ASAP
Alaska's In-State Gas Pipeline

ALASKA STAND ALONE PIPELINE/*ASAP* PROJECT

Analysis of Potential Indirect Impacts to Wetlands Related to Buried Pipeline Construction

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ACRONYMS AND ABBREVIATIONS

AGDC	Alaska Gasline Development Corporation
ASAP	Alaska Stand Alone Pipeline
bgs	Below ground surface
CRREL	Cold Regions Research and Engineering Laboratory
ft	feet / foot
GIS	Geographic Information System
HDD	horizontal directionally drilled
HGM	hydrogeomorphic
in	inch
m	meters
MAGT	mean annual ground temperature
MP	milepost
PHMSA	Pipeline Hazardous Material Safety Administration
ROW	right-of-way
RSP	Revegetation and Stabilization Plan
SEB	surface energy balance
SEIS	Supplemental Environmental Impact Statement
SPCO	State Pipeline Coordinator's Office
TAPS	Trans-Alaska Pipeline System
TAZ	Thaw Affected Zone
USACE	U.S. Army Corps of Engineers
USDOT	U.S. Department of Transportation

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1. INTRODUCTION

1.1 PURPOSE

The USACE Alaska District, in coordination with the USACE Cold Regions Research and Engineering Laboratory (CRREL), has requested that AGDC provide an analysis of whether abutting or adjacent wetlands outside the construction ROW would be impacted by indirect thaw to permafrost in undisturbed areas over the life of the project. This report provides an analysis and additional modeling to address this question.

1.2 CONSTRUCTION OF ASAP THROUGH PERMAFROST REGIONS

The Alaska Gasline Development Corporation (AGDC) has proposed to construct and operate the Alaska Stand Alone Pipeline (ASAP) as a means to transport natural gas from Prudhoe Bay to Southcentral Alaska. ASAP will require the construction of a 733-mile long, 36-inch diameter pipeline that will be buried, except at select fault crossings, bridged stream crossings, and block valve locations. The pipeline will be constructed in different permafrost regions, as generally noted in Jorgenson et al. (2008). A review of literature and geotechnical data helped to determine mainline milepost ranges for three permafrost zones, as follows:

- Continuous Permafrost: MP 0 – MP 168
- Discontinuous Permafrost: MP 168 – MP 634
- Sporadic Permafrost: MP 634 – MP 733

AGDC provided the USACE with a *Joint Application for Permit – Revised* that included typical drawings depicting pipeline engineering for different modes, seasons, and regions (AGDC 2015). The pipeline construction right-of-way (ROW) width has been proposed as a nominal 120ft-wide corridor that will also include wider areas for special design, side slope cut-and-fill, and temporary workspace. The pipeline will be revegetated following construction and maintained during the operational phase (AGDC 2016a,b). The permanent ROW has been proposed as a nominal 53ft-wide corridor that will also include wider areas for maintaining the stability of the ROW that is impacted during construction.

1.3 DIRECT IMPACTS TO WETLANDS AND UPLANDS

Direct impacts to wetlands were reported to the USACE for ASAP in the *Joint Application for Permit – Revised* (AGDC 2015) and in an *Environmental Evaluation Document* (AGDC 2016a). Direct impacts to wetlands were avoided and minimized to the extent practicable and will be mitigated through procedures described in its *Draft Wetlands Compensatory Mitigation Plan*. Direct impacts to wetlands will total 8,907.0 acres, of which 7,573.2 acres will be attributed to permanent impacts to freshwater wetlands (temporary impacts to freshwater wetlands and all impacts to intertidal / subtidal wetlands tabulated separately). The Project will also directly impact 12,330.3 acres of uplands. The ASAP Project Footprint comprising all permanent and temporary direct impacts to wetlands and uplands will be 21,237.3 acres.

1.4 THE POTENTIAL FOR INDIRECT IMPACTS TO WETLANDS THROUGH PERMAFROST THAW

As noted above, the USACE Alaska District, in coordination with the USACE Cold Regions Research and Engineering Laboratory (CRREL), has requested that AGDC provide an analysis of whether abutting or adjacent wetlands outside the construction ROW would be impacted by indirect thaw to permafrost in undisturbed areas over the life of the project. During pipeline construction, ground disturbing activities within the ROW that would impact the organic layer, such as clearing, grading, grubbing, compression, or the use of a gravel work pad, can affect surface albedo, vertical and lateral heat flux or transfer, and subsequently, thaw of permafrost. Roads and facility pads are of lesser concern because thicker gravel pads required for these facilities have insulative properties that mitigate against thaw.

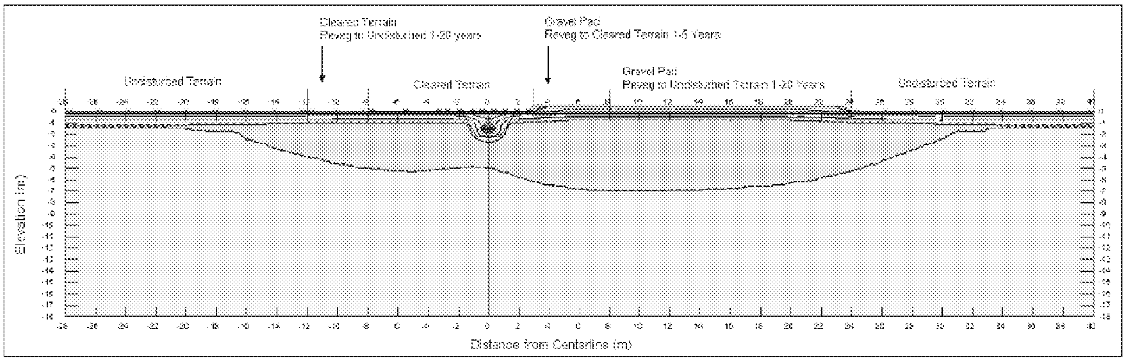
The buried ASAP pipeline was designed to receive gas from a conditioning facility at 30°F and operate at ambient ground temperatures that would range from 8°F to 30°F on the North Slope within the continuous permafrost zone (AGDC 2016a). The pipeline will operate at slightly warmer ground temperatures in the more southerly discontinuous and sporadic permafrost regions. Indirect thaw of permafrost outside the area of direct impact has the potential to occur. The driver for this indirect thaw is a change in heat balance that could result from disturbance of the organic layer within the ROW during construction (e.g., damage to or compression of the organic layer, vegetative clearing, and gravel pad placement, if applicable).

AGDC intends to institute a comprehensive monitoring program and will employ several mitigative measures to offset and minimize indirect impacts to wetlands, including a revegetation program that allows for the recolonization of the ROW by native species in non-sensitive areas and the immediate revegetation of the ROW through re-seeding in sensitive areas (AGDC 2016e). The program will employ continual detection and field maintenance activities (AGDC 2016b,e) and the use of thermosyphons or additional ditch plugs (described in AGDC 2016b) in select areas (AGDC 2016c; see also Section 7, below). Thermosyphons would be used in select areas of discontinuous permafrost where greater permafrost stability near the surface is required; field monitoring crews observing issues such as slumping or reports of suspected thaw by in-line inspection may lead to thermosyphon placement. Thermosyphons have been used historically for areas along the TAPS ROW and for other projects, such as the Alpine horizontal directionally drilled (HDD) crossing of the Colville River. Additional ditch plugs could be used where newly identified water management efforts are required. In rare instances, where thaw or slumping are identified around permanent facilities that cannot be moved (e.g., block valves) and where a power supply is available, a stationary active refrigeration unit may be employed.

AGDC's initial geothermal modeling shows that with revegetating the ROW in discontinuous permafrost terrain, the indirect permafrost thaw affected zone (TAZ) over a period of 30 years will be limited to less than 10m (35ft) beyond the directly impacted area (AGDC 2016c; Figure 1). USACE CRREL have agreed that these modeling procedures are sound and have generally agreed with the approach and results (personal communication with Kevin Bjella, USACE CRREL, as noted in Meeting Minutes from a USACE / AGDC Supplemental Environmental Impact Statement (SEIS) Progress Meeting on November 29, 2016). A robust monitoring program and other mitigative options and monitoring could further limit indirect thaw (see Section 7 for mitigative options and AGDC 2016b for monitoring program details). It is important to note, therefore, that limited indirect thaw to permafrost beneath a wetland will not necessarily result in an indirect impact to that wetland's function or value (i.e., limited, acute permafrost impact does not necessarily equate to wetland impact).

The mechanism by which indirect wetlands impacts could potentially occur would be through thaw settlement (vertical subsidence) of lands that would create a slight downward vertical ground surface displacement and a possible avenue for drainage of surface water from perennially or intermittently saturated soils. An approximately 1m thaw settlement estimate was based on approximately 5m of thaw depth below the undisturbed active layer in discontinuous permafrost terrain with an assumed 20% thaw strain. A 20% thaw strain (thaw settlement per thaw depth) of maximum subsidence is a reasonable expectation as to what would actually be observed in the field (as noted in personal communication with Kevin Bjella, USACE CRREL, as noted in Meeting Minutes from a USACE / AGDC SEIS Progress Meeting on November 29, 2016). This estimate is based on geotechnical data, permafrost modeling, knowledge of soil, hydrologic, and vegetative characteristics along the ROW, experience and engineering judgment. The potential for wetlands to be indirectly impacted due to subsidence and subsequent drainage of saturated soils varies according to region and permafrost type.

Figure 1. ROW Thaw Depth for Discontinuous Permafrost (in meters)



Notes: The Construction ROW having a nominal width of 120ft (approximately 36m, as 1m = 3.281ft) exists from approximately -12m to 24m on the lateral plane, above.

1.4.1 Continuous Permafrost (MP 0 to MP 168)

The area of continuous permafrost traversed by the pipeline (MP 0 to MP 168), is of smaller concern for indirect impacts to wetlands than in discontinuous permafrost for several reasons. First, the direct impact width will be much smaller on Alaska's North Slope due to mitigative measures that can be implemented in this region, such as the use of ice roads and ice workpads. The main impact will be through burying the pipe in a 5ft wide ditch. Trench spoils and refill would result in 32ft of direct impact to wetlands, a much narrower direct impact corridor than in discontinuous regions.

The area is characterized as a continuous permafrost region with an active layer thickness of around 2ft (24 inches) (AGDC 2016b). Since the sub-freezing pipe will be surrounded by perennially frozen soils, the cold ground temperature will limit lateral thaw. Where the pipe is relatively warm (30°F at MP 0) the active layer depth near the trench would increase somewhat. Geothermal modeling shows that this increased active layer depth would diminish rapidly within 20ft laterally from the trench centerline (see Section 2.3.1 and Figure 6, below). The pipe would become cooler with increased distance from MP 0. The soils in the impacted area adjacent to the trench will re-freeze in winter and will remain frozen for approximately three-quarters of the year. The soils directly around the sub-freezing pipe will remain frozen throughout the year.

Third, being surrounded by perennially frozen soils and relatively flat terrain means that even if thaw and subsidence did occur, saturated soils would not necessarily be able to drain, especially if in a flatter area. Drainage of wetlands would be hindered by surrounding permafrost. To keep water from flowing into and along the area where the pipe is buried, pipeline engineers intend to use common engineering practices for buried pipelines in wet areas, including ditch plugs and surface crowning, as needed (AGDC 2016 a,b,d). These practices will limit the flow of water along the pipe and help to maintain wetlands adjacent to directly impacted areas.

1.4.2 Discontinuous Permafrost (MP 168 to MP 634)

The area of discontinuous permafrost traversed by the pipeline (MP 168 to MP 634) is characterized by wide variability in the physical environment, including permafrost presence and active layer depth. Similar to the other permafrost regions, the variability in terrain unit classification also varies widely. Terrain units are subsets of land area classified by soil types that can often be characterized as either thaw-stable or thaw-unstable material. For most of this region, the pipe would cool to ambient ground temperature or cooler due to Joule-Thomson cooling.

The area of discontinuous permafrost is variable in elevation, slope, ground temperature, and wetlands type. Certain wetland types are also often associated with permafrost presence or absence. Delineated wetlands can be classified as low, medium, or high potential for permafrost to be present beneath them. Thus, the potential for indirect impacts to permafrost, thaw settlement, and subsurface drainage of wetlands is also highly variable in this region. Several years after construction, the area beneath vegetation in the indirect TAZ would be able to hold more water than before construction, but this would not necessarily impact wetland functions or values in the TAZ.

1.4.3 Sporadic Permafrost (MP 634 to MP 733 and FLMP 0 to FLMP 30)

The area of sporadic permafrost (often referred to as a 'no permafrost' area) traversed by the mainline (MP 634 to MP 733) is characterized by a general lack of permafrost or by sporadic, patchy permafrost areas. There is a very low probability of permafrost occurring in this region and therefore indirect impacts to wetlands due to permafrost thaw, thaw settlement, and drainage are not likely to occur. The Fairbanks Lateral traverses approximately 99% uplands, further reducing the possibility for indirect impacts to wetlands.

1.5 OVERALL APPROACH

The USACE has requested that AGDC report where indirect impacts to wetlands could potentially occur outside of the pipeline ROW. AGDC has developed methodology to provide this information to the USACE. AGDC will use a screening approach to eliminate areas where there is a low likelihood for impacts to occur to wetlands outside the Project ROW (Figure 2). AGDC has applied these screens, or filters, through a GIS-based approach (Attachment 2) that will remove areas where wetlands have a low likelihood of being directly impacted. The resulting areas not eliminated through this process are a subset of potentially susceptible pipeline segments within which wetlands could be indirectly impacted by additional permafrost thaw.

Figure 2. Route Application Methodology

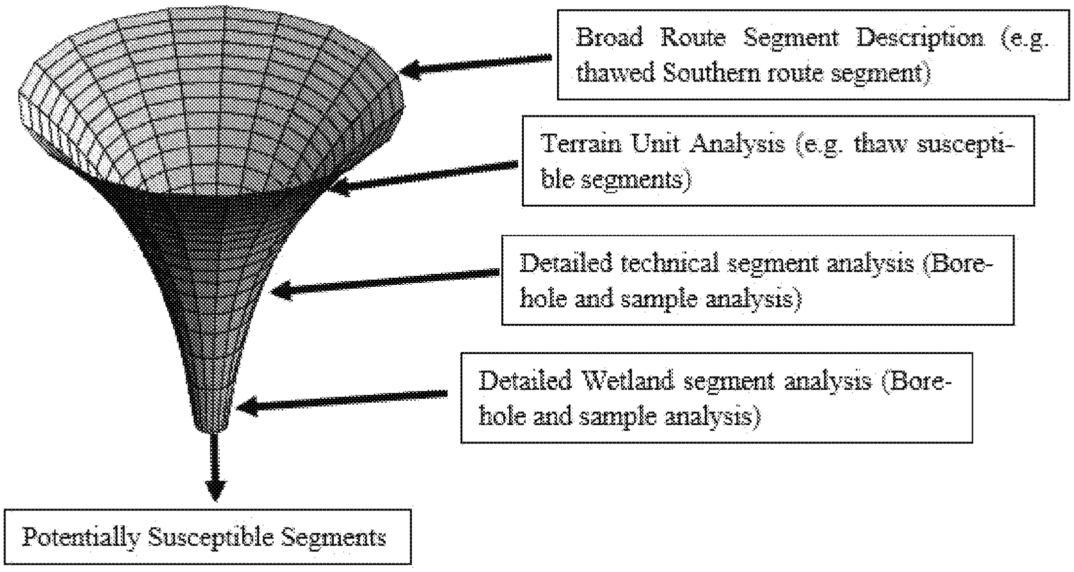
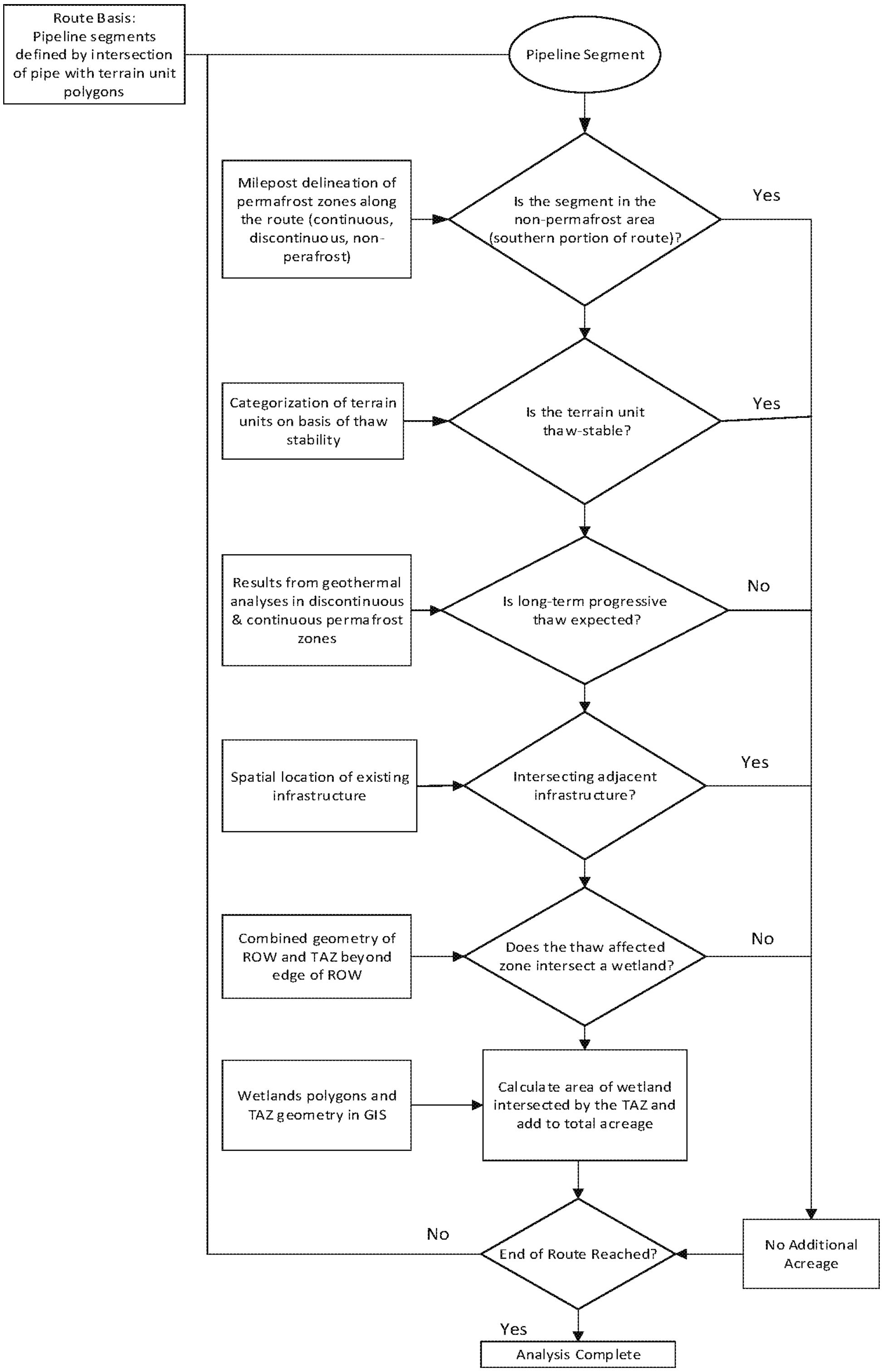


Figure 3 shows a detailed Route Assessment Methodology Flowchart used to determine the areas in which wetlands outside of the pipeline ROW could be impacted indirectly by construction over a 30-year period. It is discussed generally in this section, but in greater detail in Section 3.

The methodology begins by determining whether the route segment is in an area characterized by continuous, discontinuous, or sporadic permafrost. It then categorizes terrain unit data within the ROW on the basis of thaw-stability. Results from geothermal analysis determine whether long-term thaw is expected. The spatial location of existing infrastructure (roads, railroads, powerline, TAPS Crossings, etc.) bisecting the pipeline ROW and the indirect TAZ is then assessed to determine where permafrost is already thawed by existing infrastructure or where the permafrost is preserved with thick, insulative gravel pads near existing infrastructure.

Next, the methodology explores whether the defined TAZ could indirectly impact a wetland. The area of wetlands potentially affected are then assessed to tabulate a total wetlands impact acreage. This resulting acreage of potential indirect wetland impacts is then be categorized by wetland type to provide greater detail to the reader.

Figure 3. Route Assessment Methodology Flowchart



2. GEOTHERMAL ANALYSIS OF ROW

Geothermal analysis has been used to evaluate the effect of thermal disturbance from construction and operations on long-term thaw depths along the ASAP ROW (AGDC 2016c; Attachment 1). Geothermal analysis accounts for several important variables affecting soil temperatures including, soil material properties (such as thermal conductivity, soil moisture content, and latent heat), thermal boundary conditions (such as energy exchange at the ground surface and heat transfer between the operating pipe and the surrounding soil), and phase change and the associated latent heat of soil moisture.

In the context of route thaw settlement, geothermal analysis provides a quantitative method to determine long-term thaw depths both below the disturbed ROW and below the pipe, if any. For the pipe, the resultant thaw depth allows further analyses to evaluate potential pipe thaw settlement as required for assessing pipeline integrity. For the ROW, the geothermal analyses enable evaluation of thermal disturbance effects from construction and operations along the route and, of particular focus, the potential effect on route wetlands. It is this latter effect that is the focus of the current study with respect to wetlands outside the ROW.

The principal tool for geothermal analysis on the Project is TEMP/W, a commercial finite element program for heat transfer with the ability to evaluate the effects of phase change in the soils. It simulates the heat transfer within the ROW cross-section to determine long-term thaw depth. The modeled domain is discretized into small areal extents (finite elements) which individually evaluate the localized heat transfer within this area. When assembled, the individual elements collectively can model extensive regimes with varying constraints and conditions. Input data, simulation methodology, and results for thaw depth and ROW settlements for these finite element analyses are described in this chapter.

2.1 ROW CONSTRUCTION MODES

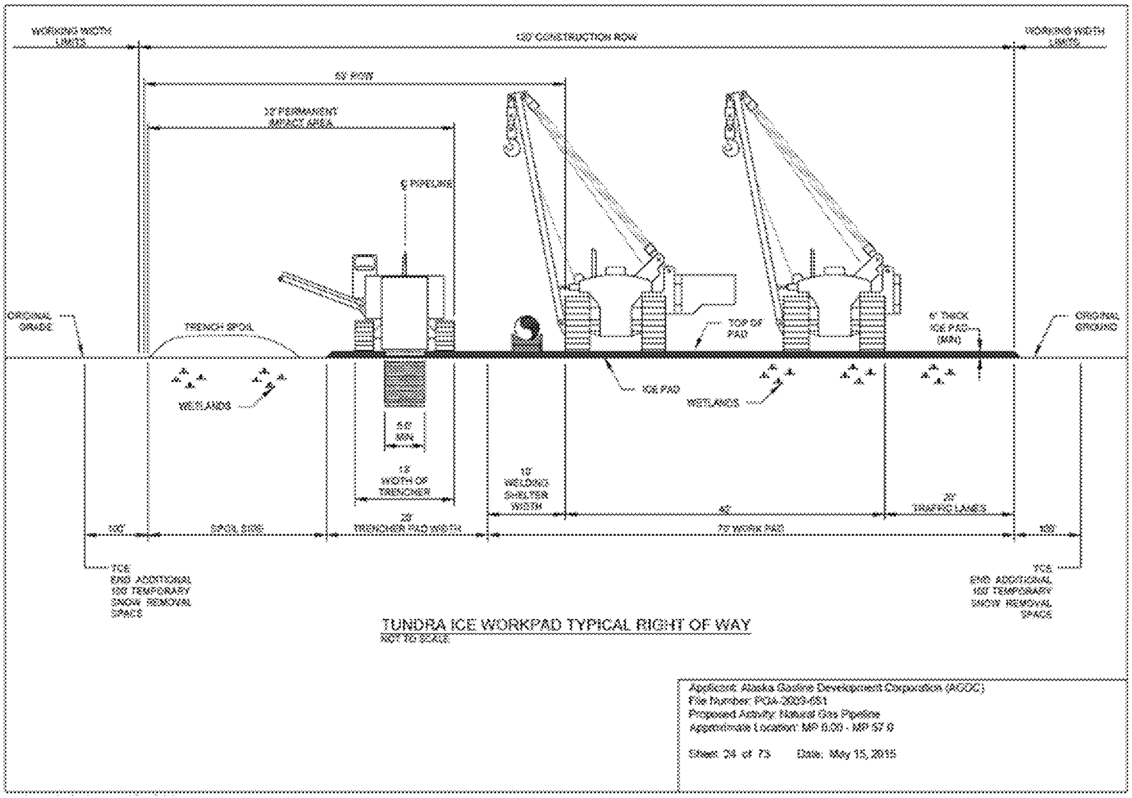
The ASAP report entitled *Design Basis - Pipeline* (AGDC 2016d) describes considerations given to the varying terrain and climatic conditions along the ROW, as well as additional considerations such as seasonal constrains and construction scheduling. Several ditch and ROW configurations or 'modes' were defined to accommodate these anticipated conditions along the proposed alignment. These construction modes were developed and intended to ensure long-term integrity of the pipeline and to protect nearby foreign structures and the environment.

2.1.1 Continuous Permafrost

For the North Slope (Arctic Costal Plane), which is underlain by continuous permafrost, an ice pad will be used in lieu of a gravel pad, which is typical for North Slope construction. The pipeline

ROW configuration is planned to be 120ft wide, nominally, although the direct impact to wetlands will only be 32ft wide (AGDC 2015; Figure 4). This includes a 90ft wide ice pad thick enough to support construction traffic on one side of the pipe centerline, and an adjacent area for trench spoil. After the construction season, the ice road will be allowed to naturally thaw and, as is typical, negligible effect on the tundra is expected.

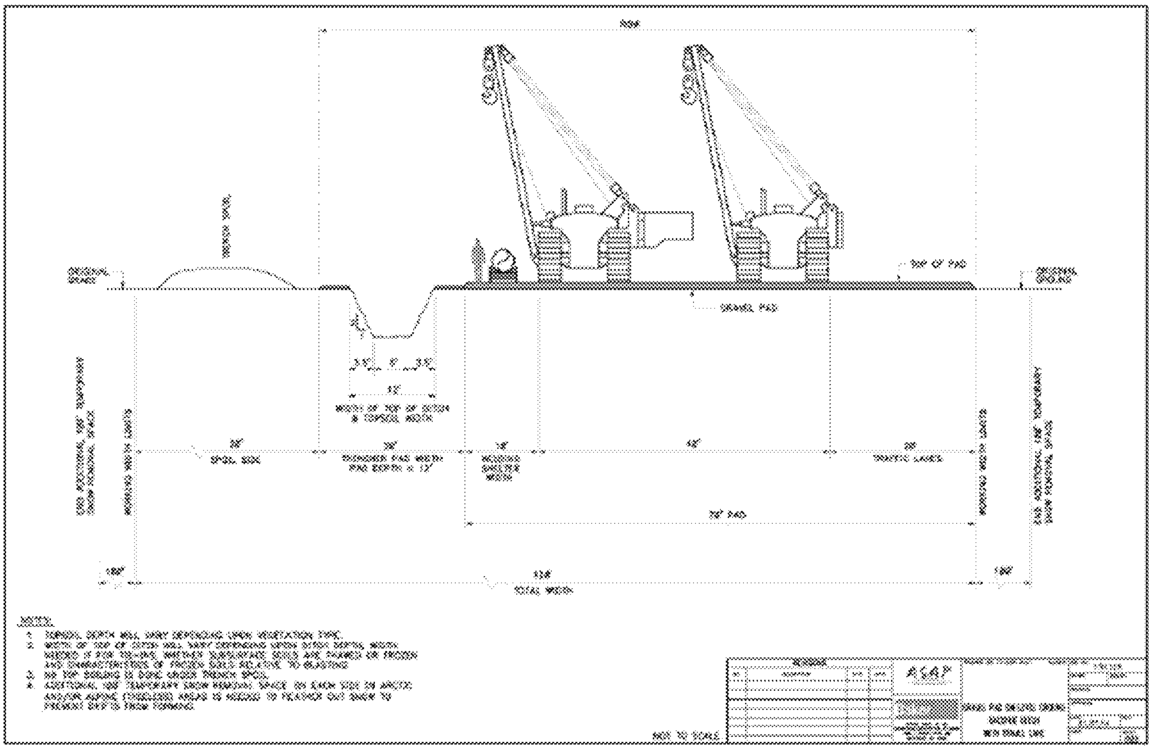
Figure 4. Construction ROW for Continuous Permafrost



2.1.2 Discontinuous Permafrost

The typical pipeline ROW configuration in discontinuous permafrost is planned to be 120ft wide, nominally, as depicted in AGDC 2015 and in Figure 5. This includes an 18in thick, 70ft wide gravel pad on one side of the pipe centerline, and a 30ft wide cleared area for trench spoil, each setback 10ft from either side of the pipe centerline. After one construction season, the permanent ROW is planned to be 53ft wide and centered over the pipe. The remainder of the pad outside of the permanent ROW will be scarified by ripping (i.e., cultivation), which will aerate the surface of the land and prepare it as a seedbed for natural colonization of vegetation (AGDC 2016e). With time, grasses and shrubs and eventually trees (in originally treed areas along the route) will revegetate the ROW. After three years, re-seeding with a prescribed seed mix will be considered if minimum ground cover standards are not met, per the ASAP Revegetation Plan (AGDC 2017). Any young trees colonizing the permanent 53ft Mainline ROW would be cleared during operations, while those beyond the 53ft ROW to the edge of the 120ft temporary construction ROW would be allowed to grow unhindered. This process of scarifying and revegetating would maintain the integrity of the land and would be less damaging than gravel removal.

Figure 5. Construction ROW for Discontinuous Permafrost



2.1.3 Sporadic Permafrost

In areas of sporadic or no permafrost in upland areas, the typical construction ROW configuration is to grade the surface. The working surface is 120ft wide and is configured similar to Figure 5 without the addition of the gravel pad.

2.2 DEVELOPMENT OF THE GEOTHERMAL MODEL

Modeling subsurface geothermal conditions requires establishment of an overall geothermal modeling approach, definition of the domain geometry, assembly of several material properties and boundary conditions, and proper model calibration. Geothermal modeling was undertaken to answer specific questions that arose as a result of an engineering design and/or a change to thermal conditions such as construction disturbance and operational conditions. Once the main objective of a geothermal analysis was established, it was necessary to undertake the modeling effort to meet the specified objectives.

The modeling procedure to determine the effects of the construction disturbance and pipeline operating conditions on the subsurface through time during the design life was described in detail in Chapter 3.2 "Modeling Subsurface Geothermal Conditions" in *Identification and Evaluation of Time-Dependent Route GeoHazards* (AGDC 2016c). To accurately model the subsurface change for any segment along the pipeline, the report lists the data that must be assembled:

- Establish the domain geometry.
- Define soil material properties.
- Specify initial temperature conditions.
- Define thermal boundary conditions.
- Determine maximum simulation time.

Using these data, a further step is required to ensure that the model will accurately reflect the segment conditions:

- Calibrate the geothermal model to reproduce existing undisturbed conditions then apply variation to boundary conditions to simulate effects of construction and/or operations.

For this study, these same steps were followed for the two ROW models examined. The analysis for continuous permafrost was evaluated specifically for MP 0 because the gas treatment plant discharges gas continuously at 30°F, which represents the worst-case scenario for continuous permafrost. South of MP0, the pipe will lose heat to the soil and will have a temperature close to that of the ambient soil temperature, so deepening of active layer depth near the trench will be less south of MP0 than at MP0.

The models were not evaluated for any specific milepost route segment, but utilize reasonably conservative values for subsurface conditions susceptible to thaw settlement. Each step for this study is examined further:

- **Establish the Domain geometry** – the domain geometry is based on the construction mode assigned for the segment. The construction mode itself is determined by the nature of the surface features (rolling tundra, hilly, swampy…) as well as by the season designated for construction of the segment. The construction modes of interest for this report include the construction mode using only an ice road (typical on the North Slope and called the North Slope Model) and a mode using a gravel pad more typical in the area of discontinuous permafrost (termed the Discontinuous Model). The basis for the Discontinuous Model is detailed in AGDC 2016c - Appendix B, "Expected Long-Term Thaw Depths in Warm Permafrost on the ASAP ROW - Technical Memorandum" while the Basis for the North Slope Model is detailed in Attachment 1 of this report.

- **Define soil material properties** – the soil properties used for the analysis of the subsurface strata are generally developed using the route database. For the North Slope Model and Discontinuous Model, the subsurface soils were chosen as typical soils susceptible to thaw settlement. The subsurface soils were accordingly considered to be composed of a single stratum of this thaw susceptible material to depth.

- **Specify initial temperature conditions** – consistent with the soil material properties, the in situ thermal state of the subsurface is generally developed using the route database. For this analysis, since the focus was on potential settlement, the in situ condition of the subsurface was considered to be initially frozen to depth.

- **Define thermal boundary conditions** – the thermal boundary conditions employed a full surface energy balance (SEB) methodology, with the input definition of the various elements of the SEB (described in detail in Chapter 3.2.5 "Ground Surface Boundary Condition" of AGDC 2016c) consistent with the route region under investigation. The SEB datasets are defined to simulate an annual variation of the region based on available climatic data from adjacent climate and weather stations. The input conditions for the SEB models are not the same, therefore – those for the North Slope Model with a construction mode utilizing an ice pad, typical of the proposed construction on the arctic plain, utilized an SEB dataset consistent with the North Slope climate. The Discontinuous Model used an SEB dataset consistent with the discontinuous permafrost region in the Fairbanks area and is described further in Chapter 3.3 of Appendix B of AGDC 2016c, while the North Slope SEB model is described in detail in Attachment 1 of this report.

- **Determine maximum simulation time** – the simulations for both models were extended to 30 years after startup. As noted below, the startup of the simulations actually predates operational startup to more accurately reflect the in situ subsurface thermal conditions.

- **Calibrate the geothermal model** - to reproduce existing undisturbed conditions, some items of the SEB model can be varied so as to better reflect the in situ subsurface conditions, as described in Chapter 3.5 of AGDC 2016c. Typically, an SEB data element pertaining to the snow cover (i.e. snow conductivity) is varied within a typical range to match the mean annual ground temperature (MAGT) of the route segment being investigated. The calibration was separately carried out for the North Slope Model and Discontinuous Model to reflect the unique conditions of those regions. The calibration of the Discontinuous Model is described further in Chapter 3.4 and 3.5 of Appendix B of AGDC 2016c, while the North Slope calibration is described in detail in Attachment 1 of this report.

  Each model with the calibrated SEB datasets for the in situ conditions were then run for a period of time before construction so as to establish the annual subsurface variation throughout the Domain that corresponds to the in situ condition. To model construction, the SEB dataset is changed accordingly to reflect changes in the surface albedo and vegetative cover and, as appropriate, additional infill material such as that for a gravel workpad.

After the construction period, the pipe temperature is defined as an additional thermal boundary condition. The pipe temperature varies throughout the year, found through a separate pipeline hydraulic analysis. (For the current study, the pipe temperature has a minimal effect on the subsurface conditions at the edge of the ROW for the ASAP pipeline). Additionally, the effect of revegetation may be introduced during the operational period.

2.3 GEOTHERMAL MODEL RESULTS

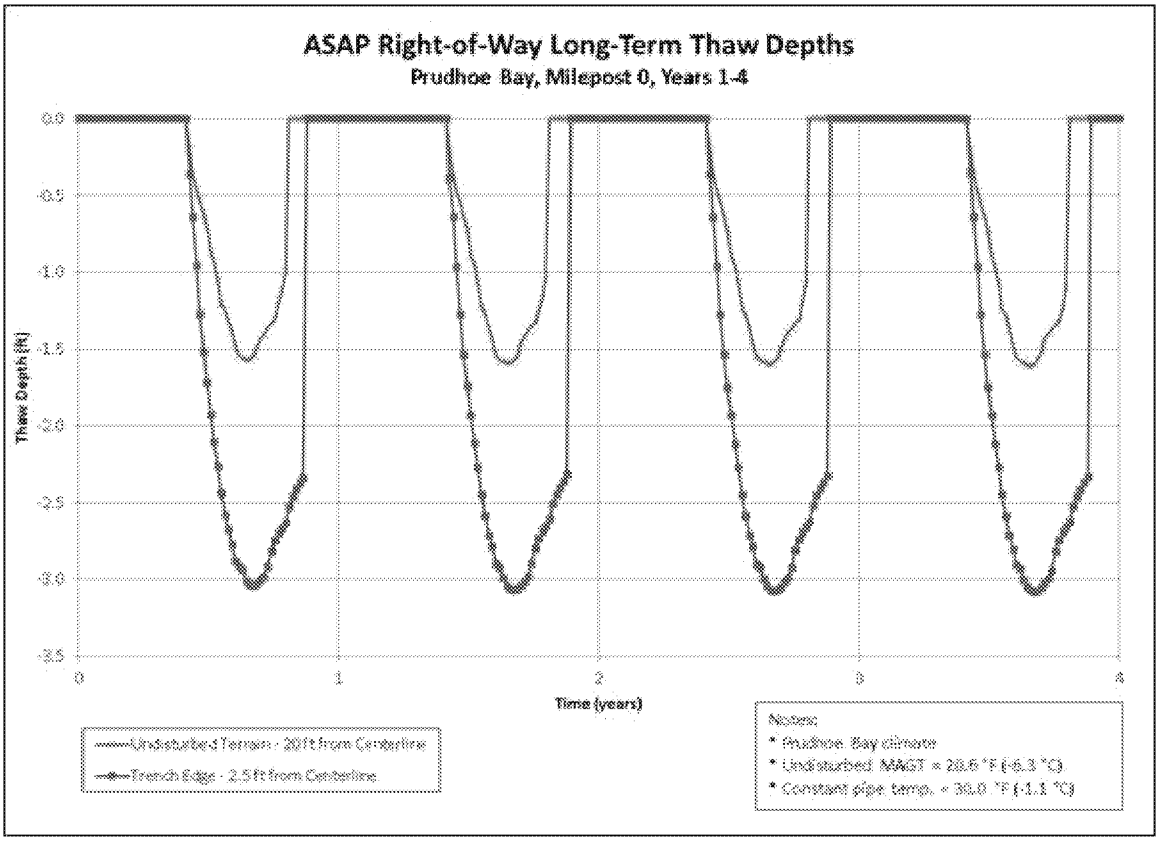
2.3.1 Long-Term Thaw Depths in Continuous Permafrost

Geothermal modeling was completed to assess the long-term thaw depths in continuous permafrost where ground surface disturbance of the tundra terrain will be minimized by the use of ice workpads. With the tundra protected from construction disturbance, there is no expected change of the thermal regime on or adjacent to the ROW, with the exception of the ground disturbance at the pipeline trench. Additional ground warming will occur from the pipeline itself where the mean annual pipeline temperature (MAPT) is warmer than the mean annual ground temperature (MAGT) in undisturbed terrain. The gas treatment plant will supply gas into the pipeline at a constant temperature of 30 °F year-round causing the largest temperature contrast between MAPT and MAGT in continuous permafrost to occur at the pipeline inlet at milepost 0 (MP 0). For this reason, geothermal modeling to assess long-term thaw depths in continuous permafrost was performed at MP 0, details of which are provided in Attachment 1 of this report.

The geothermal modeling showed that at MP 0, deepening of the active layer in the undisturbed soils near the trench reaches maximum within a year or two after construction. Thereafter, the ground temperatures vary seasonally in periodic steady-state and progressive long-term thaw deepening does not occur. In addition, the active layer at the edge of the pipe trench is expected to be about 3.1ft deep as compared to an active layer depth of about 1.6ft in undisturbed tundra terrain. Beyond 20ft from the pipe centerline, modeling showed that the pipe and trench have practically no influence on the active layer depth.

Figure 6 shows the active layer depths from the geothermal modeling over the first four years of the simulation at the trench edge (2.5ft from pipe centerline) and at 20ft from the pipe centerline. This figure shows that the increase in active layer depth at the edge of the trench occurs in the first year and does not deepen in subsequent years. There is no long-term progressive thaw or ongoing active layer deepening beyond 20ft from the trench. In all areas (undisturbed and disturbed), summer warming causes thaw from the ground surface that deepens through the summer and into the early fall (Figure 6). During the fall when air temperatures descend below freezing, active layer freezeback occurs downward from the ground surface (not shown on Figure 6) and upward from the permafrost (as shown on Figure 6 by the decreasing thaw depth after a maximum thaw depth is reached). The final part of the active layer to refreeze is at a depth of about 1 foot in undisturbed terrain (as shown for the data at 20ft from the pipe centerline in Figure 6). At the trench edge, the expected active layer freezeback is at a depth of about 2.3ft.

Figure 6. Expected Active Layer Depths Near-Pipe and in Undisturbed Terrain in Continuous Permafrost (MP 0)



2.3.2 Long-Term Thaw Depths in Discontinuous Permafrost

Geothermal modeling results to estimate long-term thaw depths in discontinuous permafrost are discussed further in Appendix B of AGDC 2016c. Figure 7 from that report (showing the expected 30-year thaw depth across the ROW in warm permafrost) is reproduced in this report as Figure 1 (note the figure axes are in meters). The thermal influence of the gravel pad extends beyond the edge of gravel pad by about 33ft in the case without an organic layer below the gravel pad which is the conservative case (the thermal influence extends beyond the edge of the gravel pad by about 26ft with an organic layer beneath the gravel pad). To be conservative in the route evaluation, an edge distance of 35ft on both sides of the ROW was used in the evaluation of all route segments that were determined to have a potential thaw settlement impact on wetlands.

2.4 ASSOCIATED THAW SETTLEMENT IN THE DISCONTINUOUS MODEL

The progression of the thaw depth for the Discontinuous Model is shown in Figure 9 of Appendix B of the *Time-Dependent Route Geohazards* report (AGDC 2016c) and is reproduced in Figure 1 in this document, above, for the governing case of a gravel workpad without an organic layer beneath the gravel pad. As shown in Figure 1, the thaw depth at the end of the 30-year analysis for the gravel pad is 25ft below ground surface while the thaw depth for the cleared terrain (but without a gravel pad) is 18ft beneath the ground surface (note that diagrams may be in feet or meters). The active layer extends 6ft below the surface, so the depth of thaw below the active layer is 19ft and 12ft for the two sides, respectively. A value of 20% for the thaw strain is used as a reasonably conservative value, resulting in an estimate of 3.8ft and 2.4ft of thaw settlement for the two sides, respectively, at the end of the design life.

The thaw settlement builds gradually, *i.e.* the time progression of thaw settlement over the design life follows the thaw depth progression, multiplied by the thaw strain of 20%. (In the case of layered strata, the thaw strain would vary by a function of depth but in this homogeneous scenario the progression is straightforward). Thus, to evaluate the progression of thaw settlement with time, Figure 9 of Appendix B of the *Time-Dependent Route Geohazards* report (AGDC 2016c) is used with the vertical scale multiplied by 0.20. It can be seen that the thaw depth, and thus the thaw settlement, progresses over the design life with a diminishing slope as time progresses. As high ice contents are found in the upper level of the permafrost table, a high thaw strain is likely to be seen at the start of the Project. However, monitoring and mitigative actions during operations are designed to be effective in blocking consequential damages.

2.5 SECTION SUMMARY

To summarize, geothermal analyses were conducted to evaluate the effect of construction disturbance, and further operational conditions, on the ASAP ROW. The focus of this study was to define the lateral extent of the thermal change and, in particular, that extent beyond the established ROW. With the evaluation of the progression of the thermal effect with time, and using a reasonably conservative value of thaw strain, the amount of concomitant thaw settlement could also be estimated.

Two models were developed for this investigation. A model for the Discontinuous Permafrost region, using climatic conditions appropriate and calibrated for the Fairbanks region was previously developed and described in Appendix B of AGDC 2016c. An additional model for the North Slope, which utilizes an ice road instead of a gravel pad to support construction, was also developed and described in detail in Attachment 1 of this report. Both models followed identical approaches for data development, subsurface modeling, climatic definition, and model calibration.

The model for the Discontinuous Permafrost region results in a thermal impact outside the ROW of a maximum of 33ft for the case of the gravel pad without an organic layer beneath the pad. It is this evaluation that results in a conservative criterion of the use of 35ft on both sides of the ROW as the basis for further route evaluation, described further in Chapter 3.

3. ROUTE APPLICATION

3.1 OVERVIEW

The geothermal evaluations that were conducted and reported in Chapter 2 utilized properties of the subsurface to find a conservative estimate of the thaw depth beneath the ROW and the associated thaw settlement. Subsurface properties can vary considerably along the ROW meaning that the conservative evaluation is not generally applicable. Some sections of the route are already thawed while other frozen sections have soils that are not susceptible to subsequent settlement upon thawing. As shown in Chapter 2, the very cold subsurface conditions of the arctic plain limit thaw settlement concerns even when thaw susceptible materials are present.

In the case of the identification of those route segments that may cause a detrimental thermal impact, ASAP used a stepped approach to identify those potentially problematic route segments. The approach, detailed below in Chapter 3.2, utilizes an increasingly fine screen to determine which route segments can be eliminated from the evaluation. The remaining route segments, i.e. those route segments that could not be eliminated based on any of the criteria for elimination, are then considered potentially problematic route segments. The process is depicted graphically in Figure 3, and described further in this Chapter. Note that the methodology allows for increasingly finer analysis of the route segments as they proceed down the funnel – such analysis depends, accordingly, on increasingly finer route segment data. The process both focuses further field determinations on those potentially problematic segments as well as determining the types of data that must be recovered. ASAP sees this as a continuing mission throughout design and continuing into Operations. Thus, the conservative evaluation discussed at this stage of ASAP design could be expected to be further refined as the project progresses and new data, whether from AGDC field investigations or incorporated from other relevant sources, is added to the project geodatabase and wetlands investigations.

3.1.1 Terrain Units

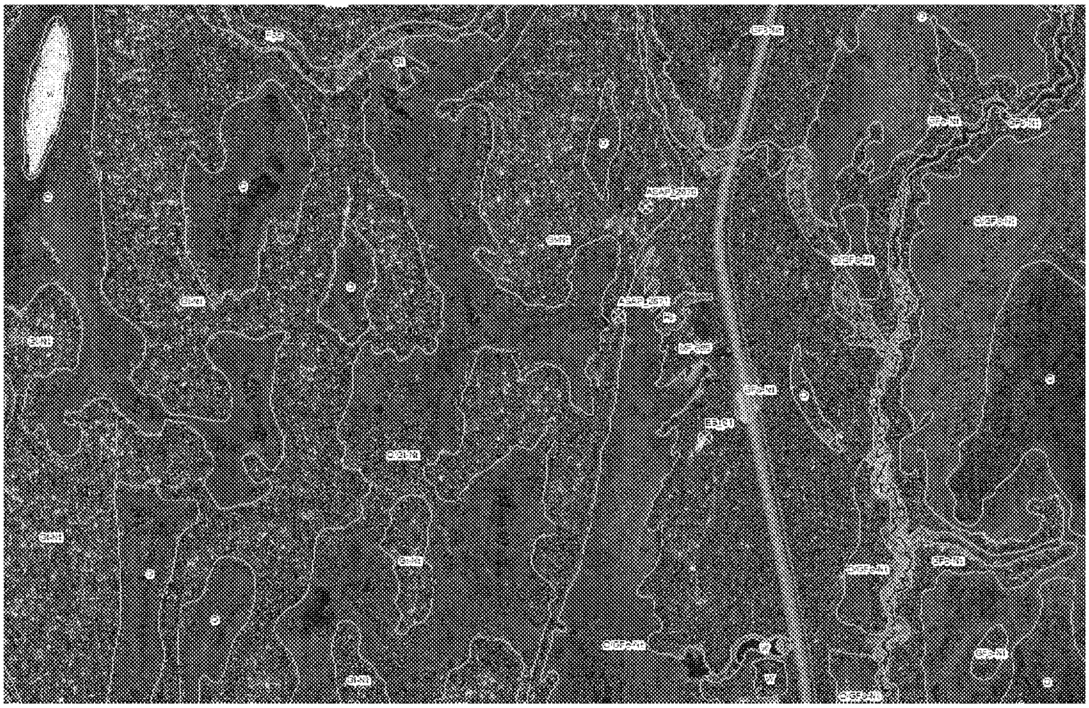
Terrain units are a mainstay of the technical route analysis and summarized further here – a more detailed description is contained in Chapter 7 of the *Time-Dependent Route Geohazards* report (AGDC 2016c).

Terrain units describe the morphology of a route area and consist of individual landforms that together, comprise the subsurface characterization. The depth or thickness of these landforms are generally described down to a prescribed distance below ground surface (bgs) although they can be extended, based on further borehole evaluations to the depth of the borehole. Two dimensional geological cross sections or 3D fence diagrams can then be created along the alignment.

Engineering data, such visual soil descriptions, soils laboratory data, ground temperature measurements, and groundwater depth measurements are then related to specific landforms and terrain units. These are documented in the ASAP geotechnical database library for use in further engineering analysis. A GIS geospatial database is used to illustrate terrain units, borehole locations, LiDAR, orthoimagery, and other data pertinent to the pipeline corridor. The GIS forms an integral part of the geohazard identification, evaluation and avoidance of pipeline route hazards in the design process.

The data can be expected to be increasingly refined and detailed as the project matures. All data used for design and all analyses have been subjected to rigorous subject matter expert review. A typical Terrain Unit map is shown in Figure 7.

Figure 7. Terrain Unit Map Example



3.2 ROW EVALUATION METHODOLOGY

As described earlier, the ROW evaluation methodology employs a series of refinements that are designed to eliminate potentially non-susceptible segments. The remaining segments at the end of the analysis are considered potentially susceptible to thermal impact of wetlands.

The analysis starts with what are considered the easiest determinations to apply to the pipeline, such as the determination as to the route delineation in the discontinuous permafrost region, the consensus area of focus. With this determination, no further data is required to refine the deliberation concerning those deleted segments. The next step is based on the evaluation of the Terrain Units, which are described in Chapter 3.1.1. The route geotechnical evaluation concluded at this point. The summary of that evaluation is discussed further in Chapter 4. Results of this evaluation, again based solely on geotechnical evaluations, were then further analyzed for wetlands impacts.

The Terrain Unit Technical evaluation was based on a segment by segment breakdown of the route into those Terrain Units that intersected the ROW. The Project geodatabase provided the terrain unit takeoff with a series of pipeline segments defined by the intersection of the pipeline centerline with each terrain unit polygon along the route. For each of these pipeline segments the, "thaw settlement potential" was identified for each landform/physiographic region combination, (from the terrain unit properties table of June 28, 2014 in Attachment 1), to determine the worst case thaw settlement potential (low, moderate or high) for each pipeline segment.

The procedure is detailed below:

1. Physiographic regions
   - Each segment was assigned a number from 1 to 7 for each of the 7 physiographic regions encountered along the route.

2. Route Terrain Unit / Physiographic Region combinations
   - The Terrain Units were uniformly formatted for processing.
   - All unique physiographic region number and terrain unit combinations from the route were associated and tabulated.

3. Terrain Unit / Physiographic Region combinations
   - Terrain unit/physiographic region combinations were compared against the available combinations from the geotechnical summary.
   - The description to a category of low, moderate, or high were uniformly formatted
     - Example: "Low to Moderate (High if excess ice in voids and fractures)" would be "Moderate, i.e. the more conservative description is retained.
   - Terrain unit/physiographic region combinations that were not specifically covered in the ASAP terrain units spreadsheet were assigned assumed thaw settlement categories.

    i. Terrain units were assumed to have similar thaw settlement categorization to terrain units in adjacent physiographic regions.
    ii. Terrain units with similar descriptions were assumed to have similar thaw settlement categorization.
  - An expanded list of thaw settlement categories for terrain units and physiographic regions was compiled.

4. Apply Terrain Unit / Physiographic Region to Route
   - The thaw settlement category for each Landform of each terrain unit in each segment was selected based on the previously evaluated Terrain Unit/Physiographic value (1 = low, 2 = moderate, 3 = high).
   - The thaw settlement category for each segment was assigned based on Landform (i.e. the worst subsurface layer regardless of strata thickness).

Terrain Unit determinations that were inconsistent with the other terrain unit conventions were evaluated separately.

3.3 POTENTIAL REFINEMENTS

As was noted earlier, there are a series of refinements that could be used as additional data, and analyses utilizing that data, are utilized. These refinements include:

- Additional borehole and soil sample data to refine the soil index properties that are used in the geothermal determination (esp. the soil moisture content).
- Additional geothermal analysis of climatic variations along the ROW.
- Additional geothermal analysis of varying vegetative cover along the ROW.
- Refinement of wetlands data in site specific locations.

Each of these effects could be expected to further eliminate those route segments which are potentially susceptible and/or to refine the extent of the thaw settlement effects, as determined by this analysis using the existing data.

4. RESULTS OF TERRAIN UNIT EVALUATION FOR THAW SUSCEPTIBILITY

4.1 EVALUATION METHODOLOGY

Following the flowchart presented in Figure 3, above, the route segments south of the discontinuous zone (i.e., south of MP 634), were screened out and excluded from the wetlands analysis since the subsurface is generally considered to be thawed and thus is not susceptible to thaw subsidence (Table 1). Similarly, route segments north of MP 168 were screened out and excluded from the study since the analysis in the areas of continuous permafrost conducted for this study and reported in AGDC 2016c, were found not to have a thermal impact outside of the ROW (Table 1). The remaining 466 miles were evaluated for potential thermal impact based on their Terrain Unit classification and the corresponding evaluation table of their thaw settlement potential (Table 1).

4.2 EVALUATION RESULTS

The Project GIS is the repository for the information that is spatially linked to the route and facility areas. It includes a spatial description of the Terrain Units along the route and was queried to find the intersection of the route with those Terrain Units using the methodology described in this document.

The results showed that for the 466 miles of the pipeline within the discontinuous region, 191.4 miles possessed a high thaw susceptibility potential, 65.5 miles possessed a moderate thaw susceptibility potential, and 178.3 miles possessed a low thaw susceptibility potential. The remaining approximately 31 miles were uncategorized and thus were conservatively assumed to have a high thaw susceptibility potential. These results are summarized below.

The 178.3 miles of pipeline ROW that possess a low thaw susceptibility potential were screened from further wetlands analysis (Table 1). The 287.7 miles that were categorized as having high or moderate thaw susceptibility potential (Table 1) were carried forward for analysis of potential indirect impacts to wetlands using further GIS queries and site-specific determinations, as reported in Chapter 5 and Attachment 2.

Table 1. Mileage of Thaw Susceptible and Non-Susceptible Land Traversed by the ASAP Mainline

CATEGORY	MILEAGE
Total Mainline Route Length	733
Excluded North of MP 168 (Continuous Permafrost)	-168
Excluded South of MP 634 (South of Discontinuous Demarcation)	-129
Excluded Low Thaw Susceptibility Terrain Units	-178.3
Remaining Potential Thaw Susceptibility	**287.7**

5. WETLANDS INDIRECT IMPACT EVALUATION

Surface water provides an important positive feedback that enhances permafrost degradation when water is impounded in subsiding depressions. In addition, groundwater in the active layer or within permafrost delivers heat and is often surrounded by thawed zones (Jorgenson, et. al, 2010). AGDC tasked its wetlands subject matter experts with evaluating which wetlands types would be generally associated with already thawed permafrost and to use this to screen areas that would be indirectly impacted by potential permafrost thaw, potential subsidence, and potential drainage.

Based on prior geothermal modeling (AGDC 2016c), there is a potential for indirect lateral permafrost thaw within a conservative 35ft TAZ on either side of the ROW due to vegetation removal within the ROW. This thaw has been modeled to extend down to a maximum 1 meter (3.3ft) bgs, however this thaw depth will be extremely variable. Therefore, it is assumed for the purposes of this study that an approximately 8 inches (or 20% of maximum) subsidence of underlying soils is possible across the entire 35ft buffer. Based on this assumption, the area within the TAZ was reviewed for potential impacts to wetlands experiencing an 8in subsidence within the TAZ.

5.1 WETLANDS APPROACH

AGDC provided its wetlands subject matter experts with a geodatabase describing terrain units with moderate or high potential for discontinuous permafrost thaw within the indirect TAZ. Qualifying areas were then evaluated for wetlands, screening out types that are generally associated with thawed permafrost. Wetlands that generally would maintain a deeper active zone or thaw bulb, under existing conditions were expected to have a low probability of experiencing an effect from subsidence because the affected areas under them would already be thawed within the interval of analysis. Wetlands types that were screened through this analysis included lakes, ponds, riverine wetlands, and wetlands with a Cowardin class that had a hydrologic modifier, indicating a permanently, semi-permanently, or seasonally flooded water regime. AGDC's wetlands subject matter experts then removed any remaining wetlands with a depressional hydrogeomorphic (HGM) class, as these also generally indicate existing thaw. Finally, uplands were screened from further analysis with the exception of those having a localized potential for impact to abutting and qualifying wetlands. Flat and slope wetlands having a saturated hydrologic modifier comprised the majority of wetland types within the indirect TAZ and were carried forward in the analysis.

The TAZ was subdivided among similar ecological units in order to evaluate wetlands within the same regional conditions. From north to south these regions included: Brooks Range (MP 168 to MP 250), Yukon (MP 250 to MP 356), Fairbanks area (MP 357 to MP 454), Broad Pass (MP 454 MP 608); and South Central (MP 608 to MP 634).

Permafrost thickness was taken into account in potential impact scenarios with respect to the potential to dewater wetlands. Thicker permafrost is generally expected toward the northern sections of the discontinuous permafrost study area (MP 168 to MP 454), and thinner permafrost is generally expected in more southerly areas from MP 454 to MP 634. The presence of standing water and shallow groundwater was also considered due to the potential of these sources to exacerbate permafrost thaw through a more efficient heat transfer process (Jorgenson et al. 2010). AGDC's wetlands scientists similarly considered the potential ponded water effect that may result in the subsidence depression.

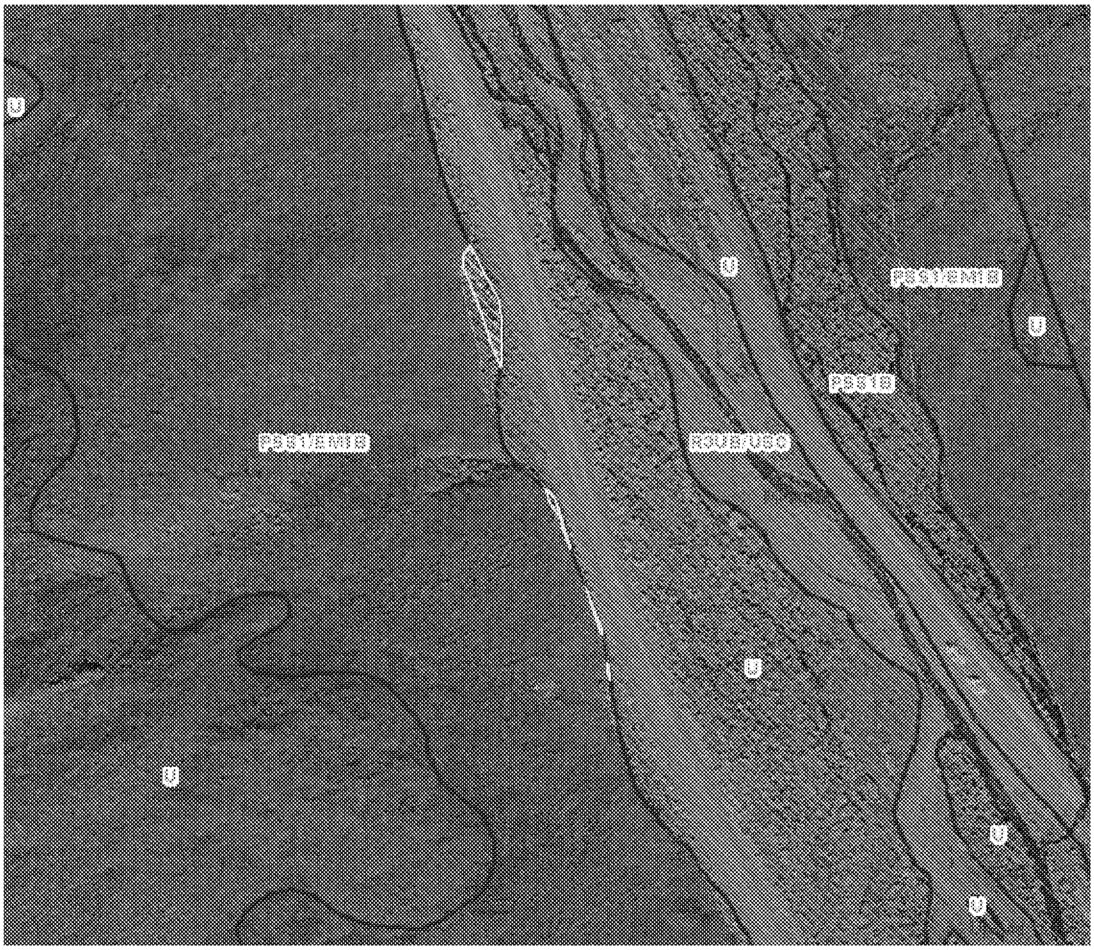
AGDC's wetlands subject matter experts have considerable field experience in the ASAP pipeline corridor, documenting that many parts of the study area are overlain by histic epipedons, which are fairly thick saturated organics over low chroma mineral soils. These soils occur primarily in scrub shrub and forested areas but also encroach in to mixed shrub and emergent wetlands. Emergent wetlands in the corridor tend to be underlain by histosols, which are thick saturated organics (fibric/histic/hemic). Emergent wetlands tend to hold more water than shrub and forested wetlands. The consultants further used vegetation signatures and Cowardin wetlands mapping to assist in determining the expected soil profile within the TAZ in order to better estimate the potential for ponding impacts and their extent. LiDAR data was also evaluated in potentially impacted areas to assist in determining the potential for surface water and the direction of shallow subsurface water flow.

The study was designed as a high-level analysis for the purposes of evaluating impacts to wetlands on a large scale, so there is a potential for some localized effects outside this level of analysis. Descriptions and visual examples are provided, below, to provide representations of these potential impacts and areas of anticipated thawing within the indirect TAZ.

5.2 BROOKS RANGE (MP 168 TO MP 250)

This area, shown in Figure 8, is not expected to result in indirect impacts to wetlands in the TAZ. This area has moderate potential for permafrost thaw and encroaches slightly into the abutting area of low potential were wetlands exist (note that some slight mapping irregularities exist between the wetlands scientists and the terrain unit modelers).

Figure 8. Moderate Potential for Permafrost Thaw in Wetlands of the Brooks Range Area (MP 168 – 250)

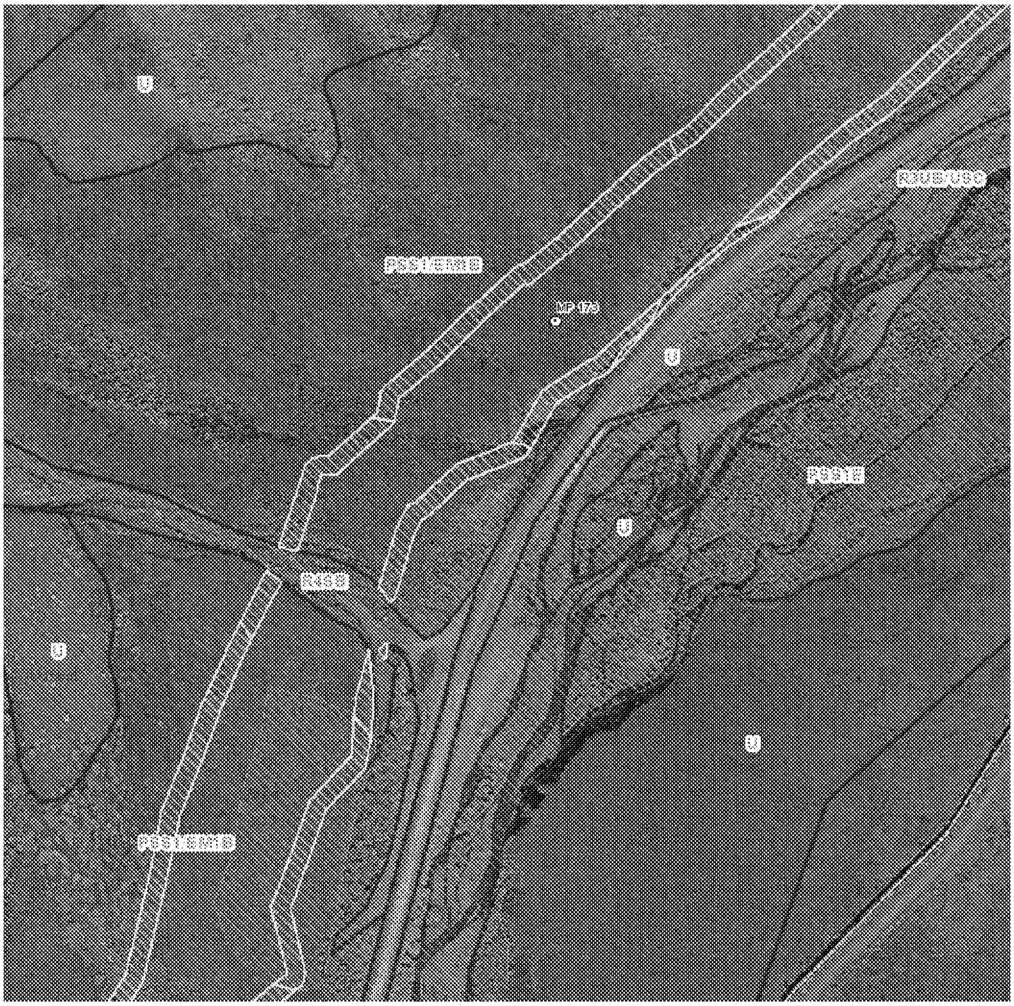


5.2.1 Brooks MP 173

This area represents mixed Scrub Shrub/ Emergent wetlands slope wetlands along the Brooks Range, and adjacent to the upstream side of the Dalton Highway (Figure 9). The wetlands within the TAZ are newly forming wetlands with fairly well-drained gravelly soils. The hydric soil indicator used is problematic soils with low carbon content described in the 2007 Supplement (Page 88, USACE 2007). The profile generally consists of 4 to 5 inches of organics underlain by course gravels that are a result of old alluvial fans at the toe of slopes.

Over time, wetlands have begun to form in these areas due to large hydrologic input and soil development that affords prevalence of hydrophitic vegetation. Field evidence showed shallow ponding and flowing water exists immediately below the organic surface; the slope toward the road allows the water to run downward to the road ditch were it is captured and directed along the road to culverts discharging to the adjacent river. While thaw settlement is expected along the upslope side of the TAZ, no ponding is anticipated due to the soil profile make up. However, for the downslope side of the TAZ, settlement could result in increasing the size of the existing roadway ditch and adding hydrology to the wetlands associated with that downstream area. For portions of the downstream side that are separated from the road ditch, the effects are expected to resemble the upstream side.

Figure 9. Downslope Area for Wetlands



5.2.2 Brooks MP 184

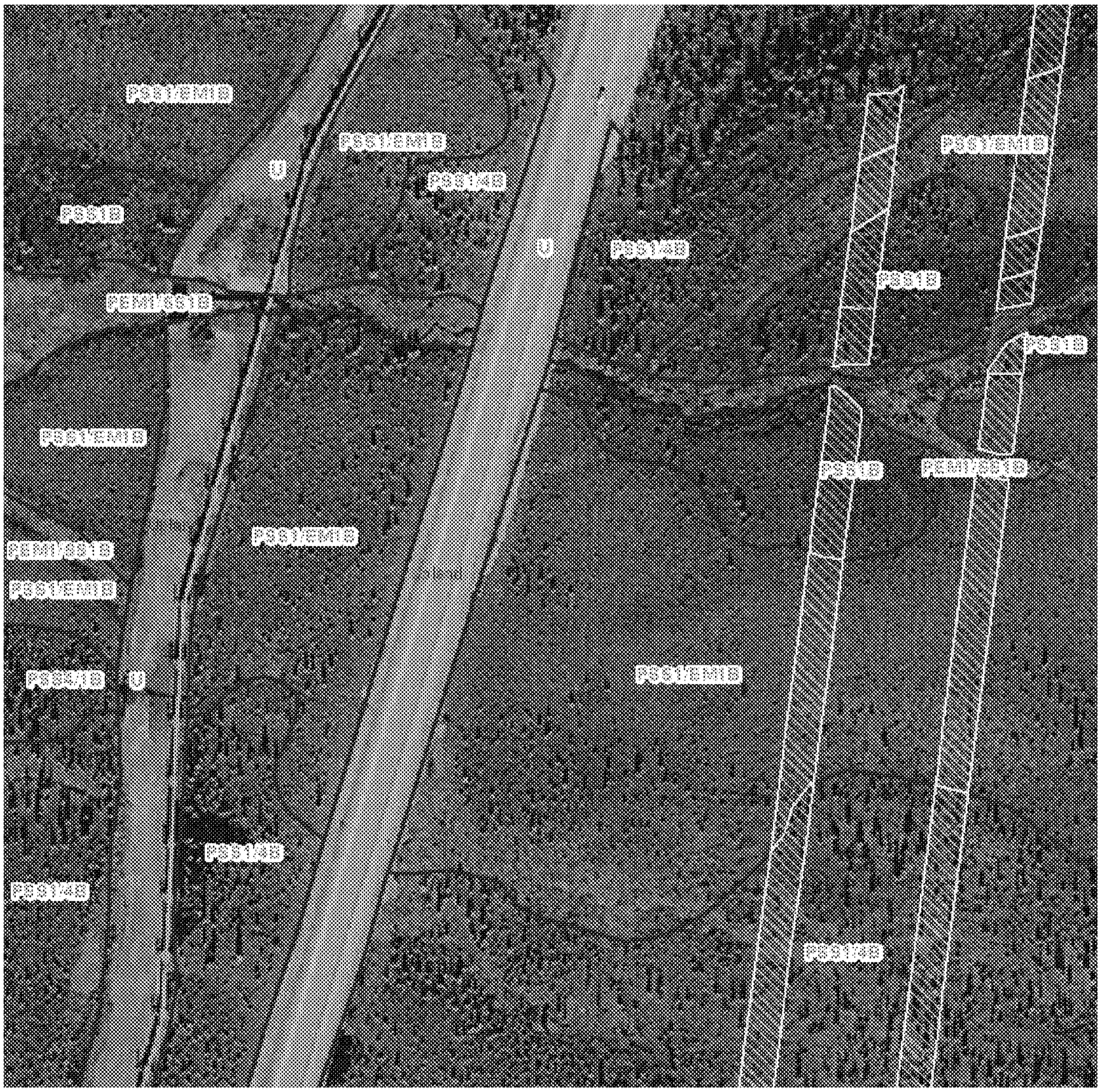
This area, shown in Figure 10, is very similar to the area at MP 173, with the exception of the soils being generally more indicative of Histic Epipedons. The vegetation has a much smaller component of emergent grasses and sedges and is typically a little drier in the subsurface because it does not receive as much water as areas that are associated with alluvial fans. These areas appear to be much older, and the hydric soils have been given time to fully develop. The difference in these areas is that the upslope side settlement could result in ponding over time due to the poor drainage of the soils. The downstream side could experience the same effect. Linear drainage down the ROW could be mitigated through ditch plugs or some other mechanism found to be appropriate and practicable for the design.

Figure 10. Brooks MP 184 Area

5.2.3 Brooks MP 219

Figure 11 is an example of a flat wetlands with a mixed vegetative makeup. While subsidence here is expected, long term results are not be expected to alter the overall makeup of the wetland. The adjacent TAPS provides a good analogy to what a similar ROW clearing would have on the nearby uncleared area. There does not appear to be a significant change to the surrounding area around TAPS over the nearly 50 years it has been operating. There could be a slight effect at the edge of the ROW, as appears to be visualized along TAPS, but the overall habitat has not changed. Should current climate trends, coupled with ROW clearing, result in impacts suggested by Smith and Riseborough (2010) (which are not observed in TAPS), then potentially mirroring what TAPS has done may be beneficial in mitigating potential impacts.

Figure 11. Flat Wetlands with Mixed Vegetative Makeup at Brooks MP 219 Area



5.2.4 Brooks MP 234

This area, shown in Figure 12, is similar to the area presented at MP 173, with increasing the hydrology around the Dalton Highway ditch; however, the ponding could last longer and result in additional permafrost thaw over time because flat wetlands with poorly drained soils would be expected to hold water longer. Emergent wetlands could form along this area due a change in the hydrology. It is possible that effect of the dust shadow from the Highway could offset increased hydrologic impacts.

Figure 12. Brooks MP 234 Area

5.3 YUKON MP 250 TO MP356

5.3.1 Yukon MP 250

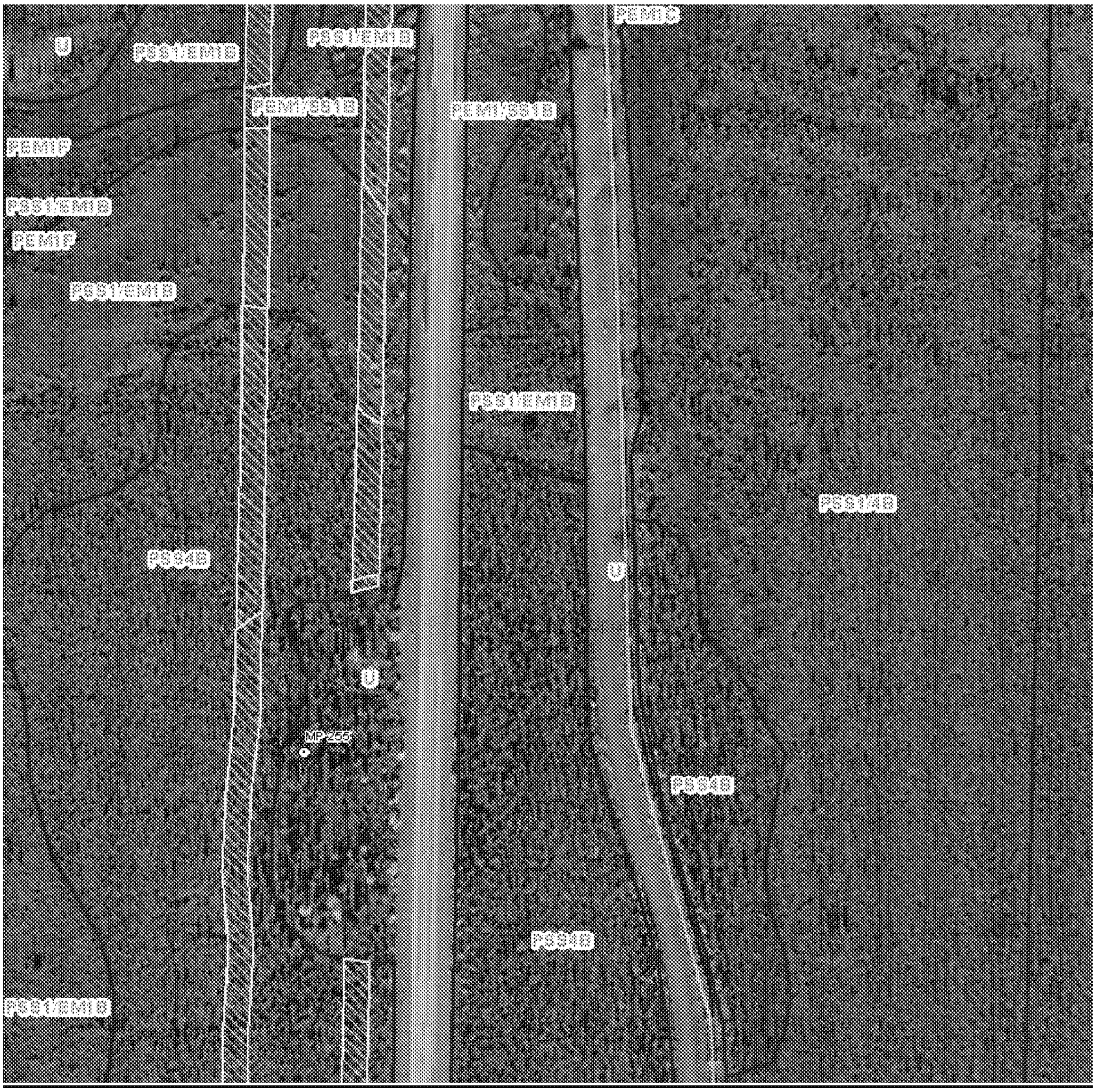
This area, shown in Figure 13, may experience significant drying along the edge of the ROW due to dryer soil conditions being better drained than the area at Brooks MP 219. The predominant deciduous scrub/shrub wetlands indicate the presence of a dryer soil profile. As evidenced along TAPS there appears to be a clear indication of taller shrubs and trees potentially developing over time at this location. The dryer soils and re-establishment of vegetation could, over time, afford a re-establishment of permafrost here. This may have been what limited the habitat change evidenced around TAPS.

Figure 13. Yukon MP 250-356

5.3.2 Yukon MP 255

This area, shown in Figure 14, is dominated by taller evergreen shrubs (PSS4B). Although the area is very similar to that at MP 250, TAPS does not show the effect of potential habitat change immediately adjacent to the ROW. The taller evergreen shrubs in the area may encroach slightly into the mixed wetlands abutting the PSS4B, but overall, no significant habitat change is anticipated.

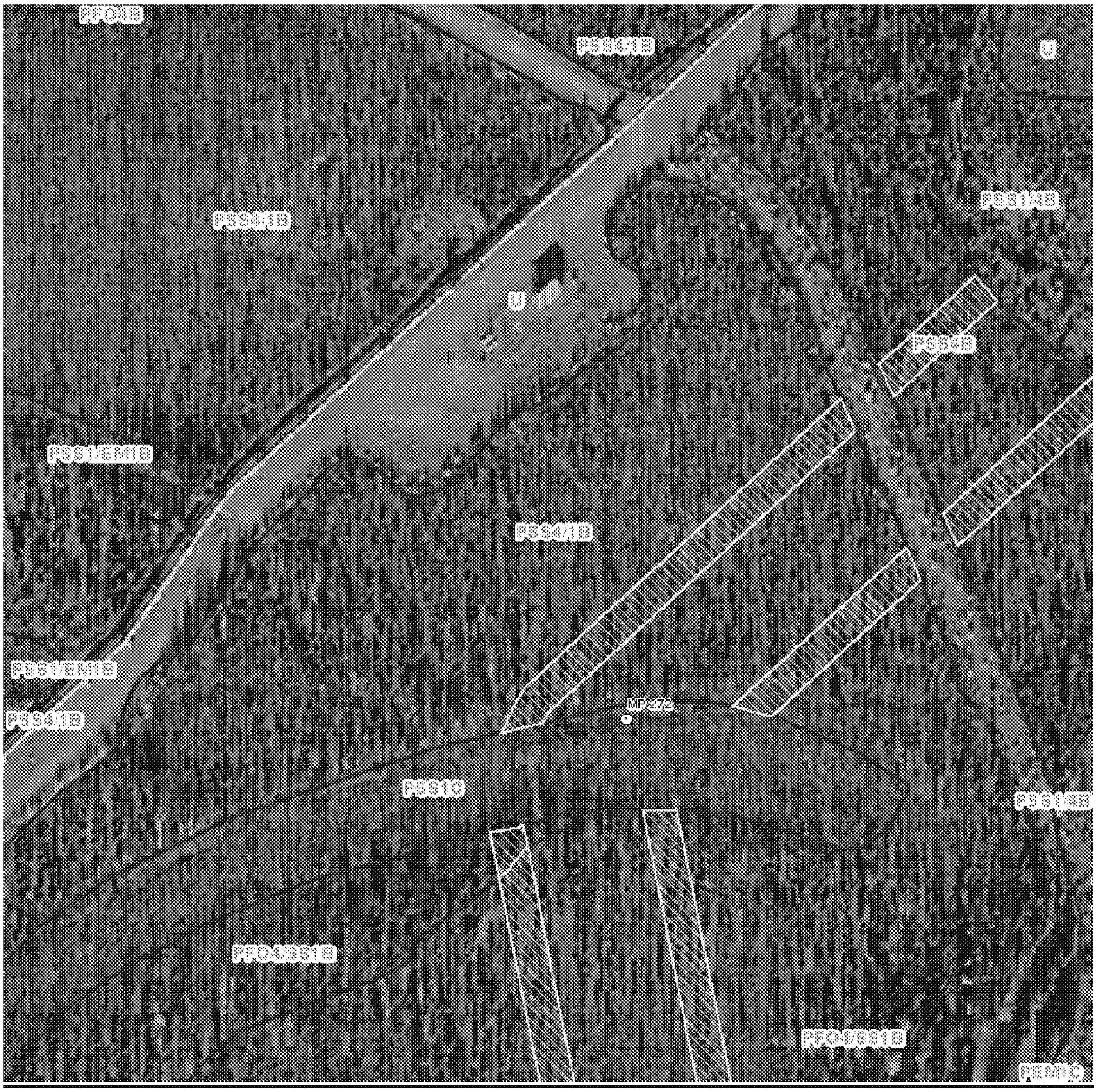
Figure 14. Taller Evergreen Shrubs Near Yukon MP 255 Area



5.3.3 Yukon MP 272

This area, shown in Figure 15, is very similar to MP 255. However, as seen along the increased cleared area near TAPS facilities, there appears to be no change in habitat adjacent to the ROW. This evidence strengthens the likelihood that ASAP ROW clearing would not result in significant impacts to the adjacent indirect TAZ.

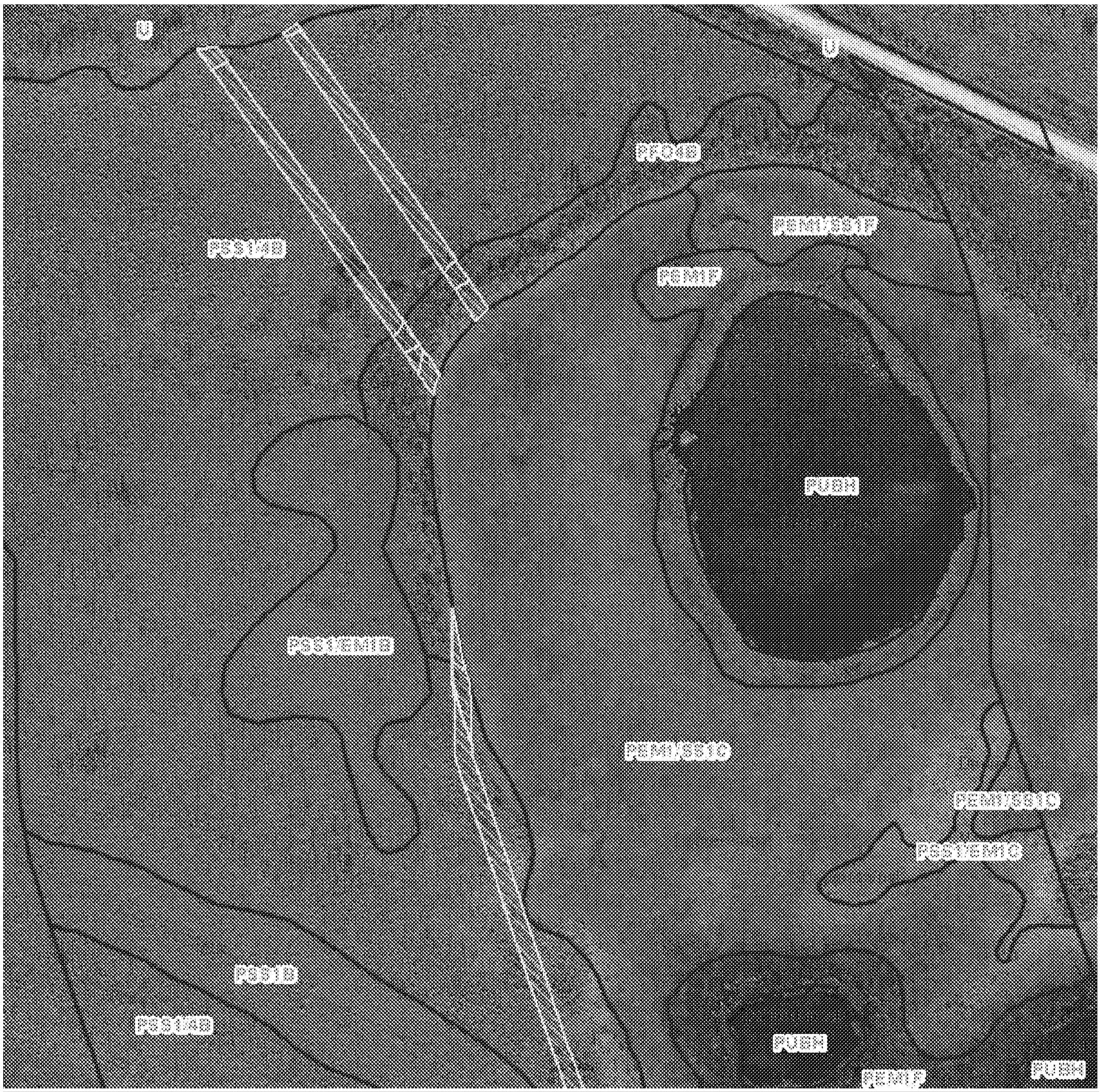
Figure 15. Yukon MP 272



5.3.4 Yukon MP 355

For areas in which the indirect TAZ is abutting a depressional wetland with increased hydrology (Figure 16), there is the potential for expanding the depressional wetland within the TAZ. This would appear to ultimately enlarge these habitats and increase the overall function and services provided by the current dryer shrub wetlands. The effect would be very limited and likely only occur at the edge of the two habitats.

Figure 16. Yukon MP 355

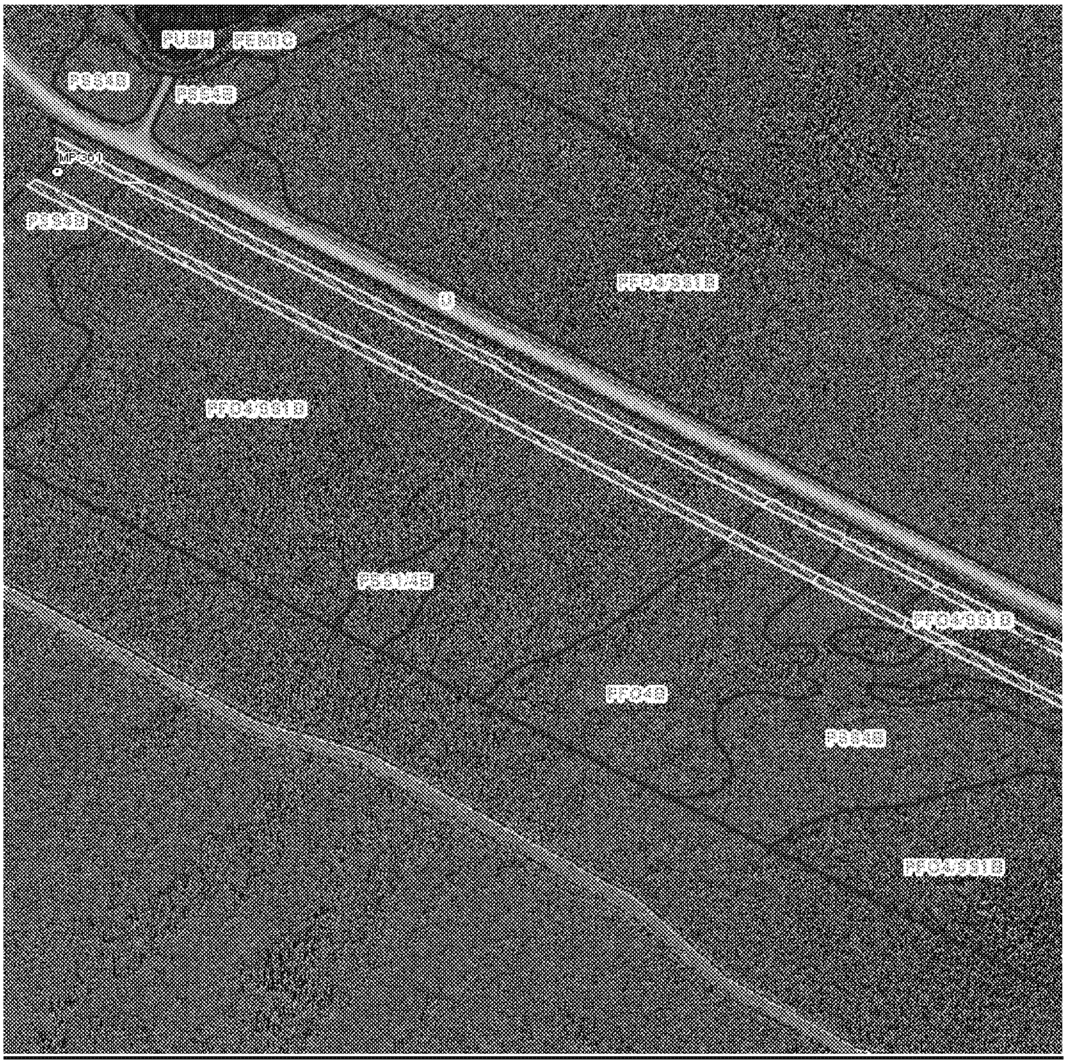


5.4 BROADER FAIRBANKS REGION (MP 357 TO 454)

5.4.1 Broader Fairbanks Region MP 361

This area, shown in Figure 17, is very similar to Yukon MP 255 except that the vegetation is composed of a forested wetland dominated by black spruce. Similar effects are anticipated in that the dryer subsurface that affords taller vegetation, and this area should not experience significant indirect impacts. The TAPS ROW in the frame seems to strengthen this prediction in that the forested side of TAPS does not exhibit a vegetative change. The shorter shrub side of TAPS does appear to exhibit a small local change in vegetation, so a similar result could occur for ASAP. No wetland conversion is anticipated.

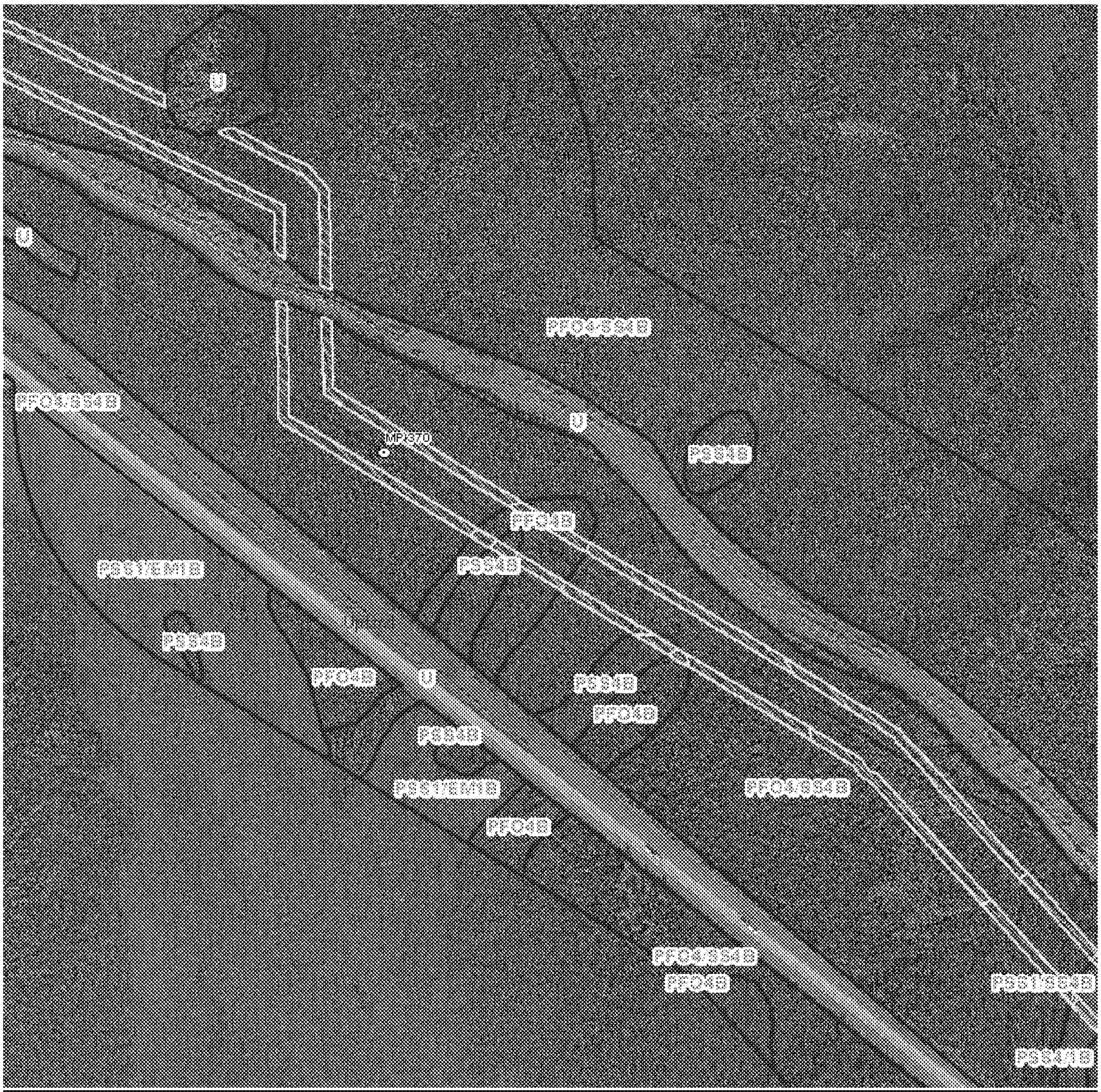
Figure 17. Broader Fairbanks Region MP 361



5.4.2 Broader Fairbanks Region MP 370

This area, depicted in Figure 18, shows a transition zone along TAPS where the pipeline goes underground. Note that the heated TAPS line does not appear to present a lateral effect on the surrounding taller flat shrub and forested wetlands. Therefore, the ASAP ROW clearing and cold gas pipeline should similarly not result in significant effects to wetlands. Also note the thin cleared ROW currently present along the TAZ; this area shows no significant impact to adjacent wetlands.

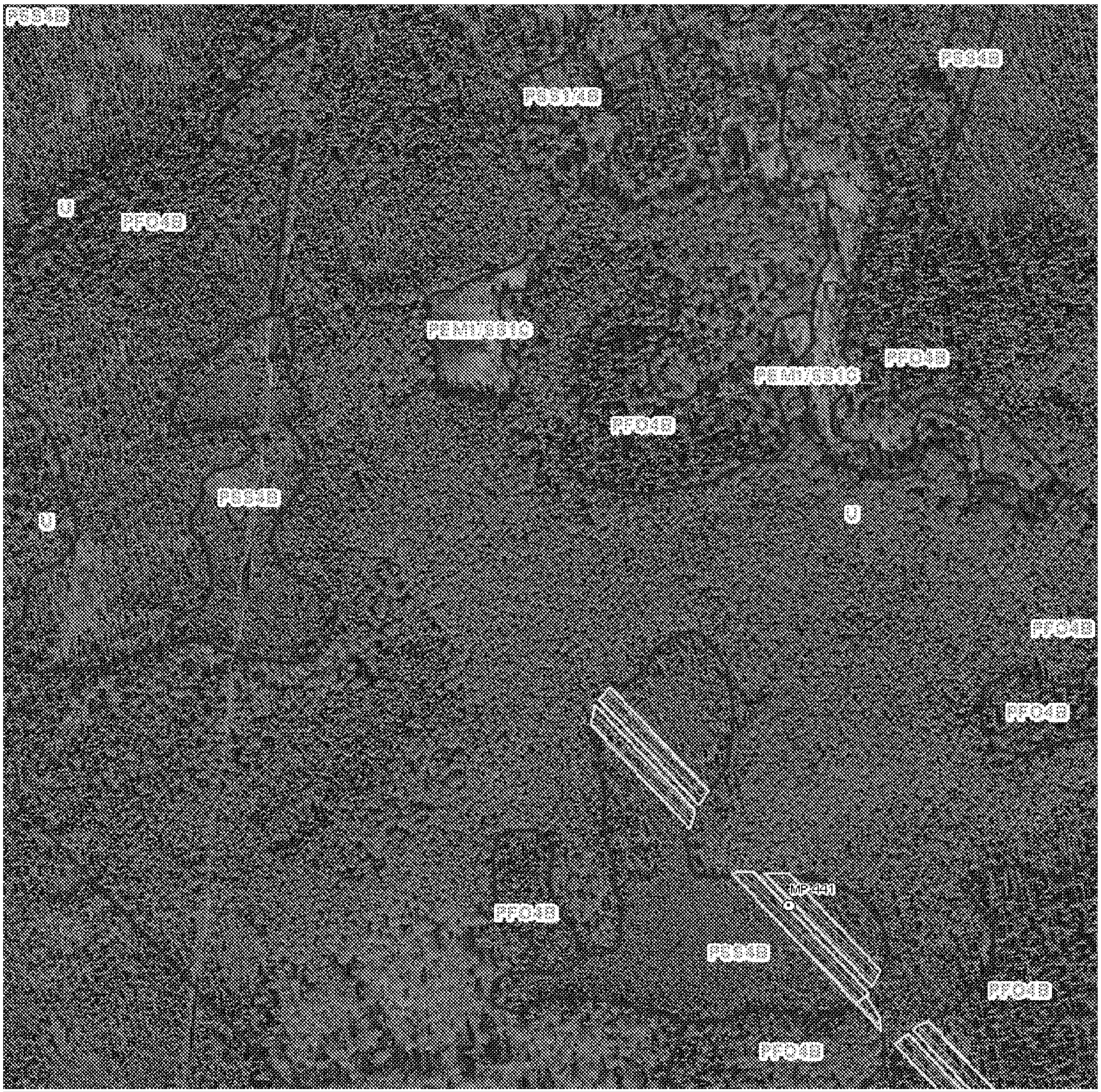
Figure 18. Broader Fairbanks Region MP 370



5.4.3 Broader Fairbanks Region MP 441

This ASAP pipeline transects taller shrub habitat in this area, and no substantial impacts to adjacent vegetation are expected in the indirect TAZ (Figure 19). As evidenced by the adjacent cut ROW in Figure 19, the impacts would be localized within the actual ROW.

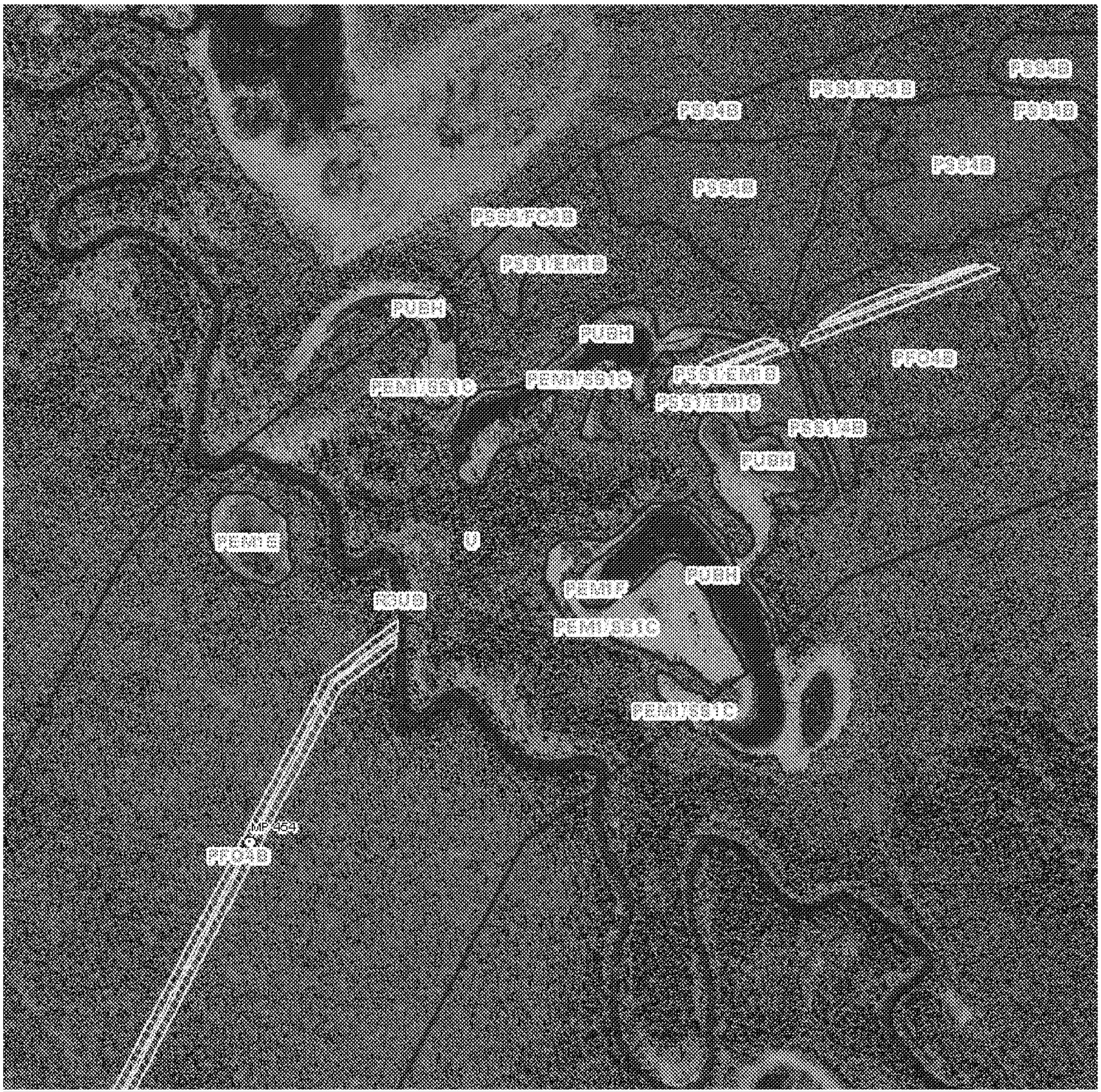
Figure 19. Broader Fairbanks Region MP 441



5.4.4 Broader Fairbanks Region MP 454

In areas, such as near MP 454 (Figure 20), where the TAZ encounters larger rivers and streams, there exists a potential for localized bank sloughing due to thaw depression. This could occur only on banks that are not depressed wetlands, or wetlands with a very wet hydrologic regime. As the extent of the thaw bulb around the hydrologic feature is unknown, the analysis remains conservative, analyzing the TAZ up to the edge of the mapped feature, when in fact the presence of the thaw bulb could result in the removal of the TAZ.

Figure 20. Broader Fairbanks Region MP 454



5.5 BROAD PASS (MP 454 TO 608)

5.5.1 Broad Pass MP 455

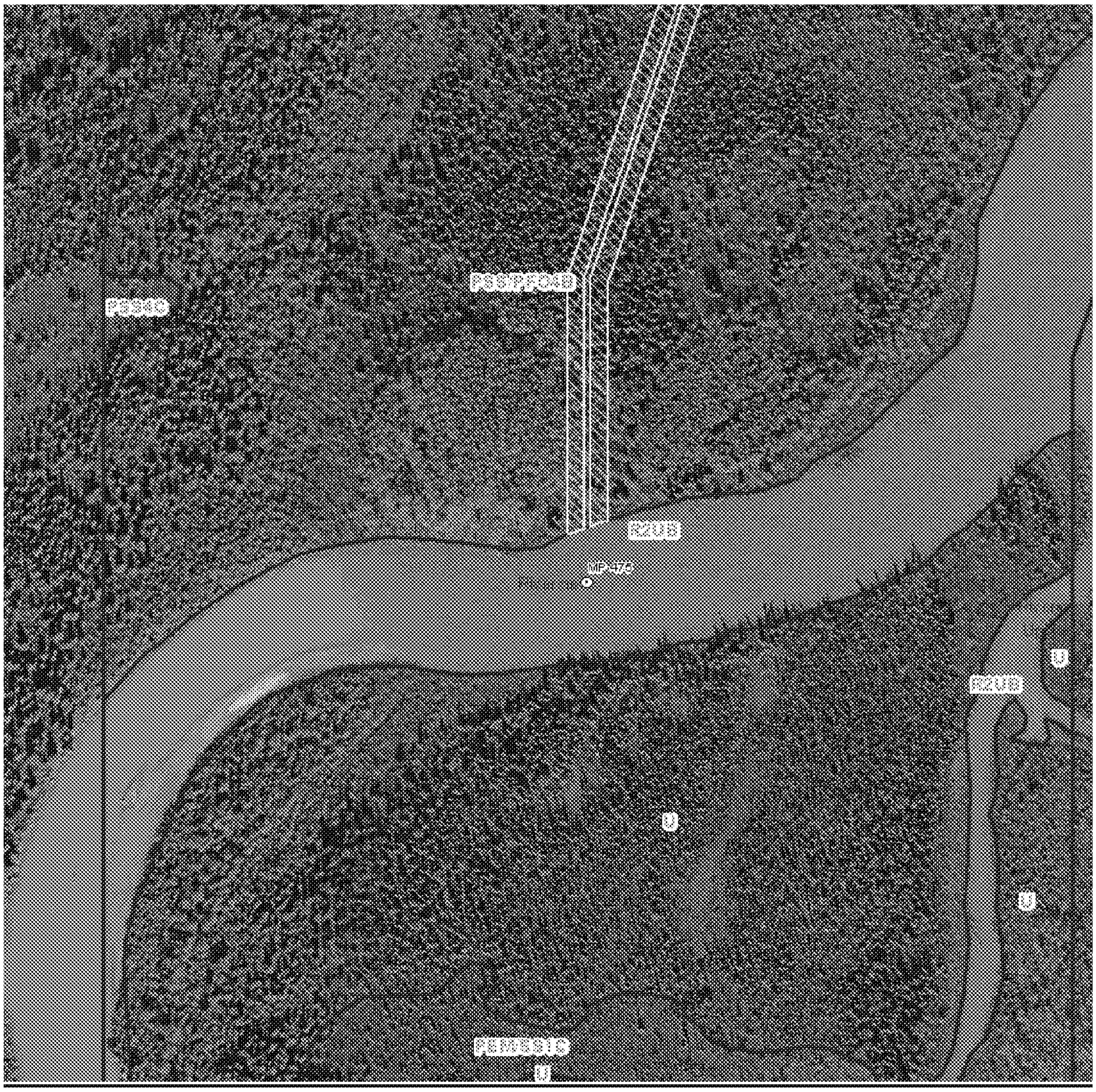
This area is dominated by forested wetlands composed of black spruce; however, they have small inclusions of shrubs and emergent vegetation (Figure 21). As shown in previous examples, areas composed of taller shrubs and forest are not likely to experience any significant impacts due to a thaw depression forming. However, there could be localized impacts in the emergent and shrub layers. These intermixed layers could indicate that soil conditions have wetter inclusions; if that is true, then ponding could occur and result in additional thaw. However, if soils are fairly well drained, then these inclusions may be altered to have taller shrubs, as seen along TAPS. The relict survey line ROW clearing appears to indicate the latter is true and that the area would not experience significant vegetative or hydrologic alteration adjacent to the ROW.

Figure 21. MP 455

5.5.2 Broad Pass MP 475

As shown along MP 454, this area may experience bank sloughing form a depression forming in the flat wetlands adjacent to the river (Figure 22). It is unlikely that significant indirect impacts would be observed if the river thaw bulb extends into the TAZ.

Figure 22. Broad Pass MP 475 Area



5.5.3 Broad Pass MP 501

It is possible that some minor upland conversion could be experienced in the TAZ in this area. Dominant saturated wetlands and a more persistent saturation to the surface are seen in the adjacent PSS4B wetlands (in the bottom left) associated with the clearing (Figure 23). It appears that, in the presence of significant surface impact, the water conditions could spread toward the upland edge and saturate the area to the point that wetlands may begin to form. While the localized change may be significant, the effect on the overall area would appear to be negligible. Additionally, some minor sloughing could occur where the TAZ crosses small water conveyances in wet depressions.

Figure 23. Broad Pass MP 501 Area

5.5.4 Broad Pass MP 548

As the TAZ moves south, there appears to be larger areas where thaw depressions are less likely. Figure 24 depicts an area very similar to other areas where the presence of adjacent ROW clearing appears to substantiate the expectation that no significant impacts would occur in areas with taller vegetation. However, near inclusions with near surface persistent saturation, additional thaw could be experienced. This would result in ponded inclusions and the establishment of emergent vegetation. Based on Figure 24, such instances do not appear to be wide-spread and are likely to be more the result of clearing associated with significant ground disturbance.

Figure 24. Broad Pass MP 548 Area

5.6 SOUTHCENTRAL MP 608 TO 634

5.6.1 Southcentral MP 613

Habitats crossed by the TAZ in the Southcentral region are very sporadic and are composed of larger scrub shrub and emergent inclusion within large upland complexes or near areas where a low probability of permafrost thaw is expected (Figure 25). Impacts in these areas most likely include ponding and sloughing of upland soils, which would expand the wetland inclusion slightly. Some persistent thawing due to water collecting in ponded areas may occur.

Figure 25. Southcentral MP 613

6. RESULTS AND FINAL ROUTE SUMMARY

AGDC directed its geothermal and wetlands subject matter experts to evaluate the potential for impacts to an indirect TAZ over a 30-year life of project. The analysis, described in detail above and in Attachments 1 and 2, resulted in the tabulation of a maximum 1,037.20 acres of wetlands that have the potential to be indirectly impacted by thawing permafrost, assuming subsidence and drainage of wetlands for all areas (Table 2). Case studies for other projects, such as TAPS, give reason to believe that actual indirect impacts to wetlands in the TAZ will be much lower than the maximum possible extent reported here.

This evaluation does not take into account continual monitoring efforts (AGDC 2016b), field investigations and activities, and mitigative options (see Section 7) that will occur during the Operations and Maintenance phase of the Project. These activities would further avoid and minimize potential indirect thaw to permafrost under wetlands. Additional impacts to permafrost that are projected as the result of climate change are also not included in these results; however, these are discussed in a separate report, entitled, 'Effect of Climate Warming on Expected Long-Term Thaw Depths on the ASAP Right-of-Way, Alaska Stand-Alone Pipeline Project' (Matrix Solutions 2017).

Table 2 provides a breakdown of potential indirect impacts within the TAZ by Cowardin classification code, terrain unit type and thaw settlement potential.

Table 2. Potential Indirect Impacts within the TAZ by Cowardin Code, Terrain Unit, and Thaw Settlement Potential

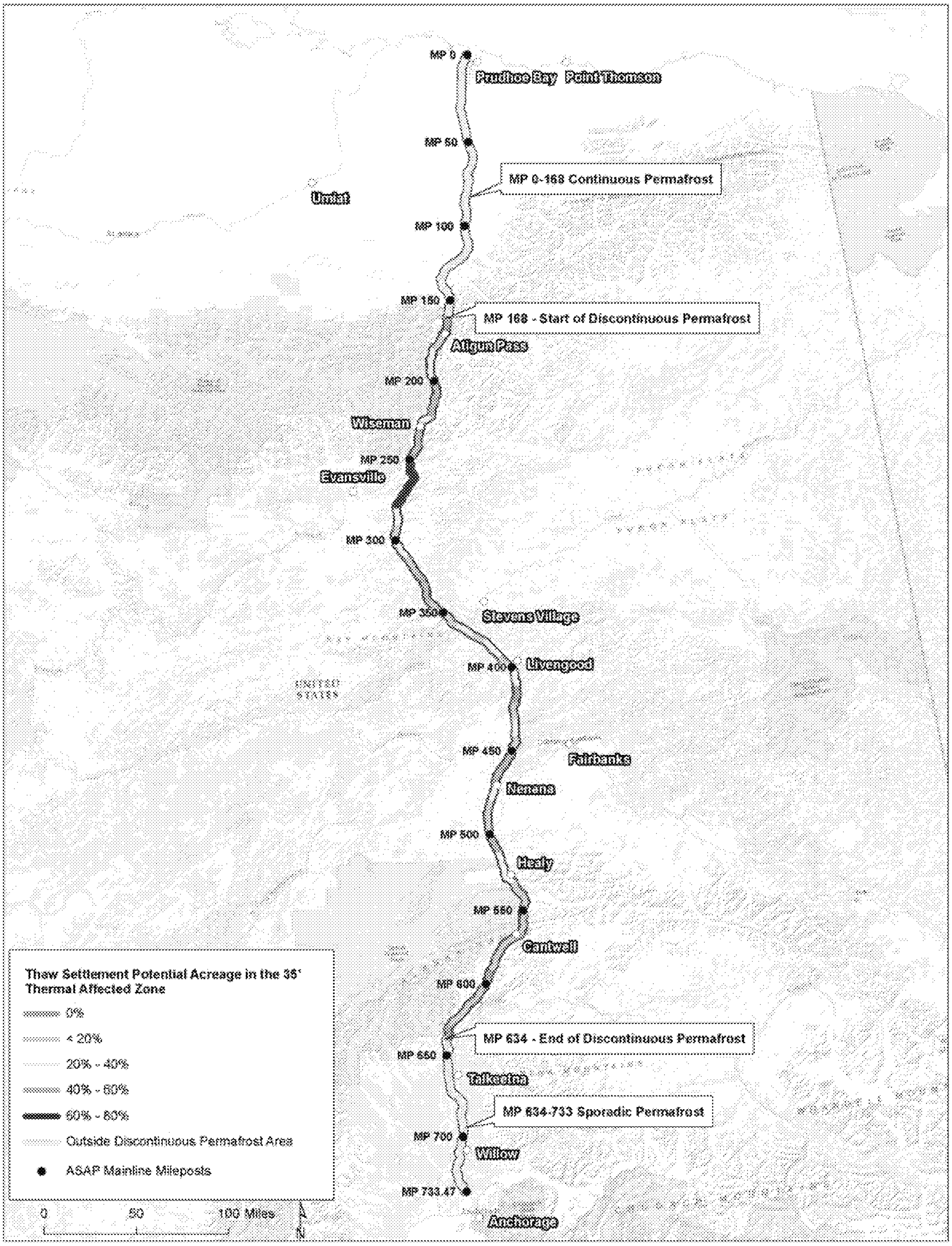
Cowardin Code	Primary Terrain Unit	Thaw Settlement Potential	Acres
PEM	C	High	0.11
PEM	Cs	High	0.08
PEM	Elx	High	0.98
PEM	Fp	Moderate	0.14
PEM	Fpa	Moderate	0.13
PEM	Fpb	Moderate	0.87
PEM	Fpm	Moderate	0.50
PEM	Fpt(ft)	Moderate	0.07
PEM	Fpt-Ca	Moderate	0.93
PEM	Fs	High	28.52
PEM	Fs(ft)	High	1.63
PEM	Fss	High	0.15
PEM	Lt	High	0.17
PEM	O	High	1.13
PFO	Unavailable	Yes - No Terrain Unit Data	5.19
PFO	C	High	0.15
PFO	Ell	High	23.12
PFO	Elx	High	34.02

Cowardin Code	Primary Terrain Unit	Thaw Settlement Potential	Acres
PFO	Fp(ft)	Moderate	0.01
PFO	Fpa	High	0.13
PFO	Fpa	Moderate	1.97
PFO	Fpab-Ca	Moderate	0.26
PFO	Fpab-Rc	Moderate	4.08
PFO	Fpb	Moderate	3.13
PFO	Fpm	Moderate	2.28
PFO	Fps	Moderate	21.57
PFO	Fpt	Moderate	0.39
PFO	Fpt(ft)	Moderate	0.02
PFO	Fpt-Ca	Moderate	0.70
PFO	Fs	High	49.52
PFO	Fsf	High	4.93
PFO	Fsf(ft)	High	1.20
PFO	Fss	High	36.46
PFO	Fssa	High	5.35
PFO	Lt	High	0.13
PFO	O	High	0.80
PSS	Unavailable	Yes - No Terrain Unit Data	13.68
PSS	C	High	39.37
PSS	Ca	High	3.02
PSS	Cg	High	7.75
PSS	Cl	Moderate	1.43
PSS	Cm	Moderate	5.92
PSS	Cmx	High	0.24
PSS	Cs	High	29.48
PSS	Ell	High	5.99
PSS	Elx	High	69.49
PSS	F(fa)	High	0.09
PSS	Ffs	High	5.13
PSS	Fp	Moderate	2.66
PSS	Fp(ft)	Moderate	0.59
PSS	Fpa	High	15.58
PSS	Fpa	Moderate	8.67
PSS	Fpab	Moderate	0.47
PSS	Fpab-Ca	Moderate	11.78
PSS	Fpab-Rc	Moderate	0.11
PSS	Fpb	Moderate	20.98
PSS	Fpm	Moderate	7.50
PSS	Fpt	Moderate	1.30
PSS	Fpt(ft)	Moderate	11.19
PSS	Fpt-Ca	Moderate	30.31
PSS	Fpt-Ho	Moderate	14.29
PSS	Fpt-Rc	Moderate	10.26
PSS	Fpw	High	0.31

Cowardin Code	Primary Terrain Unit	Thaw Settlement Potential	Acres
PSS	Fs	High	396.03
PSS	Fs(fa)	High	0.66
PSS	Fs(ft)	High	1.41
PSS	Fsf	High	3.11
PSS	Fsf(ft)	High	0.45
PSS	Fss	High	38.94
PSS	Fssa	High	16.52
PSS	GU	High	7.54
PSS	Hs	High	0.02
PSS	Lt	High	0.67
PSS	O	High	23.39
		TOTAL	**1,037.20**
This table shows the acreage within the Thaw Affected Zone where wetlands have a thaw potential and terrain units have a high or moderate thaw settlement potential. In the absence of terrain unit data, the wetlands alone indicate thaw potential. The data are grouped by Cowardin Code.			

The areas of land having thaw settlement potential, equating to a total of 1,037.2 acres within the TAZ, were found to be concentrated more heavily in some portions of the route than in others in the discontinuous permafrost region. To display this graphically, the area of land having thaw settlement potential inside the TAZ was divided by the total area of the TAZ in 10-mile increments between MP 160 and MP 640; the resulting percentages of thaw settlement potential in the discontinuous permafrost region were then mapped in 10-mile segments (Figure 26). The area with the highest percentage of thaw settlement potential (60 - 80%) existed between MP 250 – 280. Areas with moderately high percentage of thaw settlement potential (40 – 60%) existed between the ranges of MP 200 – 220, MP 240 – 250, MP 320 – 340, MP 450 – 470, and MP 500 – 510.

Figure 26. Relative Indirect Thaw Settlement Potential for Discontinuous Permafrost



7. MITIGATIVE OPTIONS

The following procedures may be employed to ensure that ROW integrity is maintained through all phases of the pipeline – Design, Construction and Operations. The following sections describe how each phase is deployed to undertake this mission so as to ensure integrity for the life of the project, employing, as required, mitigative measures for potential thermal impacts outside the ROW.

7.1 DESIGN

At this earliest phase of the project, the procedures for alignment selection are the most important to ensure minimal impact to the environment. Two guiding principles of special interest in the routing guidelines include the requirements to minimize routing through streambeds and wetlands. A large number of the latest rerouted segments in the current alignment are directly attributable to review of route wetlands and moves to adjacent segments that have no, or lessened, wetlands impact.

Another routing guideline of importance in this discussion is choice of routing segments that avoid, or minimize the impact of, potential geohazards; that is, hazards presented to the pipe and/or ROW by naturally occurring route features or those that may be altered by the project. Some of these geohazards are evident from surface traits such as earthquake fault traces and potential slope stability areas. Others, however, and as discussed in this report, as well as AGDC 2016c, are based on subsurface traits and are only discovered after detailed route evaluation and Terrain Unit identification. In many areas, the presence of subsurface frozen soils can be discerned based on the type of vegetative cover and this is a key element of project alignment studies. However, to quantify the magnitude of the hazard, subsurface investigations are conducted to find the frozen extent and the index properties of the soil regime to evaluate the impact.

These route investigations are ongoing throughout design and even into construction as will be seen in the succeeding section. As these investigations continue, potential impact areas are further evaluated and estimates refined to be more site specific. In the meantime, the project makes conservative bounding assumptions. In other words, the route evaluation based on conservative evaluations is further refined as design progresses.

Nevertheless, it is impractical, if not impossible, to avoid every route segment that may be susceptible to greater impacts from project activities and that may further impact wetlands outside the limits of the ROW. In this event, it is important to recognize the potential impact and guard against it using active design measures. The two most important design mitigative measures in this regard are revegetation and adequate surface water control.

7.1.1 Revegetation

Revegetation is the primary method for stabilization of frozen subsurface soils. The design of an active revegetation plan to restore the ground surface characteristics to the in situ condition, or an analogous condition would impede subsurface thaw. In this regard, a *Revegetation Plan* (AGDC 2016e) has been developed for the Project through efforts of the State of Alaska's Plant Material Center. The plan describes appropriate seed mixes and best practices for revegetation and soil stabilization based on the climate zones of the project.

7.1.2 Best Practice for Surface Water Control

The other design item to mitigate thaw depth progression and settlement is to employ active measures to intercept surface water flow and prevent sheetflow across and down the ROW. Surface water can be a serious erosional measure that can accelerate ROW settlement and impede other mitigative measures. The measures to control sheetflow at this time are identified, although their specific placement and sizing along the ROW requires site-specific definition during final design and even into the later project phases of Construction and Operations as discussed in succeeding sections. It is evident from experience and review of trial trenching programs that inattention to this design aspect can lead to serious erosional problems that become increasingly difficult to rectify. This topic is described in greater detail in AGDC 2016b.

7.1.3 Temperature Control

Another potential design that might be considered in some specific areas is temperature control. The most common method of temperature control along the ROW limits would be the use of thermosyphons (a.k.a. heat pipes) if the local climate is conducive to their use as described in AGDC 2016b,c. thermosyphons can mitigate thawing and stabilize thaw settlement by freezing the recently thawed ground. For the most part, however, this option is more effectively employed during Operations where site-specific monitoring can designate according site-specific requirements.

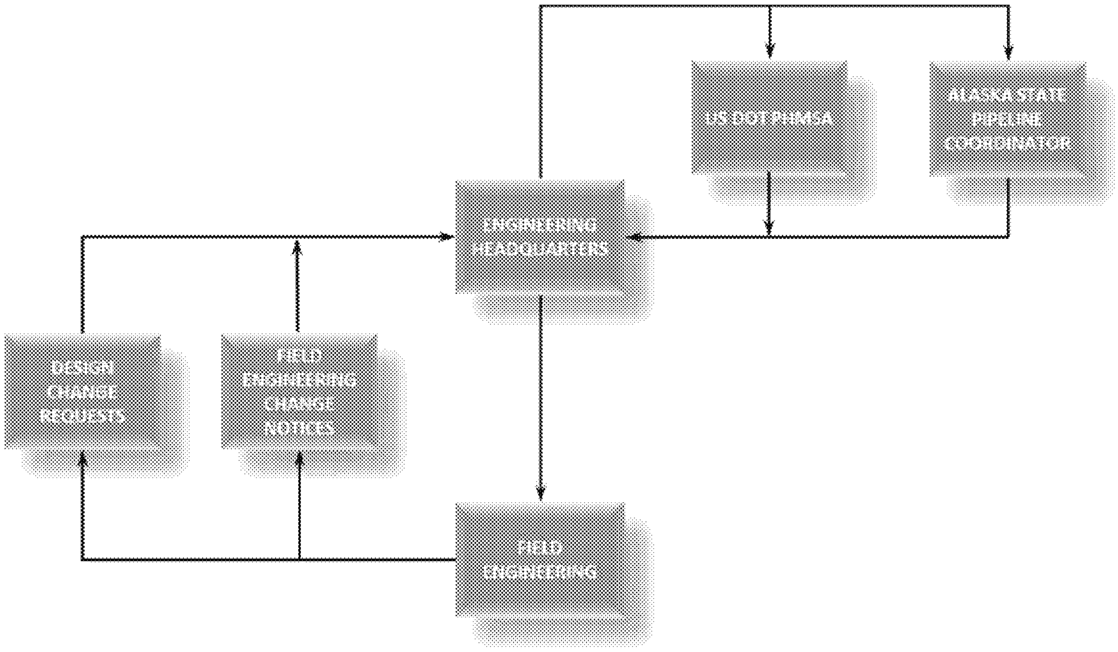
7.2 CONSTRUCTION

While the goal of the design process is to identify as accurately as possible areas where thaw settlement may be an issue, it is acknowledged there could be instances where installation conditions differ from those anticipated by design, thus requiring site-specific considerations. To address this potential scenario, the use of a field design change procedure to evaluate such areas in a timely fashion is employed. This follows the experience of TAPS Construction, as well as current North Slope Construction practices.

7.2.1 Field Design Change Procedure

A schematic of the design change control system is presented in Figure 27. This system is established to specify lines of communication, including communication with government review agencies where needed and as noted in the Figure. Depending on the circumstances of the route condition uncovered, the actionable review agency and the appropriate response procedures would differ. For issues related to pipe integrity, the USDOT PHMSA would be considered a key agency and, accordingly, issues such as a localized karst condition under the pipe centerline would require coordination with PHMSA and perhaps active coordination with the SPCO. For issues related to water crossings or ROW conditions involving wetlands, several agencies would need to be consulted.

Figure 27. Design Change Control System



7.2.2 Potential Mitigative Options during Construction

For Construction, the alignment is already well established, so rerouting outside of the detailed final alignment is not a viable option. The mitigative options are then limited to those physical measures which could be adopted during the Construction phase including:

- Micro Reroute – in some cases, the field conditions encountered might be very site specific and limited. In this case, potential reroute of the ROW pad within the lateral limits of the construction ROW, could limit expected disturbance.

- Overexcavate and replace thaw unstable material – this technique may be a viable method in some locations; the material would be excavated and removed, and foreign material imported, requiring the mining and importation of additional select fill material to backfill the removed material. This technique could be employed in areas where very high displacement strains in near surface soils are evident, such as massive ice in a near surface strata but below the active layer.

The following options would be considered in extraordinary and specific conditions since they would certainly require new materials, increased field scrutiny, and additional construction delay. Nevertheless, they are included here for completeness:

- Install localized thermosyphons, which are passive heat pipes designed for installation in select locations along the edge of the ROW to provide a thermal curtain and limit impact. Their use is discussed and depicted in AGDC 2016b,c.
- Install localized active refrigeration, such as a mechanically driven equipment that would refrigerate sections of the ground around permanent facilities where a power supply is available (e.g., use of a design similar to TAPS Pump 1 brine system)
- Workpad insulation.

7.3 OPERATIONS

The active evaluation of potential hazards to the ROW and potentially beyond the ROW, do not end with Construction. Active monitoring will be required throughout the design life, with a special focus on the early years of Operations for ROW thermal impacts since, as seen in Chapter 2. The thermal impact of the more egregious segments requiring focus should be readily evident during the early years after Construction, while the impact should level off after continued Operations.

7.3.1 Right-of-Way Monitoring Program

For operations, the evaluation of the current state of the ROW surface using monitoring information largely supplants the predictive methodologies used during the design process, and the direct evaluation of the ROW during Construction as it is being altered.

Monitoring and intervention during operations are needed to ensure ROW integrity. Even for a well-executed design based on good design tools and good input data, the overall probability of criteria exceedance for the entire pipeline ROW over the design life is non-negligible and requires continued scrutiny. Monitoring is for all hazards and not just for settlement. Unusual conditions can occur along the alignment that are more severe than selected for design, such as unexpected high water conditions or adjacent landowner activity. A project must be prepared for all eventualities during operation.

Operating experience for TAPS has clearly shown the need for such monitoring and intervention. Linewalks are an integral, and required, part of any pipeline operational plan. In the arctic especially, personnel are instructed to be aware of such surface features that may portend surface movement or other threats to integrity such as evidence of change in surface water drainage patterns, sloughing or mounding of soil, or open lateral cracking in the soil. All areas which have been mitigated during Operations will continue to be monitored for any additional issues.

7.3.2 Potential Mitigative Options during Construction

Many of the options available during Construction are also available during Operations. There is a distinct advantage in employing such options during Operations in that site-specific direct evidence is available to guide the type and extent of the options.

Surface-leveling is one possible form of intervention/mitigation that can be employed should the ROW need to be elevated from a settlement condition. New backfill material is placed in the area to be re-leveled. Care must be employed, however, to ensure that the surface characteristics are not adversely affected to further advance thaw progression.

7.4 SUMMARY

The mitigation measures employed during operations of the pipeline to mitigate thaw settlement are believed to either reduce or eliminate the impacts to wetlands in the thaw-affected zones on the outside edge of the pipeline right of way. Further, direct monitoring and mitigative options, outlined in this section, can further reduce wetlands impacts.

8. CONCLUSIONS

Ground surface disturbances during construction can cause changes in heat energy balance that could impact wetlands indirectly, outside of the project ROW. At the request of the USACE, AGDC directed its subject matter experts to carry out additional geothermal and thaw depth modeling, as well as additional wetlands analysis, to determine where changes to surface heat energy balance could occur and where wetlands could potentially be impacted within an indirect TAZ.

In continuous permafrost terrain at MP 0 the gas treatment plant will deliver gas with a year-round constant gas temperature of 30°F, which is slightly warmer than the local mean annual ground temperature of about 21°F. This will warm the permafrost around the pipe at MP 0 and will cause the active layer depth to increase in the vicinity of the pipe in this area. Ground surface disturbance at the trench on the North Slope will also contribute to slightly warmer permafrost temperatures in the vicinity of the trench. Geothermal modelling showed that the maximum annual thaw depth (active layer depth) above the pipe and at the edge of the trench (2.5ft from pipe centerline) is expected to be about 3.1ft. For comparison, the model-computed active layer depth in undisturbed terrain was 1.6ft. At MP 0 the maximum active layer depth at distances from the centerline of 5ft, 10ft and 20ft are 2.3ft, 1.9ft, and 1.7ft, respectively. The model showed that beyond 20ft from the pipe centerline, the pipe and trench have practically no influence on the active layer depth.

In discontinuous permafrost terrain, the thermal influence of the gravel pad extends beyond the edge of gravel pad by about 26ft and 33ft in the cases with and without an organic layer below the gravel pad, respectively. For assessment of indirect impacts to wetlands, a conservative distance of 35ft adjacent to the ROW was used to define an indirect TAZ. Minimal or negligible indirect impacts were expected in the more southerly sporadic permafrost area.

Existing terrain unit classifications and their thaw settlement susceptibilities, along with other geophysical data, were used as part of the methodology for determining potential wetland impacts in discontinuous permafrost. AGDC's geothermal subject matter experts assigned conservative set of criteria to terrain unit classifications with respect to thaw susceptibility to focus subsequent wetlands analyses on where thaw susceptible soils would potentially occur in the indirect TAZ. AGDC documented where a high or moderate thaw settlement potential exists under wetlands. Within the indirect TAZ, AGDC's wetlands subject matter experts applied a conservative set of criteria to further delineate which wetlands were susceptible to be impacted through subsidence or drainage as a result of indirect permafrost thaw.

Based on this comprehensive analytical screening process, AGDC's geothermal and wetlands subject matter experts determined that, without monitoring or mitigation, a maximum of 1,037.20 acres of wetlands could potentially be indirectly impacted over a 30-year period by thawed permafrost resulting from ground disturbance during construction of ASAP. However, an extensive monitoring program and mitigative options are planned to ensure that, like other belowground pipelines, any indirect impacts to permafrost and wetlands are minimized and avoided to the extent practicable.

Additional impacts to permafrost that are projected as the result of climate change are discussed in a separate report, entitled, 'Effect of Climate Warming on Expected Long-Term Thaw Depths on the ASAP Right-of-Way, Alaska Stand-Alone Pipeline Project' (Matrix Solutions 2017).

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ATTACHMENT 1 - EXPECTED LONG-TERM THAW DEPTHS IN COLD PERMAFROST ON THE ASAP RIGHT-OF-WAY, ALASKA STAND ALONE PIPELINE

Matrix Solutions Inc.
ENVIRONMENT & ENGINEERING

TECHNICAL MEMORANDUM

TO: Keith Meyer, Pipeline Engineering Manager, Alaska Gas Development Corp.
Scott Lust, Pipeline Engineer, Alaska Gas Development Corp.

FROM: Ron Coutts, Senior Geological Engineer, Matrix Solutions Inc.

RE: Expected Long-Term Thaw Depths in Warm Permafrost on the ASAP Right-of-Way, Alaska Stand-Alone Pipeline Project

DATE: July 12, 2016

1. INTRODUCTION

Thermal modeling was undertaken to determine the expected 30-year thaw depths across the ASAP pipeline right-of-way (ROW). In addition it was also necessary to assess thaw beyond the edge of the ROW in adjacent undisturbed terrain.

It is understood that information presented in this report will be passed along for review by the U.S. Army Corps of Engineers.

2. TECHNICAL OVERVIEW

Long-term ground temperatures, as characterized by mean annual ground temperature (MAGT), are a result of heat energy exchange between the ground and the above ground environment at the ground surface. The significant energy exchange components at the ground surface are solar radiation, longwave radiation emitted from the ground and snow surface, convective heat transfer with atmospheric air, and evapotranspiration from surface water evaporation and plant transpiration.

Ground surface properties such as summer and winter albedo (surface reflectivity) and evapotranspiration factor affect the net energy flux at the ground surface. For example, summer and winter albedo values, which each range from 0 to 1, affect the amount of solar radiation that is absorbed at the ground and snow surfaces respectively. An albedo value of 0.85 for snow represents 85% reflectance of solar radiation, and correspondingly, 15% absorption of solar radiation at the snow surface. Evapotranspiration factor, which also ranges from 0 to 1, quantifies the degree to which latent heat energy at the ground surface is intercepted to vaporize water by evaporation or by plant transpiration.

A surface energy balance (SEB) model for heat energy exchange at the ground surface developed by Hwang, 1976, was used to determine the net heat energy flux at ground surface nodes in a geothermal modeling finite element analysis (FEA) of heat transfer in the soil. The FEA tool used was TEMP/W (Geo-Slope 2016).

Ground surface properties of summer albedo and evapotranspiration factor were varied in the SEB model to simulate ground surface disturbances such as tree clearing, the gravel pad surface on the pipeline right- of-way (ROW), and revegetation of ground surfaces disturbed during construction and which are beyond the permanent ROW width.

This technical memo summarizes the geothermal model setup and long-term (30-year) thaw depth results calculated from geothermal modeling. The model conditions are representative of a warm permafrost area near Fairbanks with a mean annual ground temperature of 31.1°F and with ground surface disturbances on the ROW from tree clearing and gravel pad placement.

3. GEOTHERMAL MODEL SETUP

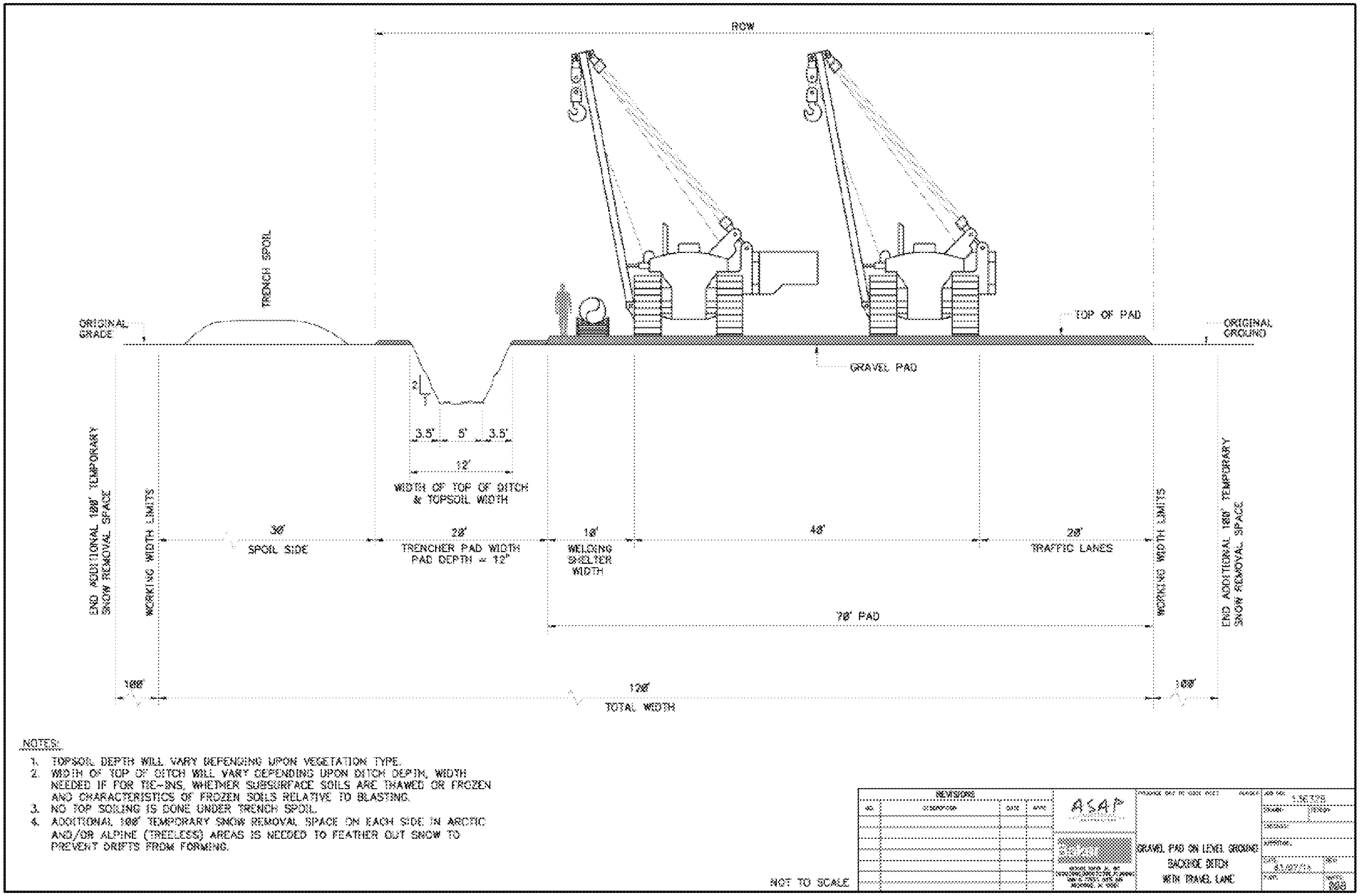
3.1 Domain Geometry

As shown in Figure 1, the typical pipeline ROW configuration in discontinuous permafrost is planned to be 120ft wide. This includes an 18in thick, 70ft wide gravel pad on one side of the pipe centerline, and a 30ft wide cleared area for trench spoil, each setback 10ft from the pipe centerline. After one construction season, the permanent ROW is planned to be 53ft wide and centered over the pipe. With time, grasses and shrubs and eventually trees (in originally treed areas along the route) will revegetate the ROW. Young trees growing on the permanent 53ft ROW will be cleared while those beyond the 53ft ROW to the edge of the 120ft temporary construction ROW will grow unhindered.

Figure 2 shows the entire geothermal modeling domain representing the typical ROW cross-section described above. Figure 3 shows a closer view of the soil types and boundary conditions over the 120ft wide construction ROW. Note that the length units in these figures are in meters, not feet, as it was necessary to perform the modeling in metric units due to current limitations in the TEMP/W add-in module that computes the surface energy balance flux boundary conditions at the ground surface.

Undisturbed terrain was modeled using an 8in thick organic peat layer overlaying a fine-grained and ice- rich mineral soil. Cleared terrain occurs on the ROW where trees were cleared and the organics layer is preserved. Equipment operating on the spoil side of the ROW during construction will compress the organic layer somewhat. To simulate this disturbance, the organic soil properties were modified to represent compressed organic peat. The 18in thick gravel pad was modeled as either being placed directly on top of the organic layer (having 'buried' organic soil properties), or, as a bounding case, with no organic layer below the gravel pad. The 36in pipe was buried with 3 feet of cover depth above the pipe.

The finite element mesh over the entire domain geometry is shown in Figure 4 and included 4721 nodes and 4621 elements. The highest temperature gradients within the modeling domain are near the pipe and downward from the ground surface. In these areas a higher node/element mesh density was used as shown in Figure 5.



NOTES:

1. TOPSOIL DEPTH WILL VARY DEPENDING UPON VEGETATION TYPE.
2. WIDTH OF TOP OF DITCH WILL VARY DEPENDING UPON DITCH DEPTH, WIDTH NEEDED IF FOR TIE-INS, WHETHER SUBSURFACE SOILS ARE THAWED OR FROZEN AND CHARACTERISTICS OF FROZEN SOILS RELATIVE TO BLASTING.
3. NO TOP SOILING IS DONE UNDER TRENCH SPOIL.
4. ADDITIONAL 100' TEMPORARY SNOW REMOVAL SPACE ON EACH SIDE IN ARCTIC AND/OR ALPINE (TREELESS) AREAS IS NEEDED TO FEATHER OUT SNOW TO PREVENT DRIFTS FROM FORMING.

Figure 1 Typical ROW in Discontinuous Permafrost

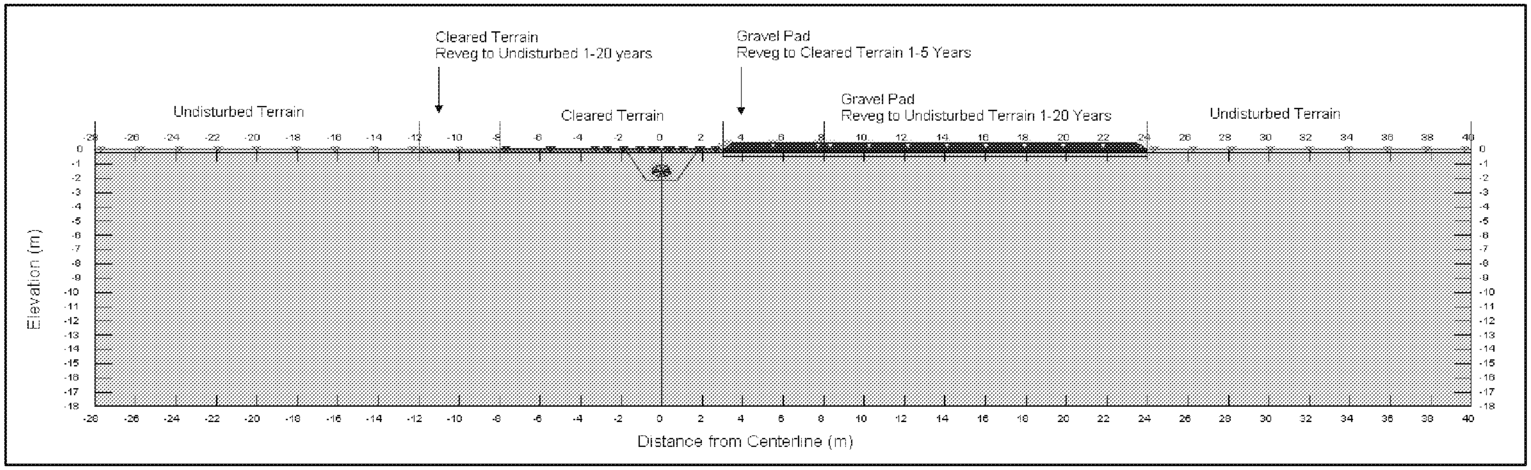


Figure 2 **Geothermal Modeling Domain**

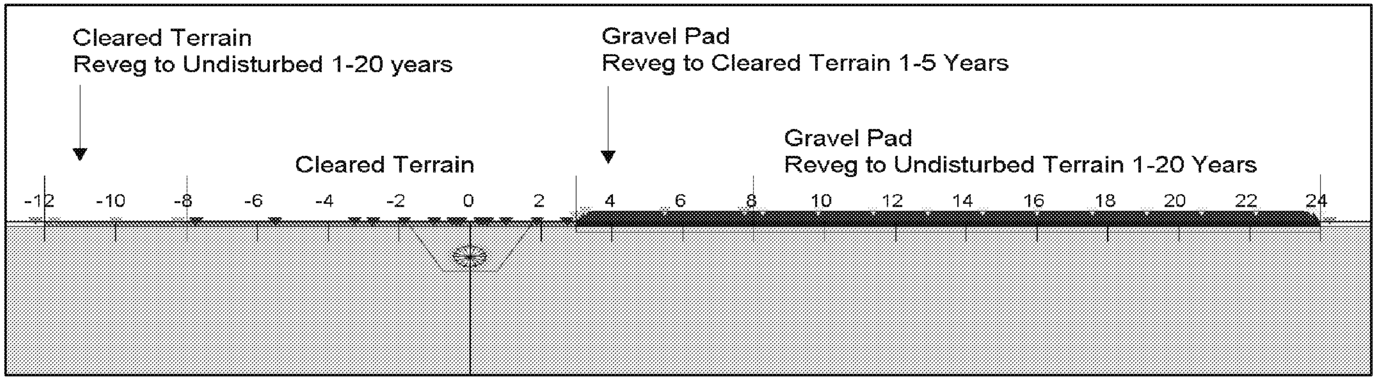


Figure 3 **Soil Types and Boundary Conditions**

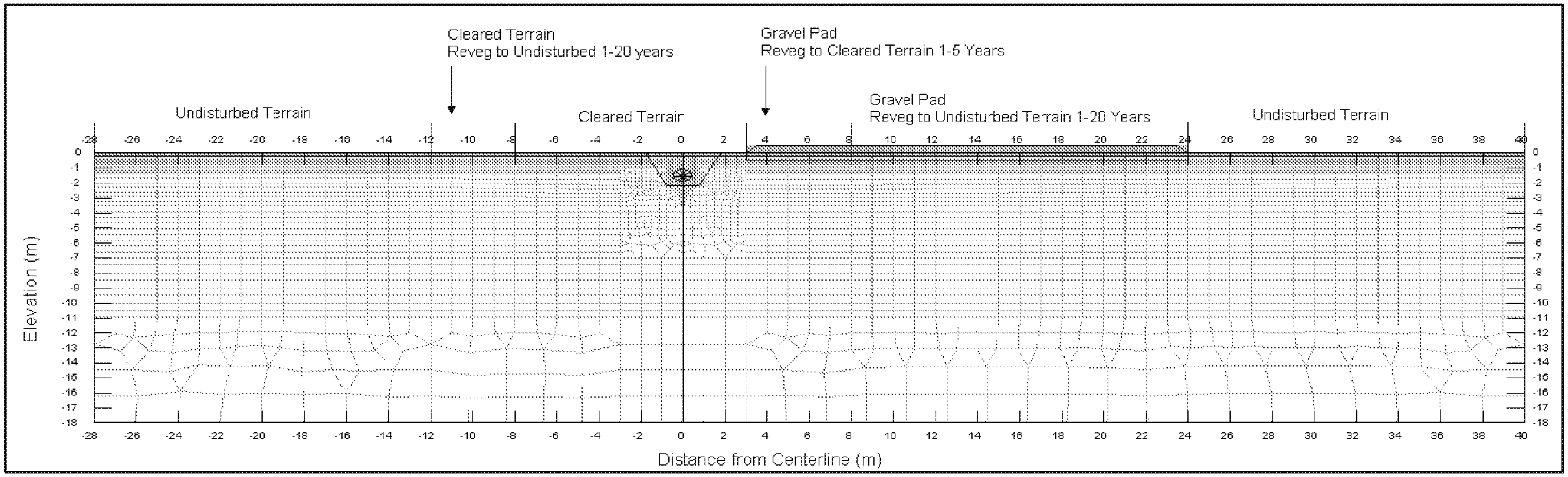


Figure 4 Finite Element Mesh

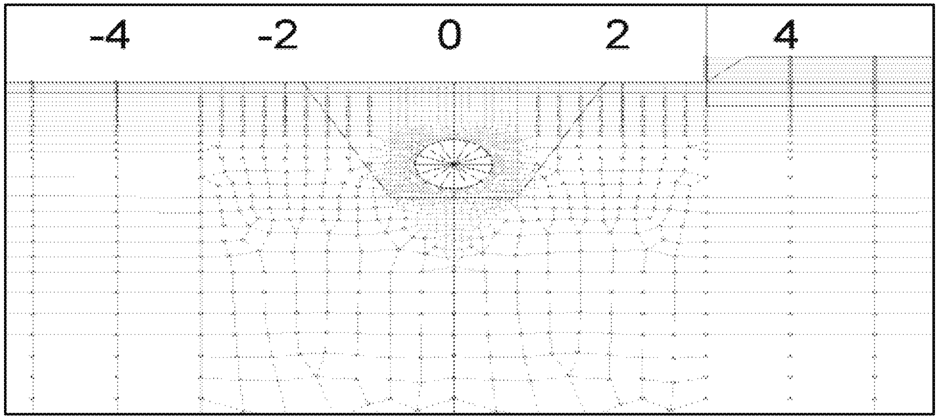


Figure 5 Finite Element Mesh near Pipe

3.2 Material Properties

Table 1 shows soil property parameters for water saturated fine-grained mineral soil at two moisture contents, for organic soils which are undisturbed, compressed and buried, and for the gravel pad material. For the modeling reported herein, 35% moisture content was used for the fine-grained mineral soil which is representative of ice-rich permafrost.

A constant snow thermal conductivity of 0.29 W/m-°C was used for all analyses and was determined by model calibration as discussed later.

Table 1 Soil Properties

Parameter	Sat. Silt & Clay Soil w=35%	Sat. Silt & Clay Soil w=25%	Organic Soil w=200%	Compressed Organic Soil w=150%	Gravel Pad w=10%	Buried Organic Soil w=140%	Unit	Description
Gs	2.67	2.67	1.4	1.4	2.67	1.4	--	specific gravity of solids
n	0.48	0.40	0.76	0.70	0.25	0.66	m3/m3	porosity
S	1.00	1.00	0.90	0.90	0.80	1.00	m3/m3	saturation
w	0.35	0.25	2.04	1.50	0.10	1.40	g/g	gravimetric water content
A	0.100	0.100	0.050	0.050	0.030	0.050	--	unfrozen water content at -1 C
B	-0.300	-0.300	-0.700	-0.700	-0.700	-0.700	--	unfrozen water content function exponent
Ku	1.20	1.40	0.40	0.43	2.70	0.60	J/(s*m*C)	unfrozen thermal conductivity of soil
Kf	2.00	2.00	0.90	0.87	3.20	2.90	J/(s*m*C)	frozen thermal conductivity of soil
L	3.34E+08	3.34E+08	3.34E+08	3.34E+08	3.34E+08	3.34E+08	J/m3	latent heat of water
Cw	4.187E+06	4.187E+06	4.19E+06	4.187E+06	4.187E+06	4.187E+06	J/(m3*C)	heat capacity of water
Ss	0.17	0.17	0.4	0.4	0.17	0.4	--	specific heat capacity of solids
Cu/Cw	0.696	0.651	0.828	0.741	0.540	0.810	--	unfrozen heat capacity of soil relative to water
Cf/Cw	0.463	0.457	0.482	0.449	0.440	0.495	--	frozen heat capacity of soil relative to water
pdry	1350	1550	340	390	2000	450	kg/m3	dry density of soil
pwat	1000	1000	1000	1000	1000	1000	kg/m3	density of water
theta	0.48	0.40	0.68	0.63	0.20	0.66	--	volumetric water content of soil
Ku	103.7	121.0	34.6	37.2	233.3	51.8	kJ/(d*m*C)	unfrozen thermal conductivity
Kf	172.8	172.8	77.8	75.2	276.5	250.6	kJ/(d*m*C)	frozen thermal conductivity
Cu	2915	2724	3467	3103	2260	3390	kJ/(m3*C)	unfrozen heat capacity
Cf	1938	1913	2018	1878	1842	2072	kJ/(m3*C)	frozen heat capacity
L	3.34E+05	3.34E+05	3.34E+05	3.34E+05	3.34E+05	3.34E+05	kJ/m3	latent heat of water

3.3 Climate Data

Table 2 provides mean monthly climate normals for Fairbanks. These data were used in the surface energy balance model to determine the net heat energy flux into or out of the ground surface at each node in the thermal model at each time step.

Table 2 Fairbanks Climate Data

Month	Air Temp (°C)	Air Temp (°F)	Wind Speed (km/h)	Wind Speed (mph)	Solar Radiation (W/m^2)	Solar Radiation (BTU/hr/ft^2)	Snow Depth (cm)	Snow Depth (ft)
January	-23.9	-11.0	4.7	2.9	7.7	2.4	46.2	1.52
February	-19.4	-2.9	6.1	3.8	34.4	10.9	58.0	1.90
March	-12.8	9.0	7.9	4.9	103.6	32.8	50.8	1.67
April	-1.4	29.5	10.4	6.5	182.6	57.9	25.7	0.84
May	8.4	47.1	12.2	7.6	227.6	72.1	0.0	0.00
June	14.7	58.5	11.2	7.0	248.9	78.9	0.0	0.00
July	15.4	59.7	10.4	6.5	216.0	68.5	0.0	0.00
August	12.4	54.3	9.7	6.0	156.4	49.6	0.0	0.00
September	6.4	43.5	9.7	6.0	92.0	29.2	0.0	0.00
October	-3.2	26.2	8.6	5.3	39.7	12.6	4.0	0.13
November	-15.6	3.9	6.1	3.8	13.6	4.3	18.1	0.59
December	-22.1	-7.8	5.0	3.1	2.9	0.9	32.3	1.06

3.4 Boundary Conditions

At the ground surface, the net heat energy flux into or out of the ground was calculated at each ground surface node of the finite element model at each time step using a surface energy balance model based on Hwang, 1976.

Ground surface properties for undisturbed terrain, the cleared ROW terrain, and the gravel pad surface are shown in Table 3. Ground surface disturbance for the cleared terrain was simulated by varying the summer albedo and evapotranspiration factors. These values have been shown to reproduce the long- term thaw depths observed at the Fairbanks Surface Disturbance Test site (Linell 1973 and Douglas et. al. 2008), however those results are beyond the scope of this document.

The side boundaries and bottom boundaries were zero-flux boundaries. As such, the geothermal model calculated the temperatures at these boundaries. The side boundaries are far enough away from the thermal disturbance of the ROW that there is no horizontal heat transfer at the sides of the modeling domain. A small non-zero geothermal heat flux could have been included at the bottom boundary, however it was not because it does not significantly affect the calculated temperatures at the relatively small scale depths here, which are on the order of tens of feet. In addition, the geothermal heat flux is very small relative to the net heat flux from energy exchange at the ground surface. Including the geothermal flux would therefore add unnecessary complexity to the model.

To simulate revegetation on the ROW, ground surface properties of summer albedo and evapotranspiration factor were linearly varied over a specified time period from their values during construction to their long-term values. For example, the cleared terrain on the spoil side of the ROW outside of the 53ft permanent ROW was simulated to revegetate from cleared terrain (during construction) to undisturbed terrain over an elapsed time period from 1 to 20 years. Similarly, the gravel pad outside of the 53ft permanent ROW was simulated to revegetate to undisturbed terrain over the same time period, 1 to 20 years. The gravel pad within the permanent 53ft ROW was simulated to revegetate to cleared terrain over a time period from 1 to 5 years. The cleared terrain on the spoil side of the ROW and above the pipe trench was simulated to remain unchanged as cleared terrain throughout the entire simulation period of 30 years.

Table 3 Ground Surface Properties

Terrain	Summer Albedo	Winter Albedo	Evapotransp Factor
Undisturbed (trees)	0.65	0.85	0.65
Cleared	0.08	0.85	0.30
Gravel Pad	0.07	0.85	0.20

Pipe temperature boundary conditions were obtained from hydraulics modeling (Baker, 2015) from ASAP pipeline milepost 440 near Fairbanks. The maximum, minimum and average pipe temperatures at MP440, used in the modeling reported herein, were 22.7°F, 42.4 °F and 32.4°F, respectively. From previous thaw depth analyses for pipe integrity, it was observed that the pipe temperatures from this set of hydraulics runs may be warm by 2°F to 3°F, which may have been the result of some conservatism in the hydraulics analysis regarding maximum gas throughput. In any event, the pipe temperatures may be slightly conservative for the thaw depth analysis presented herein but are inconsequential to maximum thaw depths on the ROW which are too far from the pipe to be influenced by it.

3.5 Model Calibration

The geothermal model was calibrated such that it would reproduce a MAGT of 31.1°F (-0.5°C) in undisturbed terrain. This is representative of warm permafrost in the Fairbanks area.

A series of one-dimensional (1D) model runs using an undisturbed soil profile was performed. For each run, a constant (time-invariant) snow thermal conductivity was used and the model was run to periodic steady-state (approximately 10 years). This technique was used to find the snow thermal conductivity value such that the model would produce the target MAGT, in this case 31.1°F for Fairbanks.

4. ROW THAW DEPTH RESULTS

If present, the top layer of organic peat soils provides an insulative layer in permafrost environments. To assess the insulative effect of preserving the organic soil layer beneath the gravel pad, a pair of two- dimensional (2D) geothermal modeling runs were performed with and without a buried organic layer below the gravel pad.

Figure 6 shows the 30-year thaw depth profile across the ROW for the case with a buried organic layer beneath the gravel pad. The edge of the gravel pad is located 24m (80ft) from the pipe centerline. As shown in the figure, the 30-year thaw depth rises towards the edge of the gravel pad and tapers to the active layer depth of the undisturbed terrain at about 32m (105ft) from the pipe centerline, or about 8m (26ft) from the edge of the gravel pad.

Figure 7 shows the 30-year thaw depth profile across the ROW for the case where the organic layer is not present beneath the gravel pad. In this case the 30-year thaw depth beneath the gravel pad is somewhat deeper, and the influence of the gravel pad thaw extents to about 34m (112ft) from the pipe centerline, or about 10m (33ft) beyond the edge of the gravel pad, which is about 2m (7ft) farther than in the case where the organic layer below the gravel pad was present.

Comparison of Figure 6 and Figure 7 shows that the 30-year thaw depths on the spoil side of the ROW are the same in both cases and as one might expect, the presence of the organic layer below the gravel pad does not affect thaw depth on the spoil side of the ROW.

Figure 8 shows the variation with time of the deepest thaw depth on each side of the ROW. As stated earlier, the cleared terrain on the spoil side of the ROW outside of the permanent 53ft cleared ROW was simulated to revegetate to undisturbed terrain over years 1 to 20. The gravel pad within the 53ft cleared ROW on the gravel pad side of the ROW was simulated to revegetate to a cleared terrain state over years 1 to 5. Outside the 53ft cleared ROW, the gravel pad was simulated to revegetate to undisturbed terrain (treed) over years 1 to 20. As shown in Figure 8 the maximum 30-year thaw depths on the spoil and gravel pad side of the ROW were calculated to be nominally 18ft and 22ft, respectively.

Figure 9 shows the same thaw depth information as Figure 8 for the case where no organic layer was present beneath the gravel pad. In this case, the 30-year thaw depth is unchanged at 18ft as mentioned earlier. Beneath the gravel pad, the 30-year maximum thaw depth increased to nominally 25ft, an increase of about 3ft from the case where an organic layer was present beneath the gravel pad.

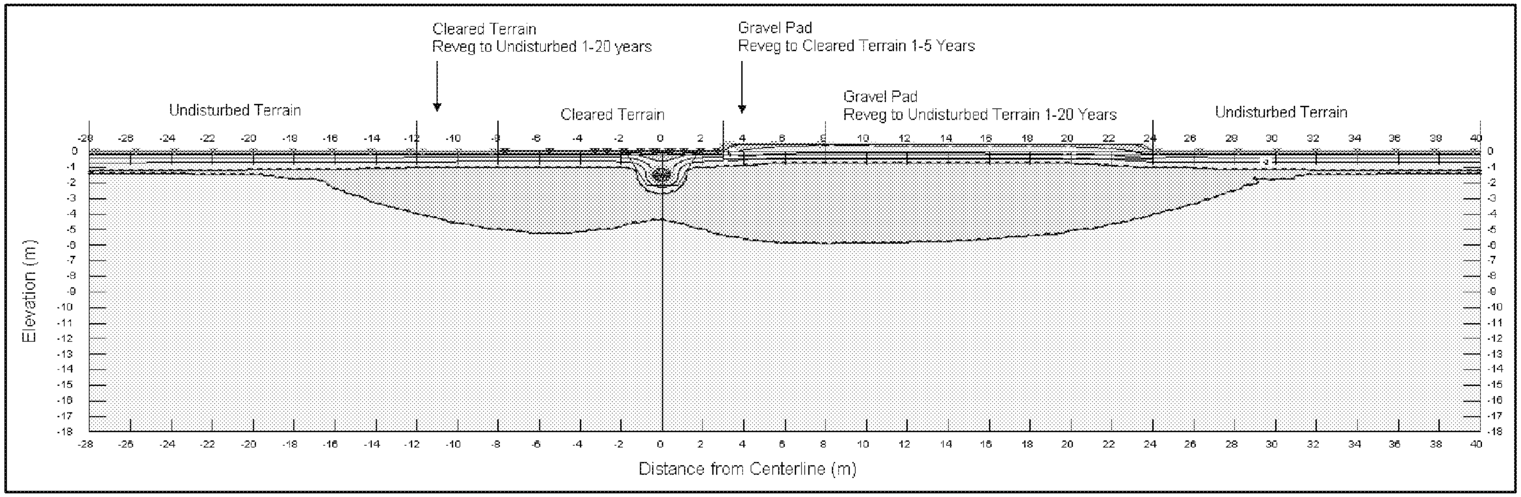


Figure 6 ROW 30-Year Thaw Depth Profile for Case with Buried Organic Layer below Gravel Pad

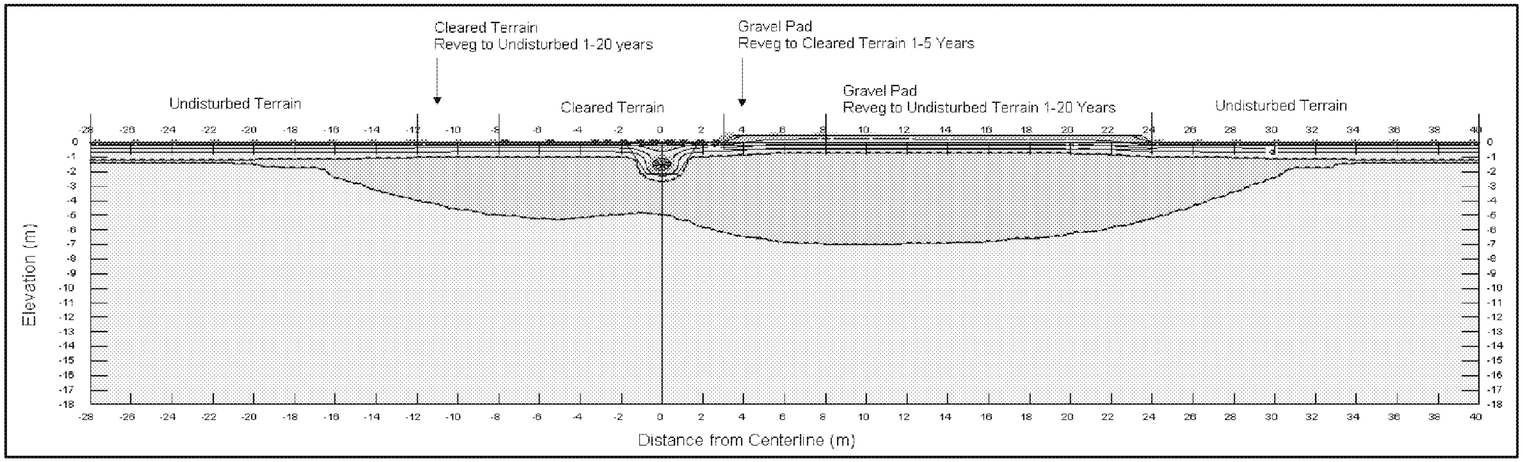
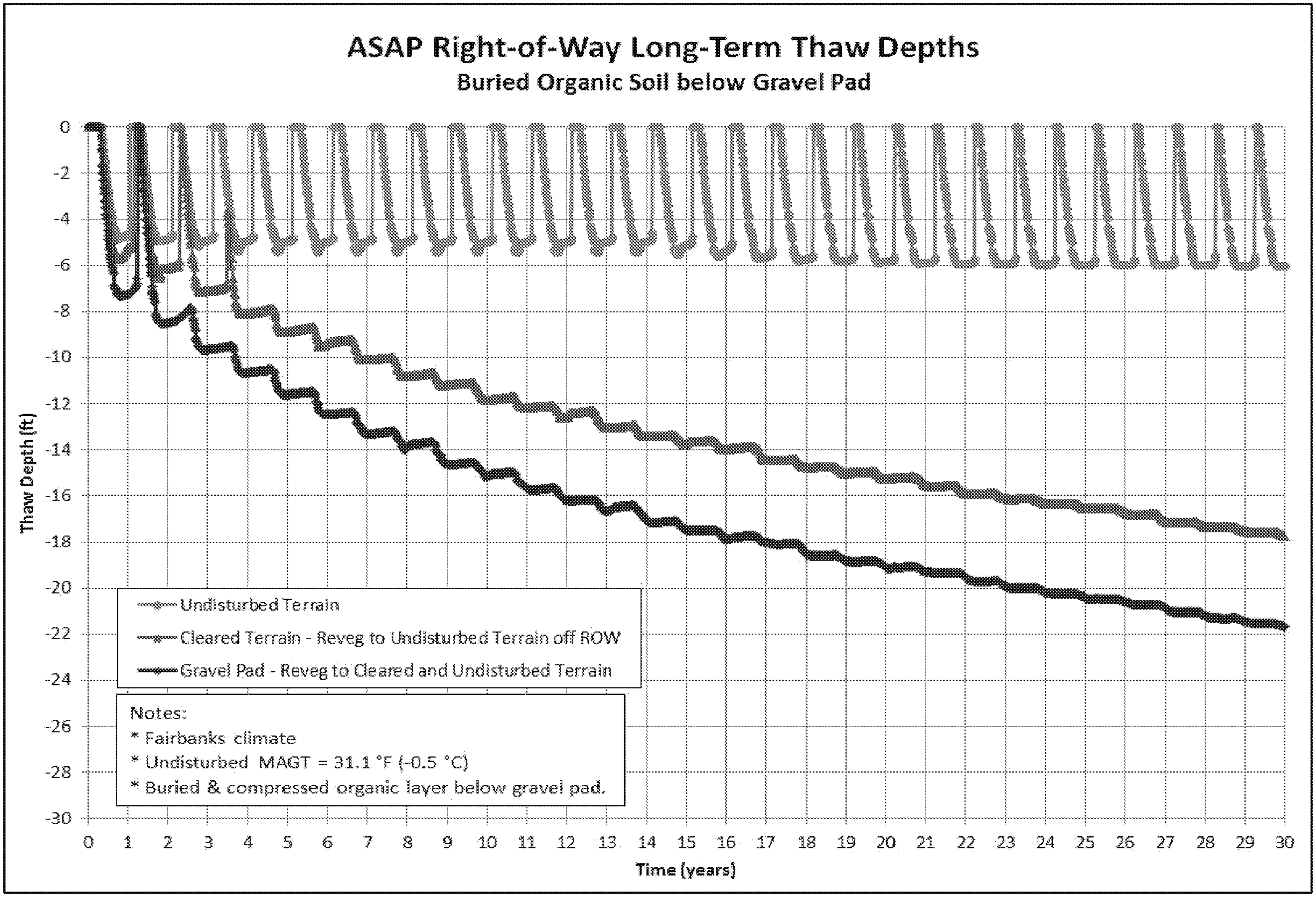


Figure 7 ROW 30-Year Thaw Depth Profile for Case without Buried Organic Layer below Gravel Pad



Notes:
* Fairbanks climate
* Undisturbed MAGT = 31.1 °F (-0.5 °C)
* Buried & compressed organic layer below gravel pad.

Figure 8 ROW Thaw Depths for Case with Buried Organic Layer below Gravel Pad

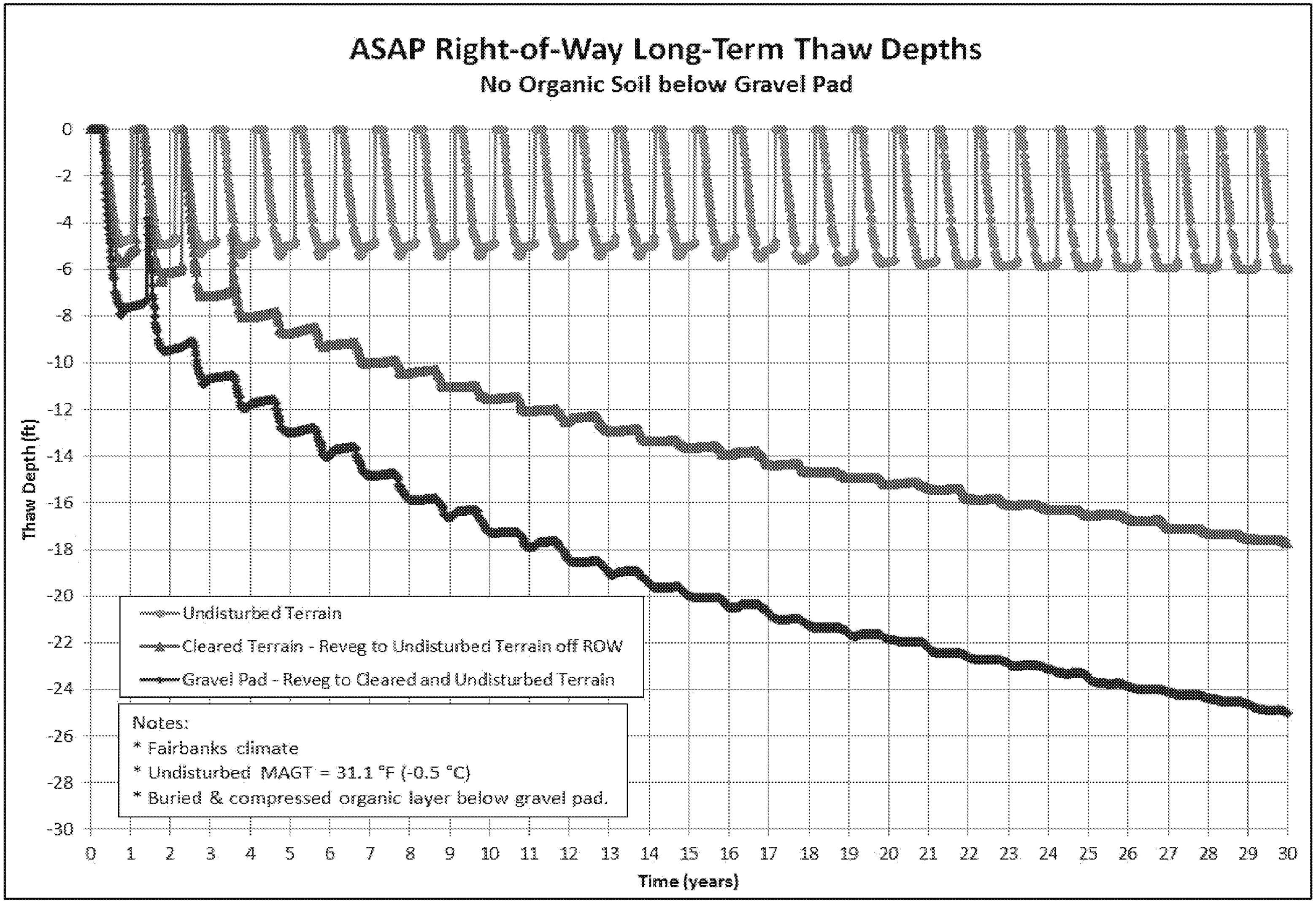


Figure 9 ROW Thaw Depths for Case without Organic Layer below Gravel Pad

5. CONCLUSIONS

The following conclusions were drawn from the thaw depth modeling results presented herein:

- Disturbances to the ground surface during construction and subsequent pipeline operations cause changes to the surface heat energy balance and a corresponding increase to net heat energy flux into the ground at the ground surface. The increase in net energy flux into the ground causes long- term progressive thaw depth deepening that does not freeze back over the winter seasons.

- It is reasonable to expect deeper thaw depth beneath the 18in thick gravel pad compared to the thaw depth beneath cleared terrain. This is a result of higher net energy influx from the gravel pad caused by higher solar radiation absorption and less evapotranspiration of the gravel pad surface compared to the vegetated surface of cleared terrain. For cleared terrain, the 30-year thaw depth was calculated to be 18ft whereas beneath the gravel pad the 30-year thaw depth was calculated to be 22ft to 25ft with and without an organic layer below the gravel pad, respectively.

- The thermal influence of the gravel pad extends beyond the edge of gravel pad by about 26ft and 33ft in the cases with and without an organic layer below the gravel pad, respectively.

6. CLOSURE

We trust that this technical memo suits your present requirements. If you have any questions or comments, please call the undersigned at 403-727-0260.

Yours truly,

MATRIX SOLUTIONS INC.

Ron Coutts, M.Sc., P.Eng. (AB) Senior Geological Engineer

7. REFERENCES

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DISCLAIMER

We certify that this letter report is accurate and complete and accords with the information available at the time the work was undertaken. Information provided by third parties is believed to be accurate but is not guaranteed. We have exercised reasonable skill, care and diligence in assessing the information obtained during the preparation of this letter report.

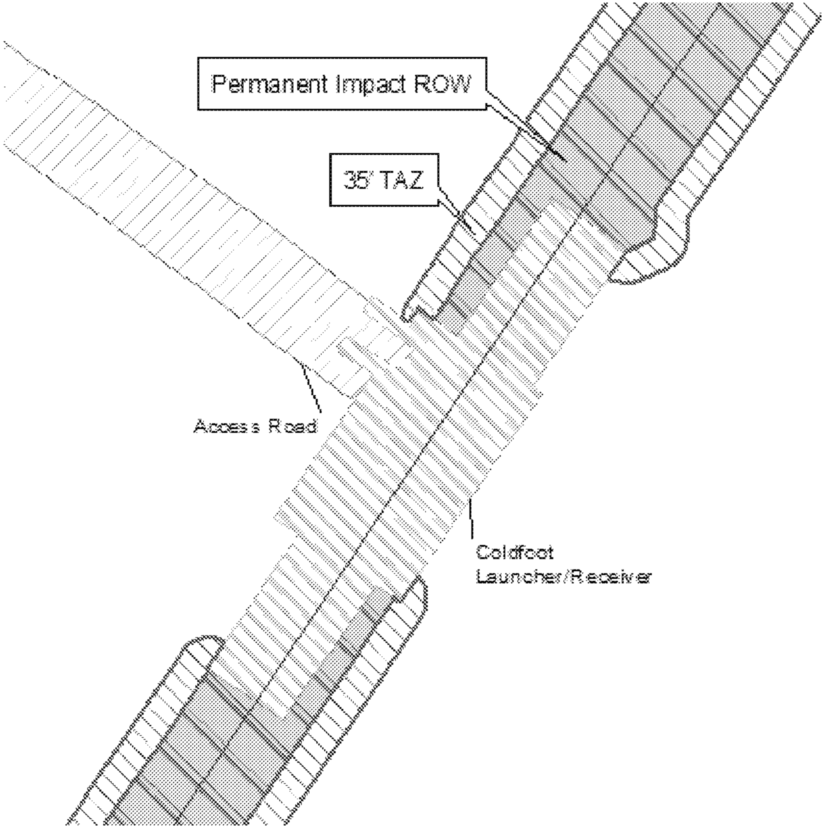
This letter report was prepared for Michael Baker Jr. Inc. and the Alaska Gas Development Corp. The letter report may not be relied upon by any other person or entity without our written consent and that of Michael Baker Jr. Inc. and Alaska Gas Development Corp. Any uses of this letter report by a third party, or any reliance on decisions made based on it, are the responsibility of that party. We are not responsible for damages or injuries incurred by any third party, as a result of decisions made or actions taken based on this letter report.

ATTACHMENT 2 – THAW AFFECTED ZONE GIS METHODOLOGY OVERVIEW

Thaw Affected Zone (TAZ) GIS Methodology Overview

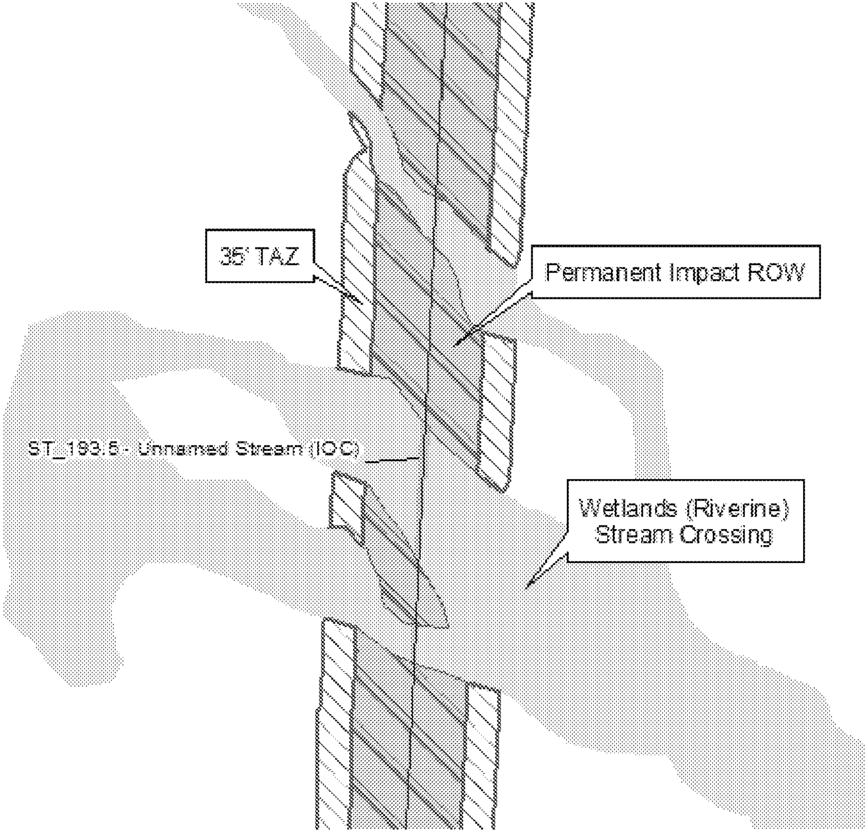
The area of interest is the ASAP Mainline from MP 168-634 and excludes the Fairbanks Lateral. The 35ft indirect Thaw Affected Zone (TAZ) was generated on the outer edge of direct Permanent impact areas within the project ROW. These impact areas included Permanent Construction Impact and HDD Entry/Exit Pad categories. Facility Pads in the ROW (Coldfoot Launcher/Receiver, Fairbanks Lateral Tie-In) did not require generation of a TAZ due to adequate pad thickness, so any TAZ adjacent to facility pads outside the ROW was removed. As the acreage of the facility pads and the Permanent Impact ROW have already been accounted for in the direct wetlands impact footprint, the indirect TAZ never overlaps these areas.

Facility Pad example:



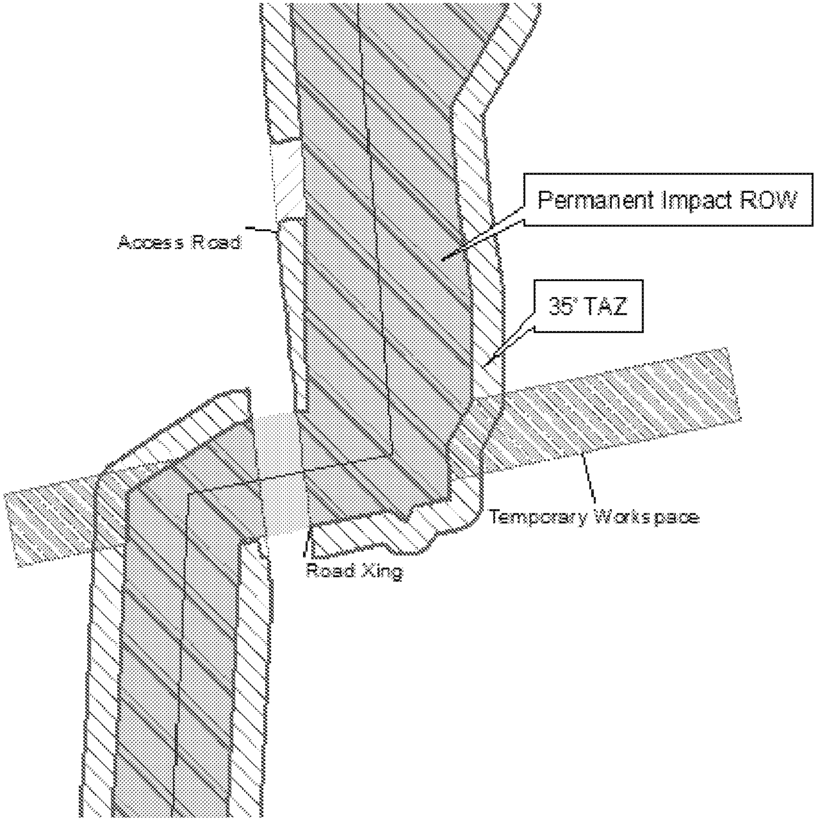
There is no TAZ applied to stream crossing features, which exist as 5' trenches (open cut or isolated open cut), bridges, and horizontal directionally drilled (HDD) crossings. These areas were excluded by trimming in GIS using the wetlands delineation definition for stream crossings. This is the same technique that was used to develop stream crossing features for the project footprint. Any wetlands layer 'ATTRIBUTE' that started with 'R' represented a stream crossing. These included HGM CLASS 'Riverine' and Cowardin codes 'Intermittent', 'Lower Perennial', 'Upper Perennial', or 'Unknown Perennial'.

Stream Crossing example:



Temporary Impact features in the project footprint ROW do not generate a TAZ. These include temporary workspaces, temporary construction impacts (e.g., matting) and HDD false ROW features. Any temporary direct impact to wetlands was previously calculated for these features. However, any adjacent TAZ from a permanent impact was allowed to overlap these features; this is due to ongoing thermal impacts after the area has been temporarily impacted.

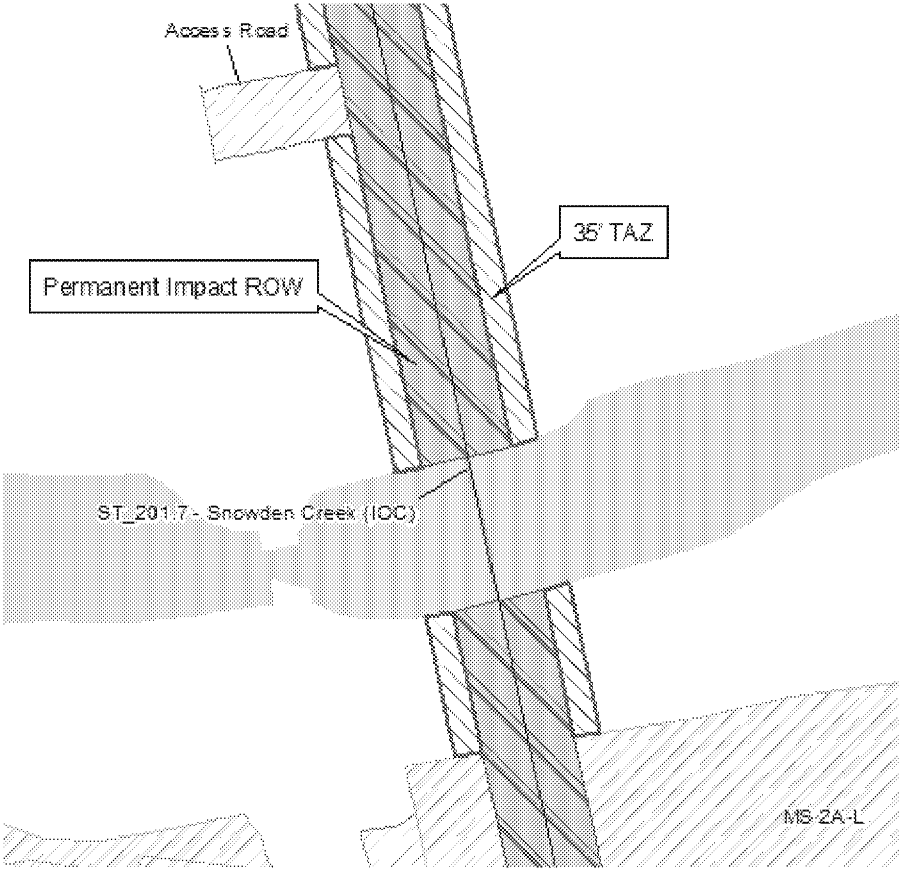
Temporary Workspace example:



Existing road crossings (e.g., Dalton Highway, Parks Highways) and existing Access Roads have been removed from the TAZ.

Other permanent impact features include new access roads, camps, pipe storage yards (PSYs), material sources and railroad sidings. These do not require and indirect TAZ per the rationale described in the main body of the report. In locations where these features overlap the ROW TAZ, the TAZ area has been removed. The direct impact for these overlapping areas has already been accounted for in previous calculations.

Access Road and Material Source example:



Thaw Affected Zone GIS Analysis Steps: