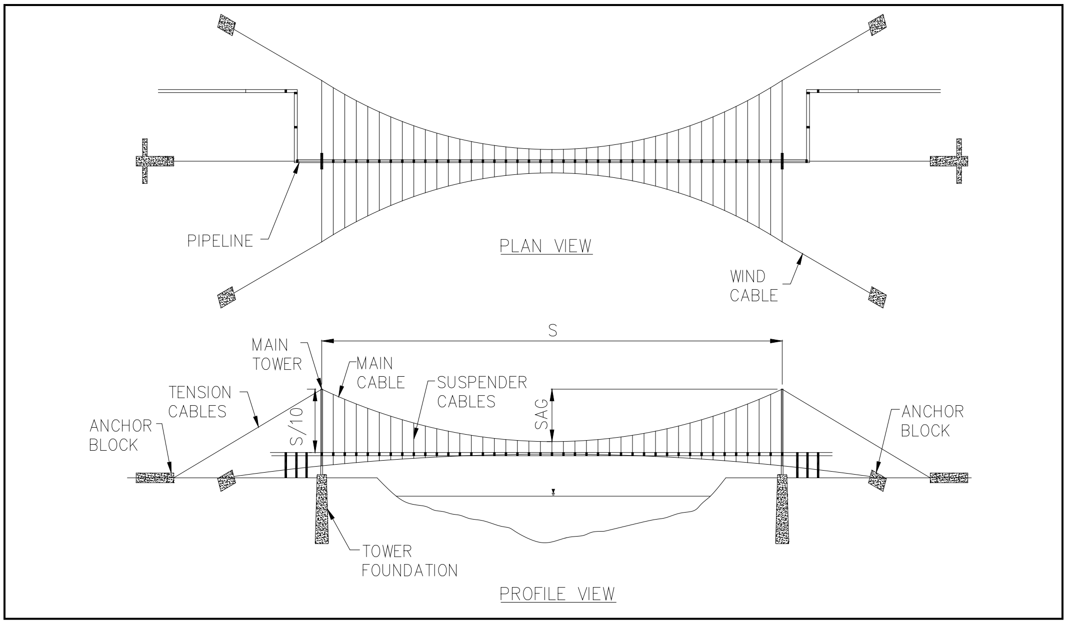
Center to center spacing of the upper chords is 6 feet, and the depth of the truss is 12 feet from center of upper chord and center of lower chord. Since the truss dimensions place the major moment resisting members at great distances from each other, a large moment of inertia results. Because of the larger moment of inertia, the truss has far greater stiffness than girder type spans, which results in significantly lower deflections. The truss described here has mid-span deflection due to self-weight of approximately 7.6 inches, and fully loaded mid-span deflection of 12.5 inches.

A triangular truss of these dimensions will result in a self-weight of approximately 300 plf.

2.3.1.3 Suspension Bridge

The suspension bridge type consists of supporting the pipeline from steel cabling draped between support towers and tied back into existing grade at the bridge ends. The towers are generally made up of rolled steel members. Span lengths from 200 feet up to 4,000 feet can be easily accomplished. Parallel, semi parallel, or locked coil strands will be the most likely cable type to be used for northern region bridges. A schematic of such a bridge is shown in Figure 11, while Figure 12 shows the TAPS Pipeline Suspension Bridge over the Tanana River.

Figure 11: Schematic of Pipeline Suspension Bridge



A suspension bridge is considered when instream structures must be avoided at relatively wide crossings (on the order of greater than 700 feet), possibly due to high costs for instream structures or where environmental considerations prevail. A suspension bridge is only reasonably considered for the crossing of the Sagavanirktok River East Channel where spanning the entire active channel might require this type of structure. As seen, the suspension bridge requires extensive structures on either bank to support the towers and cable anchorages as well as to achieve the necessary cable elevation above design high water. The impact of the visual obstruction and its effect on local stakeholders and regulatory agencies must be considered in any evaluation.

Figure 12: TAPS Pipeline Suspension Bridge over the Tanana River

The main variables of suspension bridge designs at each site include:

- Length of span.
- Cable size and cable anchorages.
- Central Tower height.

Larger spans require longer and larger diameter cable as well as taller towers. The layout of the suspension bridge would consist of a main span between the towers over the channel crossing and two trailing spans to the anchorages. The sag of the main span would have an approximate ratio of 1 / 10 to the span length.

The main suspension would be provided by two overhead cables. Resistance to wind loading is provided by two wind tie cables, laterally offset either side of the pipeline. Additional cables connect the suspension and wind tie cables to the pipeline at regular spacing.

The towers would consist of two pipes with beam or pipe diagonal and lateral bracing.

Anchorages consisting of additional pilings will also be required outboard of the towers to offset the forces from the suspension and wind tie cables.

A suspension bridge for the Sagavanirktok crossing is estimated to weigh approximately 600 pounds per lineal foot (plf).

2.3.2 Long-Span Pipeline Crossing on Piers

This bridge type consists of individual pier supports spaced to limit span lengths for which the pipeline can carry its own weight and associated external loads. A picture of the crossing of the

Miluveach River for the Alpine Pipeline on the west side of Prudhoe Bay is shown in Figure 13, while a more detailed picture of the supports is shown in Figure 14.

Figure 13: Miluveach River Crossing

Figure 14: Support Piers at the Miluveach River Crossing

The pier supports are generally made up of drilled pipe pile foundations with rolled structural steel members for pipe supports. ASTM A53 steel, or higher strength grades, are used for the pipe piles. ASTM A572 low-temperature steel is generally used for the pipe support cross members in arctic environments. Steel fracture toughness must meet the specification requirements for low temperature service. Pier support cross members and piling can be easily hauled to remote sites. Erection can usually be accomplished with a medium size crane.

For the standard 110-foot span, the mid-span deflection of the PTTL is estimated at approximately 0.8 inches. The existing Sagavanirktok River pipeline bridge has piers spaced at 150-feet. At 150-feet, the PTTL will experience mid-span deflection of approximately 2.75-inches. While not within the Exxon Mobil GP acceptable mid-span deflection of 3/4-inch, and although the expected deflection does cause the pipeline to become susceptible to wind-induced vibration (WIV), use of tuned vibration absorbers could be employed to mitigate concerns of WIV.

Increased wall thickness on the crossing could allow for longer spans between piers. With the current pipe size, maximum span length will need to be limited to 140 feet for the pipeline to remain within ASME B31.8 code allowable stresses.

Aside from the larger VSM sizes within the crossing, there would be no increase in self-weight for this type of crossing unless wall thickness is increased to accommodate larger spans.

2.3.3 Site Specific Data Requirements

Aerial specific data requirements include design-level river flood elevations, flood flow rates, ice floe size, scour depths, and subsurface temperatures. Additional geotechnical data will be required to evaluate the foundation support of any aerial structure.

For new structures with discrete foundation elements (such as piers or abutments), a minimum of one borehole is recommended at the location of each foundation element. The minimum borehole depth is 50 feet below the ground surface or the top of frozen soil, whichever is greater. The minimum recommended sample interval is 10 feet. PVC casing and temperature measurements are recommended at the location of each foundation element.

For structures with more continuous support, such as a long-span pipeline crossing, boreholes are recommended at an interval of 500 feet. The minimum depth of the boreholes is 30 feet below the ground surface or below the base of unbonded soil. The minimum recommended sample interval is 5 feet in the zones of thawed soil below the mudline and in the initial 10 feet of frozen soil and 10 feet thereafter.

3.0 GENERAL CONSIDERATIONS

3.1 HYDROLOGIC AND GEOMORPHOLOGICAL CONSIDERATIONS

Hydrology and Geomorphology were not investigated in detail for this conceptual study. Many high level assumptions were made to develop the alternatives. Since the pipeline corridor follows the existing BSOP corridor and the proposed crossing sites are at or have similar conditions, no fatal flaws regarding hydrology or geomorphology are anticipated. This will need to be verified as the project continues.

Limited data has been collected at these crossing locations since the BSOP was installed. The Alaska Department of Transportation and Public Facilities (ADOT&PF) conducted breakup studies in 2006 and 2009 as part of their Bullen Point Road project. This data would add to the limited historical data owned by oil companies who have studied this corridor. Design of the PTTL river crossings will require analysis of the most recent data to verify the findings of these former studies as well as to ensure understanding of the current site conditions. Recent data will also ensure the design for potential hydrological, hydraulic and geomorphological changes during the design life of the proposed crossings.

The design of pipeline river crossings requires a thorough consideration of many factors. For a buried pipe, the main objective is to limit any potential of the pipeline being exposed during the design life of the pipeline. The depth of burial will be determined based on scour/degradation predictions and bank migration potential at each crossing.

Aerial crossings need to consider bank migration, scour for foundation design, and ice loading/impact criteria. Almost all peak flows for North Slope streams occur during spring break-up where ice jams, ice jam flooding, and impacts from ice are normal. Crossing structures must be designed to handle these ice loadings.

3.1.1 Scour Depth

Design scour depth for the life of the project will need to be determined. The predicted maximum scour depth and a prescribed minimum cover determine the design minimum depth or elevation of the pipeline. Accurate geotechnical and hydrologic information is required.

For this analysis, scour depth estimates for the buried crossing modes were calculated using a modified Lacey's model of regime theory and the Thorne Equations. The modified Lacey's model of regime theory does not rely on discharge predictions. The model uses bankfull width and bed material as input parameters. The Thorne Equation was developed by C. R. Thorne and is based on flume and large-river experiments of bend scour where the mean bed-particle size varied from 0.3 to 63 millimeters. The equation uses the average flow depth directly upstream of the bend, width of flow and the radius of curvature at the channel centerline.

Aerial imagery was used to estimate the bankfull width. Bankfull width was limited to the most active conveyance channels within the braided and anastomosed networks. Bed material was estimated based on data presented in historic USGS reports focusing on conditions in local channels (Hodel 1986, Scott 1978).

Based on the scour estimates using the equations discussed above in conjunction with engineering judgement, scour depths were estimated for the Shaviolik, Kadleroshilik, East and West Channel of the Sagavanirktok Rivers to be 10 feet, 10 feet, 12 feet and 6 feet, respectively. A more thorough analysis must be conducted for detail design.

3.1.2 Bank Migration

Bank migration rates were not estimated for this conceptual study. Bank setbacks of 150 feet were assumed for this study to account for bank migration. Better bank migration rates and setback estimated should be made using historic aerial photography for future work phases. The more photography available, the more accurate the prediction will be. Climate change should be considered with any bank migration estimates. Bank migration on the North Slope is often a result of thermal degradation of the banks and not caused by streamflow forces. Historical photography would not provide data regarding recent warming trends. An evaluation of the potential for thermal degradation at site specific locations should be made and an appropriate safety factor included with any bank migration estimate. South or west facing banks receive the most solar input and are generally more susceptible to thermal degradation. Ice rich soils or exposed ice lenses are also highly susceptible to thermal degradation.

3.1.3 Ice

Ice forces on bridge structures will need to be taken into account for in river pier designs. Ice cover and ice jams can increase scour potential and should be considered when evaluating the design scour depths as well. For this study ice forces were not estimated and pier sizes were estimated using conservative assumptions.

3.2 GEOTECHNICAL CONSIDERATIONS

A detailed suite of geotechnical borings will be required for each crossing. For this analysis we have assumed geotechnical conditions are favorable for each mode type at each crossing location, however, this assumption is only sufficient for a concept level analysis.

The HDD mode is especially dependent of the soils traversed. Layers of fine grained soils at least 20 feet in thickness with horizontal consistency are preferred. Fine grained silts and clays are the most favorable for pipeline installation by HDD. Soils with gravel content (grain size greater than #10 sieve) over 50 percent by weight for distances of several hundred feet may lead to drill-hole stability problems. Technology is rapidly improving with HDD installation methods and tracking and guiding pilot holes is becoming more accurate. Layers of cobbles and boulders or fractured hard rock formations make HDD installations extremely difficult; however, this is an unlikely condition for these North Slope rivers.

The assumed expected soil conditions are:

- An uppermost stratum consisting of ice-rich, fine-grained soils and organic material.
- A middle stratum consisting of poorly graded gravel lenses varying in thickness, with intermittent cobbles, especially at the base of the stratum.
- A lower stratum consisting of finely graded silt and sand.
- An unfrozen soil zone under the main river channels, with frozen soils under the banks.

The majority of the HDD installation was assumed to be at depth of the lower stratum, where conditions are favorable with finely grained soils. The middle stratum with gravel content may lead to challenges at each end of the crossing, where drilling is at an angle of inclination; however, these challenges are not expected to prevent a successful installation due to the limited length of drilling in this stratum.

Pier foundations for aerial modes require information on geotechnical conditions but aren't generally as dependent on the conditions for a successful installation. Pier foundations have more design flexibility with regard to geotechnical soil properties.

3.2.1 Thaw Settlement

Potential thawing of the permafrost due to construction and/or pipeline operations must be considered. A geothermal analysis can be used to estimate changes in the subsurface thermal state cause by heat transfer from the pipeline or surface disturbance from construction activities. Thaw strain of the soils must be estimated for calculation of pipe settlement over the design life of the project. While thaw settlement potential is relatively high at the above/below ground transitions for the buried modes, the maximum operating temperature of the PTTL is relatively low (75°F) and will be even lower at the river crossing locations, therefore this potential is most likely mitigated.

4.0 MODING ESTIMATES

To provide a means for comparison for the alternative crossing designs it is necessary to find common beginning and ending geographical points at each crossing. The scope limits for each approach will be based on the maximum crossing length for any mode. The HDD option was considered as the upper bound on crossing design due to the transitions from design depth to the ground surface. Since the other crossing modes would include typical aboveground cross-country construction from the common beginning and ending points, cost for these approaches was also considered and included to make an equitable comparison.

All mode estimates were based on the cost estimate presented in the *Point Thomson Transmission Line (PTTL) Route Revision B Construction Estimate* report (AKLNG 2015) with tasks specific to the actual moding generated and substituted for certain portions of the original estimate. Cost estimates for each crossing mode were collapsed into unit costs (typically cost per foot or cost per each).

This section presents the basic cost assumptions for each mode. These base costs were then used to develop specific estimates for each crossing location as discussed in Sections 5.0, 6.0 and 7.0.

4.1 TYPICAL ABOVEGROUND CROSS-COUNTRY

The PTTL route revision B construction estimate considered a total length of aboveground pipeline of 61.1 miles with a total cost of approximately $301.8 million. This equates to approximately $935 per foot.

4.2 OPEN-CUT

The PTTL route revision B construction estimate considered a total length of open-cut installation of 6,250 feet with a total cost of approximately $10.3 million. This equates to approximately $1,650 per foot.

4.3 HDD

HDD installation costs were estimated at $4,350 per foot. This was based on $2,700 per foot for the HDD installation, approximately the average of Alaska LNG mainline estimates for HDD of the Chulitna, Koyukuk, and Deshka Rivers after appropriate scaling to account the reduction in diameter from 48-inch to 32-inch. This base cost was then increased by approximately $250 per foot for pipeline, support, and supervision crews, approximately $250 per foot for materials, $82 per foot for camp costs, and 15% increase for contractor overhead and profit. All costs except for the HDD operations were taken from the PTTL route revision B cost estimate.

4.4 AERIAL

4.4.1 Piers

With the exception of the suspension bridge options, loads from ice pans in the channel were assumed to control the sizing of the pier. Conceptual pier design consisted of two connected piles, sized as NPS 36 by 1.5-inch wall thickness piles. An 80-foot embedment depth with 20 feet of stickup for a total length of 100 feet was used. Based on this information each pier is estimated to cost $320,000.

4.4.2 Pipe Installation

The cost for the pipe installed on the bridge is estimated at approximately $450 per foot. This is based on information from the PTTL reroute revision B cost estimate for standard aboveground pipe (e.g. materials, welding, lift-up, etc.). Due to the greater lifting height for installation on the bridges there may be a slightly higher cost associated, although this is not captured in these estimates.

4.4.3 Steel Girder Bridge

Construction estimates for the steel girder bridges were based on an assumed $12 per pound of steel installed. The cost for piers must be added to the superstructure cost.

4.4.3.1 Plate Girder

The plate girder design described in Section 2.3.1.1 weighs approximately 750 pounds per foot. Therefore, the estimated cost for the plate girder option is approximately $9,000 per foot.

4.4.3.2 Box Girder

The box girder design described in Section 2.3.1.1 weighs approximately 900 pounds per foot. Therefore, the estimated cost for the plate girder option is approximately $10,800 per foot.

4.4.4 Truss Bridge

Due to the complexity of fabrication when compared with steel girder bridges, construction estimates for the steel girder bridges were based on an assumed $18 per pound of steel installed. At an estimated weight per foot of $300, the total per foot cost is estimated at $5400 per foot. The cost for piers must be added to the superstructure cost.

4.4.5 Suspension Bridge

The suspension bridge option was estimated using an all in structure cost (foundation, towers, and all other structural components) of $14,000 per foot. The cost of piers and other anchorages is included in this value.

4.4.6 Long-Span Pipeline Crossing

The long-span pipeline crossing would be constructed of the same pipe as the standard aboveground installation though with increased spans and therefore requires no additional costs other than those discussed above (i.e. piers and pipe in the crossing zone, see Section 4.4.3).

4.5 SUMMARY OF ESTIMATED UNIT COSTS

A summary of unit costs used in developing cost estimates for each crossing are presented in Table 1.

Table 1: Unit Cost Summary

Description	Installed Cost
Standard Aboveground Cross-Country	$935 per foot
Open-cut	$1,650 per foot
HDD	$4,350 per foot
Pier	$320,000 each
Pipe Materials and Installation on Aerial Crossing	$450 per foot
Plate Girder Bridge Superstructure (add pier, pipe material and installation costs) • 250-foot maximum span • 750 pounds per foot • $12 per pound	$9,000 per foot
Box Girder Bridge Superstructure (add pier, pipe material and installation costs) • 250-foot maximum span • 900 pounds per foot • $12 per pound	$10,800 per foot
Truss Bridge Superstructure (add pier, pipe material and installation costs) • 300-foot maximum span • 300 pounds per foot • $18 per pound	$5,400 per foot
Suspension Bridge Superstructure and Substructure (i.e. pier costs are included) • 1,550-foot maximum span	$14,000 per foot
Long-Span Pipeline Superstructure (add pier, pipe material and installation costs) • 140-foot maximum span • Utilizes standard aboveground pipe (i.e., no increase in wall thickness)	$0 per foot (no superstructure)

5.0 SHAVIOVIK RIVER

The Shaviovik River basin is approximately 1,580 square miles and includes all three physiographic provinces: the Arctic Coastal Plain, Foothills, and Mountains. Spring breakup is the largest annual discharge on the Shaviovik, although the system is somewhat responsive to rainfall events as part of the drainage originates in the mountains of the Brooks Range. The main tributary to the Shaviovik River is the Kavik River converging about 10 miles upstream from its mouth, which is upstream of the project crossing location. The floodplain contains extensive gravel bars, multiple channels and vegetated terraces.

General Shaviovik River crossing assumptions include:

- Bankfull elevation of 12 feet above mean sea level (MSL).
- Bank to bank channel width at the crossing is 550 feet.
- Thalweg elevation at minus 2 feet.
- Design scour depth of 10 feet below thalweg elevation (minus 12 feet MSL).
- Minimum pipe depth 5 feet below design scour elevation (minus 17 feet MSL).
- Bank migration limits of 150 feet assumed for both the east and west banks.
- Geotechnical conditions are conducive for each crossing mode.

All mode options evaluated were assumed to follow the current Route Revision C alignment. The channel has a prominent slough or channel to the east immediately upstream of the proposed crossing (Figure 15). For this evaluation the eastern transition point for all modes was moved to about 1,000 feet east of than the existing BSOP transition point to reduce potential impacts from this feature.

Bank migration may adversely affect the PTTL on the alignment used in this evaluation; therefore shifting the alignment downstream of the BSOP is strongly recommended in the next phase of the project, even though this shift would result in the need for two crossings of the BSOP.

5.1 SHAVIOVIK RIVER OPEN-CUT

The existing BSOP was constructed with an open-cut mode and the concept for an open-cut crossing by PTTL would be similar. The PTTL crossing is slightly upstream of the BSOP crossing and similar parameters are assumed. Fieldwork conducted in the winter of 2016 indicated grounded ice at the crossing. The open-cut is considered for the main East Channel only. The smaller side channels to the west will be constructed in the standard aboveground cross-country mode.

The length of the open-cut crossing is estimated at 1,500 feet.

5.2 SHAVIOVIK RIVER HDD

The following assumptions are made regarding the Shaviovik River HDD Crossing:

5.2.1 Pipeline Considerations

- Entry and exit angles of the pipe are 10 degrees from horizontal.
- The HDD profile will be at full depth before it crosses the bank migration setback point.
- The HDD length is 1,630 feet.
- Maximum radius of curvature is 3,200 feet.

- A gravel pad on each side will be approximately 20 feet x 80 feet.
- A permitable water source (e.g., a lake or lakes) is located within close proximity.

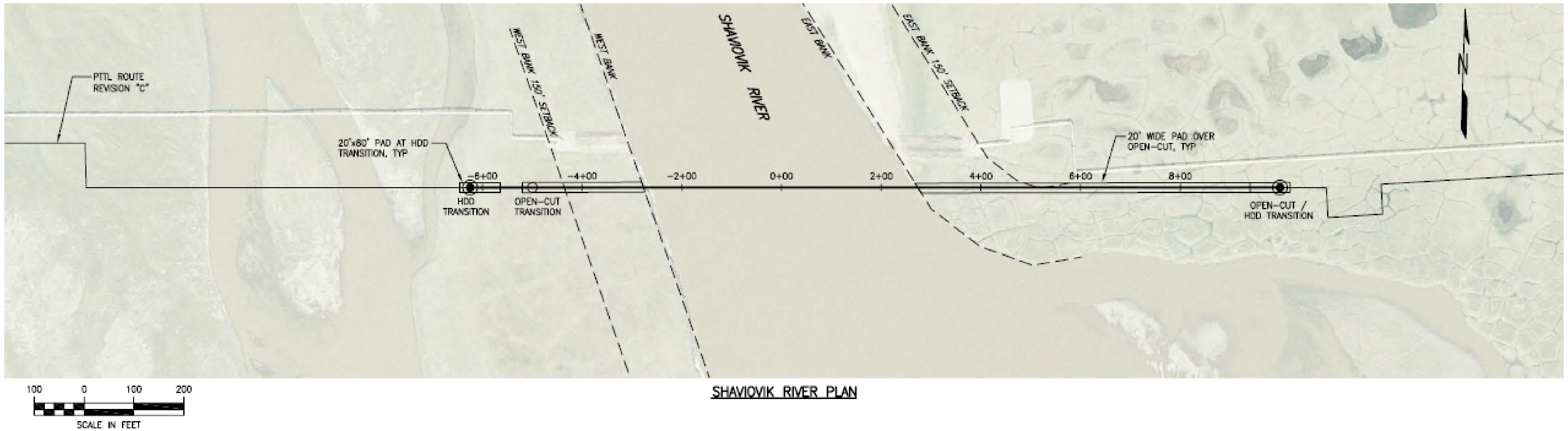
A conceptual plan and profile of the open-cut and HDD crossing modes for the Shaviovik River are presented in Figure 15.

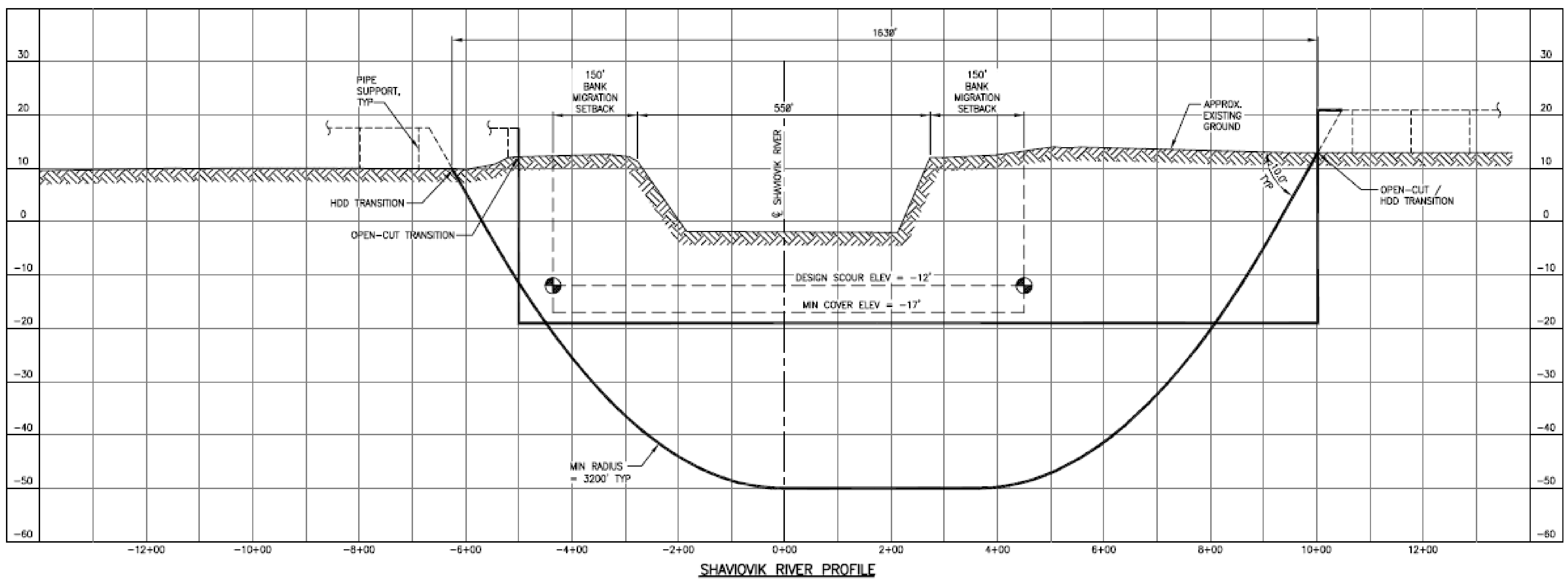
5.2.2 Geotechnical Conditions

- At the entrance and egress points, the subsurface soils from the ground surface to a depth of approximately 10 feet is assumed to consist of peat and silt. Assuming that the construction occurs in December through April, the near surface soils are anticipated to be frozen. The soil in the surficial 10 feet are anticipated to be ice-rich and massive ice may be present. On the eastern bank, the proposed pipeline entry is located in polygonal ground and vertical ice wedges may be present.
- The subsurface conditions below a depth of approximately 10 feet are anticipated on consist of frozen, well-bonded sand and gravel with excess visible ice (on the order of 5 to 10 percent by volume) and may be slightly silty.

During March 2016, soil borings indicated the ice in the channel was grounded. Although a limited thaw bulb may be present in the subsurface, the presence of grounded ice is an indication that if a thaw bulb is present, it is relatively limited in size and likely does not extend below the depth of scour and is not anticipated to impact the HDD crossing.

Figure 15: Shaviovik River Crossing





5.3 SHAVIOVIK RIVER AERIAL

The Shaviovik River crossing consists of a 550-foot minimum channel width. All aerial options were estimated to extend the same length as the open-cut mode, 1,500 feet.

- Bridge abutment piers will be located outside the bank migration zone.
- A suspension system would support the pipeline from steel cabling draped between support towers and tied back into existing grade at the bridge ends. Spanning the same length as the open-cut option (1,500 feet) would not require any vertical support member (VSM) within the channel.
- A plate girder system would consist of large built-up welded steel members spanning approximately 250 feet and would require a total of seven piers, of which three would be within the channel.
- A box girder system would consist of the box girder with vertical sides spanning approximately 300 feet, and would require a total of six piers, two of which would be within the channel.
- A triangular truss would consist of rolled steel members spanning approximately 300 feet and would require a total of six piers, two of which would be within the channel.
- A long-span pipeline crossing would consist of approximately 136 foot spans with a total of 12 piers. Four or five of the piers would be within the channel. All piers are considered the same for this study and could possibly be refined with further engineering.

5.4 SHAVIOVIK RIVER CROSSING COST SUMMARY

Based on the unit costs presented in section 4.5 the cost estimates for the different crossing modes at the Shaviovik River are listed in Table 2.

Table 2: Shaviovik River Crossing Costs

Mode	Crossing Length (feet)	Associated Aboveground Length[1] (feet)	Number of Piers	Total Crossing Cost (million)
Open-cut (Base Case)	1,500	130	0	$2.6
HDD	1,630	—	0	$7.1
Plate Girder	1,500	130	7	$16.5
Box Girder	1,500	130	6	$18.9
Truss	1,500	130	6	$10.8
Suspension	1,500	130	2	$21.8
Long-Span Pipe	1,500	130	12	$4.6

Note:
1. This is the length of pipeline that utilizes the nominal cross-country PTTL aboveground design. The additional length is included to make all crossing lengths the same, and thus the cost of the crossings comparable

6.0 KADLEROSHILIK RIVER

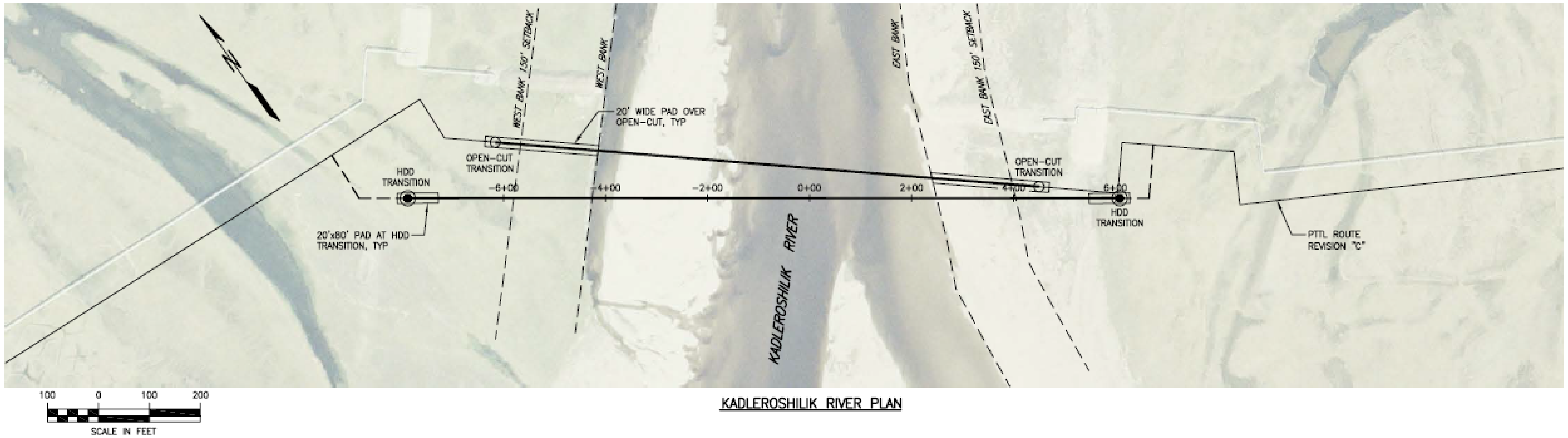
The Kadleroshilik River is a 65-mile-long coastal stream system, which drains an area of approximately 450 square miles. The basin drains mostly from the Coastal Plain with only a small percentage of the upper basin being located in the foothills to the south. The majority of runoff volume occurs during spring breakup and annual peak stage and discharge are all likely to occur in the spring due to the high percentage of the basin on the Coastal Plain, where rainfall is relatively low.

General Kadleroshilik River crossing assumptions include:

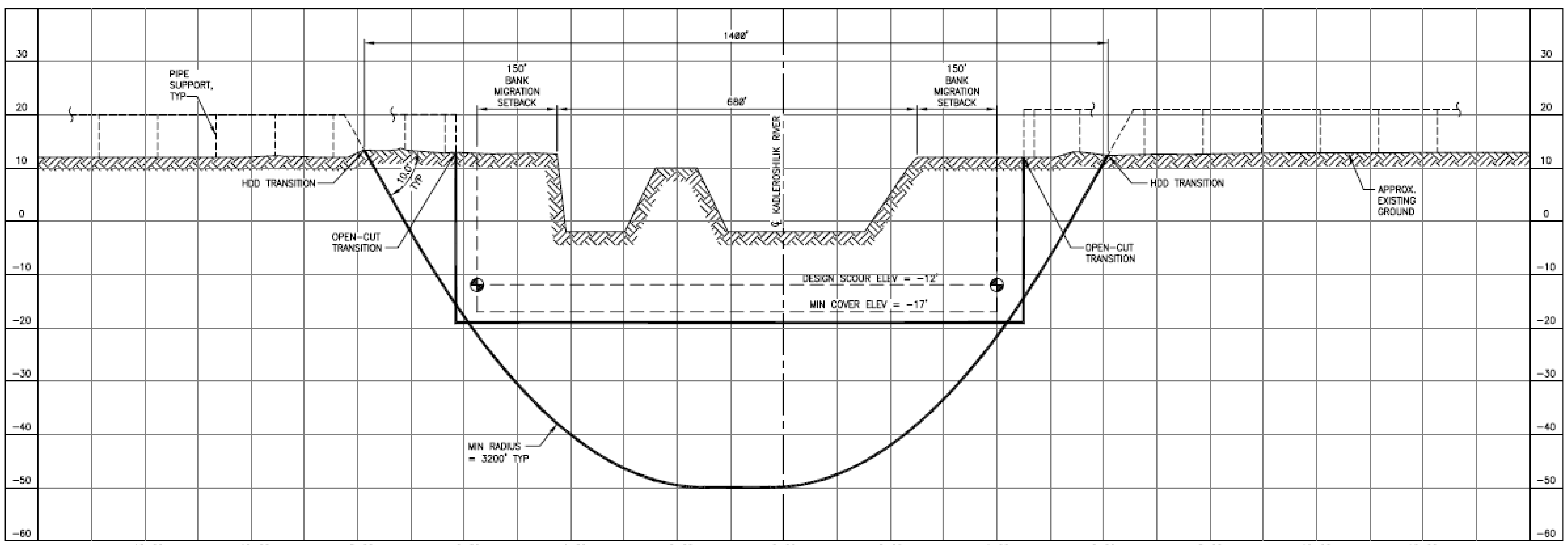
- Bankfull elevation of 12 feet above MSL.
- Bank to bank channel width at the crossing is approximately 680 feet.
- Thalweg elevation at minus 2 feet.
- Design scour depth of 10 feet below thalweg elevation (minus 12 feet MSL).
- Minimum pipe depth 5 feet below design scour elevation (minus 17 feet MSL).
- Bank migration limits of 150 feet assumed for both the east and west banks.
- Geotechnical conditions are conducive for each crossing mode.

An image of the crossing area is shown in Figure 16.

Figure 16: Kadleroshilik River Crossing



KADLEROSHILIK RIVER PLAN



KADLEROSHILIK RIVER PROFILE

6.1 KADLEROSHILIK RIVER OPEN-CUT

The existing BSOP was constructed with an open-cut mode and the concept for the PTTL will be very similar. The PTTL crossing is slightly upstream of the BSOP crossing and similar parameters are assumed. Fieldwork conducted in the winter of 2016 indicated grounded ice at the crossing.

The length of the open-cut crossing is estimated at 1,070 feet.

6.2 KADLEROSHILIK RIVER HDD

The following assumptions are made regarding the Kadleroshilik River HDD Crossing:

6.2.1 Pipeline Considerations

- Entry and exit angles of the pipe are 10 degrees from horizontal.
- The HDD profile will be at full depth before it crosses the bank migration setback point.
- The HDD length is 1,400 feet.
- Maximum radius of curvature is 3,200 feet.
- A gravel pad on each side will be approximately 20 feet x 80 feet.
- A permitable water source (e.g., a lake or lakes) is located within close proximity.

6.2.2 Geotechnical Conditions

- At the entrance and egress points, the subsurface soils from the ground surface to a depth of approximately 10 feet will consist of peat and silt. Assuming the construction occurs in December through April, the near surface soils are anticipated to be frozen. The soil in the surficial 10 feet are anticipated to be ice-rich and massive ice may be present. On the eastern bank, the proposed pipeline entry is located in polygonal ground and vertical ice wedges may be present.
- The subsurface conditions below a depth of approximately 10 feet are anticipated on consist of frozen, well-bonded sand and gravel with excess visible ice (on the order of 5 to 10 percent by volume) and may be slightly silty.

The base of the thaw zone is not anticipated to exceed the design scour depth.

6.3 KADLEROSHILIK RIVER AERIAL

The Kadleroshilik River crossing consists of approximately a 660-foot minimum channel width. All aerial options were estimated to extend the same length as the open-cut mode - 1,070 feet.

- A suspension system would support the pipeline from steel cabling draped between support towers and tied back into existing grade at the bridge ends. Spanning same length as the open-cut option (1,070 feet) would not require any VSM within the channel.
- A plate girder system consisting of large built-up welded steel members spanning approximately 215 feet would require a total of six piers, of which four would be within the channel.
- A box girder system would consist of the box girder with vertical sides spanning approximately 270 feet, and would require a total of five piers, three of which would be within the channel.
- A triangular truss consisting of rolled steel members spanning approximately 270 feet would require a total of five piers, of which three would be within the channel.

- A long-span pipeline crossing would consist of approximately 135 foot spans with a total of nine piers. Five of the piers would be within the channel. All piers are considered the same for this study and could possibly be refined with further engineering.

6.4 KADLEROSHILIK RIVER CROSSING COST SUMMARY

Based on the unit costs presented in section 4.5 the cost estimates for the different crossing modes at the Kadleroshilik River are listed in Table 3.

Table 3: Kadleroshilik River Crossing Costs

Mode	Crossing Length (feet)	Associated Aboveground Length[1] (feet)	Number of Piers	Total Crossing Cost (million)
Open-cut (Base Case)	1,070	330	0	$2.1
HDD	1,400	—	0	$6.1
Plate Girder	1,070	330	6	$12.3
Box Girder	1,070	330	5	$13.9
Truss	1,070	330	5	$8.2
Suspension	1,070	330	2	$15.8
Long-Span Pipe	1,070	330	9	$3.7

Note:
1. This is the length of pipeline that utilizes the nominal cross-country PTTL aboveground design. The additional length is added to make all crossing lengths the same, and thus the cost of the crossings comparable.

7.0 SAGAVANIRKTOK RIVER

The Sagavanirktok River is the largest river on the eastern half of Arctic Alaska and drains approximately 4,700 square miles. The river originates in the Brooks Range (elevations reaching 8000 feet) and the basin is well divided between the three physiographic regions. The main tributary to the Sagavanirktok River is the Ivishak River converges about 50 miles upstream from Prudhoe Bay. The basin traverses all three regions; summer storms will have a greater impact on peak flows. The largest recorded flood was the result of a fall rainstorm in the basin headwaters.

As the Sagavanirktok River makes its way towards the Beaufort Sea it becomes progressively more braided and the banks consist of more non-cohesive sediments. Approximately 24 miles south of the proposed crossing, the river splits into two channels. In 1982 Hydrocon Engineering measured discharge at the bifurcation during spring breakup and recorded evenly split flows between the two channels. It was noted that the intensity and location of aufeis at the bifurcation could alter the split between the channels from year to year. Based on bed sediments collected at the bifurcation and in the West Channel (Scott 1978) it is likely that the median bed material (d50) can be classified as coarse gravel.

Based on remote sensing imagery between 1955 and 1981 moderate changes to the size and location of sub-channels have transpired. The tall frozen eastern bank will retard erosion as long as it stays frozen (Hydrocon 1982). Based on current imagery the river is highly braided in the vicinity of the crossing and downstream of the existing crossing the flow splits into two channels. Thawing of the frozen banks could lead to rapid erosion of the banks.

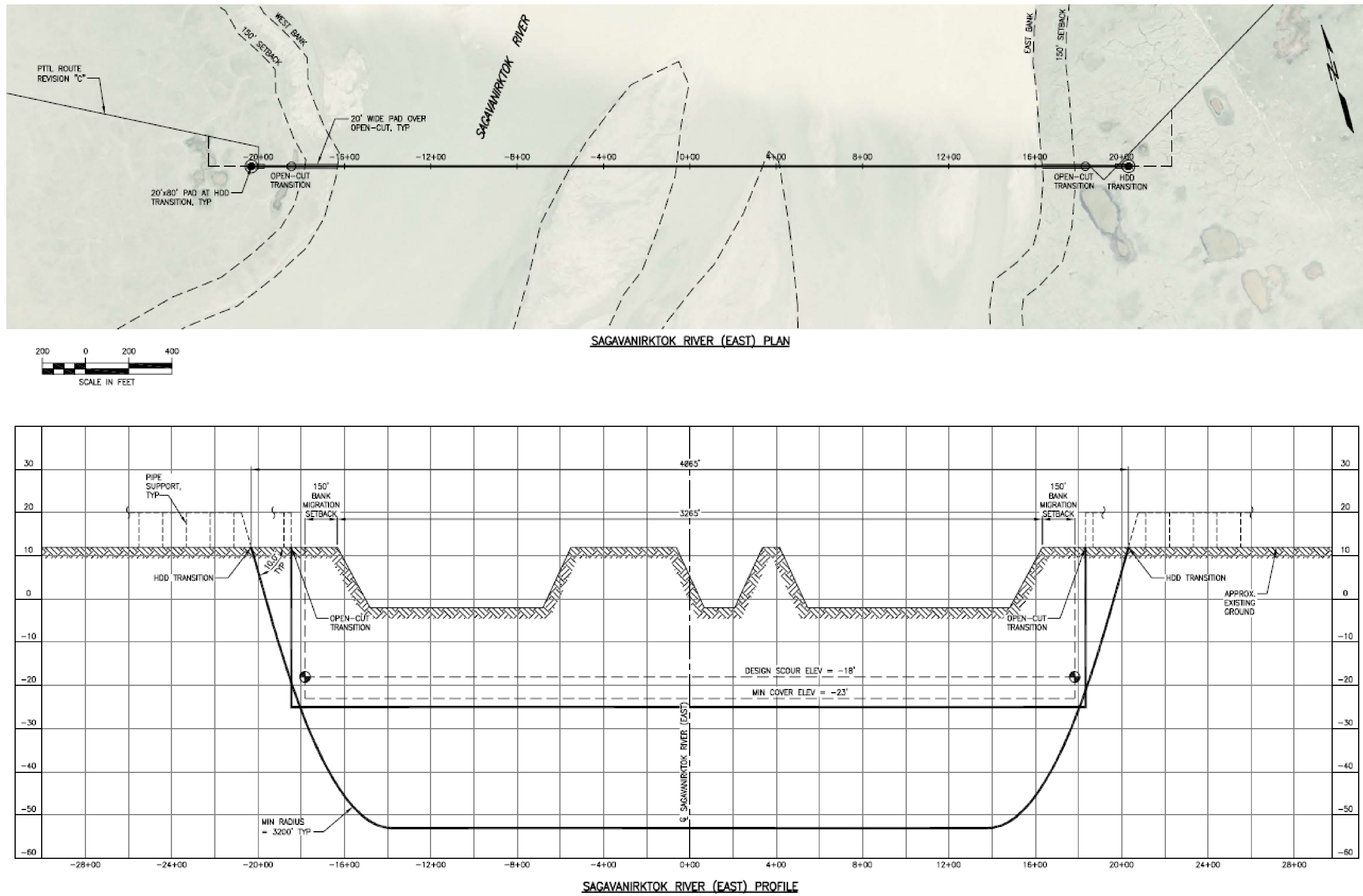
7.1 EAST CHANNEL

General East Channel Sagavanirktok River crossing assumptions include:

- Bankfull elevation of 12 feet above MSL.
- Bank to bank channel width at the crossing is 3,265 feet.
- Thalweg elevation at minus 6 feet.
- Design scour depth of 12 feet below thalweg elevation (minus 18 feet MSL).
- Minimum pipe depth 5 feet below design scour elevation (minus 23 feet MSL).
- Bank migration limits of 150 feet assumed for both the east and west banks.
- Geotechnical conditions are conducive for each crossing mode.

Aerial imagery of the crossing location is shown in Figure 17.

Figure 17: East Channel Sagavanirktok River



7.1.1 East Channel Sagavanirktok River Open-cut

Fieldwork conducted in the winter of 2016 revealed only minor flow at the crossing. Open-cut construction in the winter is feasible using concrete coating for buoyancy control and erosion control. During the summer, flow conditions would likely make open-cut construction technically impractical and winter construction would have significantly less impact on existing fish habitats.

The length of the open-cut crossing is estimated at 3,680 feet.

7.1.2 East Channel Sagavanirktok River HDD

The assumed properties of the East Channel HDD crossing would be as follows:

7.1.2.1 Pipeline Considerations:

- Entry and exit angles of the pipe are 10 degrees from horizontal.
- The HDD profile will be at full depth before it crosses the bank migration setback point.
- The HDD length is approximately 4,065 feet.
- Maximum radius of curvature is 3,200 feet.
- A gravel pad on each side will be approximately 20 feet x 80 feet

7.1.2.2 Geotechnical Conditions

- At the entrance and egress points, the subsurface soils from the ground surface to a depth of approximately 10 feet will consist of peat and organic silt. Assuming that the construction occurs in December through April, the near surface soils are anticipated to be frozen. The soil in the surficial 10 feet are anticipated to be ice-rich and massive ice may be present. On the eastern bank, the proposed pipeline entry is located in polygonal ground and vertical ice wedges may be present.
- The subsurface conditions below a depth of approximately 10 feet are anticipated on consist of frozen, well-bonded sand and gravel with excess visible ice (on the order of 2 to 7 percent by volume). The silt content is anticipated to be on the order of 8 to 15 percent.
- During field studies conducted in March 2016, flow was observed under the ice for approximately 1,000 feet. The depth of water, where observed, was on the order of two feet. However, the depth in the deeper parts of the channel may not have been observed and may be significantly deeper. As such, there is likely a moderate thawbulb under the Eastern Sagavanirktok River. The lateral extent and depth are not known, but it may be on the order of 20 feet deep.

7.1.3 East Channel Sagavanirktok River Aerial

The East Channel Sagavanirktok River crossing consists of an approximate 3,265-foot minimum channel width. All aerial options were estimated to extend the same length as the open-cut mode, 3,680 feet.

- A suspension system would suspend the pipeline from steel cabling draped between support towers and tied back into existing grade at the bridge ends. Utilizing two spans of approximately 1,850 feet would require a total of three towers, one of which would be within the channel.
- A plate girder or box girder system consisting of large built-up welded steel members spanning approximately 245 feet would require a total of 16 piers, of which 14 would be within the channel.

- A triangular truss consisting of rolled steel members spanning 285 feet would require a total of 14 piers, of which 12 would be within the channel.
- A long-span pipeline crossing would consist of approximately 136 foot spans with a total of 28 piers. Twenty-four of the piers would be within the channel. All piers are considered the same for this study and could possibly be refined with further engineering.

7.1.4 East Channel Sagavanirktok River Crossing Cost Summary

Based on the unit costs presented in section 4.5 the cost estimates for the different crossing modes at the East Channel Sagavanirktok River are tabulated in Table 4.

Table 4: East Channel Sagavanirktok River Crossing Costs

Mode	Crossing Length (feet)	Associated Aboveground Length[1] (feet)	Number of Piers	Total Crossing Cost (million)
Open-cut (Base Case)	3,680	385	0	$6.4
HDD	4,065	—	0	$17.7
Plate Girder	3,680	385	16	$40.3
Box Girder	3,680	385	14	$46.2
Truss	3,680	385	14	$26.4
Suspension	3,680	385	3	$53.5
Long-Span Pipe	3,680	385	28	$11.0

Note:
1. This is the length of pipeline that utilizes the nominal cross-country PTTL aboveground design. The additional length is added to make all crossing lengths the same, and thus the cost of the crossings comparable.

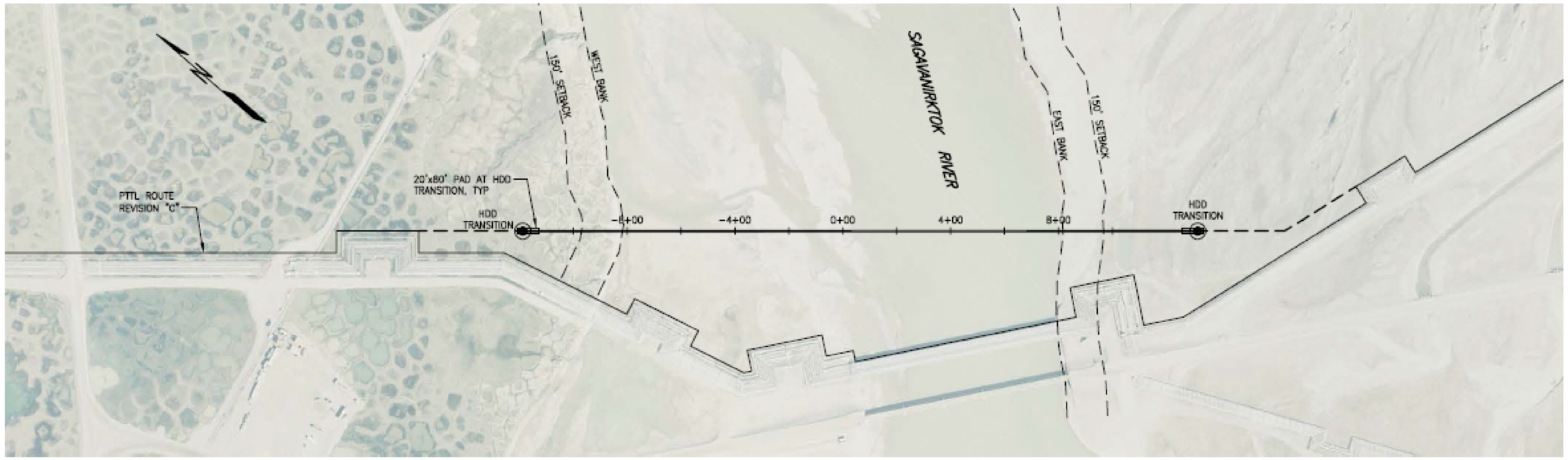
7.2 WEST CHANNEL

General West Channel Sagavanirktok River crossing assumptions include:

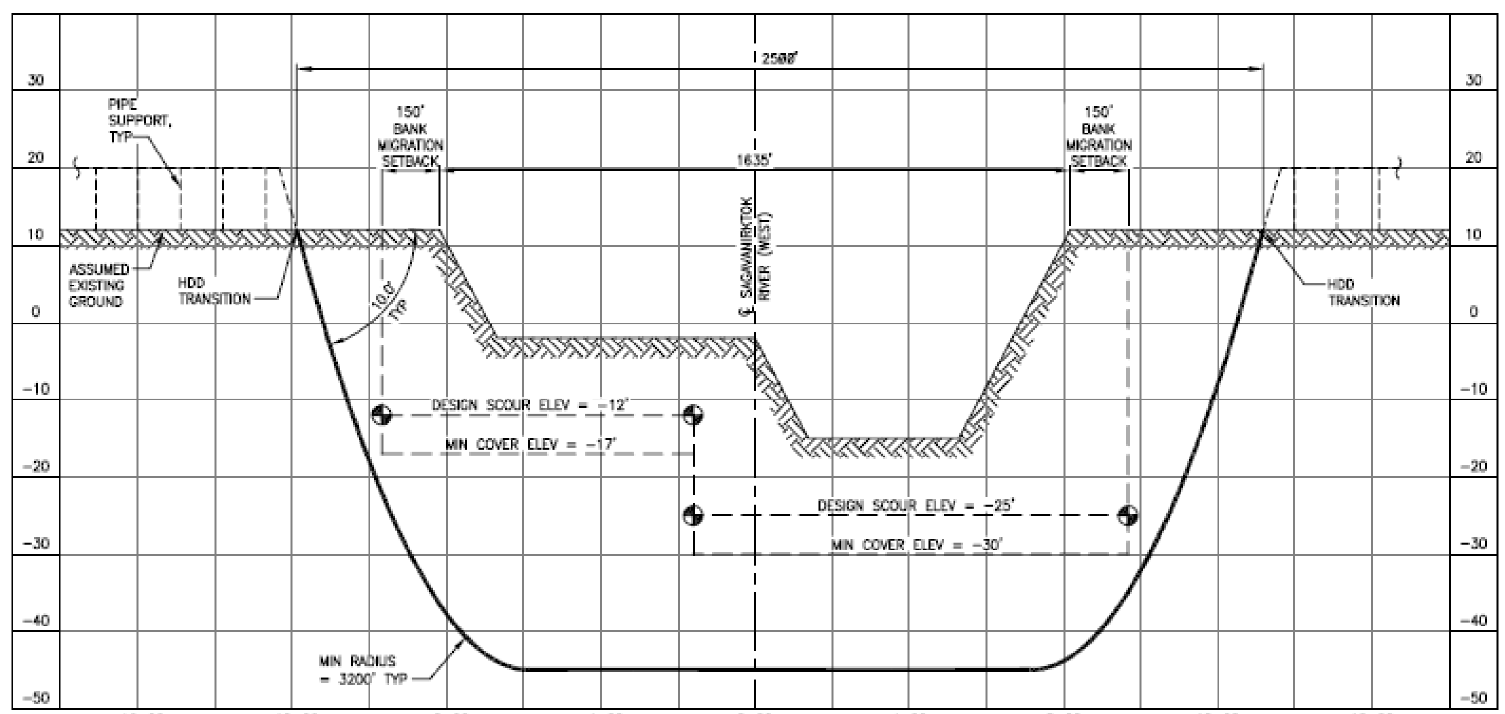
- Bankfull elevation of 12 feet above MSL.
- Bank to bank channel width at the crossing is 1,635 feet.
- Thalweg elevation at minus 2 and minus 15 feet for the west and east portions, respectively (Figure 18).
- Design scour depth of 10 feet below thalweg elevation (minus 12 and minus 25 feet MSL for west and east portions, respectively).
- Minimum pipe depth 5 feet below design scour elevation (minus 17 and minus 30 feet MSL for the west and east portions, respectively).
- Bank migration limits of 150 feet assumed for both the east and west banks.
- Geotechnical conditions are conducive for each crossing mode.

Aerial imagery of the crossing location is shown in Figure 18.

Figure 18: West Channel Sagavanirktok River Crossing



SAGAVANIRKTOK RIVER (WEST) PLAN



SAGAVANIRKTOK RIVER (WEST) PROFILE

7.2.1 Existing Pipe Bridge Considerations

The existing Sagavanirktok River crossing pipe bridge consists of an approximately 800-foot long plate girder superstructure with piers at 150-foot spacing. It is approximately 62 feet in width at the pipe support level. The bridge has 11 diaphragms in each 150-foot segment. Pipe support spans are between 35-feet and 50-feet. See Figure 18 for the general site arrangement.

It should be noted that BP Exploration, Alaska is the operator of the Prudhoe Bay Unit and will have a significant role in the decision process and requirements for use of the Sagavanirktok River pipe bridge.

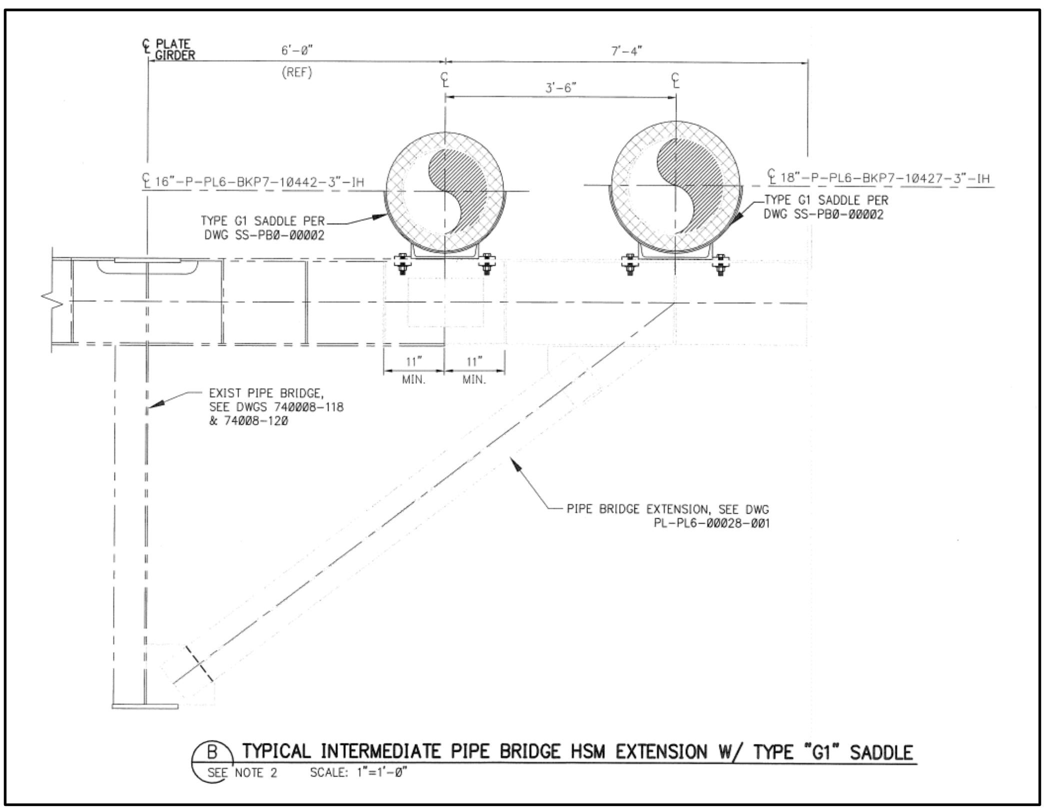
Currently there are 18 pipelines of various sizes and services using the bridge (Figure 19).

Figure 19: Sagavanirktok River Pipe Bridge Existing Pipeline Identification

Two more pipelines were added since the aerial photos in Figure 18 and Figure 19 were taken. The recently added DS 16 and DS 17 Replacement pipelines use a beam extension on the north side of the bridge (Figure 20 and Figure 21). In addition to the pipelines, there are two power cables using either side of the bridge outside the plate girders.

Figure 20: DS 16 and DS 17 Pipeline Beam Extensions

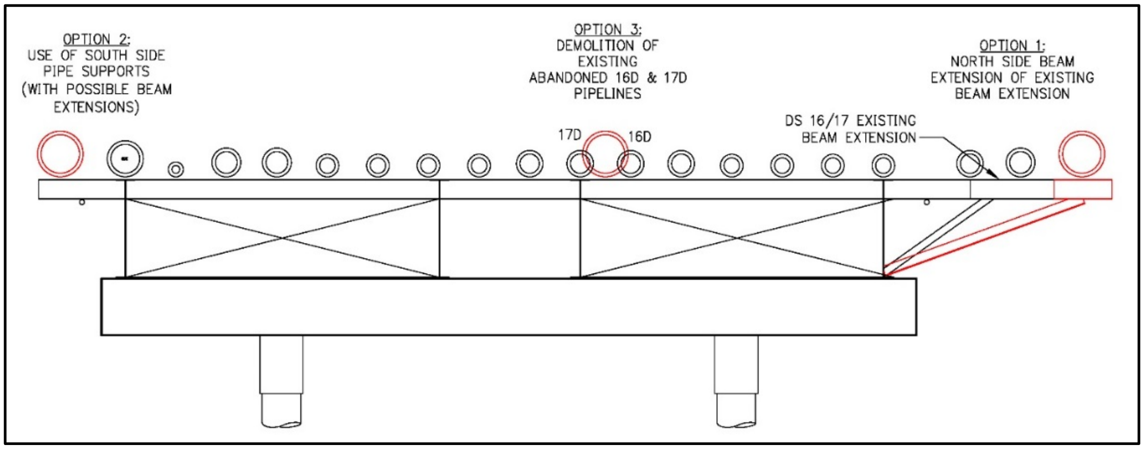
Figure 21: DS 16/17 Pipeline Replacement Bridge Beam Extensions



7.2.2 PTTL Options for Using the Existing Pipe Bridge

After examining available documentation, three options for routing the PTTL across the existing bridge were determined (Figure 22).

Figure 22: Possible PTTL Locations (in Red) on Sagavanirktok River Pipe Bridge



As seen in the figure, the options include the following:

- Option 1: Extend the existing DS 16/17 beam extensions further to allow room for the PTTL.
- Option 2: Use the existing beams on the south side of the bridge (which may or may not require beam extensions).
- Option 3: Demolition and remove the abandoned 16D and 17D pipelines and use the space for the PTTL.

The advantages and disadvantages for each option are discussed in the following sections.

7.2.2.1 Option 1: North Side Extensions

Since the DS 16/17 Pipeline replacement project previously extended the pipe support beam on the north side of the bridge, adding length to the beam extension presents some structural challenges. Based on the shapes and materials assumed in the evaluation, further bracing is not required, although bracing the weak axis of the existing extension will cut down on the expected deflections in that direction. The assumptions need to be verified in the next phase of design.

7.2.2.2 Option 2: South Side Extensions

There are no beam extensions on the south side of the bridge, rather only the stub beams from the original construction. Although the design drawing from the DS 16/17 Pipeline replacement project shows a dimension of 6 feet for the existing pipe support stubs on the bridge, dimensions from the aerial imagery appear closer to 3 feet. If the stubs are 3 feet, a beam extension will be necessary. This report assumes a 3-foot beam extension will be required. No bracing is required for strength or deflections.

7.2.2.3 Option 3: DS 16D and 17D Demolition and Replacement

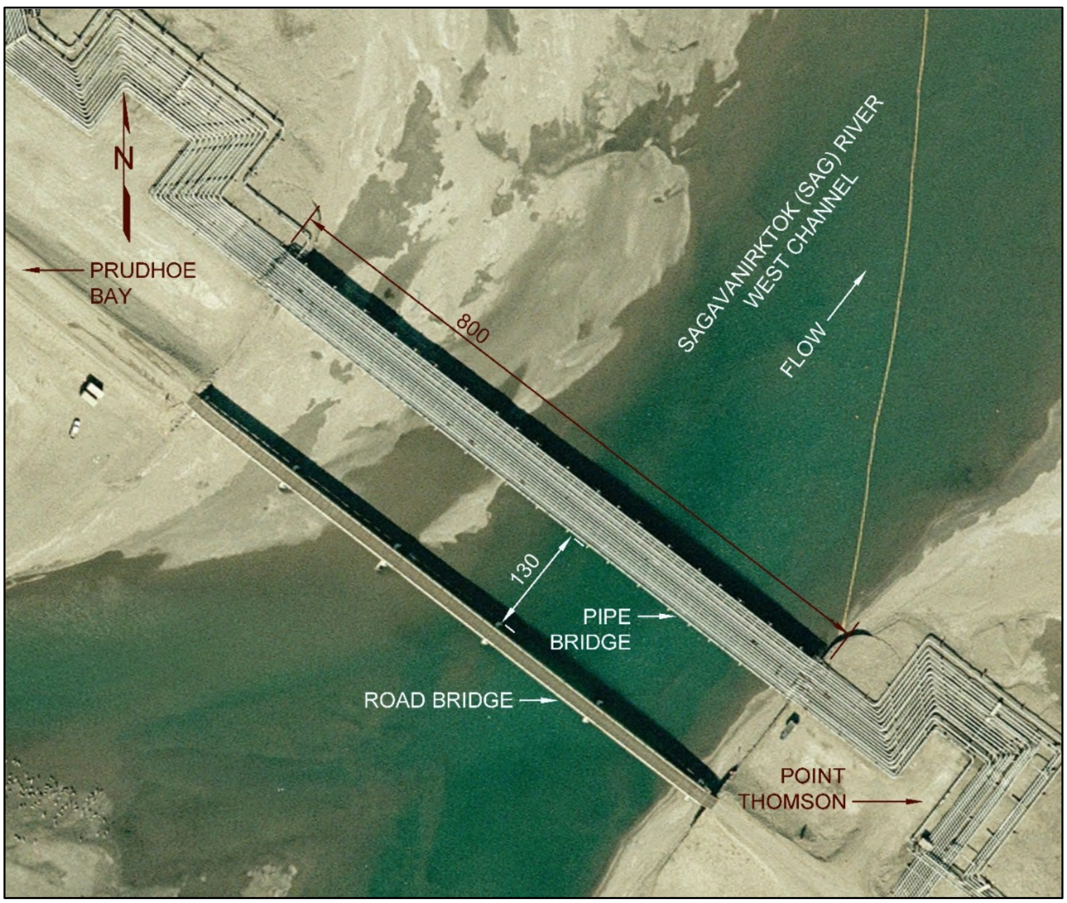
The replacement of the abandoned pipelines is the most structurally efficient use of the existing structure; however the removal of the existing lines presents substantial environmental risk and construction difficulties including lifting over multiple live pipelines. It was assumed these lines have been purged, nominally cleaned and inserted with nitrogen.

Of the three options for possible use of the existing pipe bridge, the demolition of existing lines and reuse of the open space for the PTTL has the highest cost risk due to potential unknown and onerous requirements by the facility operator.

7.2.3 West Channel Sagavanirktok River Open-cut

As discussed in the previous section, the Sagavanirktok River is highly braided closer to the Beaufort Sea, and the banks consist of more non-cohesive material. Like the East Channel, the West Channel is highly braided. Current imagery indicates a confluence of sub-channels at the existing pipe bridge for lower flows (Figure 23). During higher flows the river training structures create a significant pinch point which likely exacerbate scour. Previous depth measurements indicate a depth at the thalweg in excess of 30 feet. Bed sediments collected near the proposed crossing indicate a median bed material (D50) classified as coarse gravel.

Figure 23: West Channel Sagavanirktok River



The depth at the crossing, and expected wintertime flow, would make an open-cut extremely difficult to construct hence open-cut mode was determined infeasible and not considered further. Shallower water is likely present both upstream and downstream of the current crossing location; however, the distance is unknown and could be significant.

7.2.4 West Channel Sagavanirktok River HDD

The following assumptions are made regarding the West Sagavanirktok HDD River Crossing:

7.2.4.1 Pipeline Considerations

- Entry and exit angles of the pipe are 10 degrees from horizontal.
- The HDD crossing will be at full depth at the migration setback distance.
- The river crossing width is 1,635 feet. The bridge opening is on the order of 850 feet wide.
- The HDD length is 2,500 feet.
- Maximum radius of curvature is 3,200 feet.
- A gravel pad on each side will be approximately 20 feet x 80 feet.

7.2.4.2 Geotechnical Conditions

- At the western entrance and egress points, the subsurface soils from the ground surface to a depth of approximately 10 feet will consist of peat and organic silt. Assuming that the construction occurs in December through April, the near surface soils are anticipated to be frozen. The soil in the surficial 10 feet is anticipated to be ice-rich and massive ice may be present. The area is located in polygonal ground and vertical ice wedges may be present.
- At the eastern entrance/egress point, the soils are anticipated to be silty sand overlying sand and gravel.
- The subsurface conditions below a depth of approximately 10 feet are anticipated on consist of frozen, well-bonded sand and gravel with excess visible ice (on the order of 2 to 7 percent by volume). The silt content is anticipated to be on the order of 8 to 15 percent.
- Due to the contraction and associated scour, it is assumed there is flow in the channel under the pipe bridge throughout the year and a significant thaw bulb is anticipated. The lateral extent and depth of the thaw bulb is not known at this time, but may be on the order of 20 to 25 feet below the mudline.
- Boreholes associated with the ADOT&PF Exploration Site 10 were reviewed (2004). These boreholes were drilled near the western boundary of the active (unvegetated) West Sagavanirktok River in late September, 2001. At this time of year, the depth of thaw at the ground surface would be anticipated to approach the maximum seasonal depth. The site is located approximately 11.5 miles southwest of the crossing. Six boreholes (01-125 to 01-130) were drilled to a depths ranging from 27 to 30 feet. The soils were observed to consist of interbedded slightly silty to silty sandy gravel and gravelly sand with interbedded silt deposits. Cobbles were reported in some of the boreholes. The seasonal depth of thaw was observed range from 5.5 to 7.5 feet and the underlying soils were reported to be continuously frozen except of an unbonded zone from 14 to 16 feet in one borehole. The water table was reported to be 1 to 4 feet below the ground surface at the time of drilling.

7.2.5 West Channel Sagavanirktok River Aerial

7.2.5.1 New Aerial Crossing Considerations

The West Channel Sagavanirktok River crossing consists of a 900-foot minimum channel width.

- A suspension system would consist of suspending the pipeline from steel cabling draped between support towers and tied back into existing grade at the bridge ends. Spanning 900 feet would require no piers within the channel.
- A plate girder system would consist of large built-up welded steel members spanning 225 feet and would require three piers within the channel.
- A box girder system would consist of large built-up welded steel members spanning 300 feet and would require two piers within the channel.
- A triangular truss would consist of rolled steel members spanning 300 feet and would require two piers within the channel.
- A long-span pipeline crossing would consist of 6 piers within the channel at a span of 130 feet. All piers are considered the same for this study and could possibly be refined with further engineering.

7.2.6 West Channel Sagavanirktok River Crossing Cost Summary

Based on the unit costs presented in section 4.5, the cost estimates for the different crossing modes at the West Channel Sagavanirktok River are listed in Table 5.

Table 5: West Channel Sagavanirktok River Crossing Costs

Mode	Crossing Length (feet)	Associated Aboveground Length[1] (feet)	Number of Piers	Total Crossing Cost (million)
Modify Existing Structure (North Side) Base Case	800	2,700	NA	$4.1
Modify Existing Structure (South Side)	800	2,700	NA	$3.6
Remove Abandoned Lines and Replace	800	2,700	NA	$3.3[2]
HDD	2,500	—	NA	$10.9
Plate Girder	900	2,600	5	$12.5
Box Girder	900	2,600	4	$13.8
Truss	900	2,600	4	$9.0
Suspension	900	2,600	2	$15.4
Long-Span Pipe	900	2,600	8	$5.4

Note:

1. This is the length of pipeline that utilizes the nominal cross-country PTTL aboveground design. The additional length is added to make all crossing lengths consistent (note the HDD alignment is approximately 1,000 feet shorter than if following the existing pipelines), and thus the cost of the crossings comparable
2. BP Exploration, Alaska is the operator of the Prudhoe Bay Unit and as such will have a significant role in the decision process and requirements for use of the Sagavanirktok River pipe bridge. Due to this fact, this option has a substantial cost risk.

8.0 CONCLUSIONS

The original four major crossing designs for the PTTL were further investigated in this report. The original design chose open-cut crossing methodologies at the Shaviovik, Kadleroshilik and the East Channel of the Sagavanirktok River. The West Channel of the Sagavanirktok uses the existing bridge at that location.

All four crossings were examined to find the feasibility of alternative designs: open-cut, HDD and aerial crossings with support structures for the pipe. An alternative, simply using an unsupported pipe, was also carried ("Long-Span Pipe"), although this alternative requires a comparatively large number of in-stream ice-resistant piers and would be critically judged for additional integrity concerns. The open-cut crossing method of the West Channel of the Sagavanirktok River was determined not to be technically feasible at that location and thus was not included in further alternative comparisons. The suspension bridge crossing techniques, although technically viable, raise additional concerns regarding visual obstruction due to its high towers. All crossing alternatives, except for the open-cut of the West Channel of the Sagavanirktok, at all of the crossings were nevertheless included in the cost comparisons.

Unit costs for the alternatives were derived from the former PTTL estimate and other analyses completed for AKLNG pre-FEED studies. For the open-cut and HDD alternatives, a "per-foot" cost was derived directly from averaging the total costs of these crossings over the total length of these crossings. The weight of the superstructure for the aerial crossings was found using designs found acceptable based on structural analyses, and these "per-foot" weights, combined with the "per-pound," costs produced a per-foot cost comparable to the costs for the buried crossing methodologies. Pier costs for aerial alternatives were added separately, except for the suspension bridge whose per-foot costs included consideration for piers and anchorages.

To ensure a comparable analysis, each crossing was assigned a single crossing total length which was used for all analyses. The total length was based on the longest crossing technique, i.e. the HDD method. The other alternatives had smaller crossing lengths, but the additional cost of the extension of the nominal PTTL design to the actual crossings was included so as to better compare on an equitable basis all of the alternatives.

As mentioned, several types of aerial crossing methods were considered, although their cost generally rules them out unless there are additional negative items for the burial methods. This alternative analysis again showed the open-cut methodology to be the choice for all locations, except for the West Channel of the Sagavanirktok.

For the West Channel of the Sagavanirktok, the most economical option is to utilize the existing bridge structure at that location. However, no analysis was possible as to the ability of the structure to support the PTTL, although space could be potentially made on the existing supports with permission from the current owner/operator. In lieu of this definition, the HDD methodology would be the alternative of choice.

Based on the information presented in this report, and acknowledging the numerous assumptions and unknowns such as regulatory uncertainty, geotechnical conditions, and other factors, the recommended primary and alternative crossing modes for each river are summarized in Table 6.

Table 6: Primary and Alternative Crossing Modes Summary

River Crossing	Primary Mode	Alternative Mode
Shaviovik River	Open-Cut	Long-Span Pipeline
Kadleroshilik River	Open-Cut	Long-Span Pipeline
Sagavanirktok River – East Channel	Open-Cut	HDD[1]
Sagavanirktok River – West Channel	Existing Pipe Bridge	HDD[1]
Note: 1. Other trenchless technologies, such as DMT, should be considered in future studies.		

9.0 ACRONYMS AND TERMS

The following abbreviations and terms are used in this document

Term	Definition
ADOT&PF	Alaska Department of Transportation and Public Facilities
BSOP	Badami Sales Oil Pipeline
DMT	Directional microtunnel
HDD	Horizontal Directional Drill
MSL	mean sea level
NPS	nominal pipe size
plf	pounds per linear foot
PTTL	Point Thomson Transmission Line
TAPS	Trans-Alaska Pipeline System
VSM	vertical support member

10.0 REFERENCES

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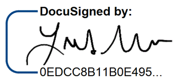
Luke Marodi luke.marodi@exxonmobil.com Security Level: Email, Account Authentication (None)	 Using IP Address: 207.228.78.134 Signed using mobile	Sent: 6/28/2016 10:42:04 AM Viewed: 6/28/2016 11:18:15 AM Signed: 6/28/2016 11:18:47 AM
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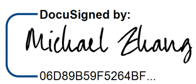
Michael Zhang michael.m.zhang@exxonmobil.com Security Level: Email, Account Authentication (None)	 Using IP Address: 158.26.33.13	Sent: 6/28/2016 11:18:50 AM Viewed: 6/28/2016 11:47:36 AM Signed: 6/28/2016 11:48:02 AM
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