Attachment 8.5

North Railway Geotechnical Recommendations

(201 Pages)

Baffinland Iron Mines Corporation
Mary River Expansion Project

Geotechnical Recommendations for Northern Railway

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Dated: [***insert current date***]

[INSERT NAME OF REPORT RECIPIENT]

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1. Introduction

Baffinland Iron Mines Corporation (BIM) currently operates the Mary River iron ore mine in Nunavut, Canada. BIM plans to increase the production to 12 Mtpa, shipping the output through Milne Port. This will be achieved by upgrading the mine fleet, constructing an approximately 110 km long rail line from the mine site to the port, building a new crushing and screening facility at the port, constructing larger ore stockpiles and building a second ore dock for ship loading.

A number of geotechnical investigation programs were initially completed between the Mary River mine site and Milne Inlet in 2006, 2007, and 2008 by Knight Piésold Consulting Ltd. (Knight Piésold), in 2010 by AMEC Earth and Environmental (AMEC), and in 2011 and 2013 by Hatch. The investigations included drilling at the Mary River mine site, the Milne Inlet port site, the Tote Road from the mine site to Milne Port site, as well as offshore investigations at Milne Port. Additional investigation programs along the approximate proposed alignment of the northern railway were executed between 2016 and 2018 by Hatch, consisting of sonic drilling and geophysics using ground penetrating radar.

The approximately 110 km proposed rail line starts at Milne Port (Km 0) and passes through approximately 20 km of Precambrian bedrock terrain, glaciofluvial sand and gravel terraces. Further south, the rail alignment spans across a relatively flat-lying ground comprising fine grained glacial till veneer overlying Paleozoic rocks of mainly dolomitic limestone units for approximately 60 km. The final stretch of the rail alignment traverses glacio-lacustrine and glaciofluvial plains, terraces, eskers and bedrock outcrops ranging from granitic gneiss to sedimentary rocks.

For detailed maps showing the geology along the rail alignment please refer to the Site Assessment of North Railway Alignment Report (H352034-1000-220-068-0001). This site assessment report was prepared as part of a site visit by Dr. Sean Hinchberger of Hatch between September 7 and 14, 2016. The site visit identified the terrain, type of permafrost of the proposed rail alignment and alternatives, and the potential quarry sites. A review of geological maps, ground truthing and samplings through the site visits using helicopter, as well as observations made from photographic records were utilized to evaluate the railway alignment.

2. Site Description Along the Northern Railway

2.1 General

The proposed railway alignment principally follows closely on the existing Tote Road, with some realignments along the line to obtain better foundation conditions. The selected alignment takes advantage of the presence of Precambrian terrain in the first approximately 25 km from Milne Inlet. The last 15 km of the line which is close to the Mary River mine site also traverses through ice poor glacial lacustrine, glacial fluvial plains, terraces and eskers which have shallow bedrock profiles. The middle approximately 75 km of the alignment travels across relatively flat lying glacial till or moraine overlying the Paleozoic rocks

(Limestone and Dolomitic Limestone units), The glacial till is generally fine grained containing silt and sand, whereas the moraines consist of sandy soils. A major deviation for the railway from the Tote Road was made in the area between approximately km 57 and 85. The deviation is required to meet the geometrical design for the railroad as there is considerable change in the ground surface elevations in the area. The allowable railway grade dictates the route along the railway in this area to avoid steep inclines and declines for the railroad and to assist in safe train handling practices.

The railway alignment, as well as the existing Tote Road is shown in a plan map as presented in Appendix A. The map also includes the locations of boreholes recently drilled in the area, as part of the 2016, 2017 and 2018 field investigation programs.

Proposed quarry locations have also been included in the plan map, sourced from the various phases of the field investigations, in which samples were being collected for physical laboratory testing. A number of sources of hard, durable granitic rocks are located closer to Milne Inlet, or near the Mary River mine site for further laboratory testing.

2.2 Permafrost and Ground Ice

2.2.1 Permafrost

The northern railway line is located on the continuous permafrost area of Baffin Island, Nunavut.

Boreholes on Baffin Island have indicated that the depth of the continuous permafrost extends approximately 500 m. The maximum annual thaw depth, also known as the active layer, ranges from 0.5 m in poorly drained low-lying areas to 2-3 m in well-drained sand and gravel areas. The permafrost measured along the railway alignment is fairly cold, at temperatures below -8°C and -10°C at depths over 10 m. .

2.2.2 Ice Rich Areas

It was found that some of the boreholes drilled during the field investigations contained large amounts of ice and, therefore, could potentially indicate the presence of large ice bodies. In the areas where high ice content were discovered during the borehole investigations, a geophysical survey was subsequently used to delineate the subsurface conditions. Typical ice bodies encountered during the field investigations are shown in Table 2-1.

The presence of large ice bodies along the initial alignment of the proposed railway were also reported during the site assessment and site visit carried out in September 2016. Preliminary recommendations for the foundation considerations of the railway embankments, and the avoidance of the massive ice bodies were presented in the Preliminary Geotechnical Recommendation for Railway Embankment report (H352034-3000-229-230-0001, Rev 2).

Table 2-1: Typical Thickness of Ground Ice Encountered during Field Investigations

Borehole	Depth from Ground Surface (m)	Inferred Ice Thickness (m)*
BH16-C008	3	>10.7
BH16-C011	1.5	>9.2
BH16-C023	6.1	>4.6
BH17-C002	2.7	>8

* Note: the base of the ice lens/body was not reached in any of these investigations.

2.2.3 *Geophysical Investigations*

In addition to field drilling and test pitting, geophysical investigations using seismic and radar surveys were undertaken to define ice rich zones in the permafrost. Seismic surveys were undertaken to determine the depth to bedrock along the alignment, as well as at the railway unloading area.

Radar surveys were conducted at seven sites along the rail deviation area subsequent to the 2018 Geotechnical Investigation to determine ice depth, thickness, and extent. The chainage of the survey areas spanned from approximately 59 km to 69 km, and 77 km to 78 km. Ice chunks and ice lenses were delineated at depths between 4 m and 9 m from the surface. Note that the above noted chainages are approximate, as the final railway alignment had subsequently been modified to avoid these massive ground ice areas.

The results of the field investigation programs, as well as the geophysical investigations are reported under the Rail Geotechnical Investigation Factual Data Report (H353004-10000-229-230-0005, Rev 2), and the GPR report on Geophysics (Project T1 7001, Revision 6, April 2016).

2.3 Railway Alignment

2.3.1 *Rail Alignment and Existing Tote Road*

The following sections contain a summary of the site descriptions observed along the rail alignment grouped by chainage. These observations are a generalization of the findings obtained from the various phases of previous field investigations, as well as the site assessment completed in September 2016. The full borehole logs should be consulted to appreciate the variability of the overburden and bedrock conditions along the alignment.

Following initial findings from the site assessment report (H352034-1000-220-068-0001), a railway design criteria document for the Stage II study was issued (H352034-3000-200-210-0001), followed by a preliminary recommendations report (H352034-3000-229-230-0001). These documents have since been updated to reflect changes and modifications, and advanced to a new project (from H352034 study to the current H353004). Alignments were further modified to minimize the route through ice rich permafrost or areas which were identified by presence of ground ice or ice bodies. The final alignment follows the latest railway design criteria and design rational report (H353004-39000-224-210-0001).

The final railway alignment as reported in the following sections has been selected based on the above noted reports, assessments and recommendations, as well as subsurface conditions. The alignment departs at some locations from the existing Tote Road to take advantage of areas which have better subsurface conditions deduced from the investigations.

2.3.2 Chainage 0+000 m to 15+200 m (15.2 km)

This section of the railway alignment is situated mainly on either till (silt, sand and some gravel) or glacial outwash terraces (gravelly sand). Locally, the alignment encroaches on a ridge of granitic bedrock that is oriented parallel to Phillips Creek and situated approximately 500 m east of the Tote Road. Granitic gneiss bedrock outcrops were noted in the investigation area along this section of the alignment. Ice rich soils are situated to the east of the proposed railway, but the whole section of the railway is located mainly on non-susceptible permafrost subgrade (ice-poor soils).

The railway alignment through this section has been optimized to minimize both the cut and fill on the existing ice-poor soils, with the following features:

- Granitic rock cuts are expected between approximately Chainages 0+000 to 0+600, 2+100 to 6+100 and 6+300 to 7+100.
- Fills on granitic rock are expected between approximately Chainages 6+200, 9+200 to 9+700.
- Fills in ice-poor permafrost are located between approximately Chainages 0+580 to 1+840, 3+900 to 3+960, 6+060 to 6+140, 7+020 to 8+060, 8+180 to 8+480, 8+560 to 8+800, 8+840 to 10+300, 10+440 to 10+460, 10+560 to 10+980, 11+060 to 11+260, 11+460 to 14+920, and 14+940 to 15+200. The maximum height of fills will be approximately 7.5 m in vicinity of Chainage 19+100. Typical fill height will be less than 3 m.
- Cuts in ice poor permafrost are expected for the remaining chainages. The maximum cuts will be approximately 5.5 m in vicinity of Chainage 19+700, and average of about 2 m.

2.3.3 Chainage 15+200 m to 16+250 m (1.1 km)

This section of the railway is generally similar to the one described in Section 2.3.2, with the exception of some ice bodies encountered in BH16-001, BH 16-B003 and BH16-004. Thickness of 1.5 to 3 m ice bodies were encountered within ice poor granular soils, making it a highly susceptible permafrost subgrade. However, the fills in this area will only have a maximum height of approximately 4.2 m and averages 2.9 m. It is expected that there will be no cut in this area (with the exception of the area around the proposed bridge). A bridge crossing is located in vicinity of Chainage 16+000 (See Section 2.4).

2.3.4 Chainage 16+250 m to 46+250 m (30 km)

The terrain in this section is generally less undulating compared to Chainage 0+000 to 16+250. Also, the Phillips Creek valley widens substantially on the east side of the creek as the creek bends southward and diverges from the granitic ridge. Along the railway alignment, bedrock will likely be located vertically below the railway.

The proposed rail alignment generally follows along the contact between the till sheet (sandy silt with gravel) and glacial outwash deposits (sand and gravelly sand), and as a result, the subgrade conditions alternate between these two domains. The sandy silt till sheet will have more potentially susceptible permafrost soils, as well as suspected ice-rich soils, as noted at the following sections:

- Granitic rock cuts are expected between approximately between Chainages 20+700 and 20+800, 21+000, 37+300 to 37+400 and 37+700 to 37+800.
- Chainages between 20+500 and 21+000 with moderately susceptible permafrost soil, but generally contain ice-poor permafrost soils. Cuts in this section have a maximum 4.7 m and averages only 2.2m high. There are only minimal fill zones with a maximum of 0.8 m high fill.
- Area in vicinity of Chainages between 25+000 and 26+000 with ground ice as detected by the radar survey. Hence the railway alignment was rerouted to avoid this area.
- Chainages from 26+000 to 26+250, and from 27+200 to 27+380 with presence of ice lenses in the soils (moderately susceptible soils). There are no cuts in this section, and the fills are only approximately 0.7m high. Ice thickness of approximately 8 m was encountered in BH 17-C002, although the remaining areas appear to have ice-poor soils. The railway alignment was rerouted to avoid this ice rich area.
- Chainages between 37+500 and 38+000 show presence of ground ice up to 0.2 m thick (potentially susceptible/ice rich permafrost soils). The cuts in this section have a maximum depth of 3.4 m deep, and the fills are relatively low, up to 4.6 m high.
- The remaining areas along the alignment will be located in ice poor soils.

In general, the overall cuts in this stretch of the railway alignment have a depth of up to 7.1 m, and average 2 m. The fills have a maximum height of 9.4 m, and average 2.2 m high.

2.3.5 Chainage 46+250 m to 48+000 m (1.7 km)

This section contains ice rich permafrost as observed in BH 17-C005 and BH16-C011. Over 9 m of ice bodies were encountered in BH16-C011. The rail alignment was rerouted in this area to avoid the ice rich permafrost. Through this almost 2 km stretch of railway alignment, the cuts vary up to 8.5 m with an average of 3.3 m; and the fills up to 6.5 m high, and averages 3.6 m.

2.3.6 Chainage 48+000 m to 58+780 m (10.8 km)

The railway alignment at approximately Chainage 57+000 deviates from the existing Tote Road by following the west side of the river, instead of crossing it approximately 2 km further south of the line.

Boreholes in this area typically encountered sand or sand with silt from the surface to termination depths. Bedrock was not reached in any of these investigations. Dolomitic limestone bedrock outcrops were also noted in vicinity of Chainages 49+300 and 49+500, running parallel to and approximately 500 m east of the existing Tote Road. The majority of this section of the railway alignment is located on ice poor permafrost soils. Ice rich permafrost soils were observed in borehole BH 17-C006 along the existing Tote Road. The rail alignment was rerouted or re-aligned to minimize route the length of the route passing through the ice rich areas. Almost the whole section is located on fills, with proposed railway embankments of up to 9.8 m high, and average 2.9 m high. Relatively short and shallow cuts of up to 3.3 m, and average 1.2 m high are located between approximately Chainages 49+140 to 49+360, 49+420 to 49+540, 49+600 to 49+620, 50+120 and 50+200, and 52+920 and 53+000.

2.3.7 Chainage 58+780 m to 69+760 m (11.0 km)

The deviated railway line stays along the western side of the river.

No boreholes were drilled in this section of the alignment as part of the 2016-17 investigations due to a lack of access to the borehole locations and weather related constraints. A seismic refraction survey was completed in this area, in which the readings indicate moderately susceptible permafrost soils. Fills in this area will have a maximum height of 16.7 m, and averages 4.1 m. Ground penetrating radar survey was also completed in the area and results were utilized to avoid areas of massive ice formations.

There are only approximately 1200 m total length of cuts in this 11 km section of the railway, having a maximum cut depth of 10.9 m, and an average cut depth of 4.7 m. They are located approximately between Chainages 58+800 and 59+360, 59+420 and 59+880, 60+100 and 60+120, and between 66+980 and 67+140.

A deep valley with a proposed fill of over 27.2 m is located between approximately Chainage 61+700 and 61+900 and may need special attention.

2.3.8 Chainage 69+760 m to 72+600 m (2.8 km)

From Chainage 69+720, the railway alignment follows the west side of the river until it approaches Chainage 71+000 where it goes across the river (bridge – See Section 2.4) and stays on the north side of the river branch towards the north to northeast direction.

The northern/western bridge approach is situated on a gently sloping till blanket, which transitions to a broad and flat alluvial plain near the bridge crossing, consisting of mostly potentially susceptible permafrost fines, wet sand materials, and with numerous small surface water bodies, which is normally associated with thermal karst and ground ice. However, there were no reports of massive ground ice in the field investigations.

This section of the railway will be located on fills, which will be up to 8.6 m high, and averages 3 m (including the railway embankments which form the bridge abutments). No cuts into bedrock are expected in this area.

2.3.9 Chainage 72+600 m to 91+000 m (18.4 km)

The railway line stays in the north west to west direction until it merges with the existing Tote Road at approximately Chainage 85+000. A bridge crossing is located in vicinity of Chainage 86+000 (See Section 2.4).

The majority of this section of the alignment is mapped as glacio-lacustrine or glaciofluvial in origin, which matches the observed materials. Ice rich soils with ice thickness from 0.6 to 3.1 m were encountered in the section between Chainages 75+750 and 77+600. Fill thickness in this area is up to 14.6 m, and averages 3 m. The cut in this section are relatively minor and up to 3.9 m, and averages 2.1 m deep. Cuts into bedrock are located approximately Chainages 73+200 to 73+600.

For the remaining ice poor permafrost sections, the cut is up to 9.6 m, averages 2.4 m; and the fill thickness is up to 12.2 m, and averages 2.2 m.

2.3.10 Chainage 91+000 m to 102+500 m (11.5 km)

The glacio-lacustrine or glaciofluvial soils continue to approximately Chainage 100+000. Ice lenses were encountered in several boreholes including a 4.6 m thick ice body encountered in BH16-C023 near Chainage 93+000 of the rail alignment. Cuts into and fills on sedimentary rock are expected for approximately Chainages 100+800 to 101+000.

Ice-rich soils are scattered between Chainages 91+250 and 95+100 (3.9 km length), with thicknesses ranging between 1 and 4.5 m; and between Chainages 95+750 and 96+000 (0.3 km length), with ice up to 1 m thick.

The BH 16-C030 along the existing Tote Road in vicinity of Chainage 102+000 has up to 6 m thick ground ice, and the alignment in this area has been deviated further to the north to avoid this ice body.

For the remaining ice poor permafrost sections, the cut is up to 8.7 m, averages 2.8 m; and the fill thickness is up to 8.9 m, and averages 3.4 m.

2.3.11 Chainage 102+500 m to Terminus (6.5 km)

This section generally consists of either a thin veneer of sand and gravel (glacial fluvial) overlying granitic bedrock or exposed granitic rock. Inferred bedrock was encountered in all of the investigations in this section. The bedrock in this area is mapped as rocks including dolomitic sandstone and undifferentiated gneiss.

A bridge crossing is located in the vicinity of Chainage 103+000 (See Section 2.4).

Ice rich soils with thickness of 0.6 m are present between Chainage 102+500 and 104+000. The remainder of the alignment is considered to be ice poor permafrost. There are small cuts in this area that are up to 3.7 m, and averages 1.8 m. The remaining fill thickness is up to 9.2 m, and averages 2.6 m. Cuts into undifferentiated gneiss are expected for approximately Chainages 102+700 to 102+900.

2.4 Proposed Bridge Locations

Drilling was completed at four bridge locations along the rail alignment. The bridge abutment boreholes for Bridges 1, 3 and 4 were completed during the 2016, and 2018 investigation; and the Bridge 2 boreholes were completed as part of the early 2017 investigation. Three additional holes were drilled for Bridge 3 (KM 86) as part of the geotechnical program completed in late 2017. The approximate chainage for the bridges are as follows:

- Bridge 1: 15+900 m.
- Bridge 2: 70+350 m.
- Bridge 3: 85+640 m.
- Bridge 4: 101+850 m.

Detailed assessments and foundation conditions at the bridge locations are excluded from this report and are reported separately (H353004-35000-229-230-0001).

2.5 Borrow Areas and Potential Quarries

Since the initial sampling and testing for potential borrow areas along the Tote Road were carried out in 2010 (Amec, 2010), Hatch carried out additional investigations for potential borrow sources and potential quarry areas in 2018. The 1st phase of the work consisted of identifying and sampling of 29 potential quarry locations along and in proximity to the railway alignment. Laboratory testing consisting of both physical and chemical tests were completed. Initial chemical tests indicate that the rock samples recovered from the field investigation do not contain potential Acid Rock Drainage (ARD)/Metal Leaching (ML) potentials. The detailed results of the test are provided in a separate report (H353004-30000-229-230-0002). Additional fieldwork to retrieve more samples in the deviation area in vicinity of Km 60 to 80 is planned for Spring 2019. This would be followed by additional tests to screen potential ARD/ML in the area.

For sources of locomotive sand, another report (H353004-00000-229-230-0006) was also prepared using samples collected from the 2016 Rail line geotechnical investigation program. A series of particle size analyses, caking tests and petrographic examinations were completed for this report.

2.6 Railway Cross Sections

Appendix C shows a number of typical cross sections of the railway, including railway cuts through bedrock, railway cuts on ice poor and ice-rich foundations, as well as typical railway fill embankment on ice-poor and ice-rich foundation.

The typical components of the railway embankments will consist of the followings from top to bottom:

- Rails and ties.
- Ballast material.
- Sub-ballast.
- Rockfill.
- Thermal insulation (if required).
- Combi-grid or geotextile (as required).
- Foundation soils or bedrock.

3. Embankment Fills

3.1 General

The embankment fills along the railway alignment have been optimized to account for the geotechnical considerations by reducing the fill embankments through the areas identified as having ground ice or ice-rich permafrost; minimizing cut and fill volumes to attain balanced excavations; as well as to meet the requirements for the railway design on grades, horizontal and vertical geometry of the alignment.

The current railway alignment is approximately 109 km long. The embankment in fills will be approximately 77% or 84 km, and the excavation cuts will have a total of approximately 25 km or 23% of the total length of the railway.

For the railway located in fills, the estimated railway foundation on bedrock, ice-poor and ice-rich soils are 1%, 60% and 16% of total length, respectively

3.2 Embankment Stability

A typical railway embankment fill consists of a rail track which sits on ties supported by ballast materials. The ballast materials will be underlain by sub-ballast overlying the granular fills above the railway subgrade.

Based on existing railways constructed in the arctic environment, such as those which were built in Alaska and Siberia, as well as in China's Tibet region, railway embankments which consist of rockfill materials will stay stable at slope of 1.5H:1V. This is also similar to typical road embankments built in the northern regions of Canada, Alaska and Siberia. Slope stability on rockfill embankment would not be an issue for the above noted slopes, as analyzed for long term and under earthquake conditions. The minimum Factor of Safety (FOS) values selected for the long term and earthquake conditions are 1.3 and 1.0, respectively, based on the Canadian Foundation Engineering Manual (CFEM, 2006). The past experience for road and railway construction in the arctic using rockfill materials will maintain the preservation of the permafrost conditions under control. Some other recommendations related to northern construction included (a) minimizing disturbance of the native soil through fill construction, and (b) construction during the winter period when the ground is frozen.

The stability of a high railway embankment, over 5 m height will also depend on the potential deformation of its foundation due to creep settlement as discussed in Section 3.4.

Over the long term, the embankment can be expected to freeze, with a similar thaw-depth to the remainder of the site (approximately up to 2 m depth). This will further support long term stability.

A slope stability analysis was performed using Geostudio's Slope/W (2016) to assess the slope stability of the proposed embankment. A 10 m embankment with a silt foundation was modelled, representing ice-poor soils. The minimum FOS for embankment slope failure is 1.4 as shown on Figure 3-1. For an embankment higher than 10 m with the same slope, it is anticipated that the Factor of Safety would not change significantly.

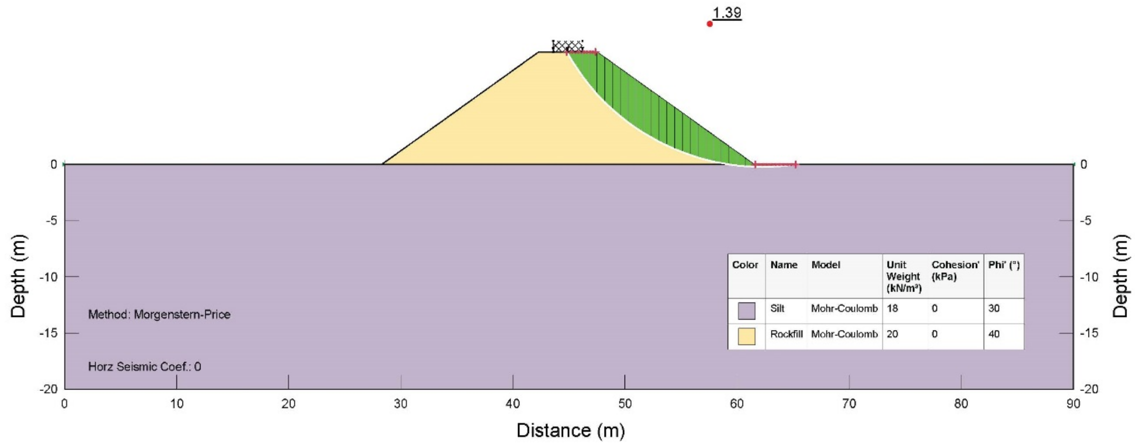

Figure 3-1: Slope Stability of 10 m Embankment over Ice-Rich Soil (silt)

To assess the embankment's performance under expected seismic conditions, the slope stability was also modelled in Slope/W for pseudo-static analysis using a horizontal seismic coefficient of 0.05. This is equivalent to approximately half of the Peak Ground Acceleration (PGA) equal to 0.09 for a 1 in 2500 year return period earthquake (approximately 0.8% occurring over 20 year design life of the embankment). The selected seismic coefficient for pseudo-static slope stability analyses typically ranges from 1/3 to 2/3 of the PGA value. The target FOS under these seismic conditions is 1.0. Based on the Slope/W modelling performed, the FOS under these seismic conditions for a 10 m tall embankment was 1.3.

Stability analyses were also run for typical embankment height of 5 m. Embankments over 10 m high are not expected to change the minimum FOS. Additional information related to the slope stability analyses for the railway embankment, including an analysis of railway embankment on sloping natural ground is presented in Appendix D.

3.3 Thaw Settlements

3.3.1 Estimated Thaw Settlements

This section provides a summary of estimated settlements along the embankment fills as a result of thawing of the permafrost. The underlying frozen soil will not settle but will undergo creep deformation as discussed in Section 3.4.

Typical ice poor permafrost soils consisting of silty and sandy soils along the majority of the railway alignment for the northern route will settle as thaw settlement where the excess ice component within the soil melts, and therefore will be limited to small settlements (in the order of 20-100 mm for the ice poor soils). Estimated thaw settlement, depending on the type of the soils have been estimated and provided as part of the Geotechnical Design Criteria. The estimates were based on properties of frozen soils based on the various literatures. There are a limited number of frozen soil samples collected during the 2018 field investigation program, however because of the vast extent of the railway line, a couple of samples may not be representative of the soil properties. The approach has been to use the estimates based on conservative design assumptions available and can only be assumed to be approximate. For discussion on creep settlement, see Section 3.4.

Table 3-1 provides a summary of the ground frost/thaw susceptibility of the Railway, including the thaw settlement estimates as provided in the design criteria (H352034-3000-200-210-0001, Rev 2).

Table 3-1: Summary of Embankment Ground Frost Susceptibility and Estimated Settlement

Embankment Sections	Ground Frost/Thaw Susceptibility	Ground Ice Content	Classification	Thaw Settlement Estimate (mm)
Km 0.0 to 15.2 Km 16.3 to 20.5 Km 21.0 to 26.0 Km 26.2 to 27.0 Km 30.0 to 37.5 Km 38.0 to 40.5 Km 43.0 to 46.3 Km 48.0 to 52.0 Km 53.3 to 59.3 Km 71.0 to 75.8 Km 85.8 to 91.3 Km 96.0 to 102.5	Non Susceptible	Non to low (ice-poor)	Segregated ice is not visible by eye[1]	<20 (20mm)[3]
Km 27.4 to 30.0 Km 40.5 to 43.0 Km 52.0 to 53.0 Km 59.3 to 60.1 Km 69.8 to 70.0 Km 70.8 to 71.0 Km 77.6 to 80.0	Potentially Susceptible	Low to Moderate (ice-poor)	Segregated ice is visible by eye, less than 25 mm (1”) in thickness[1]	20-100 (40mm)[3]
Km 20.5 to 21.0 Km 26.0 to 26.2 Km 27.0 to 27.4 Km 75.8 to 77.6 Km 80.0 to 85.8	Moderately to highly Susceptible	Moderate (ice-poor)	Segregated ice is visible by eye, less than 25 mm (1”) in thickness[1]	20-100 (60mm)[3]
Km 37.5 to 38.0 Km 53.0 to 53.3 Km 60.1 to 69.8 Km 70.0 to 70.8 Km 95.5 to 95.8 Km 103.3 to 103.8	Moderately Susceptible	Ice-rich	Ice greater than 25 mm (1”) thickness[1]	100-300 (150mm)[3]
Km 15.2 to 16.3 Km 46.3 to 48.0 Km 91.3 to 95.5 Km 95.8 to 96.0 Km 102.5 to 103.3 Km 103.8 to 109.5	Highly Susceptible	Ice-rich	Ice greater than 0.3 m [2]	>300 (400mm)[3]

Notes:
[1] Classification is based on Unified Soil Classification System of Frozen Soils
[2] Based on Roujanski et. al. (2010).
[3] Values selected for the project based on given ranges as shown
(Source: Hatch Ltd., “Mary River Expansion Study – Stage II – Railway Design Criteria and Design Rational”, H352034-3000-200-210-0001, Rev 2, 10 Jan 2017).

3.3.2 *Potential High Settlement Areas*

Table 3-2 shows the sections of the railway which have a potential for high settlement due to the presence of moderately to highly susceptible ground frost (ice-rich soils). Table 3-2 shows sections along the railway which have fill embankment over 3 m high. As shown in the table, the sections which are assumed to have moderate and highly susceptible ground surface with over 3 m high embankment represent 6.3 and 3.7 km of the total 109 km railway line, respectively. These sections are approximately 9% of the total length of the railway line. The height of the embankment fill varies from 3 m and up to over 15 m in some local areas. The section of the railway between approximately Km 60 and 70 is located in the deviation area, with only limited field investigations completed using geophysical survey. No drilling was completed in this area; and based on the topography, initial assessment of the area and the geophysical survey, this section is currently categorized as having moderately susceptible ice rich zones with potential high settlements. Therefore, in order to get a confirmation of the ice rich soils in this area, additional ground truthing such as probing, drilling and additional field assessments is recommended for this area.

Table 3-2: Fill Areas with on Ice-Rich Soils and over 3m High Rail Embankment

Ground Frost/Thaw Susceptibility	Embankment Section	Thaw Settlement Estimate (mm)	High Fill Section (> 3 m)	Approx. Length /Max. Height
Moderately Susceptible	Km 37.5 to 38.0	100-300 (150 mm)	Km 38.0 to 38.0	50 m / 4.6 m
	Km 60.1 to 69.8		Km 60.5 to 60.6	100 m / 3.9 m
			Km 60.8	40 m / 6.5 m
			Km 61.2	40 m /3.6 m
			Km 61.8 to 62.0	200 m / 27.3 m
			Km 62.1	40 m / 3.1 m
			Km 62.3 to 62.4	100 m / 3.7 m
			Km 62.7 to 62.9	260 m / 6.8 m
			Km 63.2 to 63.4	200 m / 6.4 m
			Km 63.7 to 64.1	400 m / 9.2 m
			Km 64.2 to 64.5	360 m / 6.5 m
			Km 64.6	40 m / 3.5 m
			Km 65.1 to 66.5	1360 m / 13.3 m
			Km 66.6 to 66.8	200 m / 4,8 m
			Km 66.8 to 67.0	220 m / 13.0 m
			Km 67.4 to 67.6	160 m / 4.0 m
			Km 67.6 to 68.8	1140 m / 16.7 m
			Km 69.1 to 69.4	320 m / 6.7 m
	Km 95.5 to 95.8		Km 95.5 to 95.6	100 m / 5.8 m
Highly Susceptible	Km 15.2 to 16.3	>300 (400 mm)	Km 15.2 to 16.0	800 m / 6.6 m
	Km 46.3 to 48.0		Km 46.6 to 46.8	180 m / 6.9 m
	Km 91.3 to 95.5		Km 91.6 to 91.7	100 m / 4.5 m
			Km 92.3 to 92.4	100 m / 5.2 m
			Km 92.8 to 92.9	100 m / 4.0 m
			Km 93.6 to 94.2	600 m / 9.6 m
			Km 94.4 to 94.5	100 m / 3.3 m
			Km 94.9 to 95.1	200 m / 4.0 m

Ground Frost/Thaw Susceptibility	Embankment Section	Thaw Settlement Estimate (mm)	High Fill Section (> 3 m)	Approx. Length /Max. Height
	Km 95.8 to 96.0 Km 102.5 to 109.5		Km 95.3 to 95.5 Km 95.8 to 96.0 Km 102.7 to 102.8 Km 103.8 to 104.1 Km 104.3 to 104.5 Km 104.8 to 104.9 Km 107.1 to 108.3	200 m / 6.4 m 200 m / 7.7 m 100 m / 3.6 m 300 m / 12.9 m 200 m / 9.3 m 100 m / 6.2 m 1200 m / 6.9 m

3.4 Creep Settlements

3.4.1 Estimating Creep Settlements

The concerns for excessive long term creep on ice rich soils were presented in the initial assessment report by Thurber Engineering Ltd (Thurber) for the proposed railway alignment through the southern route (E337697-2110-15-124-0002). The analyses were completed using computer program FLAC (Fast-Lagrangian Analysis of Continua). The parameters and assumptions are assumed to be conservative and were based on the ground conditions along the southern route. During the early site assessment of the northern route, the soil conditions were expected to be worse than the northern railway route. The geotechnical design basis was subsequently developed to provide parameters to be used for the design of the northern railway route (H353004-00000-229-210-0001). Creep settlement analyses were completed using Sigma/W (part of the Geostudio suite computer software), using long-term deformation modulus values for ice rich and ice poor soils as provided in the design basis document.

Analyses were carried out for embankment heights of 1, 3, 5, 7, 10, 15 and 20 m. The maximum creep settlements at the centre of the embankment, as well as the toe of the embankment were recorded and plotted against the embankment height.

Details of the creep settlement analyses are provided in Appendix E.

3.4.2 Creep Settlement on Ice-poor Soils

A plot of the estimated creep settlement for ice-poor soils (represented by sand/gravel) is shown in Figure 3-2.

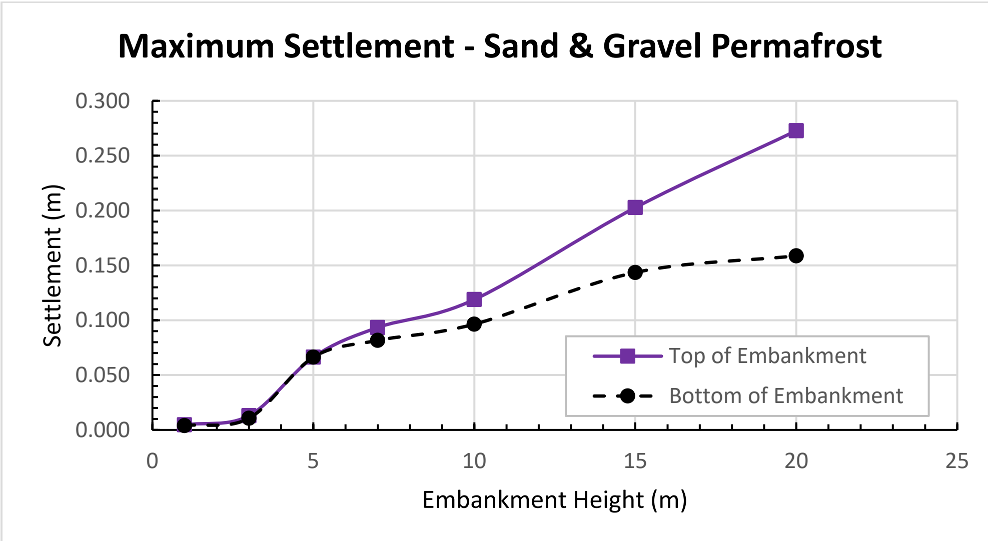

Figure 3-2: Estimated Maximum Creep Settlement vs. Embankment Height for Ice-Poor Soils (Settlements at Top and at Bottom at Centre of Embankment)

Table 3-3: Ice Poor Sections along the Railway

Chainage From	Chainage To	Approx. Length	Embankment Fill Heights	Estimated Creep[1]
Ice-poor Soils – low to none (est. settlement 20 mm)				
00+000	15+200	6.3 km	Average 3.2 m. Maximum height 7.7 m	Avg 20 mm Max 100 mm
16+300	20+500	2.6 km	Average 3.7 m. Maximum height 6.7 m	Avg 30 mm Max 90 mm
21+000	26+000	3.7 km	Average 2.7 m. Maximum height 4.9. m	Avg 15 mm Max 70 mm
26+200	27+000	0.5 km	Average 3 m. Maximum height 3.5. m	Avg 15 mm. Max 20 mm
30+000	37+500	6.2 km	Average 2.5 m. Maximum height 5.5. m	Avg 15 mm Max 75 mm
38+000	40+500	1.7 km	Average 5.5 m. Maximum height 10.8. m	Avg 70 mm Max 130 mm
43+000	46+300	2.5 km	Average 2.8 m. Maximum height 7.4. m	Avg 15 mm Max 100 mm
48+000	52+000	2.3 km	Average 4.4 m. Maximum height 6.6. m	Avg 50 mm Max 90 mm
53+300	59+300	5.5 km	Average 5.0 m. Maximum height 14.6. m	Avg 60 mm Max 200 mm
71+000	75+800	3.4 km	Average 4.5 m. Maximum height 9.9. m	Avg 55 mm Max 120 mm
85+800	91+300	4.6 km	Average 3.2 m. Maximum height 6.6. m	Avg 20 mm Max 90 mm
96+000	102+500	3.5 km	Average 2.9 m. Maximum height 9.2. m	Avg 10 mm Max 110 mm
Ice-poor Soils – low to moderate (est. settlement 40 mm)				
27+400	30+000	1.6 km	Average 2.7 m. Maximum height 8.3. m	Avg 10 mm Max 100 mm
40+500	43+000	1.6 km	Average 2.9 m. Maximum height 5.3. m	Avg 10 mm Max 65 mm

Chainage From	Chainage To	Approx. Length	Embankment Fill Heights	Estimated Creep[1]
52+000	53+000	0.5 km	Average 1.4 m. Maximum height 2.0. m	Avg 5 mm Max 10 mm
59+300	60+100	0.8 km	Average 5.5 m. Maximum height 7.3. m	Avg 60 mm Max 100 mm
69+800	70+000	0.2 km	Average 2.1 m. Maximum height 2.5. m	Avg 5 mm Max 10 mm
70+800	71+000	0.2 km	Average 2.3 m. Maximum height 2.6. m	Avg 10 mm Max 10 mm
77+600	80+000	1.8 km	Average 4.3 m. Maximum height 11.5. m	Avg 50 mm Max 135 mm
Ice-poor Soils – moderate (est. settlement 80 mm)				
20+500	21+000	0.1 km	Average 0.3 m. Maximum height 0.3. m	negligible
26+000	26+200	0.2 km	Average 0.7 m. Maximum height 0.8. m	negligible
27+000	27+400	0.4 km	Average 2.0 m. Maximum height 2.8. m	Avg 5 mm Max 10 mm
75+800	77+600	2.2 km	Average 2.5 m. Maximum height 8.1. m	Avg 10 mm Max 100 mm
80+000	85+800	4.6 km	Average 2.4 m. Maximum height 5.3 m	Avg 10 mm Max 80 mm

Notes:
[1] Maximum creep settlement at the center of the embankment for stated average and maximum embankment heights (See Figure 3-2).
[2] A local area at approx. Ch. 61+900 has an embankment height of 26.3 m with estimated creep settlement of 320 mm

3.4.3 *Creep Settlement on Ice-rich Soils*

A plot of the estimated creep settlement for ice-rich soils (represented by silt) is shown in Figure 3-3.

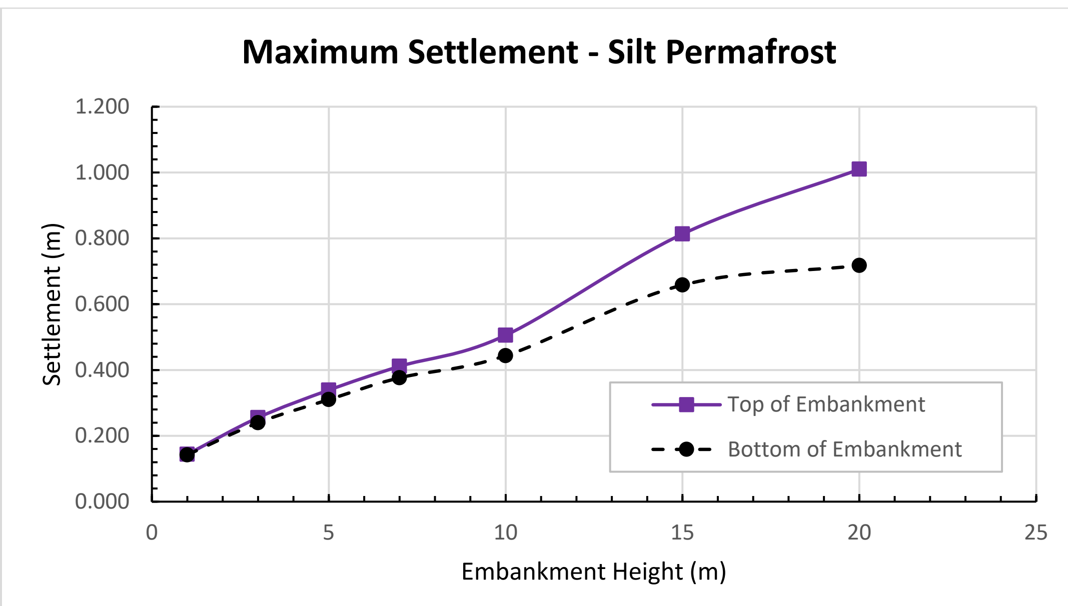

Figure 3-3: Estimated Maximum Creep Settlement vs. Embankment Height for Ice-Rich Soils (Settlements at Top and at Bottom at Centre of embankment)

Table 3-4: Ice Rich Sections along the Railway

Chainage From	Chainage To	Approx. Length	Observed Ice Thickness[3]	Embankment Fill Heights	Estimated Creep[1]
15+200	16+250	1.1 km	up to 3 m	Average 2.9 m. Maximum height 4.2 m	Avg 270 mm Max 320 mm
37+500	38+000	0.5 km	0.2 m (ice lenses)	4.6 m	Max 340 mm
46+300	48+000	1.7 km	up to 9 m	Fills up to 6.5 m, averages 3.6 m	Avg 240 mm Max 400 mm
58+780	69+760	11 km	Radar survey indicated as moderately susceptible	Fills up to 16.7 m, averages 4.1 m	Avg 320 mm. Max 880 mm [2]
91+300	96+000	4.1 km	1.0 to 4.5 m	Fills up to 9.6 m, averages 3 m	Avg 270 mm, Max 480 mm
102+500	104+000	1.1 km	0.6 m	Fills up to 12.9 m. averages 3.1 m	Avg 270 mm, Max 700 mm [2]

Notes:
[1] Maximum creep settlement at the center of the embankment for stated average and maximum embankment heights (See Figure 3-3).
[2] Creep settlement can be reduced by additional berm in this localized area
[3] As observed along initial alignment from drilling field investigation programs

3.5 Total Settlement Estimates (Thaw plus Creep Settlements)

Table 3-5 shows the estimates of total settlement anticipated along the railway embankment, based on the estimated thaw and creep settlements provided in Sections 3.3 and 3.4, respectively.

Table 3-5: Estimated Total Settlements (including Creep) Along the Railway

Chainage From	Chainage To	Approx. Length and Soil Type	Embankment Fill Heights (m) A - Average M - Max	Est. Settle-ment (mm) [1]	Est. Creep (mm) A – Average M - Max	Est. Total Settlement (mm) A – Average M - Max
00+000	15+200	6.3 km Ice-poor	A - 3.2 M - 7.7	20	A - 20 M - 100	A - 40 M - 120
15+200	16+250	1.1 km Ice-rich	A - 2.9 M - 4.2	400	A - 270 M – 320	A - 670 M – 720
16+300	20+500	2.6 km Ice-poor	A - 3.7 M - 6.7	20	A - 30 M - 90	A - 50 M - 110
20+500	21+000	0.1 km Ice-poor	A - 0.3 M - 0.3	80	negligible	A – 80 M - 80
21+000	26+000	3.7 km Ice-poor	A - 2.7 M - 4.9	20	A - 15 M - 70	A - 35 M - 90
26+000	26+200	0.2 km Ice-poor	A - 0.7 M - 0.8	80	negligible	A – 80 M - 80
26+200	27+000	0.5 km Ice-poor	A - 3 M - 3.5	20	A - 15 M - 20	A - 35 M - 40
27+000	27+400	0.4 km Ice-poor	A -2.0 M - 2.8	80	A - 5 M - 10	A - 85 M - 90
27+400	30+000	1.6 km	A - 2.7	40	A - 10	A - 50

Chainage From	Chainage To	Approx. Length and Soil Type	Embankment Fill Heights (m) A - Average M - Max	Est. Settle-ment (mm) [1]	Est. Creep (mm) A – Average M - Max	Est. Total Settlement (mm) A – Average M - Max
		Ice-poor	M - 8.3		M - 100	M - 140
30+000	37+500	6.2 km Ice-poor	A - 2.5 M - 5.5	20	A - 15 M - 75	A - 35 M - 95
37+500	38+000	0.5 km Ice-rich	4.6 m	150	A – 340 M – 340	A – 340 M – 340
38+000	40+500	1.7 km Ice-poor	A - 5.5 M -10.8	20	A - 70 M - 130	A - 90 M - 150
40+500	43+000	1.6 km Ice-poor	A - 2.9 M - 5.3	40	A - 10 M - 65	A - 50 M - 105
43+000	46+300	2.5 km Ice-poor	A - 2.8 M - 7.4	20	A - 15 M - 100	A - 35 M - 120
46+300	48+000	1.7 km Ice-rich	A – 3.6 M – 6.5	400	A - 240 M - 400	A - 640 M - 800
48+000	52+000	2.3 km Ice-poor	A - 4.4 M - 6.6	20	A - 50 M – 90	A - 70 M – 110
52+000	53+000	0.5 km Ice-poor	A - 1.4 M - 2.0	40	A - 5 M - 10	A - 45 M - 50
53+300	59+300	5.5 km Ice-rich	A - 5.0 M - 14.6	150	A - 60 M - 200	A - 210 M - 350
59+300	60+100	0.8 km Ice-poor	A - 5.5 M -7.3	40	A – 60 M - 100	A – 100 M - 140
58+780	69+760	11 km Ice-rich	A – 4.1 M – 16.7 [2]	150	A - 320. M – 880 [2]	A - 470 M – 1030 [2]
69+800	70+000	0.2 km Ice-poor	A - 2.1 M -2.5	40	A - 5 M - 10	A - 45 M - 50
70+800	71+000	0.2 km Ice-poor	A - 2.3 M - 2.6	40	A – 10 M - 10	A – 50 M - 50
71+000	75+800	3.4 km Ice-poor	A - 4.5 M - 9.9	20	A - 55 M - 120	A - 75 M - 140
75+800	77+600	2.2 km Ice-poor	A - 2.5 M -8.1	80	A - 10 M - 100	A - 90 M - 180
77+600	80+000	1.8 km Ice-poor	A - 4.3 M - 11.5	40	A – 50 M - 135	A – 90 M - 175
80+000	85+800	4.6 km Ice-poor	A - 2.4 M - 5.3	80	A - 10 M - 80	A - 90 M - 160
85+800	91+300	4.6 km Ice-poor	A - 3.2 M - 6.6	20	A - 20 M - 90	A - 40 M - 110
91+300	96+000	4.1 km Ice-rich	A – 3.0 M – 9.6	400	A - 270 M – 480	A - 670 M – 880
96+000	102+500	3.5 km Ice-poor	A - 2.9 M - 9.2	20	A - 10 M - 110	A - 30 M - 130
102+500	104+000	1.1 km Ice-rich	A – 3.1 M – 12.9	400	A - 270 M -700	A - 670 M -1100

Notes:
[1] Maximum creep settlement at the center of the embankment for stated average and maximum embankment heights (See Figure 3-3).
[2] A local area at approx. Ch. 61+900 has an embankment height of 26.3 m with estimated creep settlement of 1200 mm, and with total settlement of 1350 mm. Presence of ice-rich soils in this section need confirmation through additional ground truthing.

As shown in Table 3-5, the estimated total settlements which can be expected for the railway embankment are summarized as follows:

- For ice-poor soils, the average total settlement is estimated to vary up to 90 mm over the life of the embankment. The average height of the embankment on ice-poor soils is in the order of 3 m. Maximum settlement can be as high as 350 mm for up to 15 m high embankment on ice-poor soils.
- For ice-rich soils, the average total settlement is estimated to vary from 200 mm and up to 670 mm over the life of the embankment. The average height of the embankment on ice-rich soils is just under 4 m high. Maximum settlement can be as high as 1100 mm on embankment as high as 17 m.
- There is a fill embankment in vicinity of Km 61.9 which will have up to 26.3 m fills. It is expected that the base of the fill will be in bedrock. Maximum settlement can be as high as 1350 mm. Specific considerations are needed in this section, ground conditions in the area will need to be confirmed. Culverts in this area will need to be designed to allow for the high fill embankment.
- Construction of benches along the slope of the high embankment will help to reduce the high embankment load. Typical benches will be at a height of H/3 or H/6. Benching should be considered for embankments with heights of over 8 m. Multiple benches at 6 m height intervals may need to be considered for fill embankment over 16 m high.
- Additional design analyses will be required to confirm the needs of benching and localized details for high embankment areas such as those which are over 10 m high and located at approximately Kms 38.9, 58.8, 60.2, 60.3, 61.9, 65.2, 65.6, 65.8, 66.9, 67.8, 68.2, 72.8, 77.3, 78.0, 93.5, 103.6, and 104.2.

3.6 Thermal Analyses

Thermal analyses were completed on typical fill sections using a similar model and parameters from the model developed for the proposed rail line cuts (H353004-00000-229-030-0001). The model was run for 20 years using the same climate data for the rail line cuts, using climate change considerations according to the geotechnical design basis document (H353004-00000-229-210-0001, Rev 0). There were three (3) sizes of embankments analyzed, 1.65 m, 5 m and 10 m. Each embankment was run with both a native sand and gravel material and a native silt material, representing ice-rich and ice-poor soils.

In the thermal analyses for the fills, initial runs were completed without insulation. As the initial soils have undergone cyclic periods of freeze and thaw every year, the active zone has been developed prior to the placement of fills on top of the native soils. So, the criteria for the railway embankment on fills is to ensure that the fill placement will not result in any permafrost degradation beyond what has previously occurred within the active zone.

Figure 3-4 to Figure 3-7 show the long term results of the thermal analyses for 1.65 m and 5 m embankment fills for both ice-poor (sand and gravel) and ice-rich (silt) soils. The model runs for the 10 m embankment fill was also completed, and with similar non-detrimental effects to the underlying permafrost.

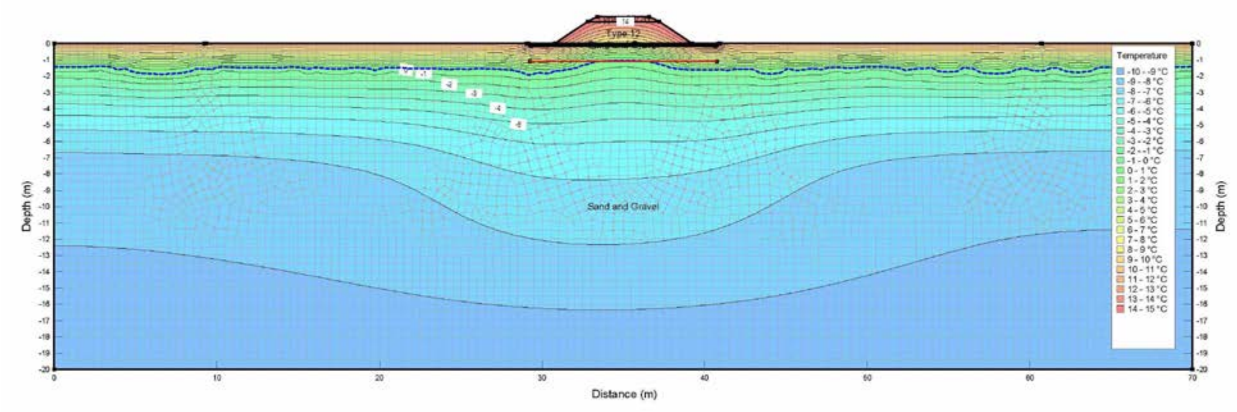

Figure 3-4: Thermal Analyses – 1.65 m Embankment Fill on Sand and Gravel

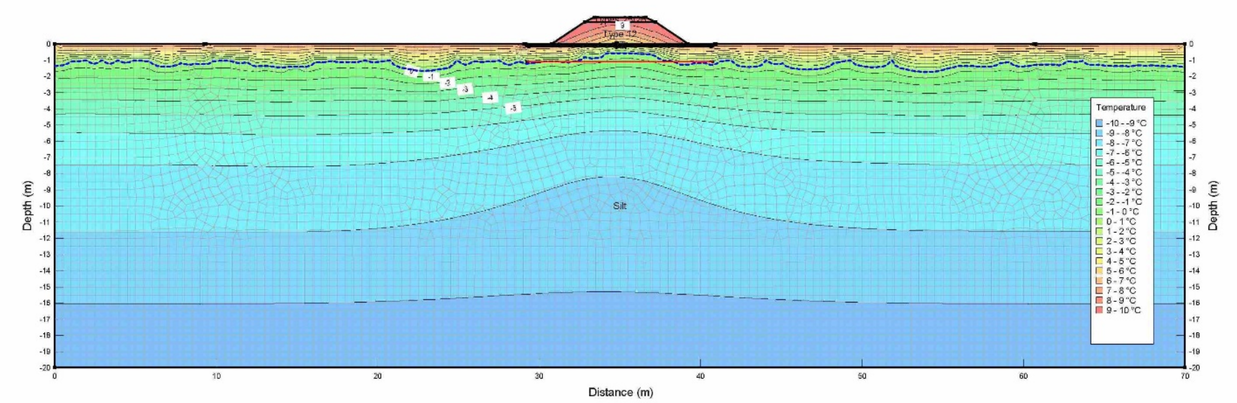

Figure 3-5: Thermal Analyses – 1.65 m Embankment Fill on Silt

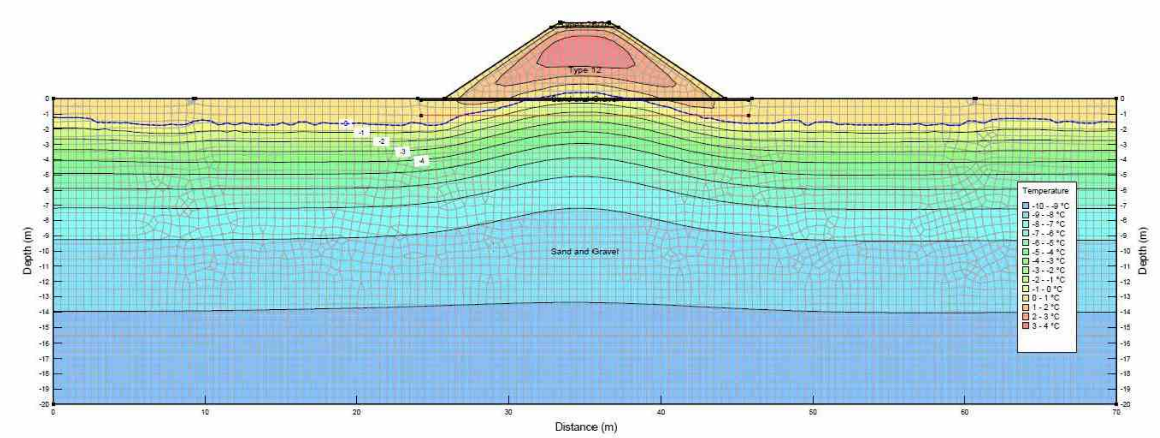

Figure 3-6: Thermal Analyses – 5 m Embankment Fill on Sand and Gravel

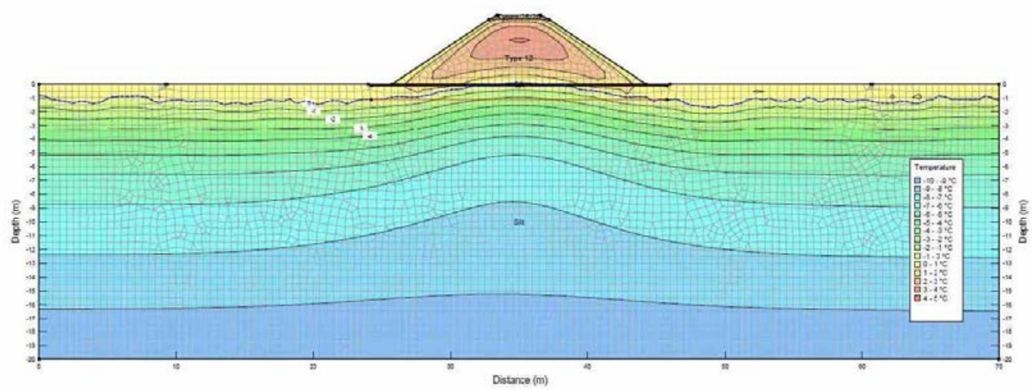

Figure 3-7: Thermal Analyses – 5 m Embankment Fill on Silt

As shown on the above figures, the native soil for either ice poor (sand and gravel) or ice-rich (silt) conditions at the active zone (approximately 1.5 to 2 m depth below the existing ground) remains frozen. Therefore, there is no degradation of the permafrost soil below this level as a result of the embankment fills. The situation is better for higher embankments (5 m or 10 m), as the fill will act as insulation cover in long term conditions.

Detailed analyses and their results are provided in Appendix F.

4. Excavations/Cuts

4.1 General

The embankment cuts along the railway alignment have been optimized to account for geotechnical considerations by reducing the excavations through the areas identified as having ground ice or ice rich permafrost overburden; minimizing cut and fill volumes to obtain balanced excavations; as well as to meet the requirements for the railway design on grades, horizontal and vertical geometry of the alignment.

The current railway alignment is approximately 109 km long. The embankment in fills will be approximately 77% or 84 km, and the excavation cuts will have a total of approximately 25 km or 23% of the total length of the railway.

For the railway located in cuts, the estimated railway foundation on bedrock, ice-poor and ice-rich soils are 7%, 12% and 4% of the railway total length, respectively

Table 4-1 provides a summary of the cut excavation along the railway alignment.

Table 4-1: Cuts along the Railway Alignment

Chainage	Approx. Total Section Length	Approx. Length of Cut Sections	Max. Cut Height (m)	Descriptions
Km 0.0 to 15.2	15.2 km	6.3 km	5.5	Cuts represents approximately 48% of section’s length, mostly on ice-poor permafrost. Some cut will be on bedrock. Average cut: 2 m
Km 15.2 to 16.3	1.1 km	0 km	-	Cuts represent approximately 18% of section’s length, all in ice rich permafrost
Km 16.3 to 46.3	30.0 km	3.7 km	7.1	Cuts represents approximately 21% of section’s length. Average cut: 2 m
Km 46.3 to 48.0	1.7 km	0.6 km	8.5	Cuts represent approximately 47% of section’s length in ice rich permafrost, with average cut: 3.3 m
Km 48.0 to 58.8	10.8 km	0.5 km	3.3	Cuts represents approximately 19% of section’s length, mostly on ice-poor permafrost. Average cut: 1.2 m
Km 58.8 to 69.8	11.0 km	1.2 km	10.9	Cuts represents approximately 4% of section’s length, mostly on ice rich permafrost. Average cut: 4.7 m
Km 69.8 to 72.6	2.8 km	0 km	-	Cuts represents approximately 14% of section’s length, no cuts in ice rich/ice poor area
Km 72.6 to 91.0	18.4 km	3.3 km	9.6	Cuts represents approximately 15% of section’s length, mostly on ice-poor/ice rich permafrost. Average cut: 2.4 m
Km 91.0 to 102.5	11.5 km	3.1 km	8.7	Cuts represents approximately 33% of section’s length, mostly on ice-poor/ice rich permafrost Average cut: 2.8 m
Km 102.5 to Terminus (109.5)	7.0 km	1 km	3.7	Cuts represents approximately 19% of section’s length, mostly on ice rich permafrost. Some cut will be on bedrock. Average cut: 1.8 m

4.2 Excavation on Overburden

4.2.1 Slope Stability

Slope stability analyses were completed using Slope/W software by Geostudio. The analyses were based on a slope with thaw/frozen interface represented by the assumed thickness of the active zone of the permafrost soil. The following assumptions were made for the analyses:

(1) The cut slope is assumed to be overburden ice-poor soils. This is represented with sand to sand and gravel soils, with soil strength properties as per the Geotechnical Design Basis documents: phi' = 32 degrees, and c'= 0. This soil properties used are conservative values to represent the worst case conditions for the ice-poor soils at the site.

(2) The thickness of the active zone is estimated based on the average and actual thermistor readings of selected boreholes established at Mary River, which vary between approximately 2 and 2.5 m depths. A 2.5 m active depth is used in the analyses to separate the thawed and frozen soils. This value had also been confirmed by thaw depth estimates at the Mary River airstrip using various methods, such as Nixon and McRoberts Formula (based on Stefan equation), modified Bergren equation, and US Army TM 5-853-3 method. Therefore, the resulting slip surface with the minimum FOS was checked to ensure the slip surface was not more than the thickness of active layer.

(3) No analyses were carried out for the overburden on ice-rich soils. As presented in the thermal analyses in Section 4.4, insulation and granular soil cover is recommended for the cut slopes on ice-poor soils. Therefore, with the on-slope insulation, the cut slopes are assumed to be frozen, and stability of frozen soils will not be an issue.

(4) The toe of the slope is frozen, as insulation will be applied along the base of the railway cut and under the embankment fills.

(5) Frozen soils have friction angle (phi') of 32 degrees for ice poor soils, and a cohesion value estimated based on assumed volumetric ice content of soil as per Arenson/Springman/Nater document.

(6) The minimum general global FOS for earthworks as per the CFEM (CFEM, 2006) is between 1.3 and 1.5. Based on a paper for the Mackenzie Gas Project in the Northwest Territories, Hardy Associates utilized a minimum Factor of Safety of 1.3 for the ice-poor soil, and 1.5 for the ice-rich soils (ColtKBR, 2006). The lower Factor of Safety requirement is chosen based on the conservative friction angle used for the ice-poor soil at Mary River project (Minimum Factor of Safety 1.3).

The results of the slope stability analyses have a min. FOS of 1.3, as shown in Figure 4-1 which is acceptable based on the above noted assumptions. Sensitivity analyses show that the Factor of Safety can be improved by flattening the slope to 2.5H:1V. However, flattened slopes will have a larger surface area, which may be subjected to solar radiation exposure and hence could induce thawing in the summer. Therefore a 2H:1V slope would be a better slope to preserve permafrost conditions.

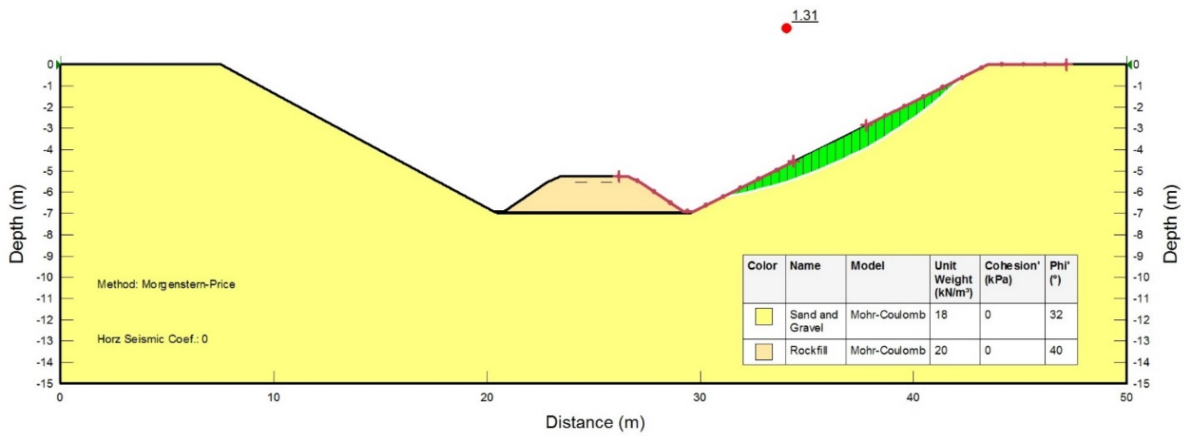

Figure 4-1: Slope Stability Analysis of 7m Cut in Ice-poor (sand and gravel) Soils

It is recommended that the flattening of the slope as noted above or the steepening of the slope to allow for daylighting when cutting into a slope hill shall be determined in the field during construction, where the site conditions, extent and geometry of the excavations can be better evaluated. Flatter slopes with some benches at every 3 to 5 m cut heights may be required for safety during construction, if warranted.

Based on the empirical relationship for the soil friction angle and the cut slope, sensitivity analyses determined the factors of safety values as shown in Table 4-2.

Table 4-2: Cuts along the Railway Alignment

Friction Angle (degrees)	Slope	Slope Angle (degrees)	Factor of Safety (FOS)
32	2H:1V	26.6	1.3
32	2.5H:1V	21.8	1.6
32	3H:1V	18.4	1.9

Slope stability analysis was also performed for ice-rich silty soils, neglecting the potential for the thawing of ice-rich zones to allow for progressive ravelling of the slope. Surficial failures of thawed silt (with a phi' of 30º), had a FOS of 1.21. With the inclusion of the pseudo-static horizontal seismic coefficient, it had a FOS of 1.18. However, it is recommended that for the cuts in ice-rich soils, the excavated surface be covered with rockfill which would increase the stability of the slope. Additional information on the slope stability analyses is provided in Appendix D.

4.2.2 Rebound

Excavated areas along the railway will experience some degrees of rebound from the unloading of the excavated materials. The railway embankment will be added afterward and will consist of granular fill of at least 1.5 m thick.

Overburden rebound is expected to be relatively small as the existing ground surface is mostly granular with little fines. The deeper zones may contain larger fine content such as till deposits, but they will be located below the active zones and therefore will be completely frozen.

It is expected that any rebound will occur during construction and will be accommodated to achieve the final railway grade.

4.3 Bedrock Excavation

Bedrock may be present during the excavation of the ground surface for the first 10 to 15 km of the railway line, between approximately Km 40 and 80 where the overburden overlies the sedimentary limestone bedrock, and in the areas between Km 100 and the end of the railway line at Mary River.

Typical bedrock encountered in the area may have weathering from permafrost, and therefore may be fragmented at the surface.

Typical excavation in sound bedrock shall stay stable at slopes of 8V:1H to 10V:1H. If the bedrock is weathered, a flattened slope of 4V:1H to 1V:1H, depending on site conditions, may be required. Because of variability on site conditions along the railway line, as well as the varied overburden thicknesses, bedrock excavation can only be assessed at the site during excavations.

4.4 Thermal Analysis

Thermal analyses on excavation cuts were completed and reported in document H353004-00000-229-030-0001. The analyses also include climate change considerations, based on a 20 year period projection of global warming potential to year 2039. Assumptions made for the analyses are provided in the referenced document. Details of the analyses are provided in Appendix G. For the thermal analyses of the rail track at the bottom of the cut, a criteria of a minimum -3°C temperature is required at 1 m depth. This is necessary to ensure that there will be no degradation of the permafrost below the cut, as the exposed cut initially was never subjected to freeze and thaw cycles, and there is a need to preserve the initial condition of the cut (i.e., to keep the exposed cut frozen as much as possible). Note that this condition was not imposed for the thermal analyses of fill embankments as provided in Section 3.5, as the upper 1.5 to 2 m has been an active zone prior to the placement of fills.

A summary of the analyses is provided as follows:

- 100 mm thick installation (typically consists of high density polystyrene) will be required at the base of the railway embankment excavation.
- 50 mm thick insulation will be required along the sides of the 2H:1V cut slopes containing ice rich soils. A 300 mm of sub-excavation is recommended followed by placement of 300 mm of granular fill and the insulation layer.
- No insulation will be required along the sides of the 2H:1V cut slopes containing ice poor soils.

- Insulation layer should be protected and secured by placement of a minimum of 200 mm thick cover acting as a ballast.
- Drainage ditches are recommended at the toe of the cut slopes with a minimum slope of 0.2%.
- Cut depths were initially analyzed for base width of 9 m and height of 7 m. The analyses have been updated to include cuts which is 10 m wide and 10 m deep.

5. Culverts

5.1 General

As the railway line traverses between Milne Inlet and Mary River, the railway embankment stays relatively close to the existing Tote Road to take advantage of the ice-poor subsoil conditions which have been shown to perform well throughout the operation of the Tote Road during the past decade. In order to ensure drainage and water movements along the various watersheds, culverts will be constructed to manage water flows in the summer periods.

Currently, a total of approximately 450 culverts will be installed under and crossing the railway tracks. The current design of these culverts employ culverts with diameters of 900 mm, 1200 mm, 1500 mm and 1800 mm. The approximate distributions of the culverts are as follows:

- 900 mm dia. culverts: 77%.
- 1200 mm dia. culverts: 12%.
- 1500 mm dia. culverts: 7%.
- 1800 mm dia. culverts: 4%.

Table 5-1 shows the culverts along the railway which underlie embankment over 10 m high. The majority of the remaining culverts are located under embankments which are typically lower than 5 m high.

Table 5-1: List of Culverts which are Located over a 10 m High Embankment

Culvert No.	Chainage	Approx. Embankment Height (m)	Assumed Type of Permafrost Soil
CV 4-1	4+420	11.8	Ice poor - Non susceptible
CV 58-6	58+840	14.0	Ice poor - Non susceptible
CV 58-7	58+860	11.6	Ice poor - Non susceptible
CV 60-2	60+200	10.8	Ice poor – potentially susceptible
CV 60-3	60+330	12.3	Ice poor – potentially susceptible
CV 62-1	61+920	23.7 - highest	Ice rich – moderately susceptible *
CV 65-1	65+160	13.3	Ice rich – moderately susceptible *
CV 65-2	65+600	11.6	Ice rich – moderately susceptible *
CV 65-2b	65+860	11.7	Ice rich – moderately susceptible *
CV 67-1	66+940	13.0	Ice rich – moderately susceptible *
CV 68-1/1a	67+780	16.7	Ice rich – moderately susceptible *
CV 68-3/4	68+200	14.9	Ice rich – moderately susceptible *
CV 68-5	68+340	14.3	Ice rich – moderately susceptible *
CV 77-2	77+280	15.5	Ice poor – highly susceptible
CV 78-3	78+040	10.5	Ice poor – potentially susceptible
CV 103-1	103+600	13.0	Ice rich – Potentially susceptible
CV 104-3	104+200	10.4	Ice rich – moderately/highly susceptible

Notes: * permafrost soil conditions to be confirmed

5.2 Culvert Deformations

Long term deformation under the culverts were analyzed for various height of embankment fills for both ice-poor and ice- rich foundation soils. The analyses were completed as part of the creep settlement calculations for the railway foundations, as described in Appendix E. Sigma/W of Geostudio computer software suite was used in the analyses, with soil parameters as defined in the geotechnical design basis (H353004-00000-229-210-0001).

Figure 5-1 and Figure 5-2 shows the creep deformation of the culverts for the various embankment height, for ice-poor and ice- rich soils, respectively. Thaw settlement shall be added to the creep deformation to come up with total settlement of the culverts. For ice-poor soils, it was indicated in Section 3.3 that settlement will be in the order between 20 and 100 mm. For ice rich soils, the values range from 100 to over 300 mm.

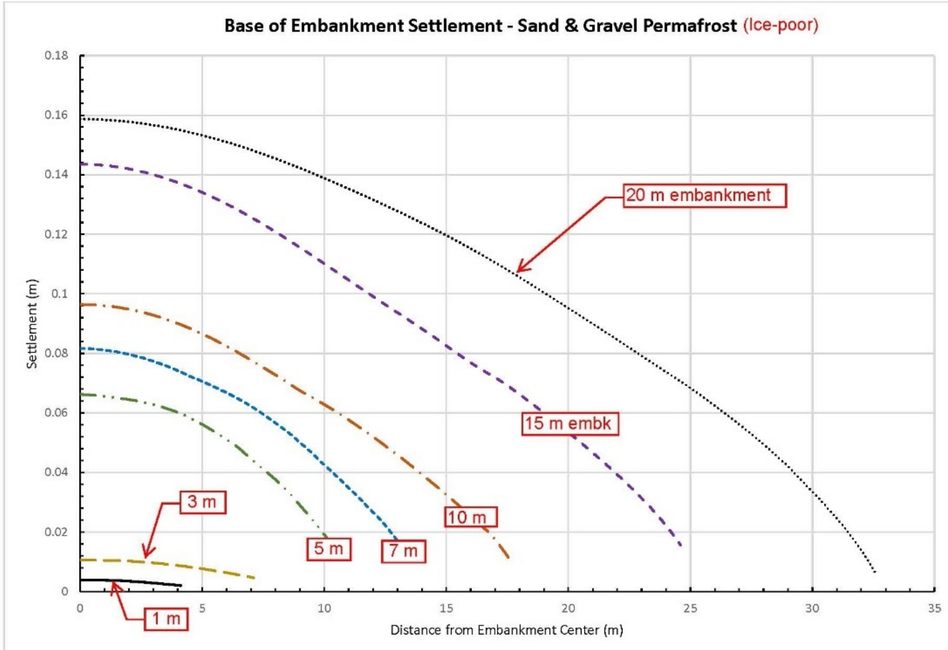

Figure 5-1: Long Term Creep Deformation from CL of a Culvert under Various Embankment Heights on Ice-poor Soils (Sand and Gravel)

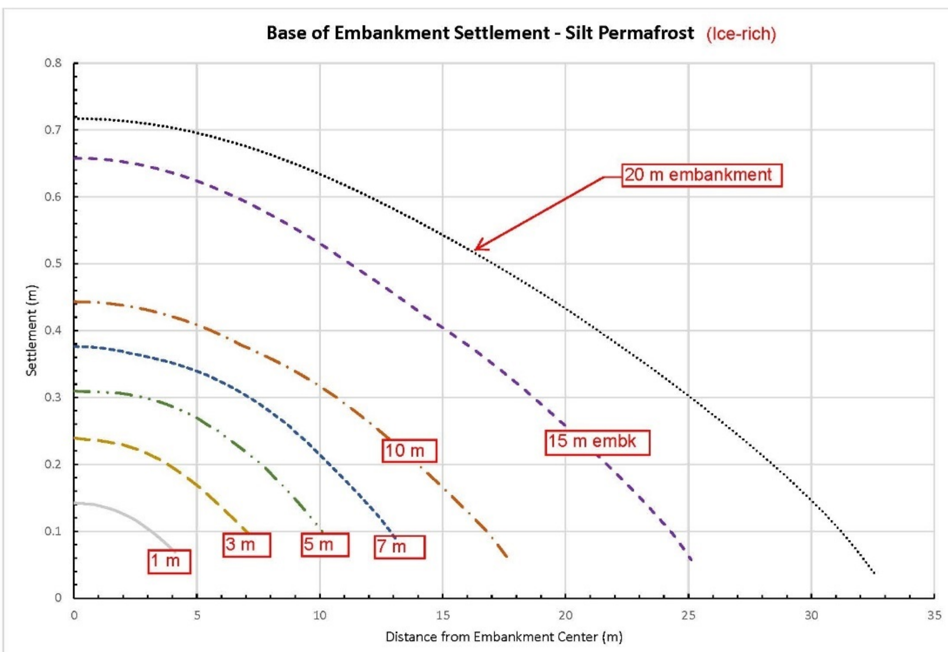

Figure 5-2: Long Term Creep Deformation from CL of a Culvert under Various Embankment Heights on Ice-rich Soils (Silt)

For a list of culverts which are located over a 10 m high embankment, see Table 5-1, the culverts are generally under 15 m high for ice-poor soils. The maximum creep settlement for these culverts, as indicated in Figure 5-1 will be in the order of 100 and 140 mm. Adding the thaw settlement, the maximum settlement at the centre of the embankment will be in the order of 200 to 340 mm. These are typical maximum values, as the majority of the culverts will be covered under 5 m high embankments.

For ice-rich soils, and for 15 m high embankments, the maximum settlement in the centre of the embankment will be in the order of 800 to 1000 mm. High strength culverts may be required for culverts under high embankment. In addition, some benching will help to reduce the high embankment load and reduce settlements, as the load will be spread to a larger area.

5.3 Culvert Thermal Analyses

Culverts allow the passage of water underneath the rail embankment. They also allow hot and cold air to pass through during the summer and winter seasons, respectively. This presents the risk of melting the permafrost underneath the culverts compared to the adjacent subsurface during the summer seasons, with increased potential for differential settlement localized to the culvert areas (in a speedbump shape). In order to determine the adequacy of the specified insulation geometry/arrangement, thermal modelling was completed on the typical culvert cross sections for a varying range of embankment fill heights.

This section provides the assessment methodology, the summary of the results, and recommendations for insulation requirements for the scenarios identified in this project. Reference documents related to use of culvert in arctic environment were reviewed as part of the assessment (Alaska Dept of Transportation -1984, Perier-Dore-Burn on Effect of Water Flow, Zhang/Michalowski - GeoCongress 2012).

5.3.1 Thermal Modelling

This section presents relevant information related to the thermal model set-up.

5.3.1.1 Modelled Scenarios

Table 5-2 outlines the cases run in the thermal models. The fill heights range from 2.1 m to 10 m to capture the typical fill heights found in the rail embankments. All culvert sizes were run with a single barrel, and with the maximum number of barrels corresponding to each barrel size. All models were run for both Sand and Gravel and Silt subsurface conditions, with ice-poor and ice-rich to be encapsulated by the Sand and Gravel and Silt subsurface, respectively.

Table 5-2: Definition of Cases being Modelled

<table>
<tr><th>Culvert Barrel Diameter (mm)</th><th>Number of Barrels</th><th>Fill Heights (m)</th><th>Subsurface</th></tr>
<tr><td rowspan="2">900</td><td>1</td><td rowspan="2">2.1, 3, 4, 5, 10</td><td></td></tr>
<tr><td>3</td><td rowspan="6">Sand and Gravel (ice-poor) and Silt (ice-rich)</td></tr>
<tr><td rowspan="2">1200</td><td>1</td><td rowspan="2">2.4, 3, 4, 5, 10</td></tr>
<tr><td>3</td></tr>
<tr><td rowspan="2">1500</td><td>1</td><td rowspan="2">2.7, 3, 4, 5, 10</td></tr>
<tr><td>4</td></tr>
<tr><td rowspan="2">1800</td><td>1</td><td rowspan="2">3, 4, 5, 10</td></tr>
<tr><td>12</td><td></td></tr>
</table>

5.3.1.2 *Model Geometry*

The culvert model geometry was based off the typical cross sections for the single and multiple barrel pipe culverts, Hatch drawings H353004-30000-224-294-0002-0001 and H353004-30000-224-294-0002-0001 for the single and multiple barrel pipe culverts, respectively. The arrangement for the single and multiple barrel culverts are very similar and feature a trapezoidal shape of Type 26 fill surrounding the culverts, with the rest of the rail embankment composed of Type 12 fill. Below the culvert invert is 300 mm of Type 26 fill on top of 100 mm layer of insulation sandwiched between two 100 mm layers of Type 9 Dry Sand. Details of the typical culvert cross sections can be found in Appendix H. The thermal modelling was based on the longitudinal section of the rail embankment (viewed perpendicular to the rail track and culvert barrel – longitudinal model) to investigate the potential for differential settlement along the length of the rail track. The culvert barrel invert was assumed to be level with the native ground surface elevation.

5.3.1.3 *Material Properties*

The materials used include Type 9, 12 and 26 fill, ballast and insulation. The thermal properties are sourced from the Geotechnical Design Basis (H353004-00000-229-210-0001) and summarized in Table 5-3 below.

Table 5-3: Thermal Properties of Materials

Material	Frozen Thermal Conductivity (J/s/m/°C)	Unfrozen Thermal Conductivity (J/s/m/°C)	Frozen Volumetric Heat Capacity (J/m³/°C)	Unfrozen Volumetric Heat Capacity (J/m³/°C)	Insitu Water content (%)	Insitu Volumetric Water content (m³/m³)
Fill (Types 9, 12, and 26, Ballast, and Sub-ballast)	4.5	3.0	2,400,000	3,000,000	2	3.6
Silt	2.0	1.3	2,200,000	2,200,000	30	45
Sand/Gravel	3.0	2.0	2,600,000	2,600,000	15	25.5
Insulation	0.035	0.035	37,500	37,500	0	0

5.3.1.4 *Boundary and Initial Conditions*

The boundary and initial conditions are sourced from the “Geotechnical Design Basis” (Document # H353004-00000-229-210-0001). Details of the defined boundary and initial conditions are discussed in this section.

Initial Conditions: The initial temperature profile was set up for the month of September, sourced from a representative thermistor installed in borehole BH2007-10 from a site investigation report by Knight Piesold (2008). The month of September was chosen as the ground temperatures are the highest, capturing the worst case scenario in the modelling.

Bottom Boundary: As specified in the Design Basis, the temperature at the bottom boundary (depth of 20 m below existing ground) was set to -10°C.

Side Boundaries: Left and right boundaries: In accordance with the Geotechnical Design Basis, these were assumed to be no-flow boundaries, which is the default boundary condition in a finite element analysis (i.e., heat neither enters nor exits through these boundaries).The boundary conditions and typical meshing used in the Finite Element (FE) models are presented in Appendix F. The boundary conditions could be established more accurately if additional ground temperature monitoring data was to be provided to Hatch.

Top Boundary: It was assumed that the top of the rail embankment experienced a ground temperature that fluctuates in accordance with the mean monthly air temperature averaged between the Milne Port Site and Mary River Mine Site (2006-2015), sourced from CIRNAC response document (181231 CIRNAC IR 14 – Response). A monthly air temperature increase was applied to the averaged mean monthly air temperatures annually starting from 2010 to the end of planned mine operation at year 2039 to factor in the effects of global warming. This air temperature increase was based on the climate change temperature increases outlined in Table 2-5 of the Geotechnical Design Basis (H353004-00000-229-210-0001, Rev 0).

There is a non-linear relationship between the mean annual air temperatures and the mean annual ground surface temperatures, which can be corrected for using the “n-factor”. The “n-factor” is an empirically determined function coefficient found by correlating the ground surface boundary conditions with the air temperature. The mean monthly air temperature is modified during thermal analysis using the freezing factor (n_f) and the thawing factor (n_t) for freezing and thawing seasons, respectively. See Table 2-3 in the Geotechnical Design Basis for the N-factors used in this analysis.

While the longitudinal models allow the examination of the embankment for the potential of differential settlement, it does not take into account the heat flow from the sides of the embankment. In order account for the aforementioned heat flow, a constant 2°C was added to each month of the climate change considered averaged mean monthly air temperatures. This constant temperature was determined from calibrating the longitudinal embankment model to the cross-section model of the rail embankment.

Culvert Boundary: The culvert boundary condition is assumed to also fluctuate with the changing air temperature, and to model both the air flow through the culvert and water seepage from leakage, a constant 2°C was added to the Top Boundary Condition. The aforementioned temperature increase was determined by calibrating the longitudinal model to the measurements provided in the Interaction of Gravel Fills, Surface Drainage, and Culverts with Permafrost Terrain report by the U.S. Army Cold Regions Research and Engineering Laboratory (1984).

5.3.1.5 Failure Criteria

To reduce the likelihood of differential settlement caused by culvert crossings, fill heights where the active zones remains in the native subsurface, the active zone beneath the culvert footprint should be level with the active zone beneath the rail embankments adjacent to the culvert footprint. This would allow the subsurface to settle evenly as the native material is frozen at the same elevation beneath and adjacent to the culvert footprint, for the active zones penetrating into the native material.

For embankment fill heights causing the active zone to rise above the native subsurface into the fill material, the active zone should be at, or above the bottom of the insulation beneath the culvert footprint. For active zones contained within the embankment fills, ensuring the active zone is not deeper than the bottom of insulation keeps the active zone within the rockfill, which is non-frost susceptible and not at risk of differential settlement.

Details regarding the failure criteria can be seen in Figure 5-3 and Figure 5-4 below.

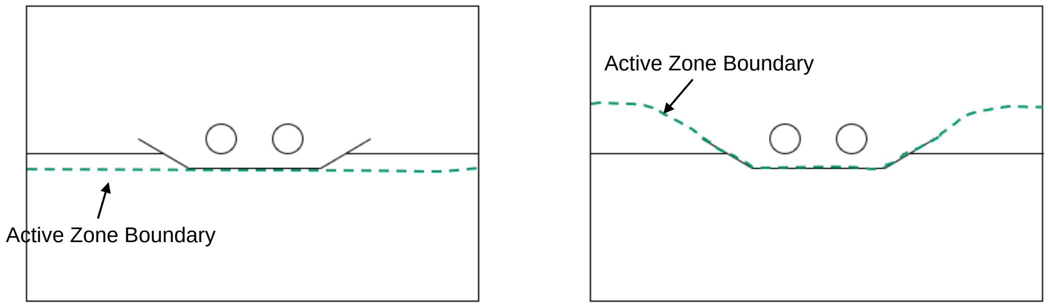

Figure 5-3: Acceptable Active Zone Orientations

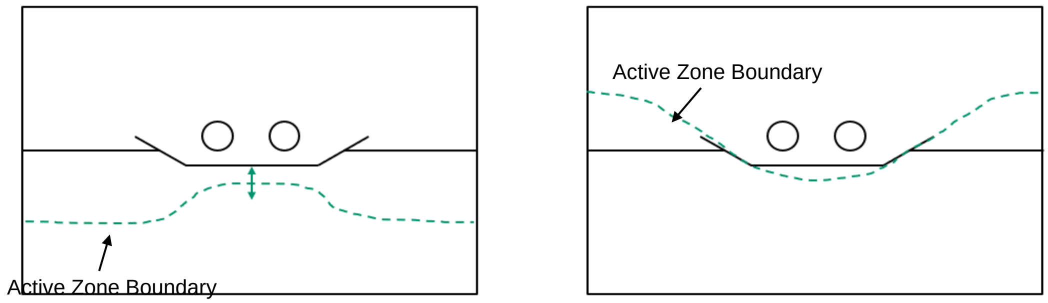

Figure 5-4: Unacceptable Active Zone Orientations

5.3.2 *Results*

The geometries outlined in the Single and Multiple Barrel Pipe Culvert Cross Section Drawings (H353004-30000-224-294-0002-0001 and H353004-30000-224-294-0002-0001) were used in the thermal modelling. Using the 100 mm thick insulation placed just under the culverts, the initial thermal model runs produced modelling results which do not meet the failure criteria outlined above. As seen in Figure 5-5 for a 900 mm barrel culvert in Silt material at 20 years, the flat insulation geometry is inadequate to prevent heat infiltration into the native material.

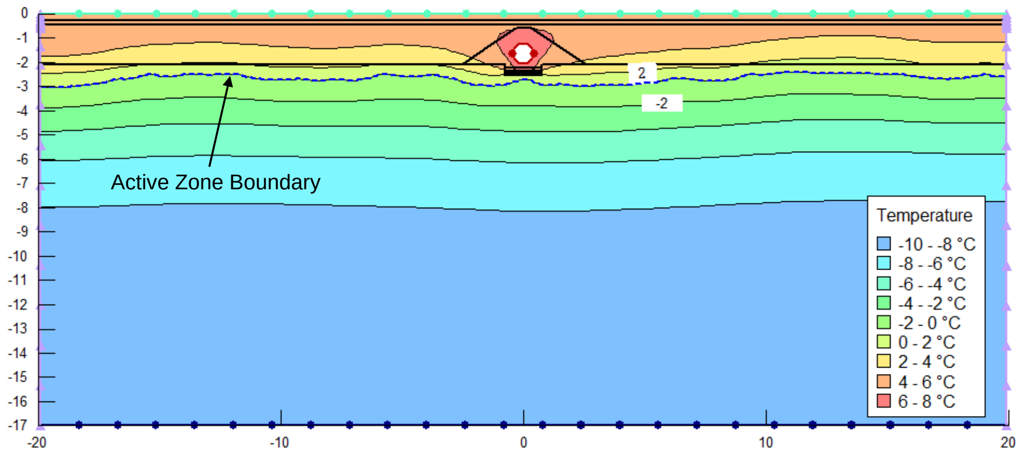

Figure 5-5: Original Insulation Geometry for 900 mm Barrel Culvert Overlain by 2.1 m of fill, at 20 years in Silt Material

In order to prevent heat infiltration into the native subsurface, the insulation geometry was altered to include two sloped insulation panels (side panels) connected at both sides to the flat insulation panel beneath the culvert. The side panels will have the same insulation thickness as the flat panel, sloped at 1.5H:1V, and terminated at the intersection with the Type 26 and Type 12 material. A detailed drawing of the proposed insulation geometry can be found in Appendix H. Using the proposed insulation geometry, the thermal modelling results show the heat from the culvert being contained within the Type 26 fill, as seen in Figure 5-6 below.

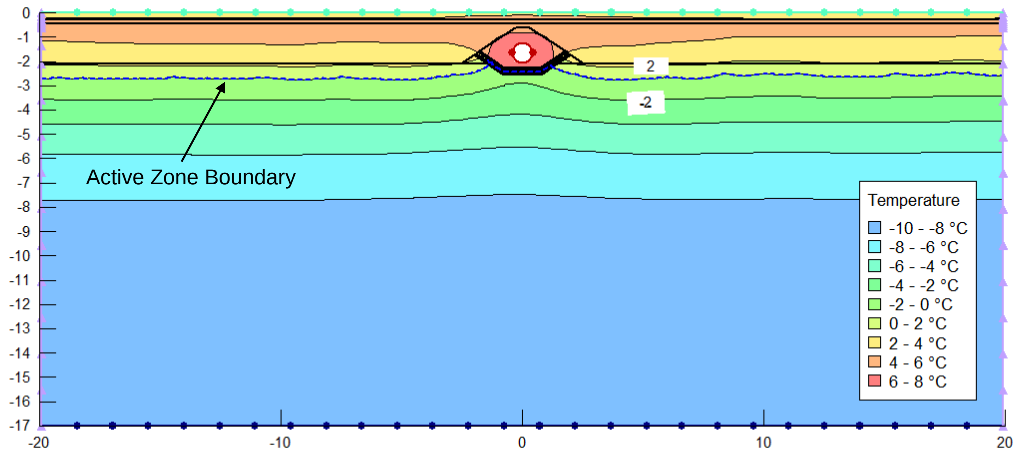

Figure 5-6: Modified Insulation Geometry for 900 mm Barrel Culvert Overlain by 2.1 m of Fill at 20 Years in Silt Material

In order to meet the active zone depth criteria, set out in section 5.3.1.5, sub-excavation is required to place the insulation at the same depth as the active zone adjacent to the culvert area. Table 5-4 outlines the recommended insulation thickness and sub-excavation depth for all culvert pipe diameters and fill heights. It should be noted the insulation and sub-excavation recommendations are based on Silt (Ice-Rich) subsurface due to the increased depth of the active zone penetration.

Table 5-4: Summary of Results

Culvert Diameter (mm)	Number of Culverts	Fill Height (m)	Insulation Thickness (mm)	Amount of sub-excavation beneath culvert barrel invert (m)
900	1	2.1,3	100	1.2
		>4		0.6
	3	2.1,3		1.2
		>4		0.6
1200	1	2.4,3		1.2
		>4		0.6
	3	2.4,3		1.2
		>4		0.6
1500	1	2.7,3		1.2
		>4		0.6
	4	2.7,3		1.2
		>4		0.6
1800	1	3		1.2
		>4		0.6
	12	3		1.2
		>4		0.6

6. Erosion and Sedimentation Controls

The railway embankment fills contain mainly of rockfill materials, which is essential in preserving the permafrost conditions of the underlying foundation. Rockfill embankments typically have larger size particles than earth or soil embankments and therefore are not easily eroded because of their larger size particles

However, to prevent any erosion and their transport to nearby water bodies, it is important that the drainage ditches contain adequate rock-size particles to meet the run-offs during thaw melts and summer conditions, as well as any exposed slopes such as in excavation cuts, etc. All excavation cuts along the hill should have side ditches lined with geotextile and appropriate rock slope protection.

In sections of the railway cuts on existing sand and sandy soils, appropriate slope protection will be required.

Ditches which have long slopes may need to have some ditch checks along the slope made of rockfill mounds, etc. Some armouring may be required in areas where the ditches meander or bend.

Slope protections will be required for bridge abutments areas, in the vicinity of culvert’s entrance and exit locations.

As part of the Adaptive management strategy during construction, as well as during the operation of the railway, field inspection and monitoring will be conducted along the railway on regular basis. Any issues related to erosion and sedimentation occurring along the ditches and the railway route will be reported and medial measures will be taken to minimize further impact

7. Northern Railway Recommendations

7.1 General

The northern railway alignment has been selected and designed to avoid ground ice areas and to traverse along the more favourable ice-poor soils as determined from a number of field subsurface geotechnical investigation programs, and the initial site assessment of the route. The route follows closely with the existing Tote road, which has proven track record of its performance and as it is currently in operation to deliver mine products from the mine site to Milne Inlet. Re-alignment and deviations were included in the selection of the final route of the railway line to find better ground, and to meet with the railway grades and geometry requirements. The alignment also takes into account for minimizing cuts on permafrost soils, and to preserve the permafrost conditions of the soils. Rockfill embankment is the solution to build the railway on permafrost to reduce thaw degradation of the permafrost.

The northern railway design also includes the plans for continual monitoring and an adaptive management plan, where cut slopes will be monitored for excessive deteriorations, test fills and cuts to monitor excessive settlement, instability/sloughing and subsurface temperatures in order to do periodic maintenance. As part of maintenance, additional insulation or soil cover will be provided in areas showing increased settlement beyond expectations. Aerial assessments will be undertaken to find standing water or other features on the ground and adjacent areas.

7.2 Railway Deviation Area

The railway deviation area between Km 57 and 85 have very limited borehole data, except in the proposed bridge abutment areas, and some geophysical radar surveys. The deviation is required to meet with the railway elevation grades, as the existing Tote road has relatively steep slopes through the area, which cannot be accommodated for the railway design.

To confirm the permafrost type of foundation soils along the deviation area, it is important that ground truthing be performed. This could be carried out as an additional drilling investigation prior to the construction and/or field assessment using portable drill rigs (probe holes). Additional field site trips and mapping of the area may also be helpful to look for and identify presence of ground ice in the area. However, it is essential that samplings of overburden soils will be completed to determine the permafrost conditions encountered at the site, including potential ground ice or thick ice bodies.

Additional ground truthing may also be required in other areas of the railway route where some minor re-alignments were included during the design phase.

The additional ground truthing will be useful for the final confirmation of the railway alignment, and to confirm the permafrost soil conditions and their associated expected settlement estimates for some relatively high embankment fill areas.

7.3 Embankment Fills and Cuts

To enhance the embankment stability and to reduce excessive settlements, the placement of a layer of Combi-grid or equivalent on the native soils after excavation (exposed subgrade) is recommended in suspected ice-rich areas, or in other areas where the encountered soil conditions are considered to be below ideal conditions (such as soft ground, poor drainage areas, presence of ponding water, etc.). To estimate the amount of Combi-grid required for the railway, an analysis of the dimensions and soil properties of cuts and fills for every 100 m of railway was performed. It was assumed that 100% of ice rich cuts would require Combi-grid. For fill on ice rich soils it was assumed 60% of these areas would require Combi-grid. For fill placed on ice-poor soils it was assumed 5% of the areas would require Combi-grid. A summary of the length of rail that meet each of these criteria and the estimated amount of Combi-grid required are shown in Table 7-1. Note that this estimate is preliminary as the site conditions will be better defined as the railway construction progresses. However, this can be used for logistical purposes for supply of the materials on site during construction.

Table 7-1: Summary of Comb-grid Required

	Approx Length of Rail Requiring Grid (m)	Approx. of Grid Required (m^2)
Ice-Rich Cuts	4200	40,000
Ice-Rich Fill	10440	200,000
Ice-Poor Fill	3300	60,000
Total	18000 (rounded)	300,000

It is also advisable that an early placement of test embankment sections be completed at selected cut and fill locations, depending on the schedule of construction. The locations of these test sections shall be selected in areas of high fill placement or high cut areas, and/or in areas which are suspected to contain ice-rich soils depending on the construction schedule. The test fill and cut areas will be subjected to observation and monitoring to confirm the method of construction, performance of the embankments such as settlements, and slope stability.

Test fill areas may include areas where benching may be required to reduce embankment load. As the construction of the railway embankment will extend more than one season, the early [art of the construction can be utilized to construct such test fill and test cut areas, adding some instrumentation for monitoring and observation purposes. Bench heights (such as H/3 or H/6 where H is the final height of the embankment fill) and widths can be incorporated into the test fill sections.

Embankment cut test sections may be subjected to observation and monitoring to confirm the method of excavation, cut slope stability performance, as well as performance of the embankment fill built in cut sections, such as settlements, and slope stability.

7.4 Insulation

As indicated in Section 4.4, the placement of a 100 mm thick insulation along the base of the cut sections is recommended based on the thermal analyses. However, placement of insulation on a slope may be difficult to construct, and therefore not practical. It is therefore recommended that insulation (thickness of 50 mm) be placed initially only on the cut slopes where, as determined in the field, ice-rich excavation has been found to be problematic. Test sections in cut areas shall also be used to confirm the soil conditions and to determine the cut slope’s performance, and to address the need for additional insulation in these areas.

It is proposed that the test sections in cut areas include monitoring devices installed in the cuts to monitor the behaviour of the area during construction. Parameters to monitor will include thermal gradient of the ground in several areas of the cross section, and inclinometers in critical slopes locations. Other types of monitoring might include periodic Lidar surveys using survey targets along the slope cut in the test sections. A key element in a monitoring program will be using an observational approach. Periodic field inspections should also be completed, including walkdowns at the cut areas and inspection of any potential failure, local instability or sloughing. A detailed monitoring program will need to be designed and established as part of the instrumentation and monitoring with additional measures taken as part of the adaptive management approach. This strategy is also used to manage proper remedial actions for other cases where there may be potentially unforeseen warmer conditions encountered in the area.

7.5 Culverts

Based on the culvert thermal analysis, the recommendations for the culverts are summarized in the following:

- The insulation should be placed below the culvert as specified in the original drawings and extended out to the sides at a 1.5H:1V slope, terminating at the intersection with the Type 26 and Type 12 material. For more details see drawings in Appendix H.
- 100mm of insulation is recommended beneath all culvert installations for all soil conditions to avoid thawing and deformation that could lead to differential settlement.
- For fill heights less than 4 m, sub-excavation to a total depth of 1.2 m below the culvert invert is required to place the top of the insulation layer at 1m below the culvert invert.

During the spring thaw, water will typically flow through the surface on partially frozen ground and through the drainage ditches to the entrances of the culverts. To avoid ponding of warm water at these entrance areas and seeping through the granular fill or thawing the underlying permafrost soils, a geomembrane liner shall be installed at the entrance of each of these culverts.

Culvert installation in high embankment can be carried out in the early part of the construction as part of test fill sections as described in Section 7.3. Observations and settlements can be monitored to check the behaviour of the culverts under high embankment loads. Flattening of the side slopes may be required through the use of benching in order to reduce load by redistributing the load into a larger area.

8. References

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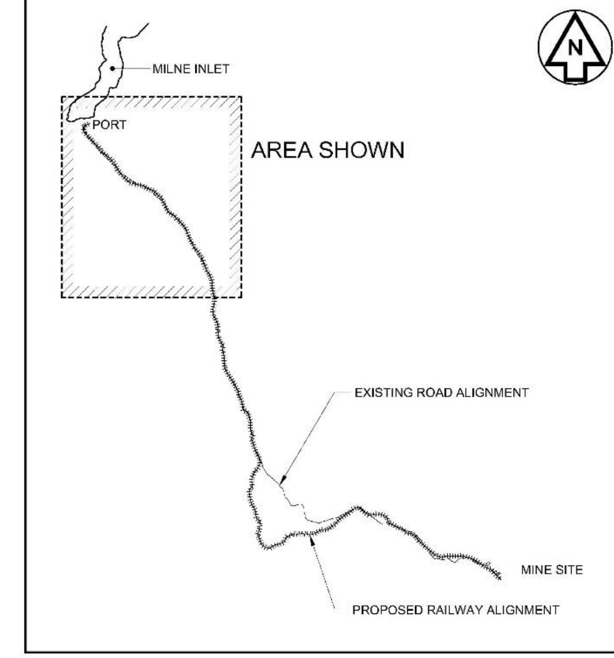
Appendix A

Northern Railway Alignment



KEY PLAN

0 10 20 30 40 50 kilometres

SCALE 1:500 000

LEGEND

- AS-BUILT BOREHOLE LOCATION
- CHAINAGE POINT ALONG RAIL ALIGNMENT
- SEISMIC LINE LOCATION
- GROUND PENETRATING RADAR SURVEY (GPR) AREA
- PROPOSED RAILWAY
- EXISTING TOTE ROAD

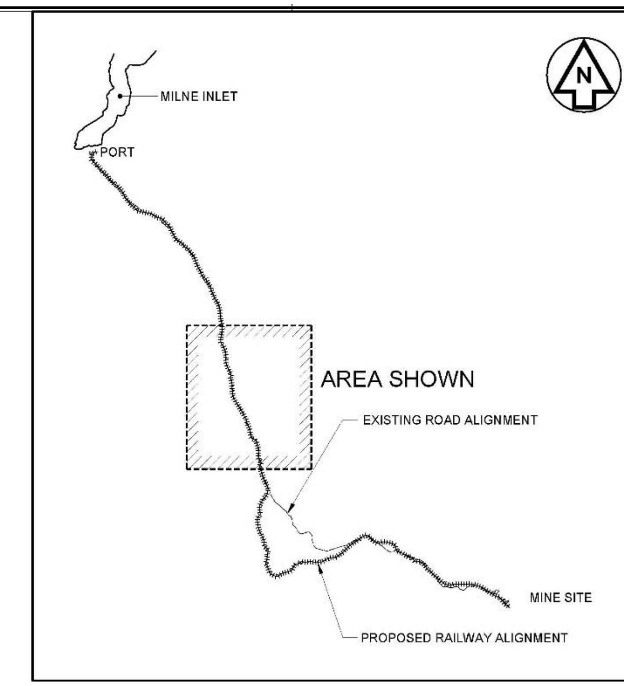
0 1 2 3 4 5 KILOMETRES

SCALE 1:50 000 (B1 SHEET)

SOURCE: H353004-10000-229-230-0005

NORTHERN RAILWAY ALIGNMENT
SHEET 1 OF 4

SOURCE: H353004-10000-229-230-0005



KEY PLAN

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SCALE 1:500 000

LEGEND

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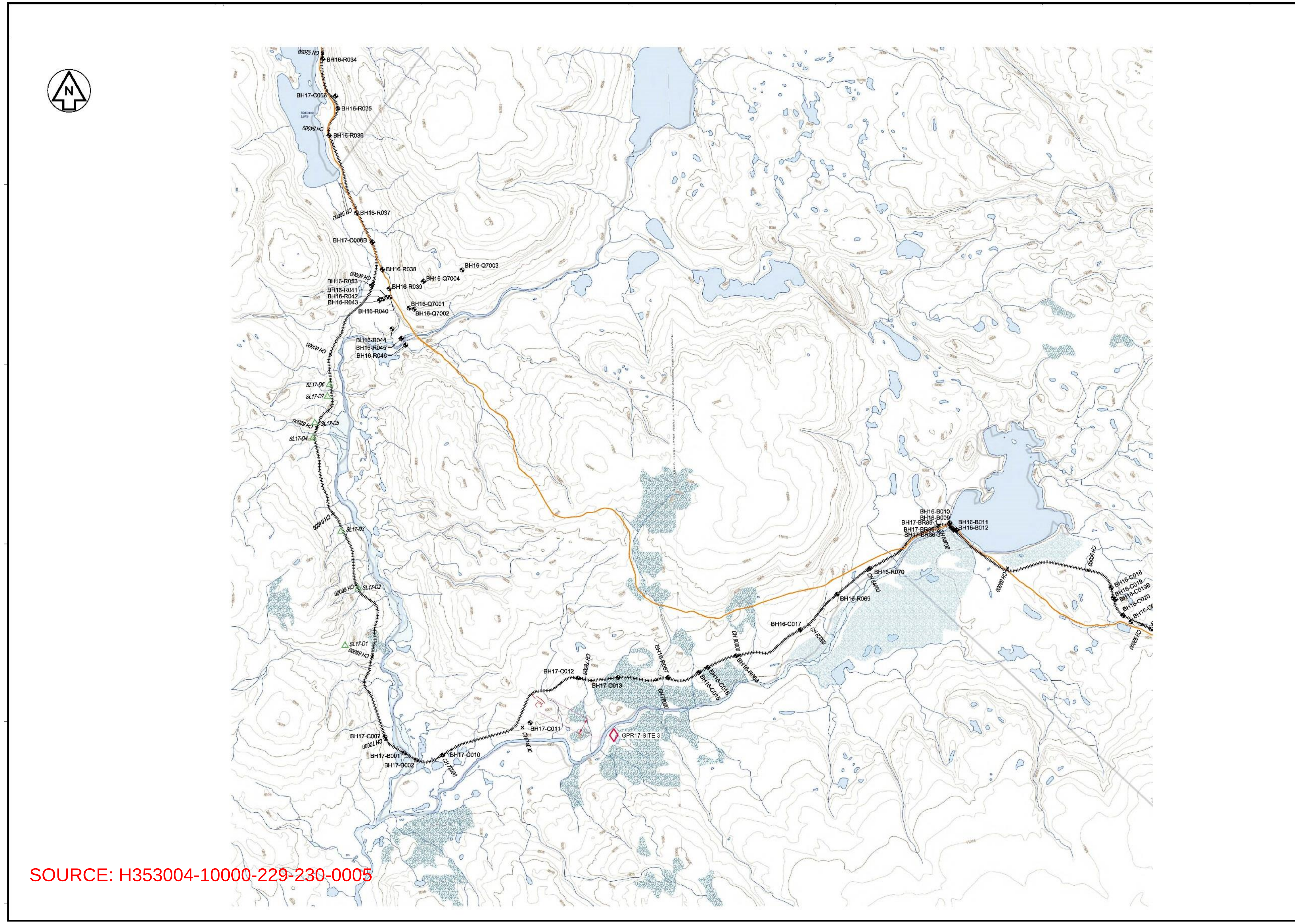
- CHAINAGE POINT ALONG RAIL ALIGNMENT
- SEISMIC LINE LOCATION
- GROUND PENETRATING RADAR SURVEY (GPR) AREA
- PROPOSED RAILWAY
- EXISTING TOTE ROAD

0 1 2 3 4 5 KILOMETRES

SCALE 1:50 000 (B1 SHEET)

NORTHERN RAILWAY ALIGNMENT
SHEET 2 OF 4



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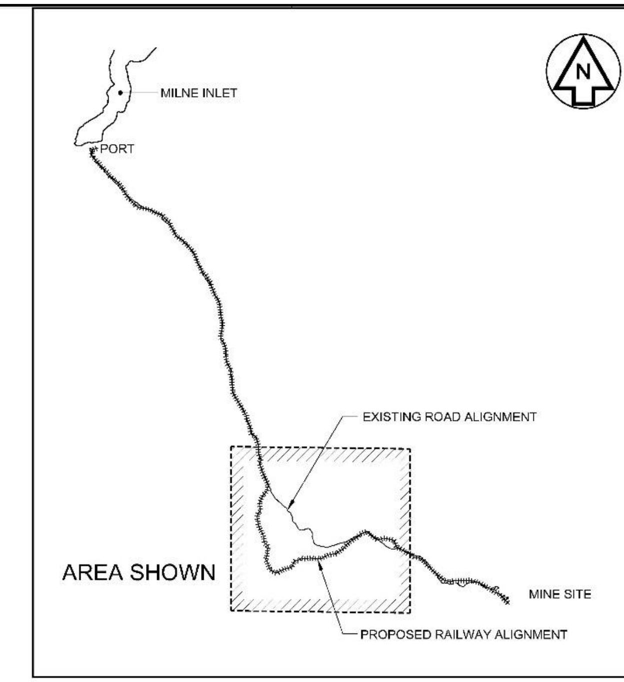


KEY PLAN

0 10 20 30 40 50 kilometres

SCALE 1:500 000

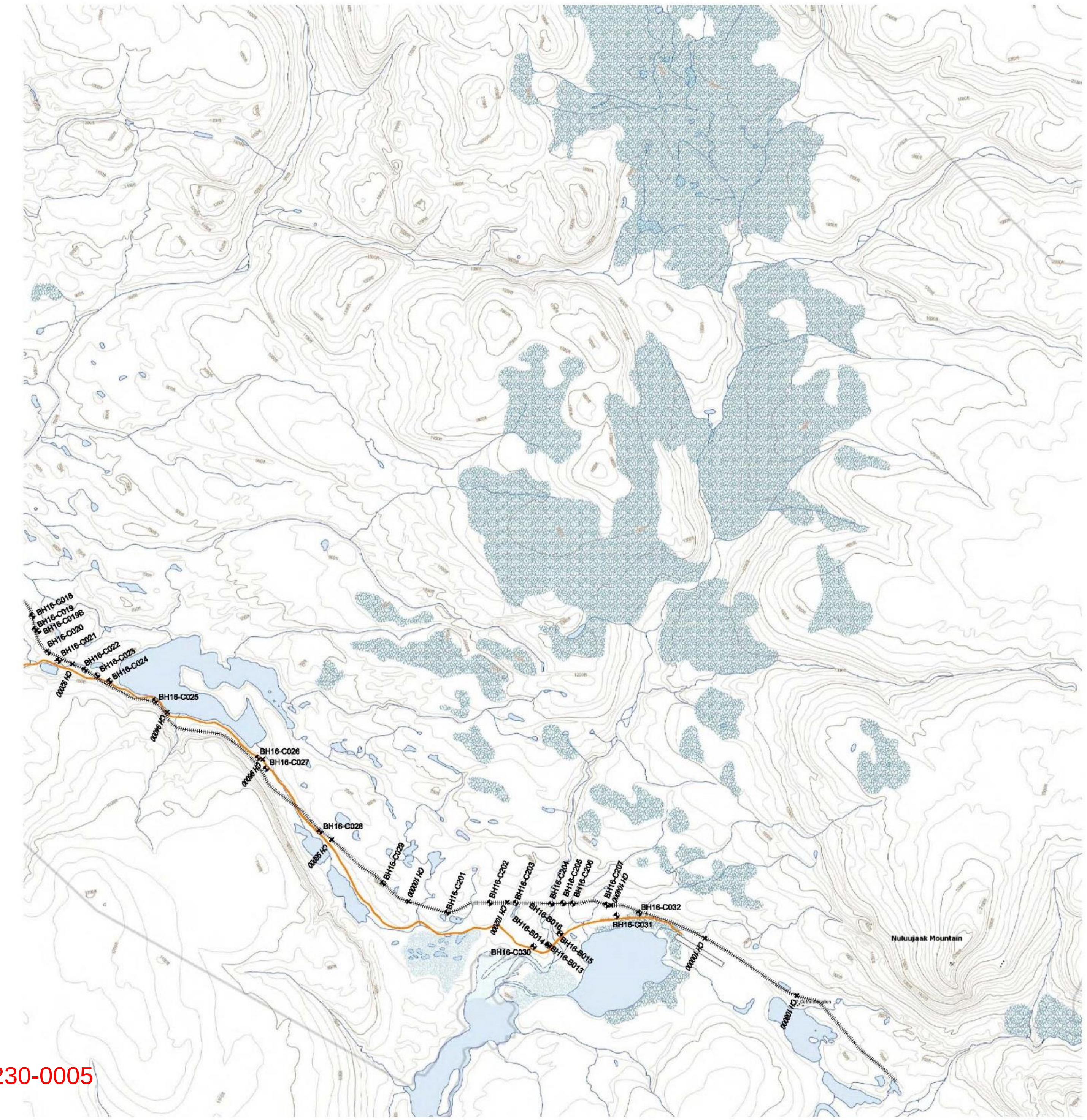
LEGEND

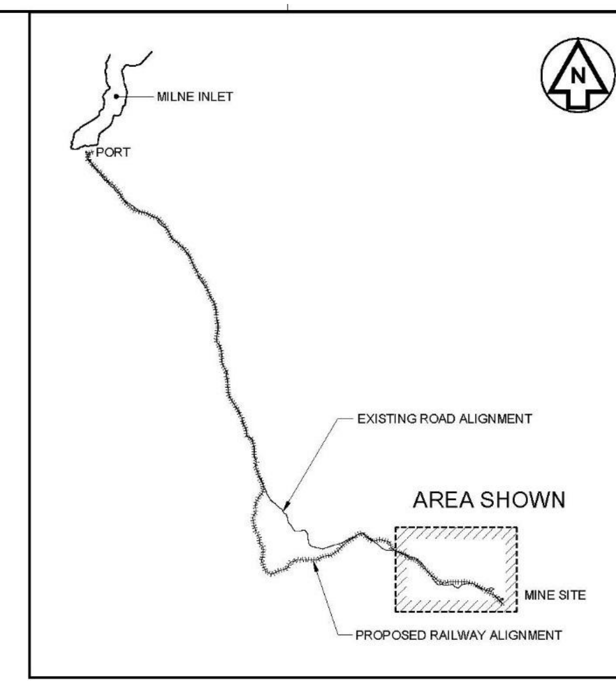
- AS-BUILT BOREHOLE LOCATION
- CHAINAGE POINT ALONG RAIL ALIGNMENT
- SEISMIC LINE LOCATION
- GROUND PENETRATING RADAR SURVEY (GPR) AREA
- PROPOSED RAILWAY
- EXISTING TOTE ROAD

0 1 2 3 4 5 KILOMETRES

SCALE 1:50 000 (B1 SHEET)

NORTHERN RAILWAY ALIGNMENT
SHEET 3 OF 4





KEY PLAN

0 10 20 30 40 50 kilometres

SCALE 1:500 000

LEGEND

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- CHAINAGE POINT ALONG RAIL ALIGNMENT
- SEISMIC LINE LOCATION
- GROUND PENETRATING RADAR SURVEY (GPR) AREA
- PROPOSED RAILWAY
- EXISTING TOTE ROAD

0 1 2 3 4 5 KILOMETRES

SCALE 1:50 000 (B1 SHEET)

SOURCE: H353004-10000-229-230-0005

NORTHERN RAILWAY ALIGNMENT
SHEET 4 OF 4

Appendix B

Profile Along the Railway

BASIS FOR SOIL DESCRIPTION

(Based on AS1726-1993 - Geotechnical Site Investigations, with modifications)

GRAPHIC SYMBOLS FOR SOILS

GRAVEL
- poorly graded -
- well graded -

SAND
- poorly graded -
- well graded -

SILT
- of low plasticity -
- of high plasticity -

CLAY
- of low plasticity -
- of high plasticity -

ICE -

COBBLES AND BOULDERS -

ORGANIC/ PEATY SOIL -

FILL/ MADE GROUND -

Composite soil types are presented using combined symbols, eg. **Gravelly Sandy CLAY**

GROUNDWATER OBSERVATIONS

Permanent Water Level

Temporary Water Level

Inflow into Pit or Borehole

Outflow/ Water Loss in Borehole

Slow Inflow/ Seepage into Pit or Borehole

SAMPLE TYPES

Disturbed bag sample

Bulk Disturbed (>20kg)

Hollow Stem Auger Core

Auger Flight Cuttings

Standard Penetration Test (SPT), with Disturbed Split-Spoon Sample

SPT (no recovery)

Thin walled "undisturbed" push tube sample eg. U60, U100 etc

Sample attempted with no recovery

BASIS FOR ROCK DESCRIPTION

(Based on AS1726-1993 - Geotechnical Site Investigations, with modifications)

GRAPHIC SYMBOLS FOR SOILS

GRAVEL
- poorly graded -
- well graded -

SAND
- poorly graded -
- well graded -

SILT
- of low plasticity -
- of high plasticity -

CLAY
- of low plasticity -
- of high plasticity -

FINE GRAINED TAILINGS -

COBBLES AND BOULDERS -

ORGANIC/ PEATY SOIL -

FILL/ MADE GROUND -

Composite soil types are presented using combined symbols, eg. **Gravelly Sandy CLAY**

GRAPHIC SYMBOLS FOR ROCKS

SEDIMENTARY

- SHALE
- CLAYSTONE
- SILTSTONE
- SANDSTONE
- CONGLOMERATE
- BRECCIA

CARBONATE

- LIMESTONE
- Calcareous CLAYSTONE
- Calcareous SILTSTONE
- CALCARENITE
- CALCIRUDITE
- CALCRETE

IGNEOUS

- COARSE GRAINED
- MEDIUM GRAINED
- FINE GRAINED
- DOLERITE

METAMORPHIC

- COARSE GRAINED
- MEDIUM GRAINED
- FINE GRAINED

EVAPORITES

- GYPSUM

CORE LOSS

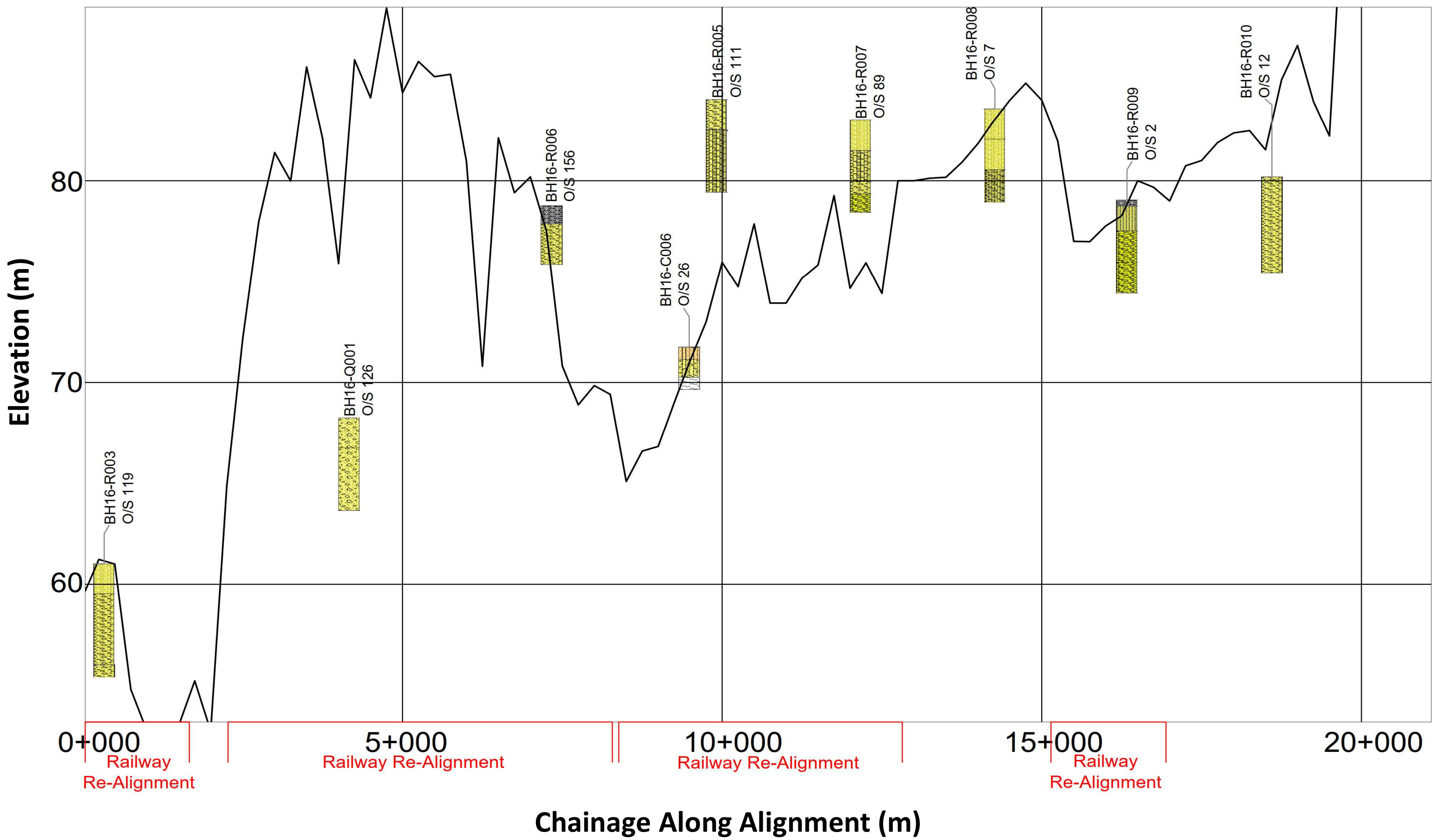
Additional rock graphics may be added for specific projects.

GROUNDWATER OBSERVATIONS

- Permanent Water Level
- Temporary Water Level
- Inflow into Pit or Borehole
- Outflow/ Water Loss in Borehole
- Slow Inflow/ Seepage into Pit or Borehole

SAMPLE TYPES

- Disturbed bag sample
- Bulk Disturbed (>20kg)
- Hollow Stem Auger Core
- Auger Flight Cuttings
- Standard Penetration Test (SPT), with Disturbed Split-Spoon Sample
- SPT (no recovery)
- Thin walled "undisturbed" push tube sample eg. U60, U100 etc
- Sample attempted with no recovery



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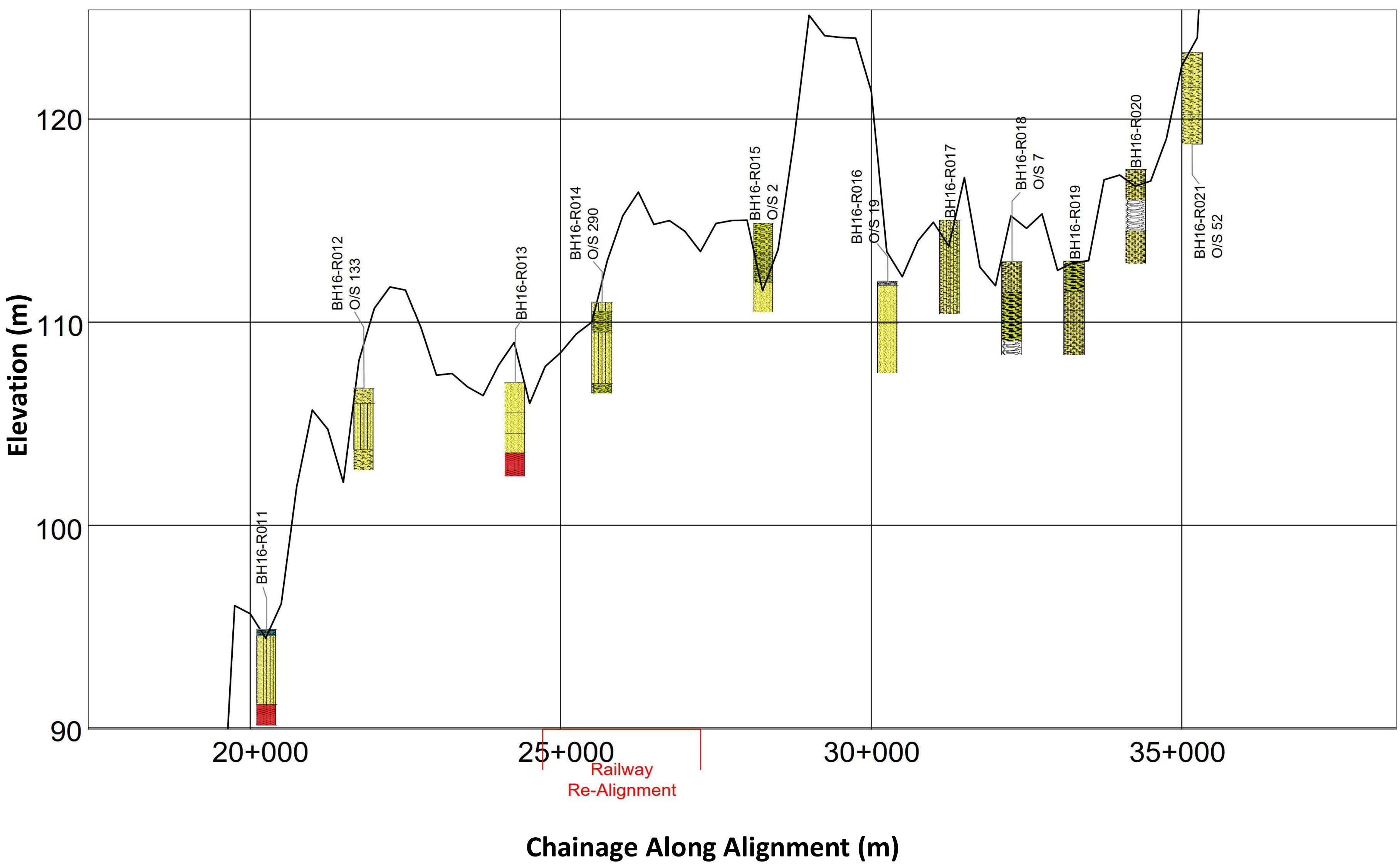
	Checked By	-	-			



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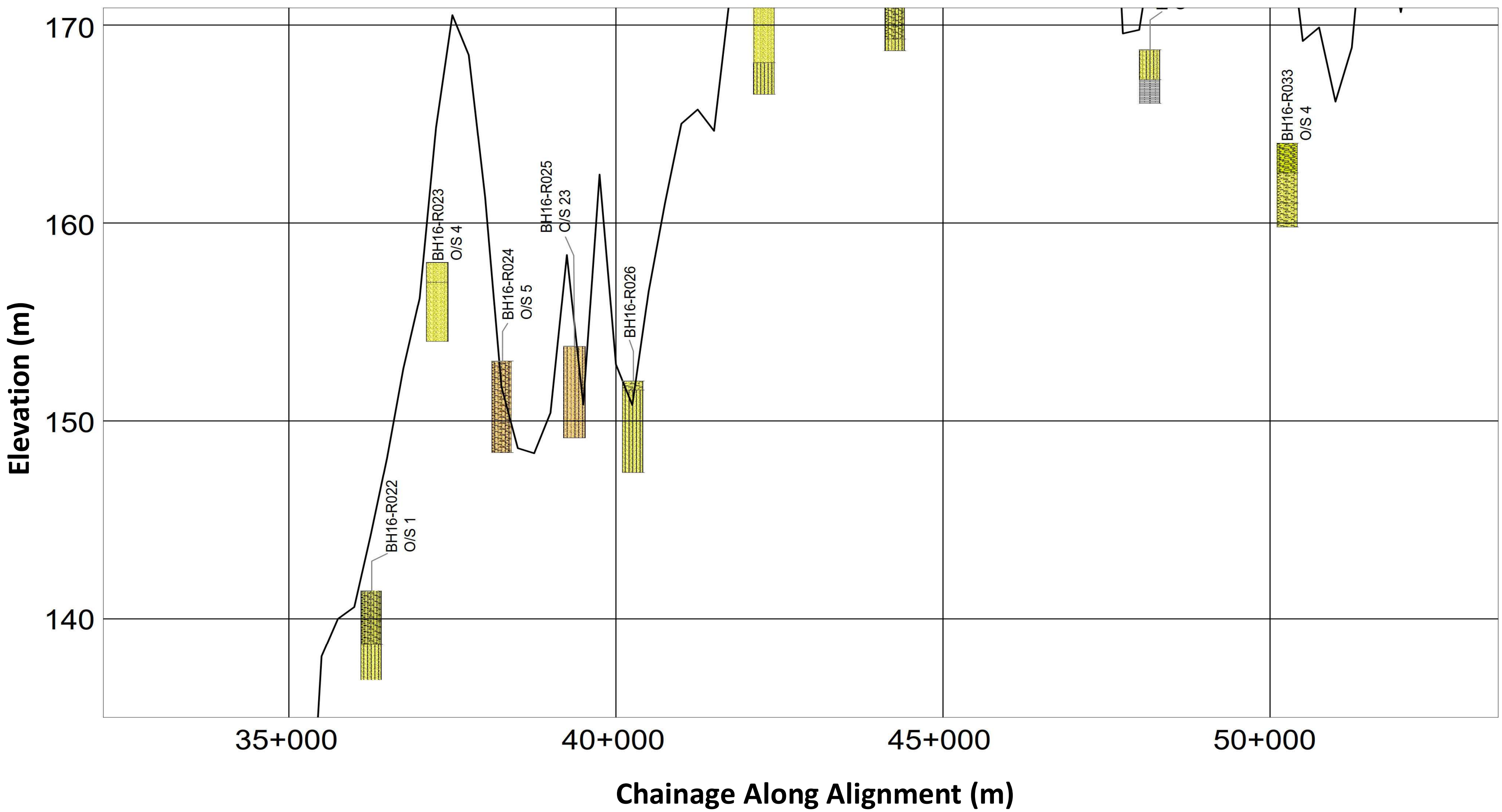

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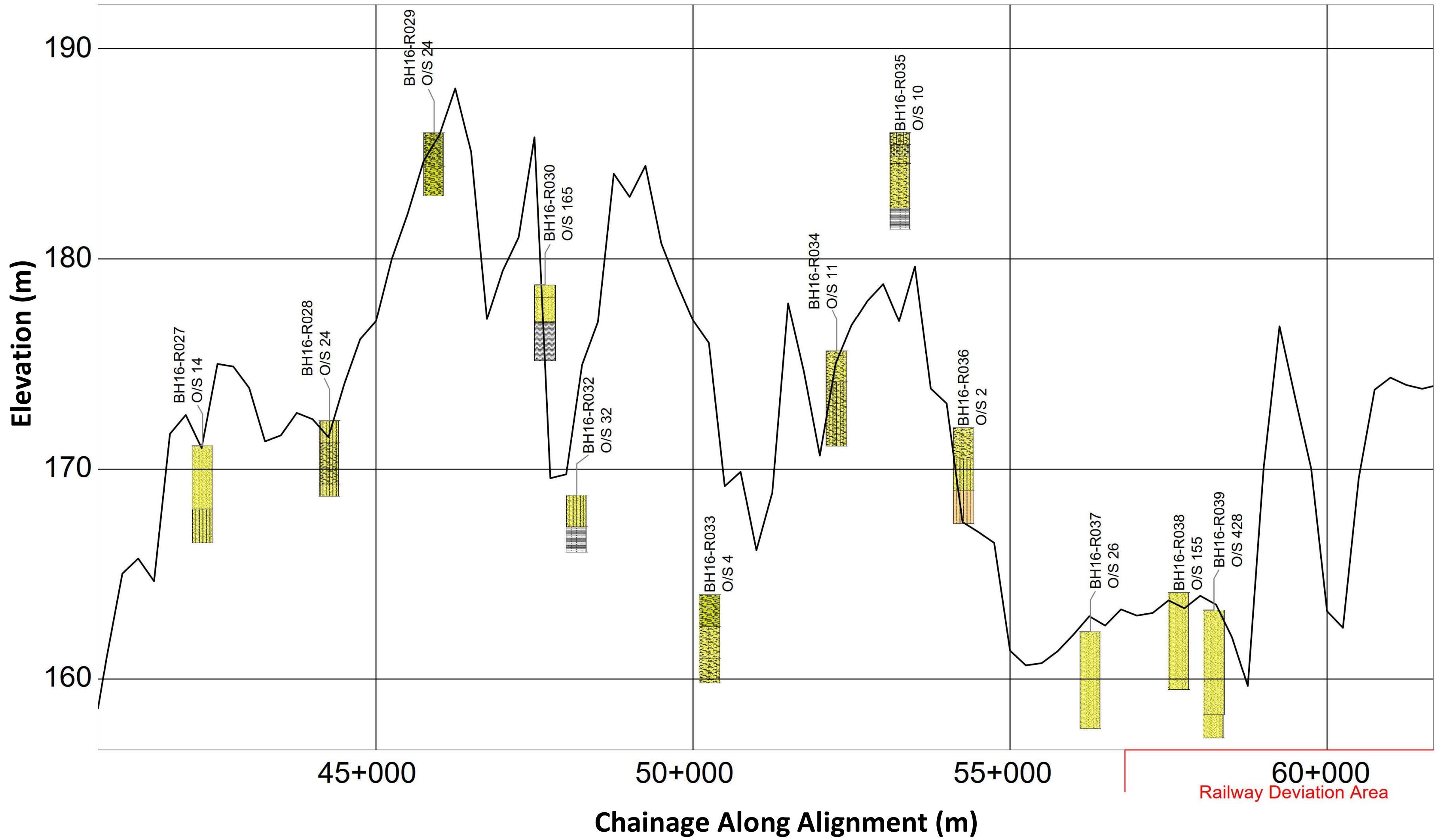

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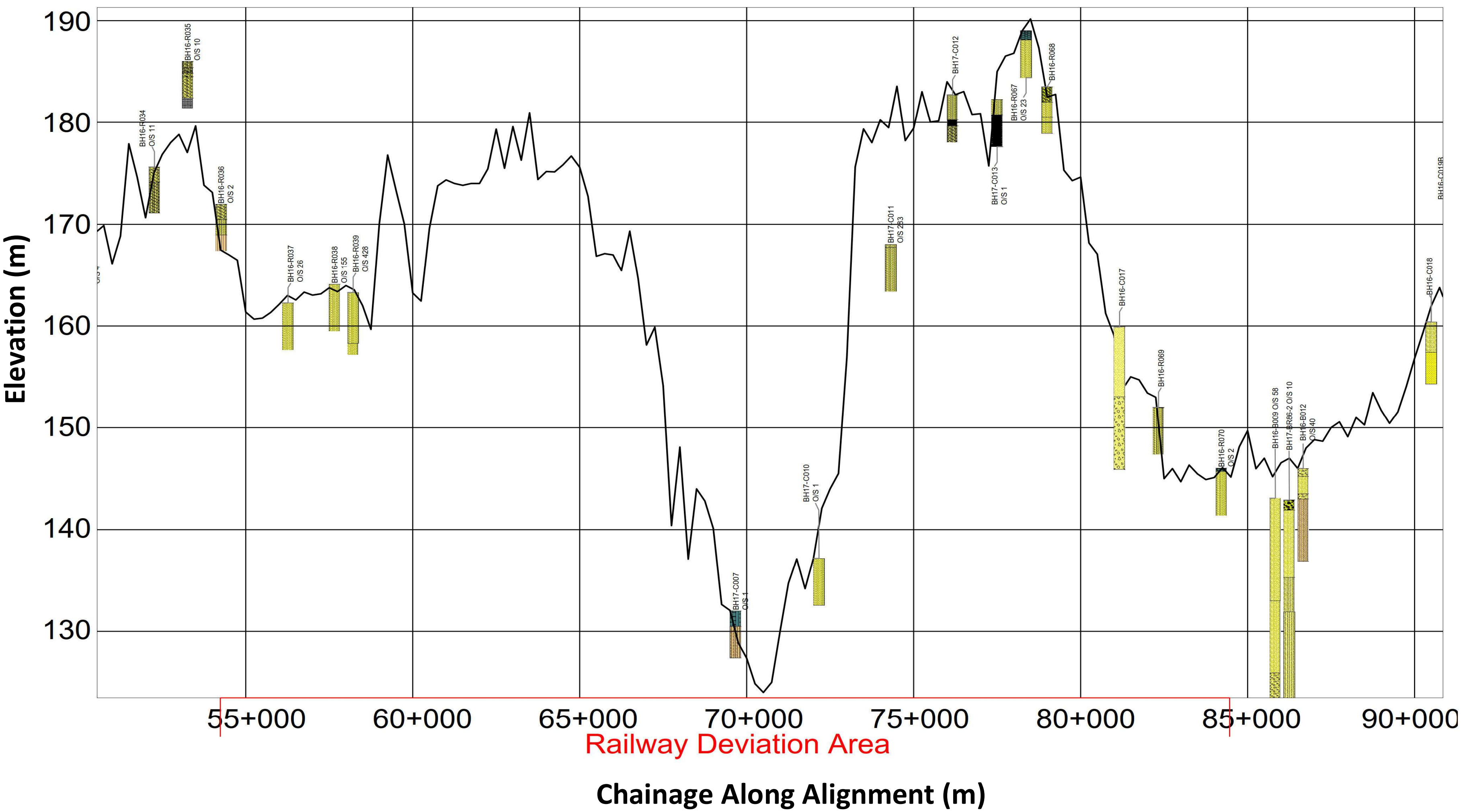

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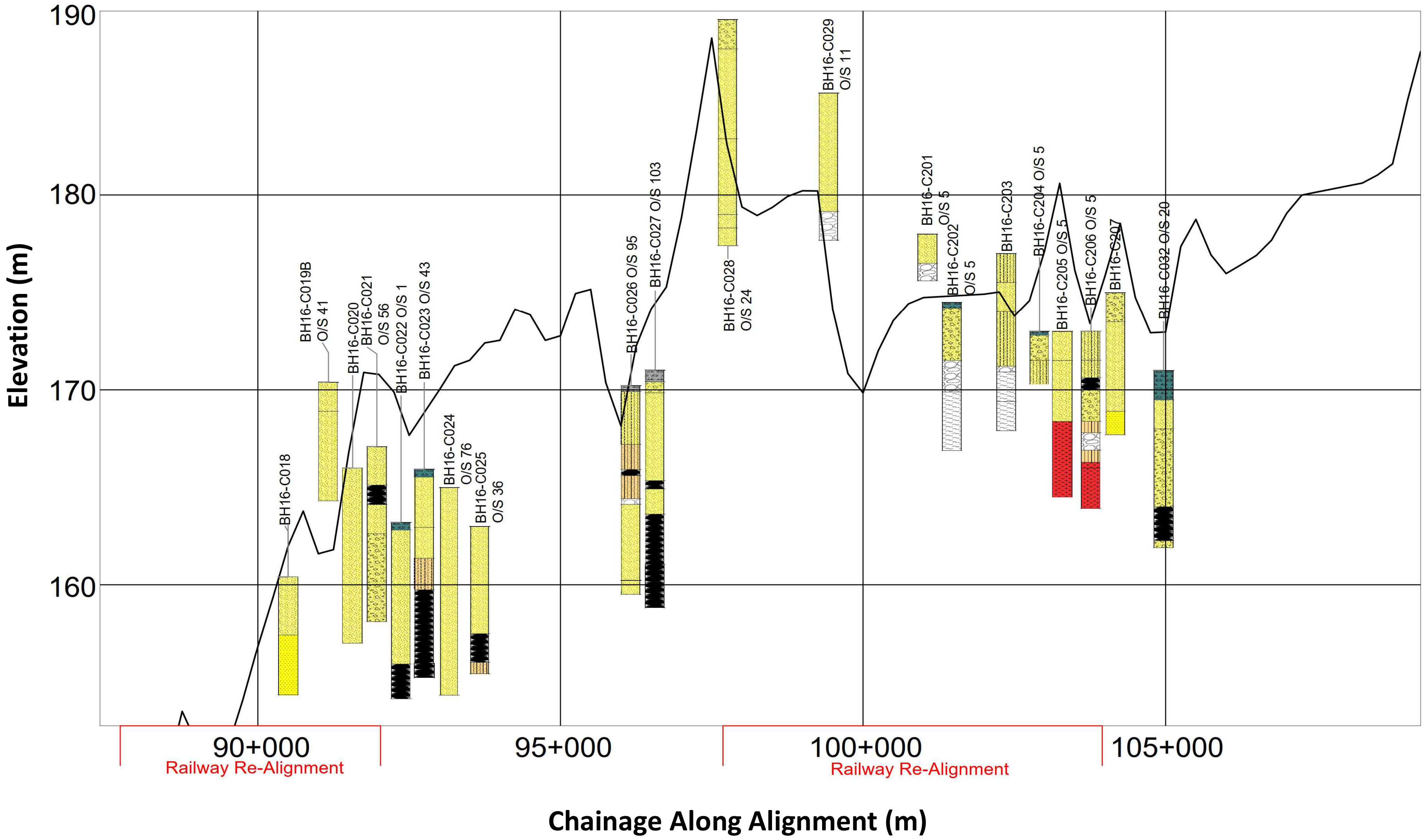

Figure 6	**Project Number**	H353004	**Rev** A	Baffinland Iron Ore Mines	HATCH
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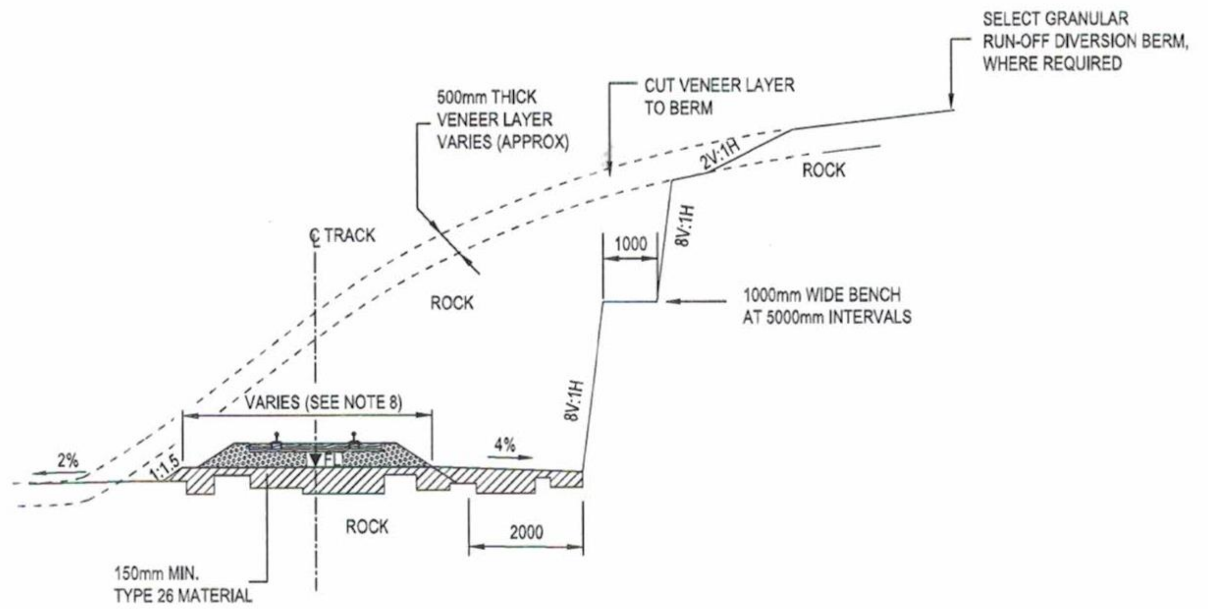
	Checked By	-	-		

Appendix C

Typical Railway Cross Sections

APPENDIX C-1
TYPICAL RAILWAY CUT THROUGH BEDROCK



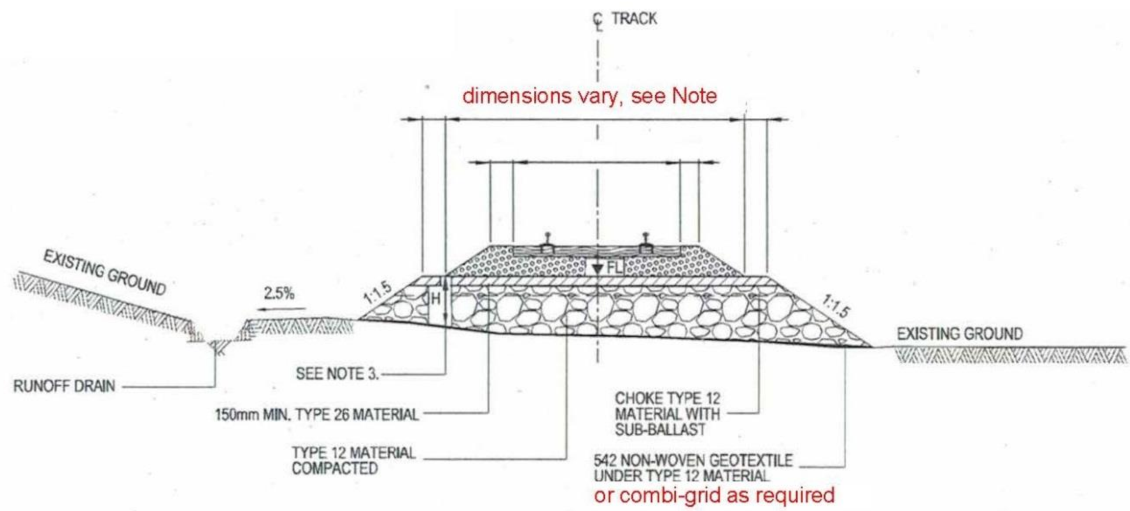
TYPICAL CROSS SECTION (CUT IN GRANITIC ROCK)

NTS

NOTE:

1. MATERIAL TYPE DEFINITION:
   TYPE 12: RUN OF QUARRY/ ROCK FILL LAYER
   TYPE 19: RIP RAP LAYER
   TYPE 25: BALLAST LAYER
   TYPE 26: SUB-BALLAST LAYER
   VENEER LAYER: INSITU SAND AND GRAVEL LAYER
2. PROPOSED EMBANKMENT DOES NOT HAVE SUITABLY WIDE SUB-BALLAST SHOULDERS. EMPLOYER SHALL DEVELOP SAFE OPERATING PROCEDURES FOR ACCESS TO INSPECT AND REPAIR TRAIN EQUIPMENT IN THE CASE OF A BREAKDOWN ON A HIGH EMBANKMENT.
3. FOR SUPERSTRUCTURE DETAILS REFER TO DRAWING H353004-30000-224-294-0003-0001.
4. LONGITUDINAL SLOPE ON RUNOFF AREA TO BE 2 % WHERE PRACTICAL.
5. THIS DRAWING WAS PREVIOULSY ISSUED AS H353004-00000-220-294-0004-0001.
6. THESE TYPICAL SECTIONS ARE APPLICABLE TO ICE RICH PERMAFROST SOILS.
7. H = 800mm TO UNDERSIDE OF POLYSTYRENE INSULATION
8. FORMATION WIDTH VARIES:
   R > 800m AND TANGENT TRACK : 5212mm
   400m < R ≤ 800m : 5612mm
   R ≤ 400m : 5812mm
   WHERE R: RADIUS (HORIZONTAL ALIGNMENT)
9. FL : FORMATION LEVEL.

APPENDIX C-2
TYPICAL RAILWAY CROSS SECTION FILL



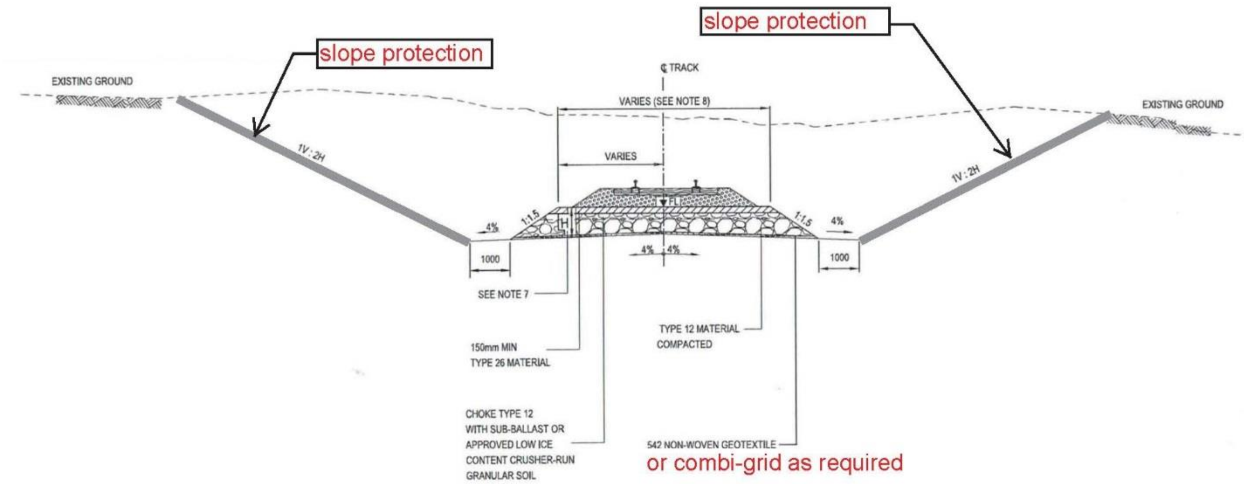
TYPICAL CROSS SECTION (FILL)

Note: dimensions vary depending on track radius or tangent track

NOTE:

1. MATERIAL TYPE DEFINITION:
   TYPE 12: RUN OF QUARRY/ ROCK FILL LAYER
   TYPE 19: RIP RAP LAYER
   TYPE 25: BALLAST LAYER
   TYPE 26: SUB-BALLAST LAYER
   VENEER LAYER: INSITU SAND AND GRAVEL LAYER
2. PROPOSED EMBANKMENT DOES NOT HAVE SUITABLY WIDE SUB-BALLAST SHOULDERS. EMPLOYER SHALL DEVELOP SAFE OPERATING PROCEDURES FOR ACCESS TO INSPECT AND REPAIR TRAIN EQUIPMENT IN THE CASE OF A BREAKDOWN ON A HIGH EMBANKMENT.
3. FOR SUPERSTRUCTURE DETAILS REFER TO DRAWING H353004-30000-224-294-0003-0001.
4. LONGITUDINAL SLOPE ON RUNOFF AREA TO BE 2 % WHERE PRACTICAL.
5. THIS DRAWING WAS PREVIOULSY ISSUED AS H353004-00000-220-294-0004-0001.
6. THESE TYPICAL SECTIONS ARE APPLICABLE TO ICE RICH PERMAFROST SOILS.
7. H = 800mm TO UNDERSIDE OF POLYSTYRENE INSULATION
8. FORMATION WIDTH VARIES:
   R > 800m AND TANGENT TRACK : 5212mm
   400m < R ≤ 800m : 5612mm
   R ≤ 400m : 5812mm
   WHERE R: RADIUS (HORIZONTAL ALIGNMENT)
9. FL : FORMATION LEVEL.

APPENDIX C-3
TYPICAL RAILWAY CUTS IN ICE-POOR SOILS



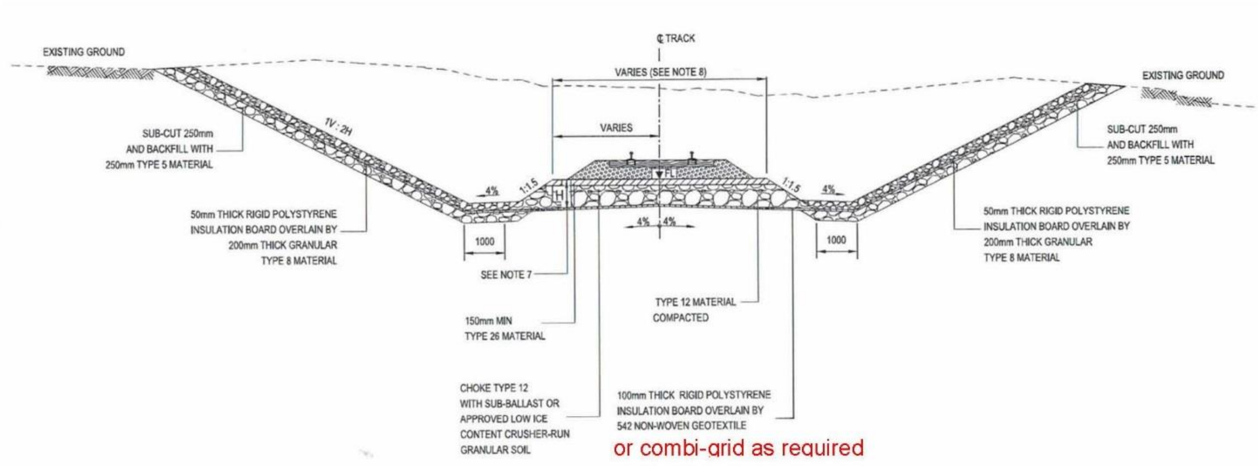
TYPICAL CROSS SECTION (CUT IN ICE POOR PERMAFROST)

NTS

NOTE:

1. MATERIAL TYPE DEFINITION:
   TYPE 12: RUN OF QUARRY/ ROCK FILL LAYER
   TYPE 19: RIP RAP LAYER
   TYPE 25: BALLAST LAYER
   TYPE 26: SUB-BALLAST LAYER
   VENEER LAYER: INSITU SAND AND GRAVEL LAYER
2. PROPOSED EMBANKMENT DOES NOT HAVE SUITABLY WIDE SUB-BALLAST SHOULDERS. EMPLOYER SHALL DEVELOP SAFE OPERATING PROCEDURES FOR ACCESS TO INSPECT AND REPAIR TRAIN EQUIPMENT IN THE CASE OF A BREAKDOWN ON A HIGH EMBANKMENT.
3. FOR SUPERSTRUCTURE DETAILS REFER TO DRAWING H353004-30000-224-294-0003-0001.
4. LONGITUDINAL SLOPE ON RUNOFF AREA TO BE 2 % WHERE PRACTICAL.
5. THIS DRAWING WAS PREVIOULSY ISSUED AS H353004-00000-220-294-0004-0001.
6. THESE TYPICAL SECTIONS ARE APPLICABLE TO ICE RICH PERMAFROST SOILS.
7. H = 800mm TO UNDERSIDE OF POLYSTYRENE INSULATION
8. FORMATION WIDTH VARIES:
   R > 800m AND TANGENT TRACK : 5212mm
   400m < R ≤ 800m : 5612mm
   R ≤ 400m : 5812mm
   WHERE R: RADIUS (HORIZONTAL ALIGNMENT)
9. FL : FORMATION LEVEL.

APPENDIX C-4
TYPICAL RAILWAY CUTS IN ICE-RICH SOILS



TYPICAL CROSS SECTION (CUT IN ICE RICH PERMAFROST)

NTS

NOTE:

1. MATERIAL TYPE DEFINITION:
   TYPE 12: RUN OF QUARRY/ ROCK FILL LAYER
   TYPE 19: RIP RAP LAYER
   TYPE 25: BALLAST LAYER
   TYPE 26: SUB-BALLAST LAYER
   VENEER LAYER: INSITU SAND AND GRAVEL LAYER
2. PROPOSED EMBANKMENT DOES NOT HAVE SUITABLY WIDE SUB-BALLAST SHOULDERS. EMPLOYER SHALL DEVELOP SAFE OPERATING PROCEDURES FOR ACCESS TO INSPECT AND REPAIR TRAIN EQUIPMENT IN THE CASE OF A BREAKDOWN ON A HIGH EMBANKMENT.
3. FOR SUPERSTRUCTURE DETAILS REFER TO DRAWING H353004-30000-224-294-0003-0001.
4. LONGITUDINAL SLOPE ON RUNOFF AREA TO BE 2 % WHERE PRACTICAL.
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6. THESE TYPICAL SECTIONS ARE APPLICABLE TO ICE RICH PERMAFROST SOILS.
7. H = 800mm TO UNDERSIDE OF POLYSTYRENE INSULATION
8. FORMATION WIDTH VARIES:
   R > 800m AND TANGENT TRACK : 5212mm
   400m < R ≤ 800m : 5612mm
   R ≤ 400m : 5812mm
   WHERE R: RADIUS (HORIZONTAL ALIGNMENT)
9. FL : FORMATION LEVEL.

Appendix D

Slope Stability of Fills and Cuts

APPENDIX D

SLOPE STABILITY OF FILLS AND CUTS

1. **Soil parameters**
   3 types of soils: ice-rich (silt), ice -poor (sand and gravel), and rockfill

Soil Type	Unit Weight (kN/m3)	Cohesion' (kPa)	Phi' (degrees)
Rockfill	20	0	40
Silt (ice-rich)	18	0	30
Sand and gravel (ice-poor)	18	0	32

2. **Assumptions**

   Earthquake conditions: PGA = 0.09.
   Seismic Coefficient used = 0.05
   Stability analyses were run for surficial slope failures (except for embankment fill) as below the active zone, soil is assumed frozen
   Slope Cuts
      Height of cuts - 7 m Note that selected height is arbitrary. Slopes will be covered with stronger rockfill slope protection layer for ice-poor soils.
   Embankment Fills
      Height of fills – 10 m. Note that chosen height is arbitrary. Base of the embankment is assumed to be frozen. Part or core of the rockfill embankment may also be frozen, and will improve stability shown.
   Railway embankment fill with equivalent surcharge load of 90 kPA representing Standard E90 train load over width of 2.6 m

3. **Minimum Required Factor of Safety (FOS)**
   Long Term Conditions 1.3 to 1.5
   Earthquake Conditions 1.0

4. Stability Runs for 10 m Railway Embankment rockfills

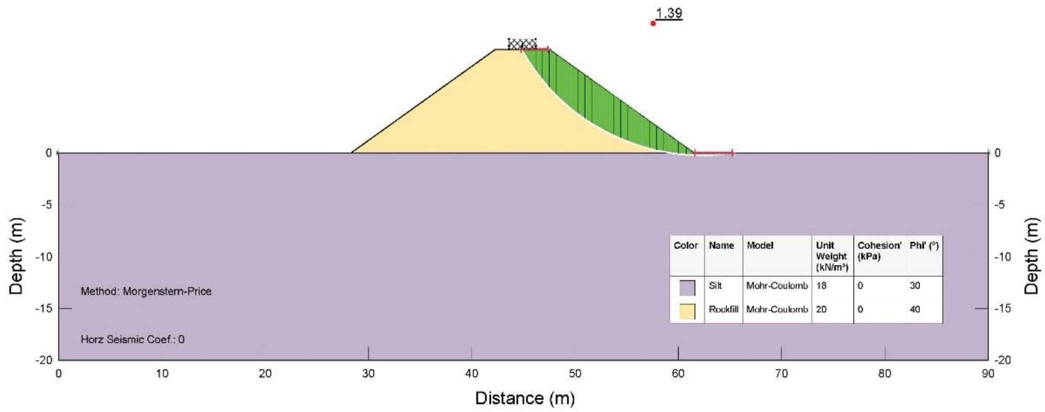


Figure 1: Slope stability of rockfill embankment over silt, 10 m fill – Min FOS = 1.4

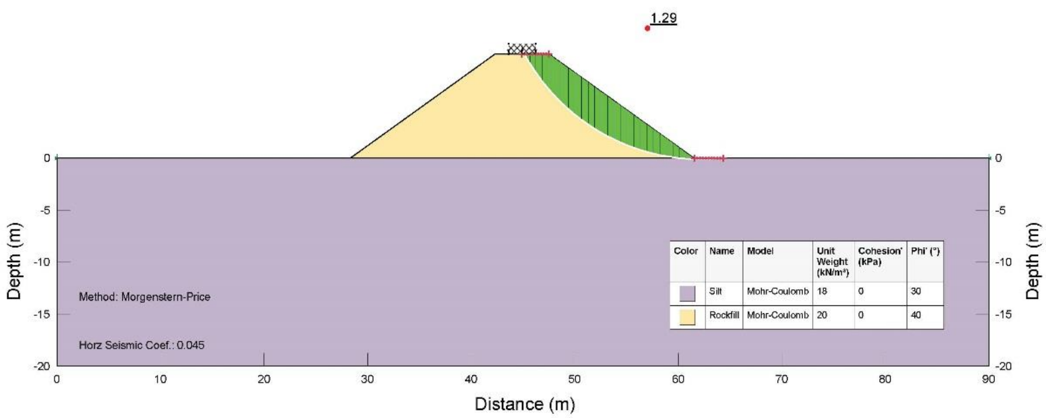


Figure 2: Slope stability of rockfill embankment over silt, 10 m fill, with a horizontal seismic coefficient of 0.045. Min FOS= 1.3

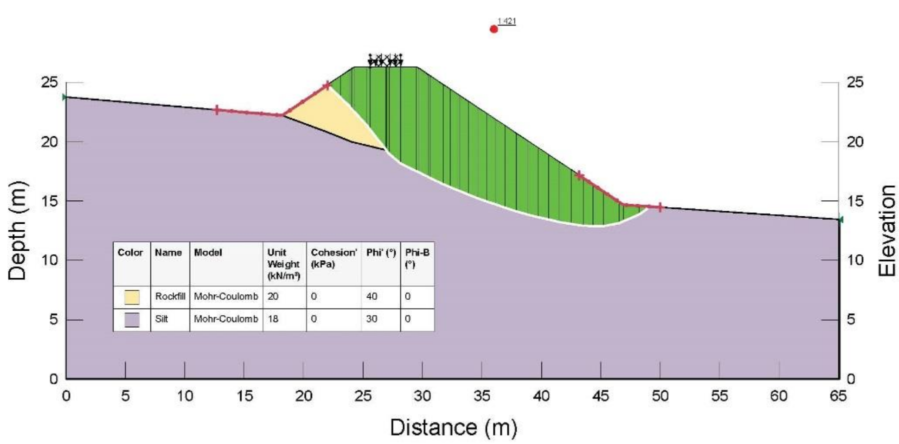


Figure 3: Slope stability of rockfill embankment over silt on sloping ground surface. Min FOS= 1.4

5. Stability Runs for 5 m Railway Embankment Fills

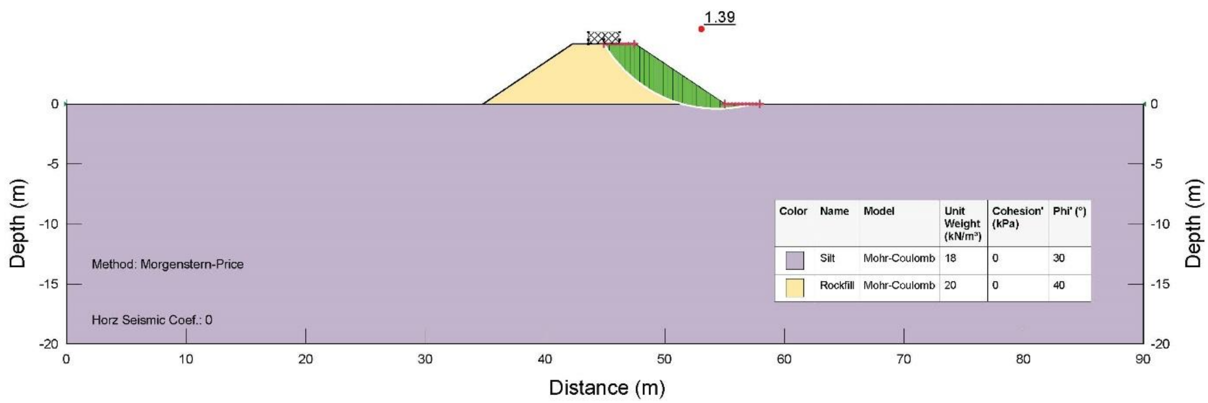


Figure 4: Slope stability of rockfill embankment over silt, 5 m fill – Min FOS = 1.4

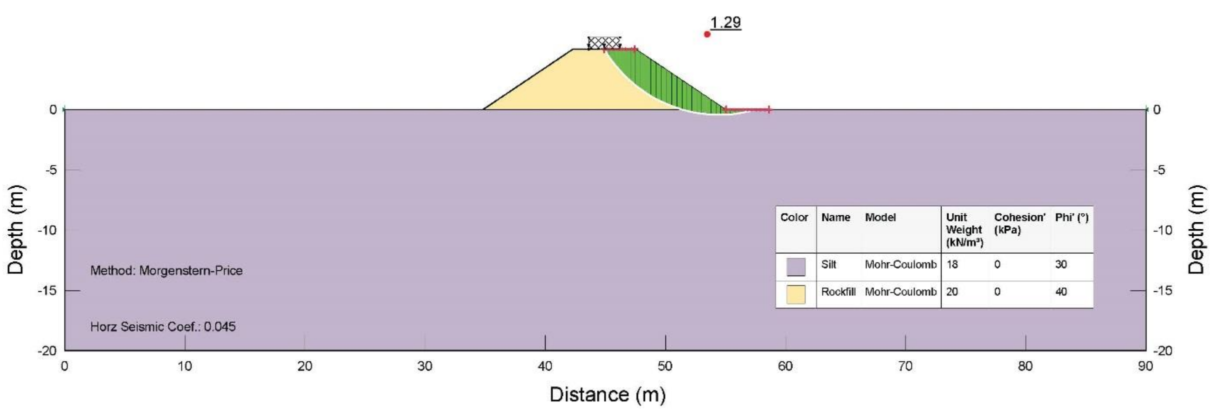


Figure 5: Slope stability of rockfill embankment over silt, 5 m fill, with a horizontal seismic coefficient of 0.045 – Min FOS = 1.3

6. Stability Runs for Railway Cut Slopes on Ice-poor Soils

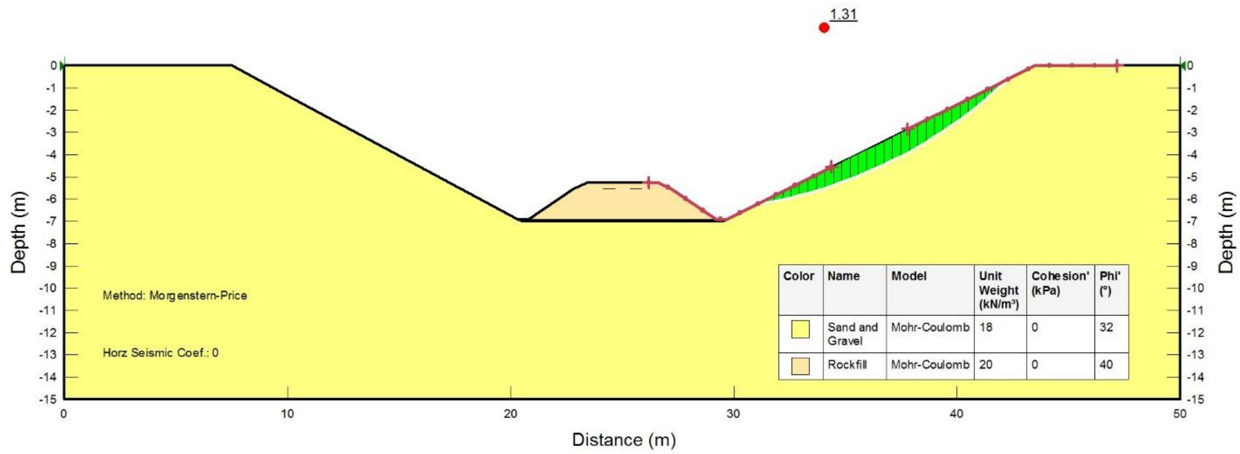


Figure 6: Slope stability of sand and gravel (non-ice rich) soil, 7 m cut. Min FOS = 1.3

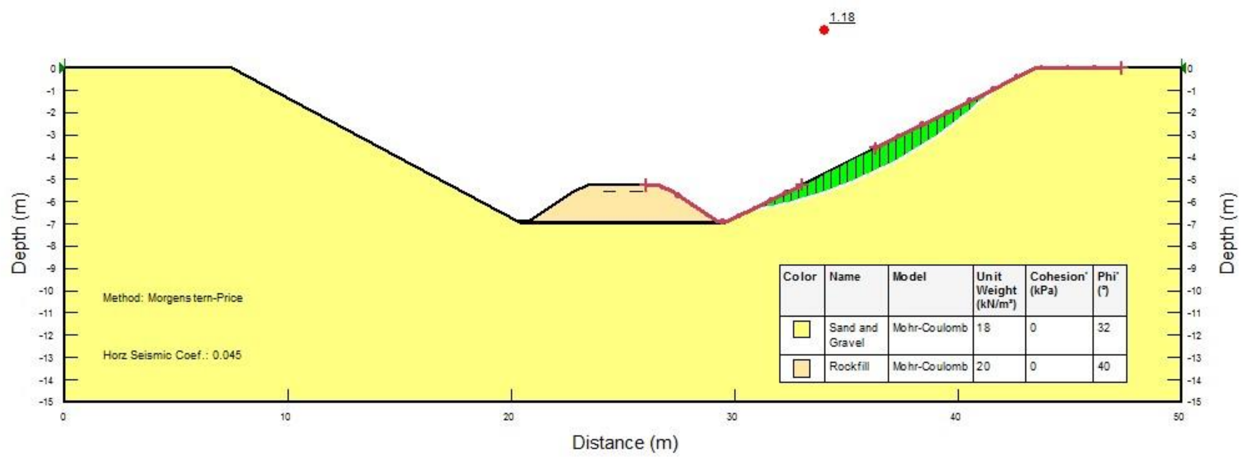


Figure 7: Slope stability of sand and gravel (non-ice rich) soil, 7 m cut, with a horizontal seismic coefficient of 0.045.

7. Stability Runs for Railway Cut Slopes on ice-rich soils

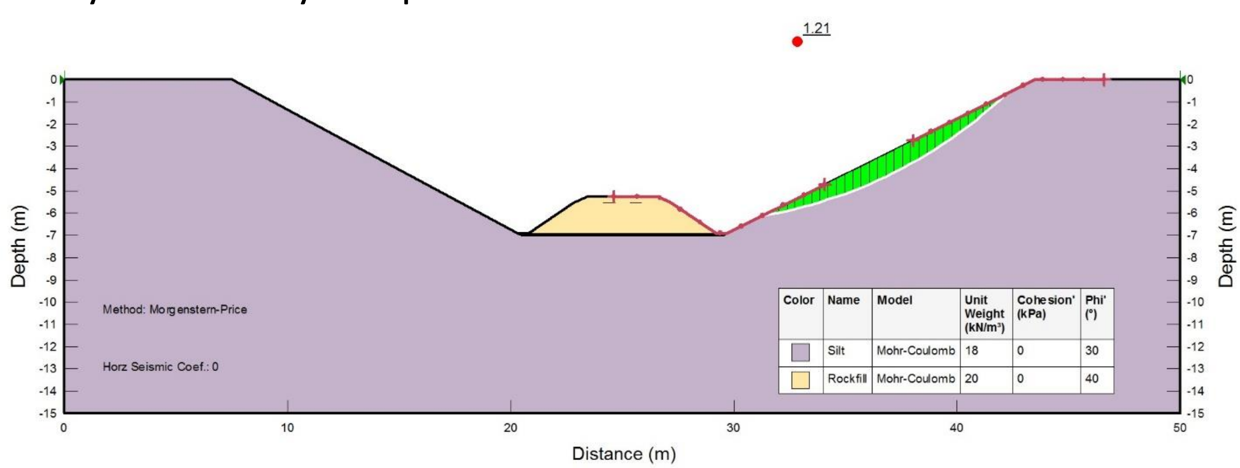


Figure 8: Slope stability of silt soil, 7 m cut. Min FOS = 1.2 (See Note)

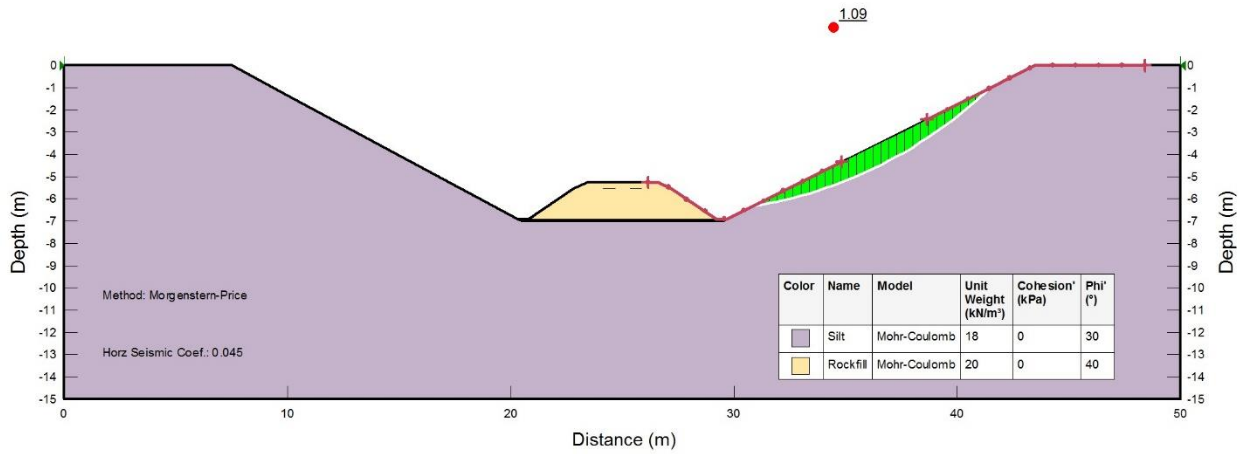


Figure 9: Slope stability of silt soil, 7 m cut, with a horizontal seismic coefficient of 0.045 – FOS = 1.1 (See Note)

Note that for cut slopes, granular rockfill layer will be added along the slope which would make the slope to be stable and protect the underlying silt .

Appendix E

Creep Settlement Analyses

APPENDIX E

CREEP SETTLEMENT ANALYSES

1. Soil Parameters

The representative soil properties have been referenced from the Geotechnical Design Basis.

Design Parameters for Permafrost Materials:

Material	Temperature	Depth	Long-term Equivalent Deformation Modulus	Poisson's Ratio	Unit Weight	Strength Parameters for Creep Analysis (20-year design life)	
	°C	m	Ec (MPa)	-	kN/m³	C'_{LT} (kPa)	Φ'_{LT}
Silt	-0.4 to -7	0 - 7.5*	22	0.33	18	0	30
	<-7	7.5 - 30	44				
Sand and Gravel	-0.4 to -7	0 - 6*	80				32
	<-7	6 - 30	160				

**The bottom boundary of the -0.4 °C to -7 °C zone is horizontal outside of the rail embankment footprint. The bottom boundary rises to the surface (or side boundary) at a slope of 1.5H:1V starting at the horizontal location of the rail embankment toe.*

Design Parameters for Granular Fill Materials

Material	Temperature	Long-term Equivalent Deformation Modulus	Poisson's Ratio	Unit Weight	Strength Parameters for Creep Analysis (20-year design life)	
	°C	Es (MPa)	-	kN/m³	C'_{LT} (kPa)	Φ'_{LT}
Ballast	All Temperatures	30	0.33	20	0	40
Sub-Ballast	All Temperatures	30	0.33	20	0	40
Embankment Fill (Type 8 or Type 12 Rockfill)	All Temperatures	70	0.33	20	0	40

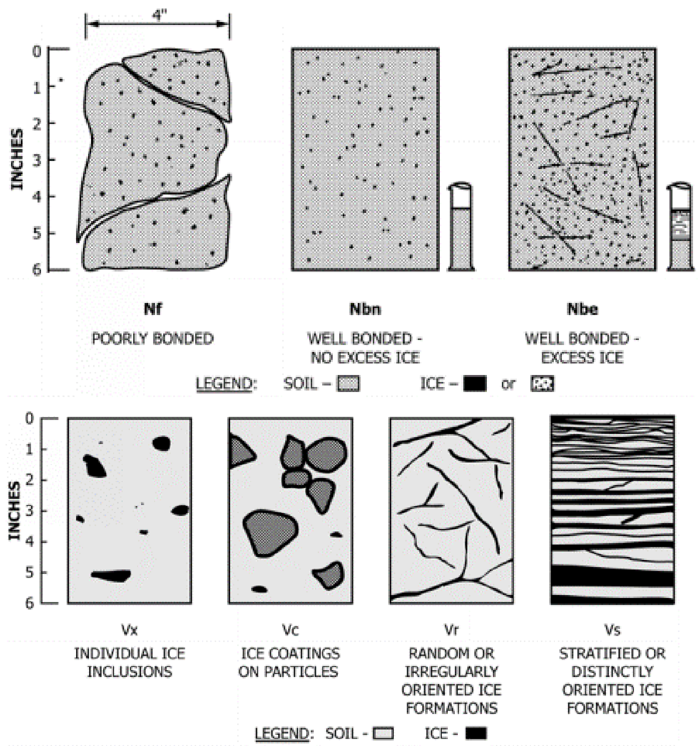
2. Assumptions

- Depth of unyielding bedrock or equivalent layer is 30m below the existing ground surface
- Depth of the -7C isotherm below the existing ground surface is 7.5m for Silt permafrost and 6m for Sand and Gravel permafrost.
- The influence of the active zone has not been considered, and its impact is expected to be minimal for large embankments.

- An equivalent surcharge of 22.5 kPa, or approximately 25% of a Cooper E90 train load, has been considered across the full embankment width for long-term creep settlement.
- Total settlement includes elastic deformation in the fill materials due to self-weight and the considered train loads.

Material	Moisture Content	Ice Type*	Organics
Silt	20% to 40%	Nf, Nbn, Nbe, Vx, Vc, Vr	None
Sand and Gravel	10% to 20%		None

**Abbreviations from ASTM D4083 – Standard Practice for Description of Frozen Soils (Visual-Manual Procedure).*



3. Sigma-W Runs:

Foundation Soil	Case No.		Embankment height
Ice-rich (silt)	Case 1 to 7	Case 1	1 m
		Case 2	3 m
		Case 3	5 m
		Case 4	7 m
		Case 5	10 m
		Case 6	15 m
		Case 7	20 m
Ice-poor (sand and gravel)	Case 8 to 14	Case 8	1 m
		Case 9	3 m

		Case 10	5 m
		Case 11	7 m
		Case 12	10 m
		Case 13	15 m
		Case 14	20 m

4. Vertical Displacements – Ice-rich (Silt) Foundation
Figures 1 to 7

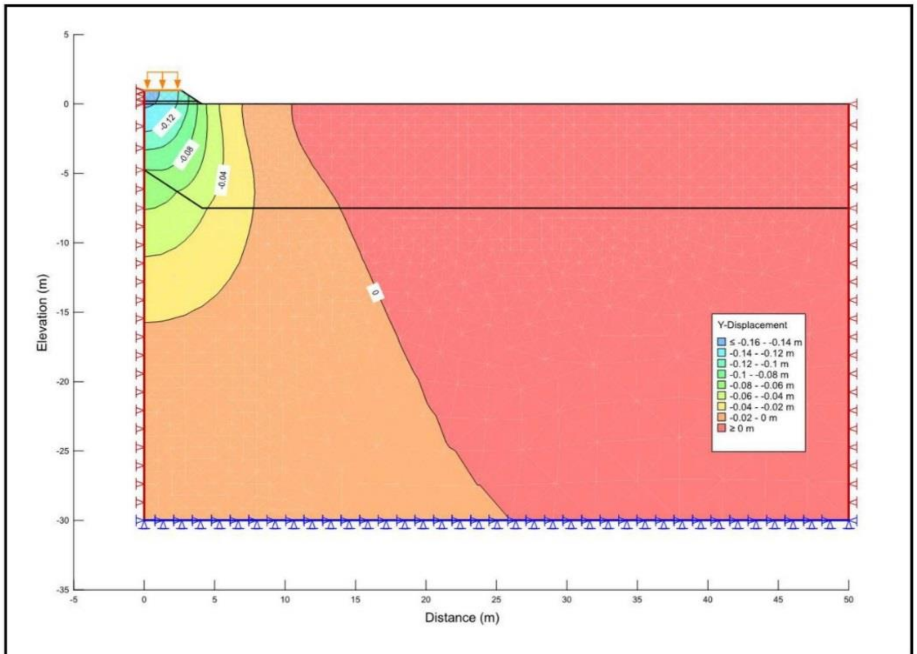


Figure 1	Case 1: 1 m Embankment, Silt Permafrost - Y Displacment	Project Number	H353004	Rev	A	Baffinland Iron Mines	HATCH
		By	MY	4/18/2019			
		Checked By	-	-		Rail Embankment	

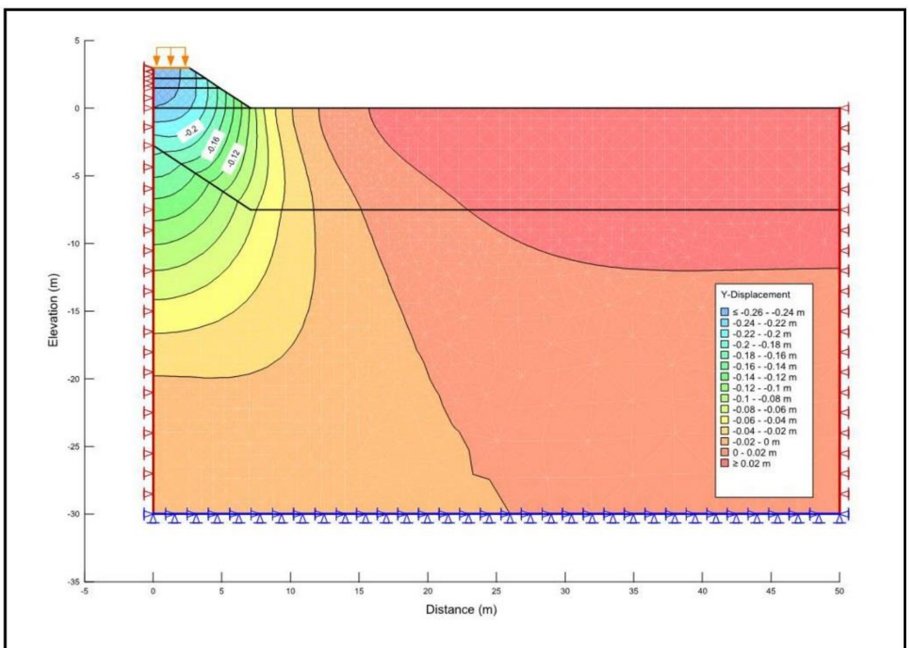


Figure 2	Case 2: 3 m Embankment, Silt Permafrost - Y Displacment	Project Number	H353004	Rev	A	Baffinland Iron Mines	HATCH
		By	MY	4/18/2019			
		Checked By	-	-		Rail Embankment	

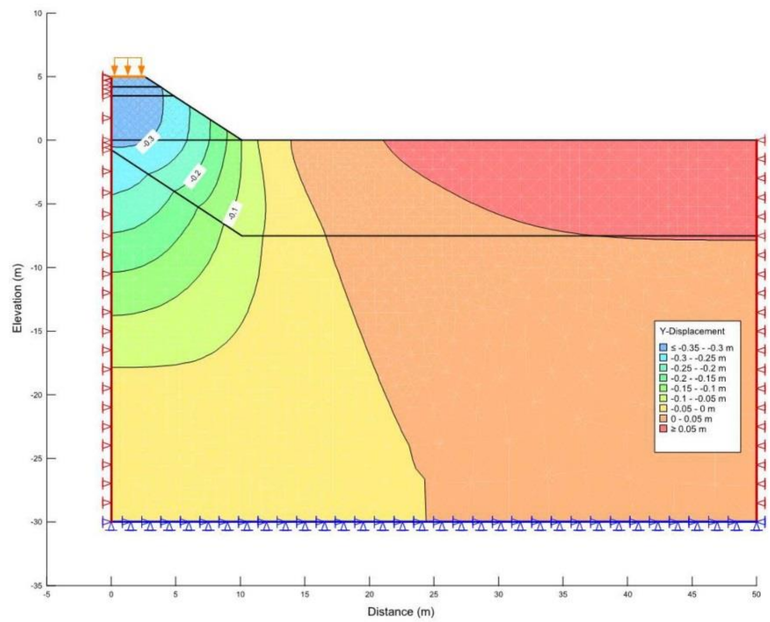


Figure 3	Case 3: 5 m Embankment, Silt Permafrost - Y Displacment	Project Number	H353004 Rev A	Baffinland Iron Mines	HATCH
		By	MY 4/18/2019		
		Checked By	- -	Rail Embankment	

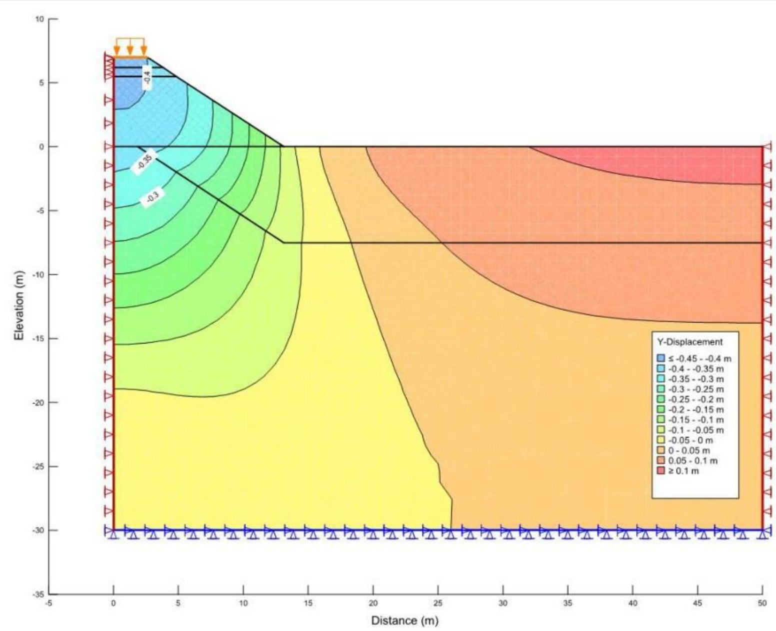


Figure 4	Case 4: 7 m Embankment, Silt Permafrost - Y Displacment	Project Number	H353004 Rev A	Baffinland Iron Mines	HATCH
		By	MY 4/18/2019		
		Checked By	- -	Rail Embankment	

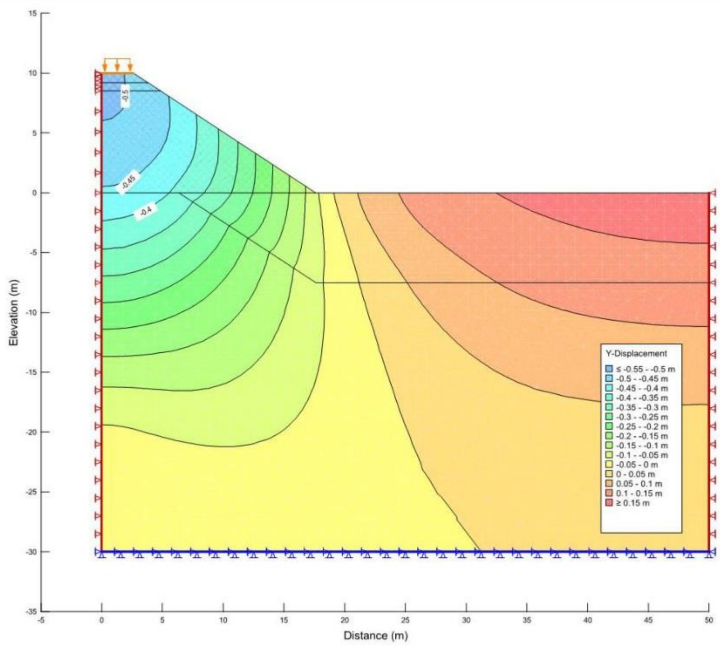


Figure 5	**Case 5: 10 m Embankment, Silt Permafrost - Y Displacment**	**Project Number**	H353004	**Rev**	A	**Baffinland Iron Mines**
		By	MY	4/18/2019		
		Checked By	-	-		Rail Embankment

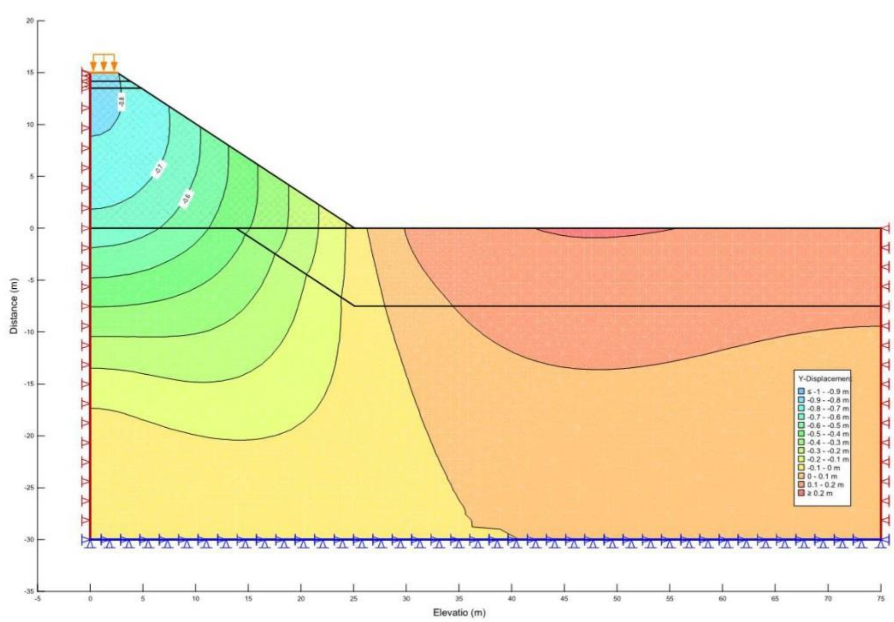


Figure 6	**Case 6: 15 m Embankment, Silt Permafrost - Y Displacment**	**Project Number**	H353004	**Rev**	A	**Baffinland Iron Mines**
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		Checked By	-	-		Rail Embankment

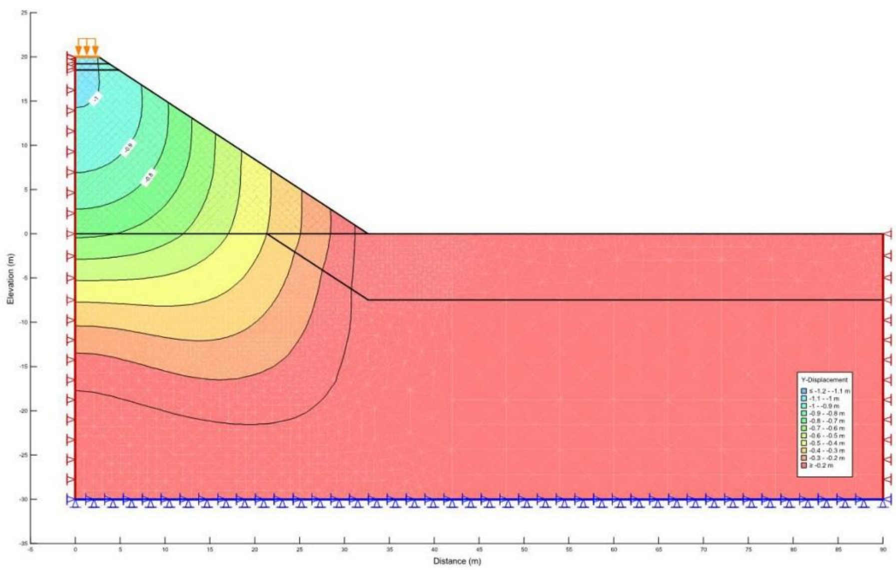

Figure 7	**Case 7: 20 m Embankment, Silt Permafrost - Y Displacment**	**Project Number**	H353004	**Rev** A	**Baffinland Iron Mines**	**HATCH**
		By	MY	4/18/2019		
		Checked By	-	-	Rail Embankment	

5. Vertical Displacements – Ice-poor (Sand and Gravel) Foundation
Figures 8 to 14

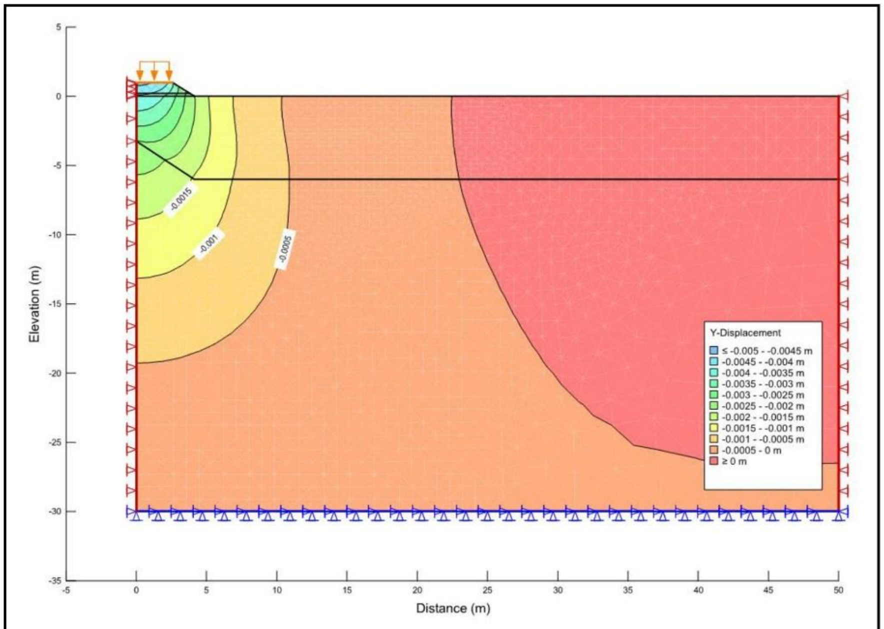

Figure 8	Case 8: 1 m Embankment, Sand and Gravel Permafrost - Y Displacment	Project Number	H353004	Rev A	Baffinland Iron Mines	HATCH
		By	MY	4/18/2019		
		Checked By	-	-	Rail Embankment	

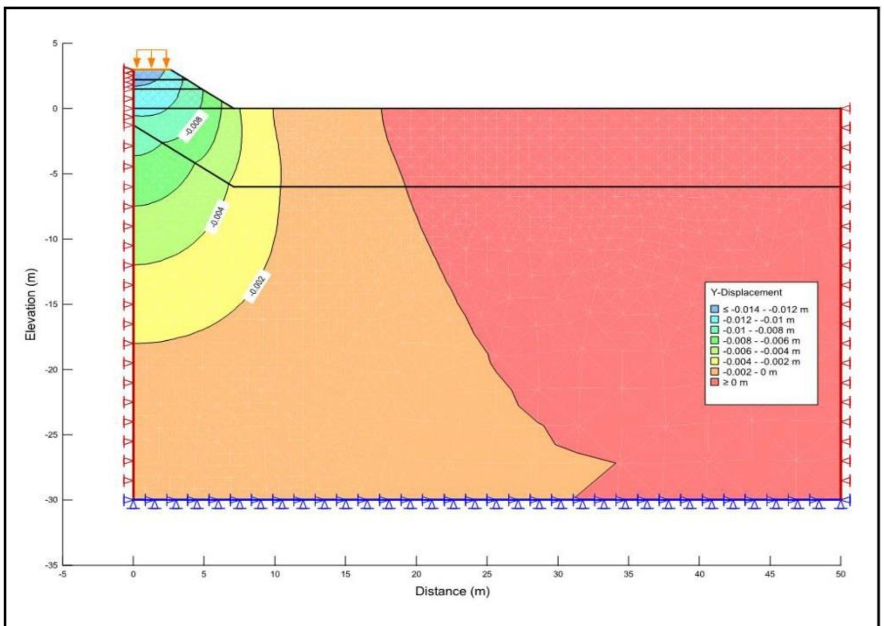

Figure 9	Case 9: 3 m Embankment, Sand and Gravel Permafrost - Y Displacment	Project Number	H353004	Rev A	Baffinland Iron Mines	HATCH
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		Checked By	-	-	Rail Embankment	

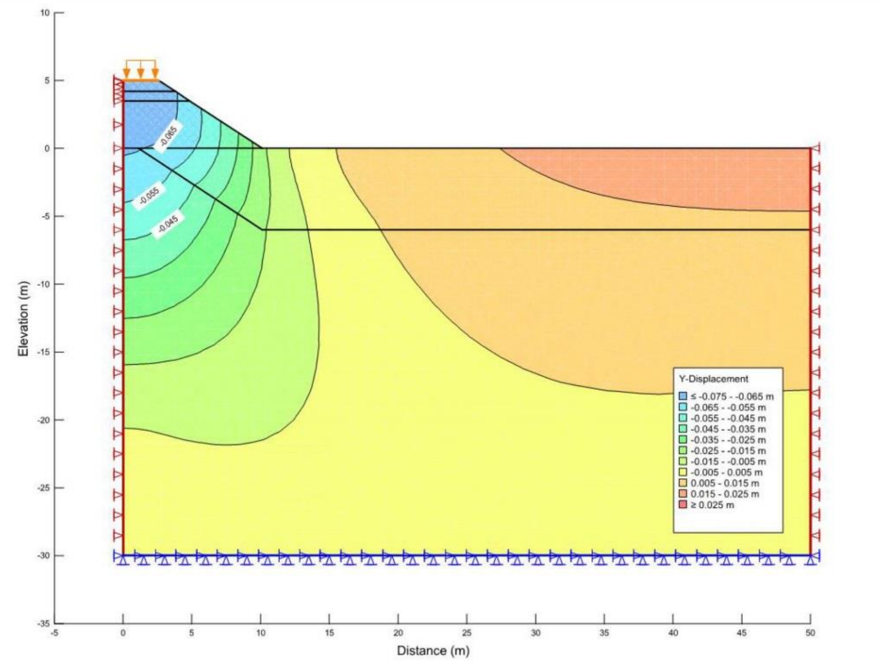

Figure 10	Case 10: 5 m Embankment, Sand and Gravel Permafrost - Y Displacment	Project Number	H353004	Rev	A	Baffinland Iron Mines	HATCH
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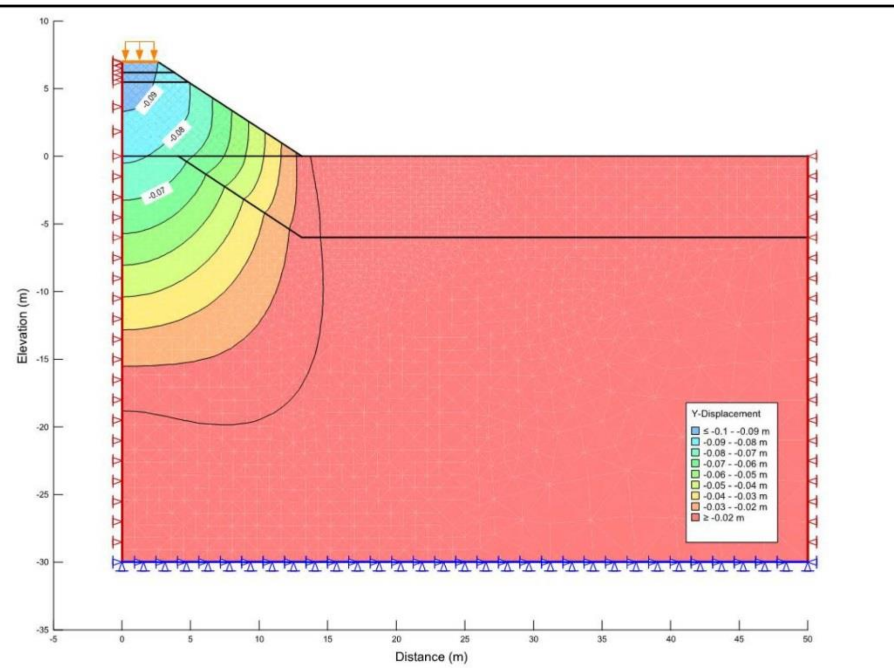

Figure 11	Case 11: 7 m Embankment, Sand and Gravel Permafrost - Y Displacment	Project Number	H353004	Rev	A	Baffinland Iron Mines	HATCH
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		Checked By	-	-		Rail Embankment	

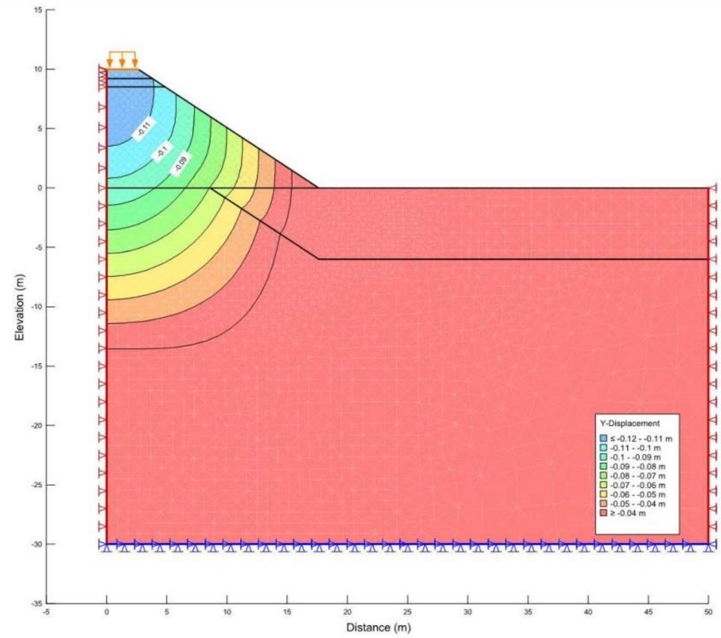

Figure 12	Case 12: 10 m Embankment, Sand and Gravel Permafrost - Y Displacment	Project Number	H353004	Rev	A	Baffinland Iron Mines	HATCH
		By	MY	4/18/2019		Rail Embankment	
		Checked By	-	-			

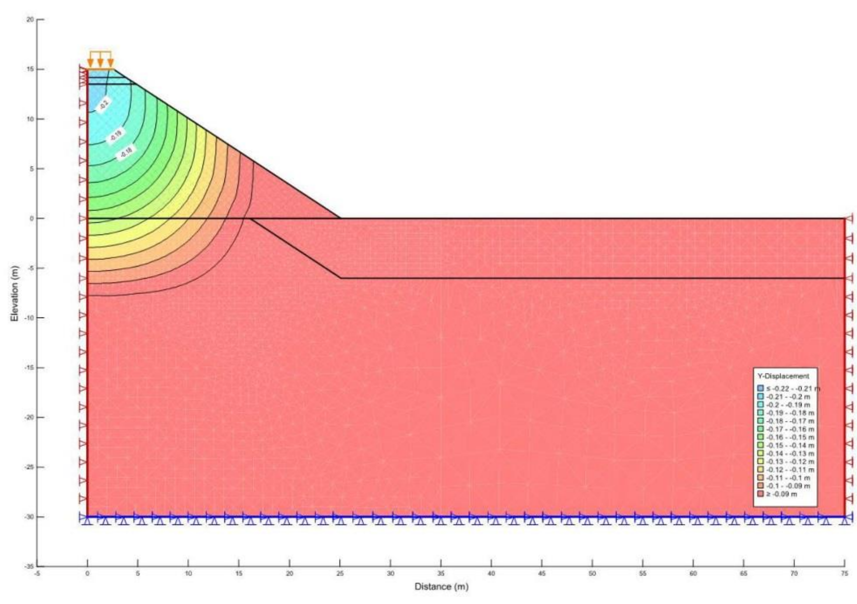

Figure 13	Case 13: 15 m Embankment, Sand and Gravel Permafrost - Y Displacment	Project Number	H353004	Rev	A	Baffinland Iron Mines	HATCH
		By	MY	4/18/2019		Rail Embankment	
		Checked By	-	-			

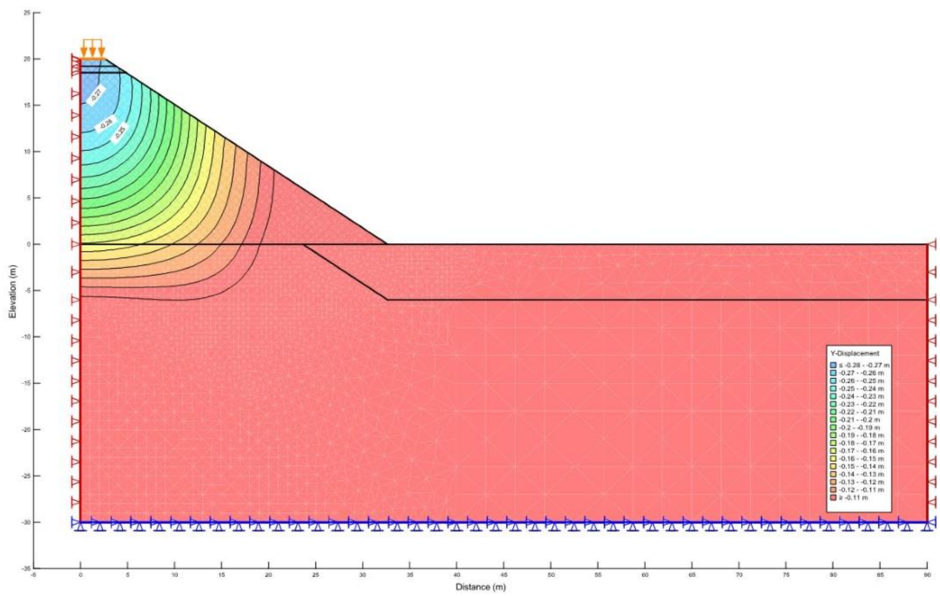

Figure 14	Case 14: 20 m Embankment, Sand and Gravel Permafrost - Y Displacment	Project Number	H353004	Rev A	Baffinland Iron Mines	HATCH
		By	MY	4/18/2019		
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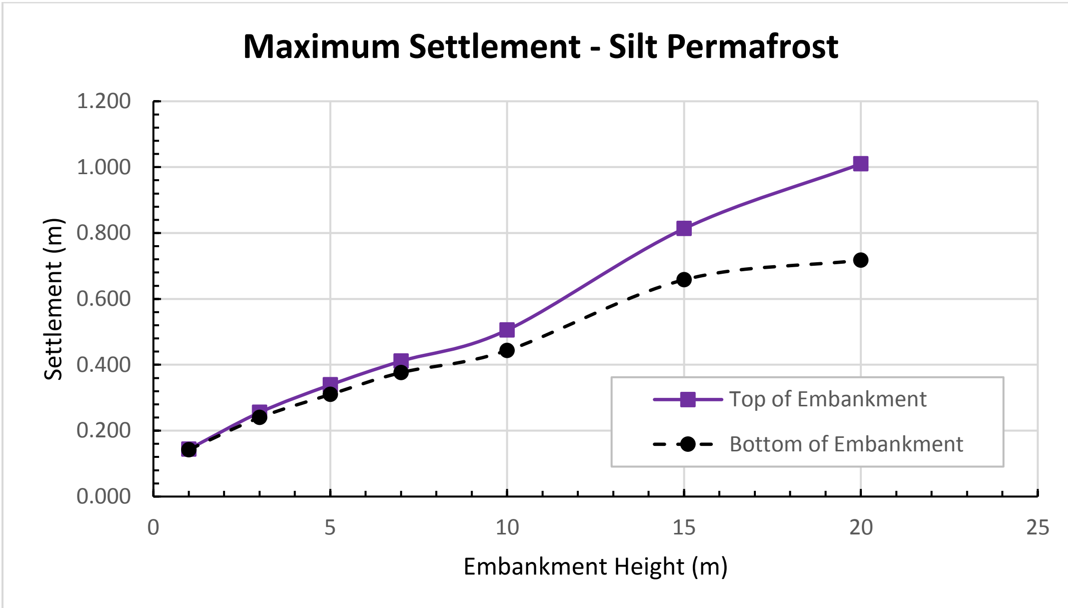
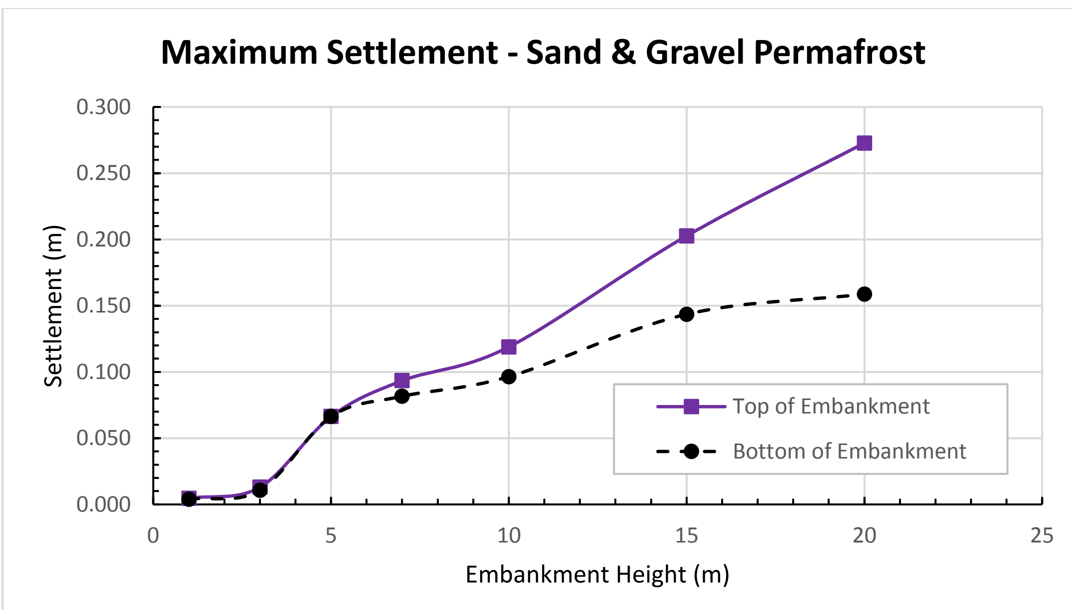
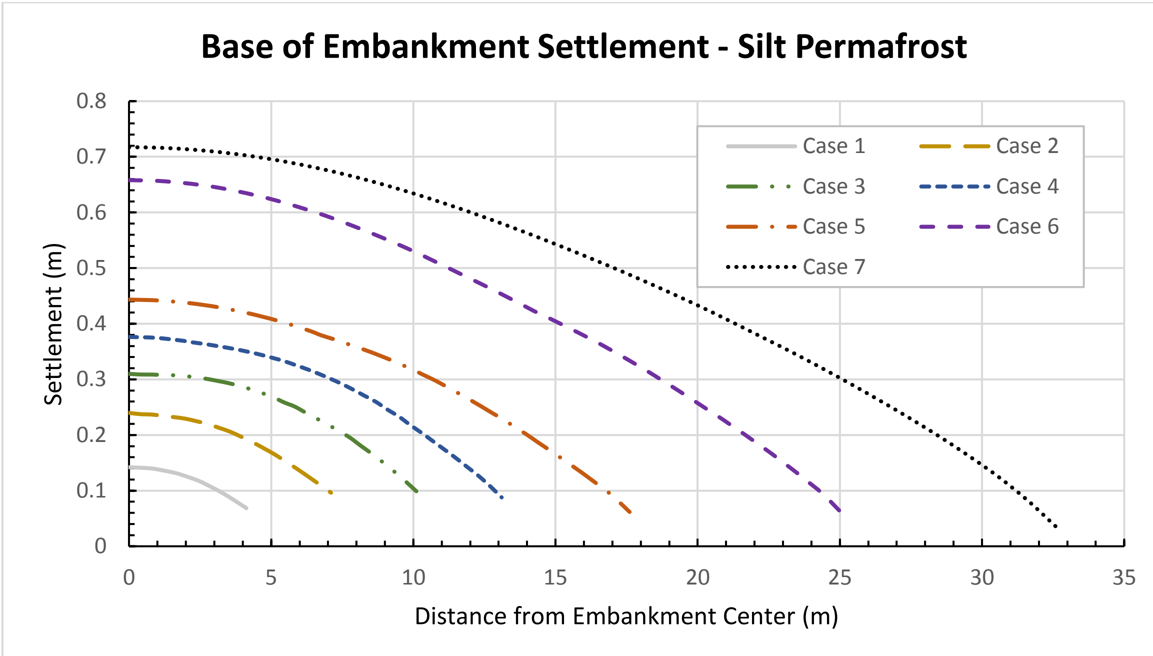
6. Maximum Creep Settlement – Ice Rich (Silt) Foundation



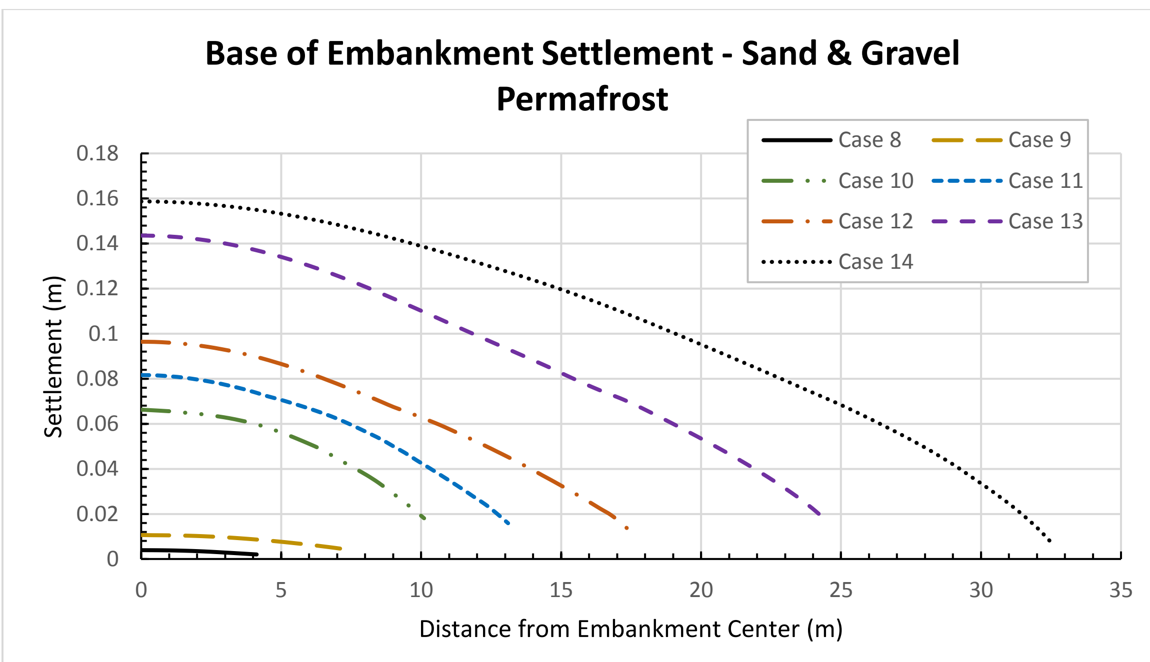
7. Maximum Creep Settlement – Ice Poor (Sand and Gravel) Foundation



8. Culvert Deformations – Ice-rich (Silt) Foundation



9. Culvert Deformations – Ice-poor (Sand and Gravel) Foundation



Appendix F

Thermal Modelling on Fills

APPENDIX F

THERMAL MODELLING ON FILLS

1. **Soil parameters**

   3 types of soils: ice-rich (silt), ice -poor (sand and gravel), and Fills (Types 5,25,8 and 12)

Table F1 - Assumed and Calculated Thermal Properties

Material	Frozen Thermal Conductivity (J/s/m/°C)	Unfrozen Thermal Conductivity (J/s/m/°C)	Frozen Volumetric Heat Capacity (J/m^3/°C)	Unfrozen Volumetric Heat Capacity (J/m^3/°C)	Insitu Water content (%)	Insitu Volumetric Water content (m^3/m^3)
Fill (Types 5, 25, 8 and 12)	4.5	3.0	2,400,000	3,000,000	2	3.6
Silt	2.0	1.3	2,200,000	2,200,000	30	45
Sand/Gravel	3.0	2.0	2,600,000	2,600,000	15	25.5
Insulation	0.035	0.035	37,500	37,500	0	0

2. **Assumptions**

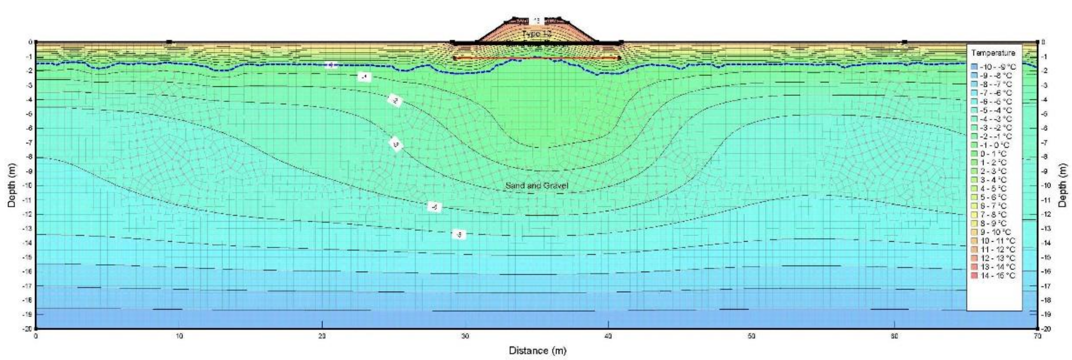
   Climate Change model for 20 year design life (2019 to 2039)

   Thermal modeling run without insulation

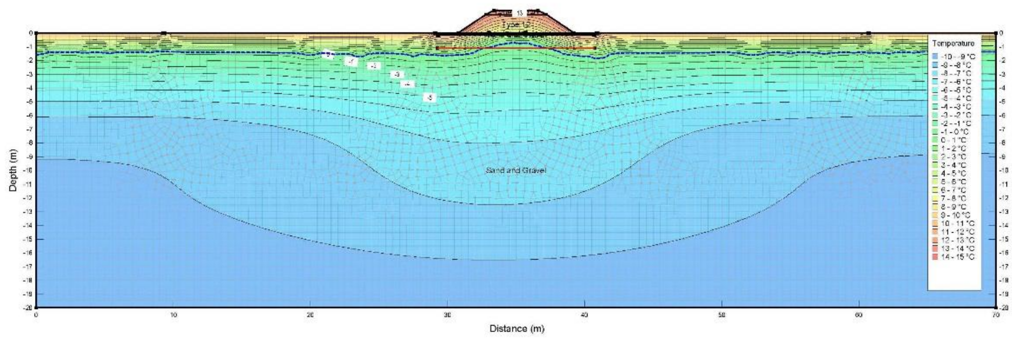
3. **1.65 m High Embankment Fill**

   a. **Ice-poor Soil (Sand and Gravel) Foundation**

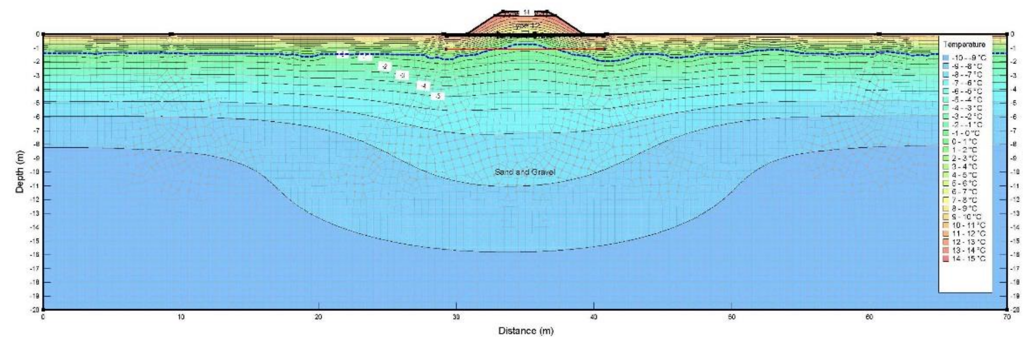
      2 year



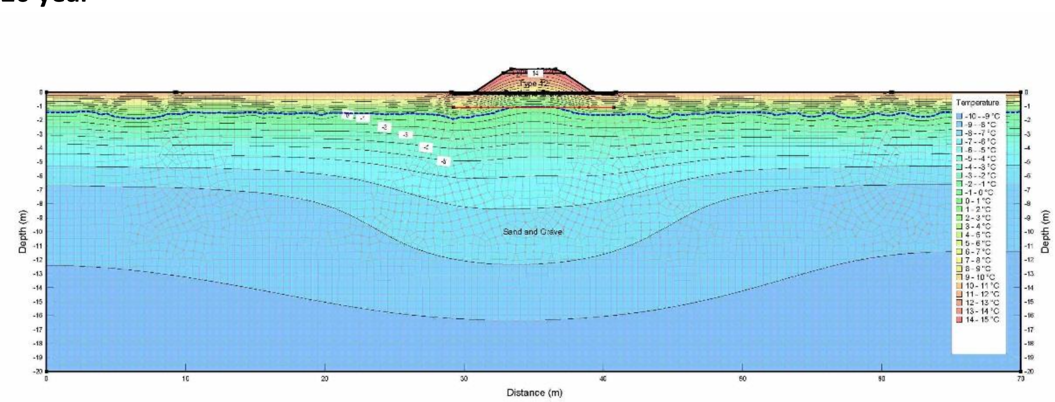
5 year



10 year

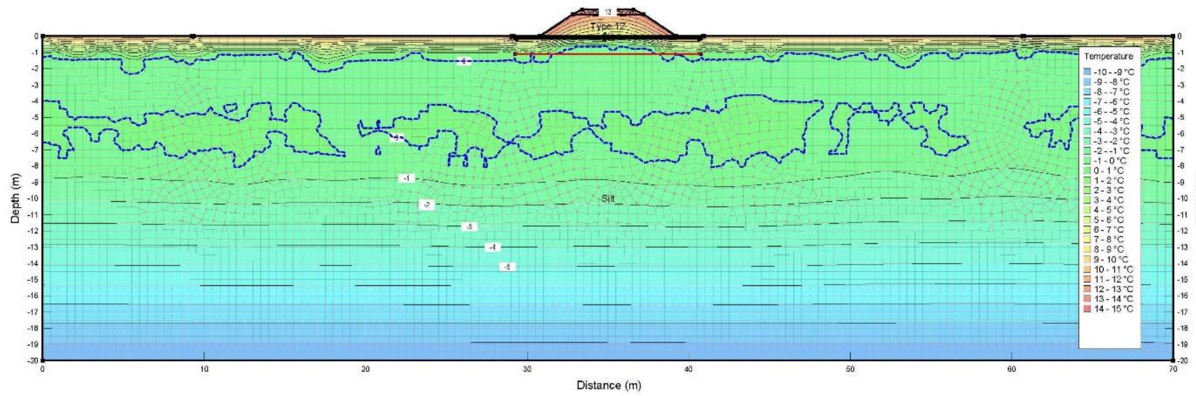


20 year

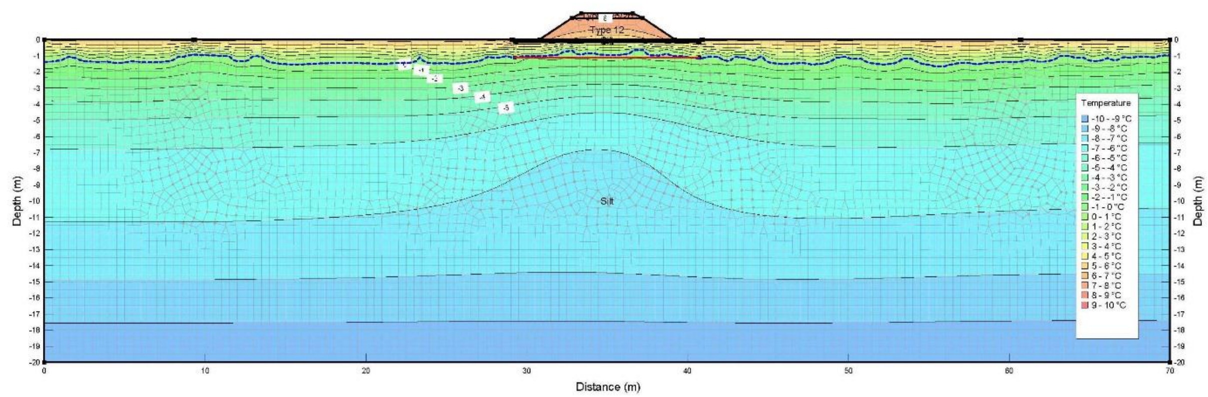


b. Ice-rich Soil (Silt) Foundation

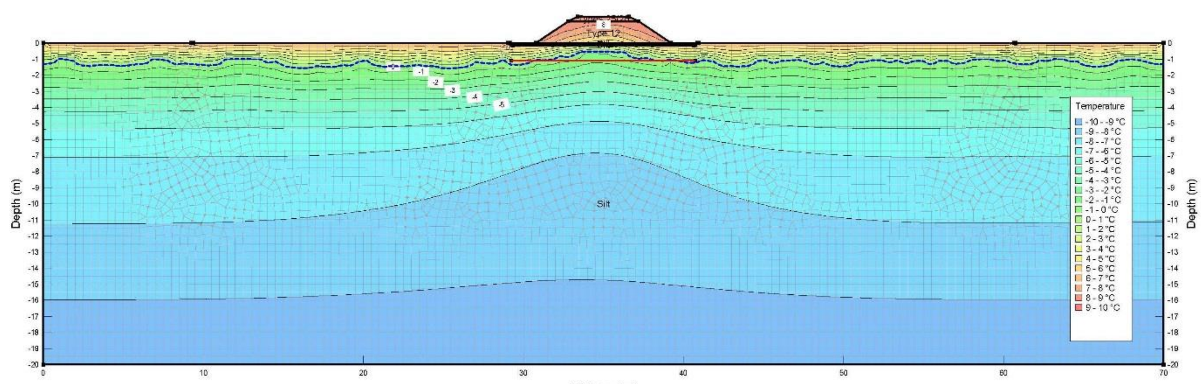
2 year



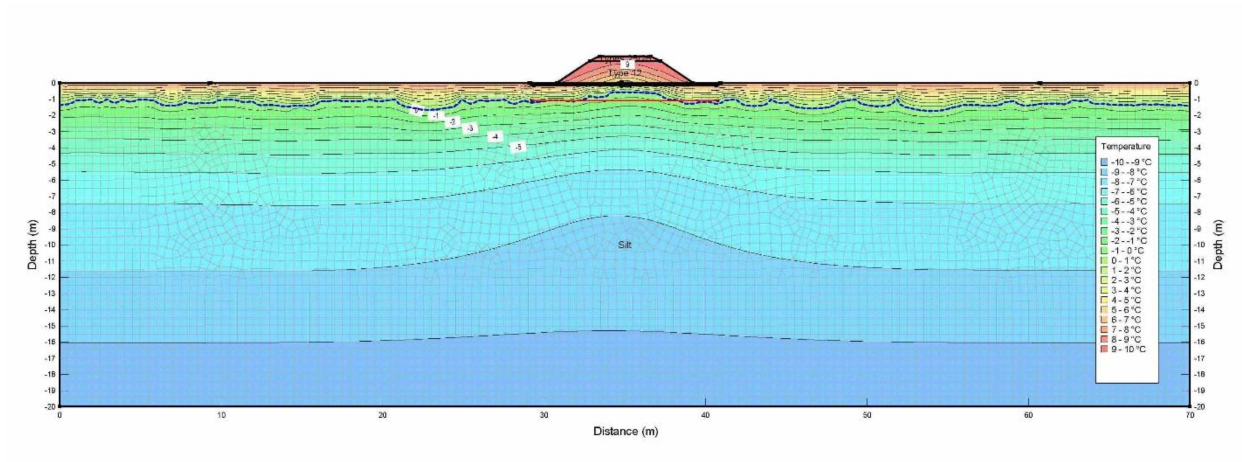
5 year



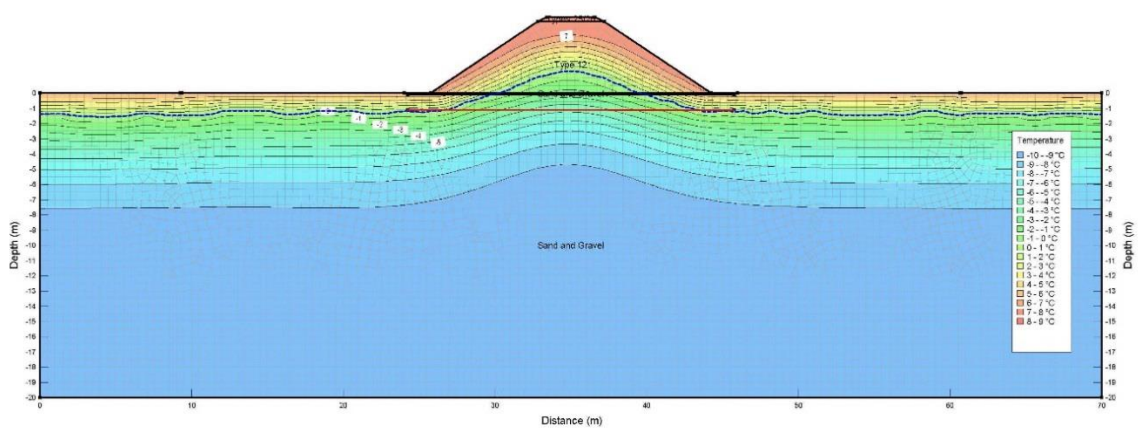
10 year



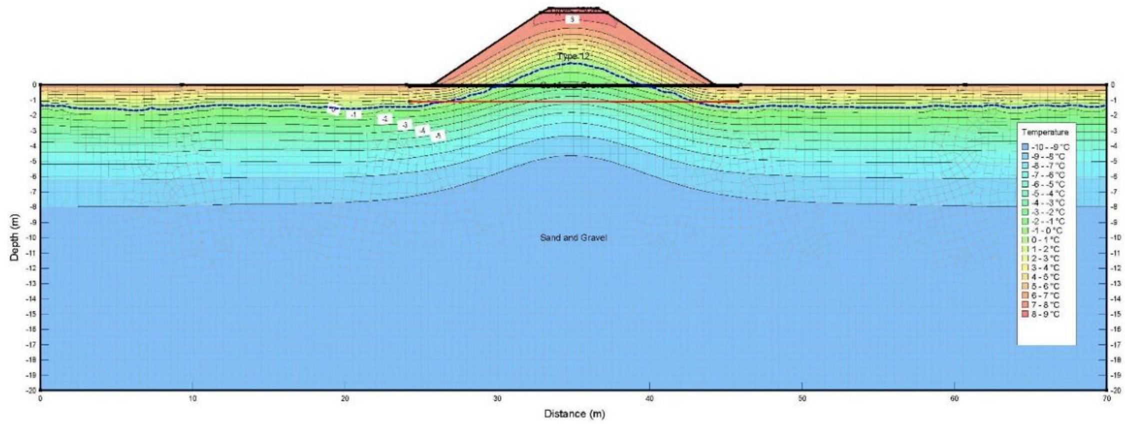
20 year



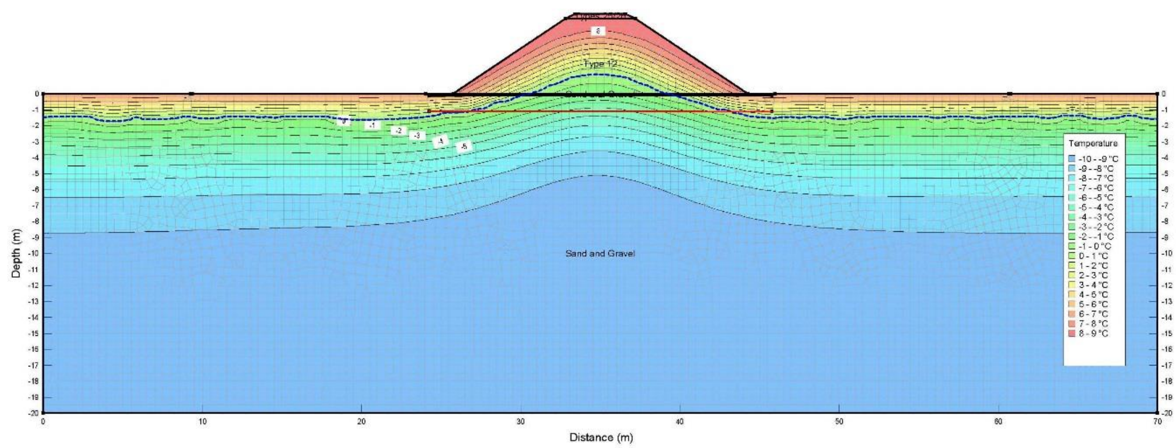
4. **5 m High Embankment Fill**
   a. **Ice-poor Soil (Sand and Gravel) Foundation**
      2 year



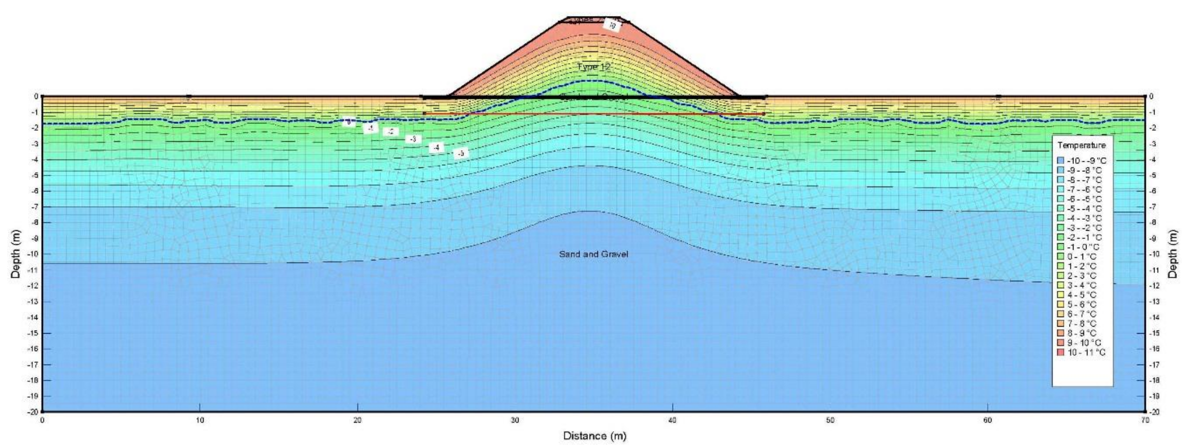
5 year



10 year

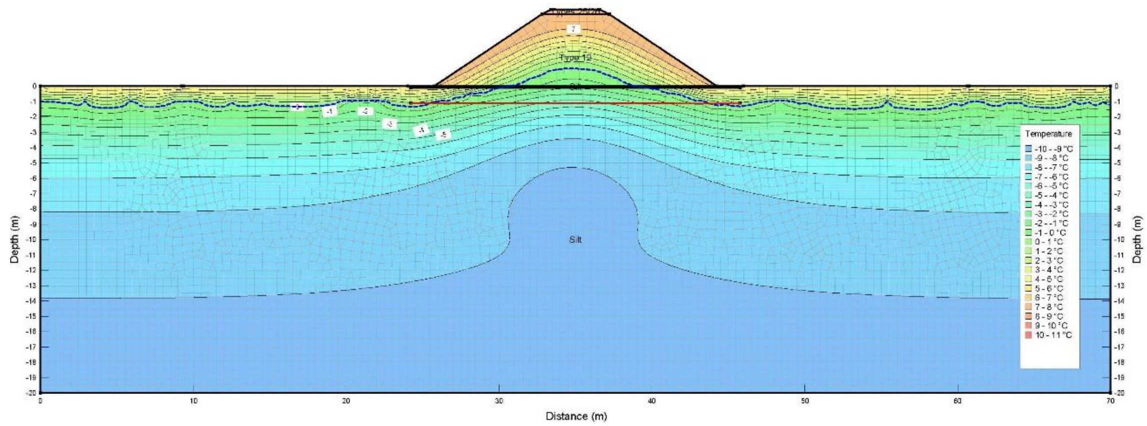


20 year

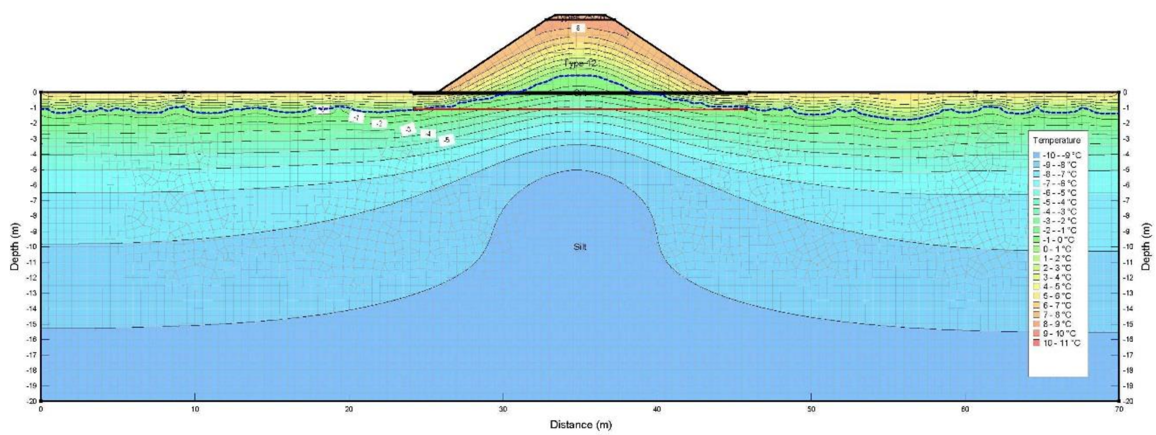


b. Ice-rich Soil (Silt) Foundation

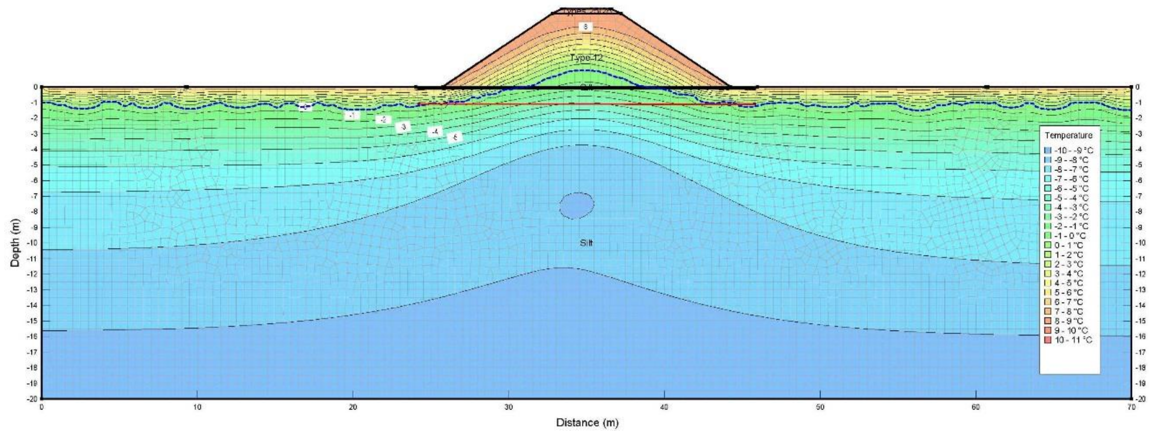
2 year



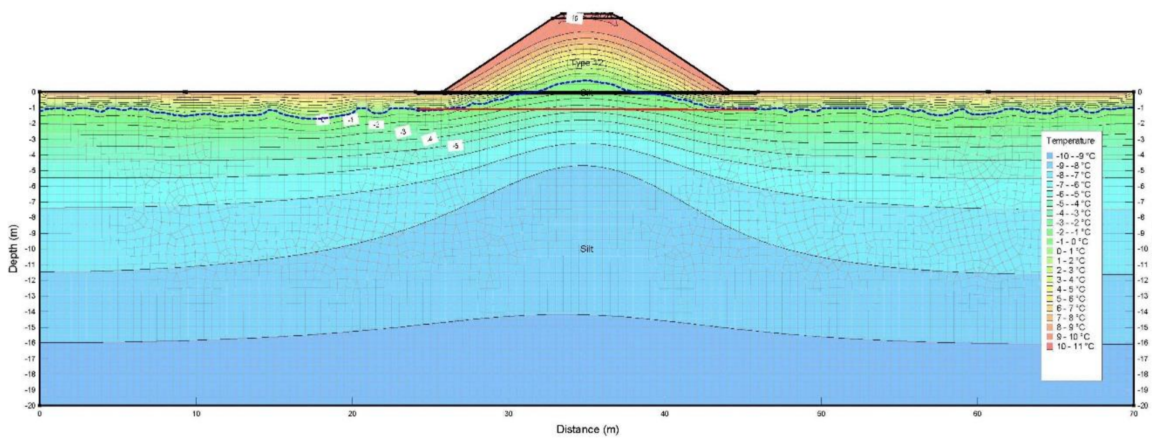
5 year



10 year

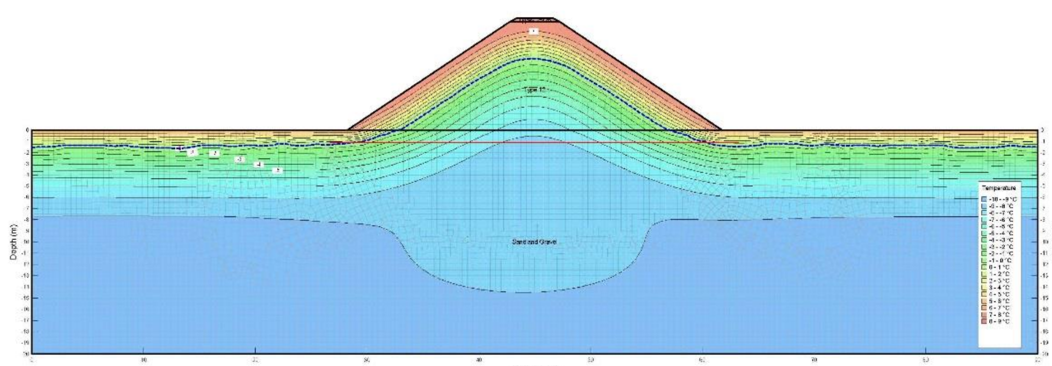


20 year

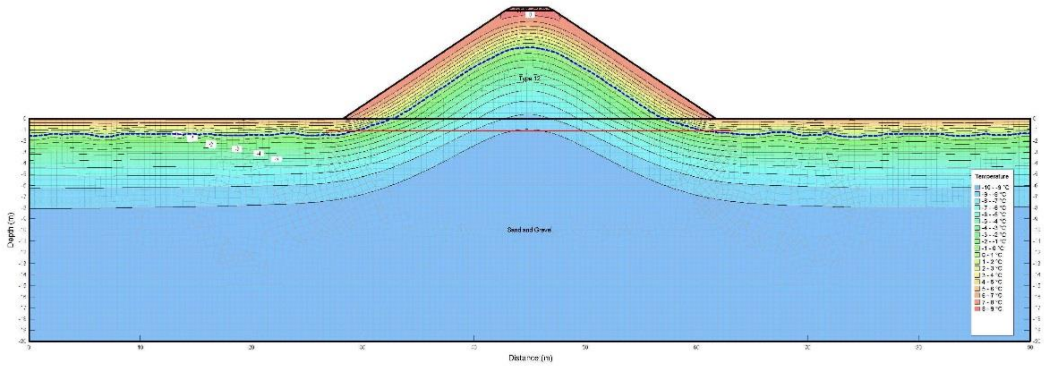


5. **10 m High embankment Fill**
   a. **Ice-poor Soil (Sand and Gravel) Foundation**

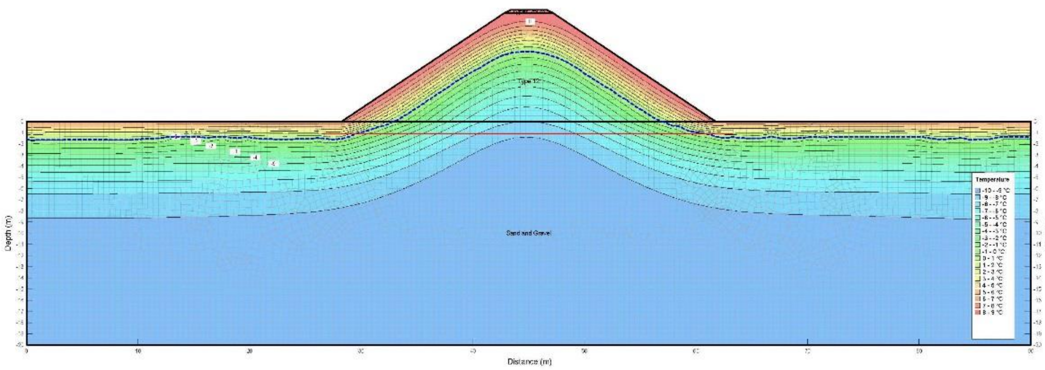
   2 year



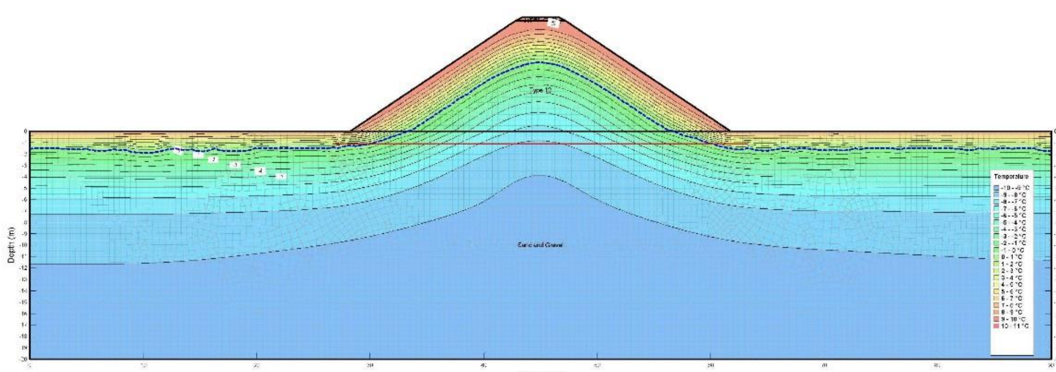
5 year



10 year

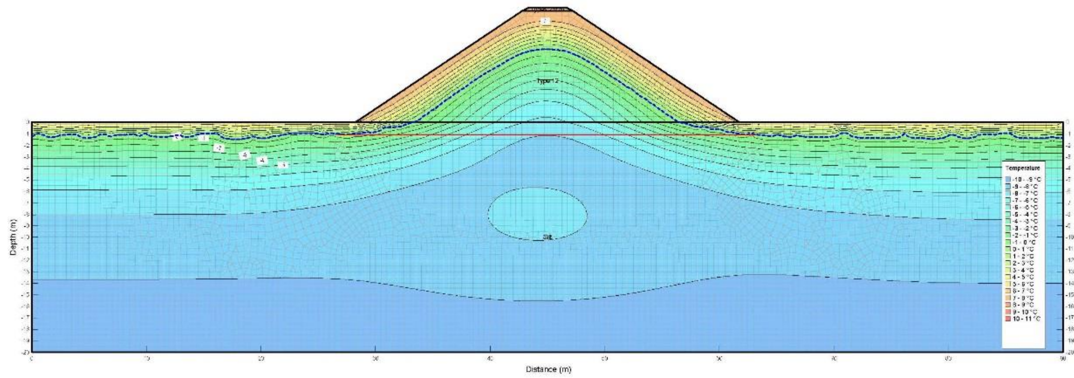


20 year

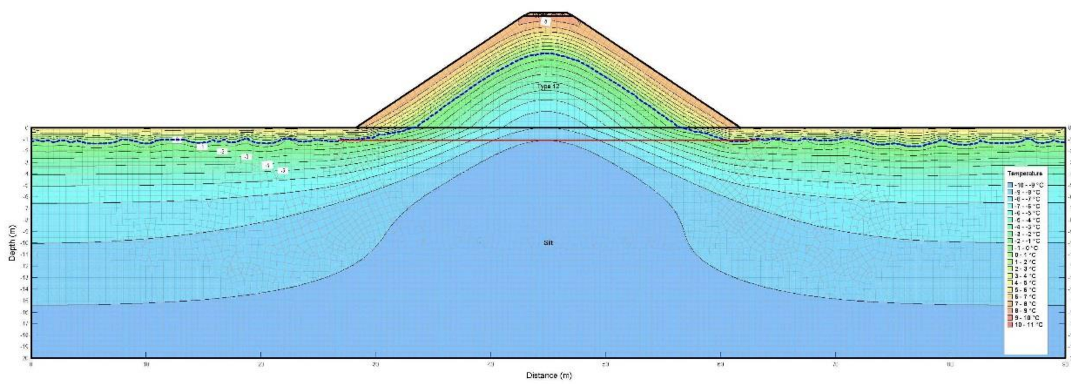


b. Ice-rich Soil (Silt) Foundation

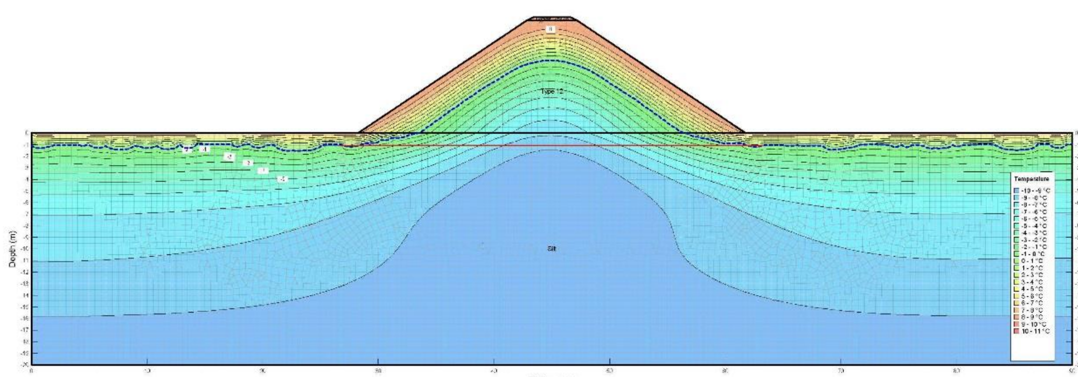
2 year



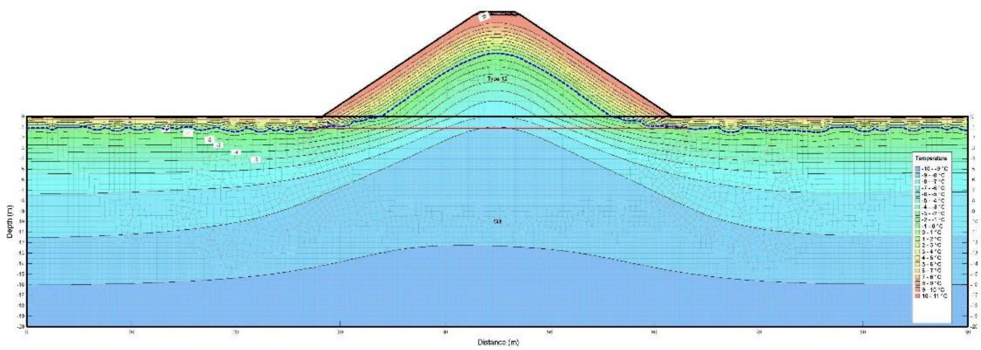
5 year



10 year



20 year



Appendix G

Thermal Modelling on Cuts

Project Memo

H353004

April 19, 2018

To:	**BIM**	**Hatch**	From:	Yasmin Fakli
	Fay Pittman	Fanus van Biljon		Hani Ghiabi
	Rinaldo Stefan			Josephine Morgenroth
				Michael Yang
cc:	Warren Hoyle			

Baffinland Iron Mines Corporation
Mary River Expansion Project

Thermal Analysis of Proposed Rail Line Cut Sections

1. Introduction

Baffinland Iron Mines (BIM) plan to increase the Mary River Mine production to 12 Mtpa, shipping the increased output through Milne Port. This will be achieved by upgrades including the construction of a 110 km long rail line connecting the mine site to the Milne port, a new crushing and screening facility at the port, larger ore stockpiles and a second ore dock for ship loading.

Hatch Ltd. (Hatch) has reviewed the documents related to the design of the rail line along with information regarding soil conditions, climate data, and thermal properties of the materials, and performed a thermal analysis on the typical cuts to be excavated along the proposed rail line. Thermal analysis was carried out to provide recommendations for insulation requirements for cuts in areas including ice-rich and non-ice-rich types of permafrost.

This technical memorandum provides the assessment methodology, the summary of the results, and recommendations for insulation requirements for the scenarios identified in this project.

2. Background Information

2.1 Rail Design

The typical railway sections for cuts were modeled based on the recommendations provided in “Preliminary Geotechnical Recommendation for Railway Embankment - Between Milne Inlet and Mine Site” (Document # H352034-3000-229-230-0001). As a result, a slope ratio of 2H:1V was used for the side cut slopes along with a 9 m-wide base required for construction of the rail line embankment.

2.2 Permafrost and Frozen Ground Definitions

The following definitions pertain to permafrost and frozen ground regions:

Permafrost: Permafrost, or perennially frozen ground, is defined as soil or rock having temperatures below 0 °C during at least two consecutive winters and the intervening summer (Brown and Kupsch 1974).

Active Layer: In environments containing permafrost, the active layer is the top layer of soil that thaws during the summer and freezes again during the cold season.

Non-ice-rich Permafrost: defined here as permafrost that does not contain massive ground ice or ice lenses.

Ice-rich Permafrost: defined here as permafrost containing massive ground ice or ice lenses. When ice-rich permafrost is thawed under drained conditions, it undergoes volume changes and settlement.

2.3 Site Geotechnical Conditions

Between September 2016 and May 2017, Hatch carried out a two-phase geotechnical investigation program. In Phase1, which occurred in 2016, a total of 113 boreholes were drilled ranging from a depth of 1.5 m to 30 m. There were 88 boreholes drilled along the proposed rail alignment, 12 boreholes drilled at the proposed bridge abutments, 15 boreholes at Milne Port and 5 boreholes drilled at the proposed quarry locations. During the second phase of the investigation program, carried out in 2017, a total of 14 boreholes were drilled ranging from a depth of 4.6 m to 25.9 m. There were 12 boreholes drilled along the proposed rail alignment, and 2 boreholes drilled at the proposed bridge abutments.

The rail alignment, beginning at Milne Port, passes through approximately 20 km of Precambrian bedrock terrain, glaciofluvial sand, and gravel terraces. Further south, the rail alignment spans across a relatively flat lying ground comprising fine grained glacial till veneer overlying Paleozoic rocks mainly dolomitic limestone units for approximately 60 km. The final stretch of the rail alignment traverses glaciolacustrine and glaciofluvial plains, terraces, eskers and bedrock outcrops ranging from granitic gneiss to sedimentary rocks.

During this investigation, several areas with ice-rich permafrost were found including:

- A large ice body at the cut location at Km 26.7 on the proposed rail alignment 3 m below the existing ground surface elevation.
- A large ice body at the cut location at Km 47.3 on the proposed rail alignment 3 m below the existing ground surface elevation.
- Frequent ice inclusions of irregularly oriented excess ice were found at the boreholes drilled between Km 92 and Km 96 of the proposed rail alignment.

2.4 Climate Conditions

For the thermal analysis, historical mean monthly air temperatures were sourced from Environment Canada’s 1981-2010 Canadian Climate Normals for Pond Inlet, NU (Table A-1 presented in Appendix A).

3. Thermal Analysis

The purpose of the thermal analysis is to predict the thermal regime of the sections including cut in permafrost zone and to provide recommendations in order to minimize the disturbance of the permafrost layers. Geostudio TEMP/W version 2012, a two-dimensional Finite Element (FE) software developed by Geo-Slope International Ltd, was used for this study.

3.1 Modelled Scenarios

The cases presented in Table 1, were modeled in this thermal analysis. These cases are representing 2 different cut depths (2m and 7m), 2 subsurface materials (Silt, Sand, and Gravel), and various insulation arrangements.

It should be noted that in Cases A-7 and B-7, a layer of crushed fill is extended on the side slopes with the purpose of protecting the slopes from sloughing for silt subsurface.

Table 1: Definition of Cases Modelled in TEMP/W

<table>
<tr><th>Case</th><th>Subsurface Material</th><th>Cut Depth (m)</th><th>Insulation Type</th></tr>
<tr><td>A-1</td><td rowspan="3">Sand and Gravel</td><td rowspan="7">2</td><td>None</td></tr>
<tr><td>A-2</td><td>On base</td></tr>
<tr><td>A-3</td><td>On base and slopes</td></tr>
<tr><td>A-4</td><td rowspan="4">Silt</td><td>None</td></tr>
<tr><td>A-5</td><td>On base</td></tr>
<tr><td>A-6</td><td>On base and slopes</td></tr>
<tr><td>A-7</td><td>On base and crushed fill on slopes</td></tr>
<tr><td>B-1</td><td rowspan="3">Sand and Gravel</td><td rowspan="7">7</td><td>None</td></tr>
<tr><td>B-2</td><td>On base</td></tr>
<tr><td>B-3</td><td>On base and slopes</td></tr>
<tr><td>B-4</td><td rowspan="4">Silt</td><td>None</td></tr>
<tr><td>B-5</td><td>On base</td></tr>
<tr><td>B-6</td><td>On base and slopes</td></tr>
<tr><td>B-7</td><td>On base and crushed fill on slopes</td></tr>
</table>

3.2 Boundary and Initial Conditions

The boundary and initial conditions are sourced from the “Geotechnical Design Basis” (Document # H353004-00000-229-210-0001). Details of the defined boundary and initial conditions are discussed in this section.

Initial Condition: The initial temperature profile was set up for the month of July, sourced from a representative thermistor installed in borehole BH2007-10 from borehole report by Knight Piesold (2008). The thermal model was then run for two weeks with exposed cuts and a mean air temperature estimated for July 2019. This was done, based on the proposed construction schedule, to calculate the initial ground temperature conditions once the construction of the railway embankment is completed.

Top boundary: It was assumed that the top of the soil profile and edge of excavation or insulation boundaries experienced a ground temperature which fluctuated in accordance with the temperature variation shown in Appendix A, Figure A-2. This temperature variation represents the estimated mean monthly temperature of Pond Inlet, NU for a 2 year period beginning at 2029 with global warming temperature increase applied starting from 2010. The temperature profile was chosen to commence at year 2029 to simulate the operation of the railway halfway in the operating period from 2019 to 2039. Temperature increases from global warming was applied to the base mean monthly temperature of Pond Inlet, NU for the periods from 1981 – 2010 to the year 2029 and beyond. An in-depth analysis of global warming scenario will be covered in Section 4.1.

There is a non-linear relationship between mean annual air temperatures and mean annual ground surface temperatures, which was accounted for by correlating the ground surface boundary conditions with the air temperature using an empirically determined function coefficient called the “n-factor”. The mean monthly air temperature was modified using the freezing factor (n_f), and the thawing factor (n_t) for freezing and thawing seasons, respectively. Table 2 outlines the N-factors applied for various subsurface materials, sourced from the Geotechnical Design Basis.

Table 2: N-factors for Various Subsurface Materials

Material	N – factors	
	Freezing (n_f)	Thawing (n_t)
Sand and Gravel	0.7	1.2
Silt	0.5	1.2
Fill	0.8	1.5

Bottom boundary: As specified in the Design Basis, the temperature at the bottom boundary (depth of 20 m below existing ground) was set to -10°C.

Left and right boundaries: In accordance with the Design Basis, these were assumed to be no-flow boundaries, which is the default boundary condition in a finite element analysis (i.e., heat neither enters nor exits through these boundaries).The boundary conditions and typical meshing used in the FE models are presented in Appendix B. The boundary conditions could be established more accurately if additional ground temperature monitoring data was to be provided to Hatch.

3.3 Material Properties

The subsurface materials stratigraphy was selected based on the data obtained from 2016 geotechnical investigation and available technical references (e.g., Andersland and Ladanyi, 2004; Fillion, Cote and Konrad, 2011). The parameters used in the thermal analysis are summarized in Table 3 sourced from the Design Basis.

Table 3: Assumed and Calculated Thermal Properties

Material	Frozen Thermal Conductivity (J/s/m/°C)	Unfrozen Thermal Conductivity (J/s/m/°C)	Frozen Volumetric Heat Capacity (J/m³/°C)	Unfrozen Volumetric Heat Capacity (J/m³/°C)	Insitu Water content (%)	Insitu Volumetric Water content (m³/m³)
Fill (Types 5, 25, 8 and 12)	4.5	3.0	2,400,000	3,000,000	2	3.6
Silt	2.0	1.3	2,200,000	2,200,000	30	45
Sand/Gravel	3.0	2.0	2,600,000	2,600,000	15	25.5
Insulation	0.035	0.035	37,500	37,500	0	0

The insulation (polystyrene) layer was modelled with a thickness of 100 mm and 50 mm over the base and side slopes, respectively. It should be noted that, the thermal conductivity values used for “Ballast/subballst” and “run of quarry” are grouped within “Fill”, and do not take into account the convection effect within these fill materials.

3.4 Failure Criteria

For rail line foundation, it is assumed that the failure can be avoided when the subsurface material in the zone 1 meter below the base of the rail embankment is protected by not allowing this layer to reach a temperature above -3◦C (Line A). Also, it is assumed that for cut slopes below the original active zone, slope failure can be avoided by maintaining the temperature in a zone 1 meter below the cut faces below -2◦C for ice-rich layers (Line B) and below 0◦C for ice-poor layers (Line C). The reference lines can be found in Figure 1.

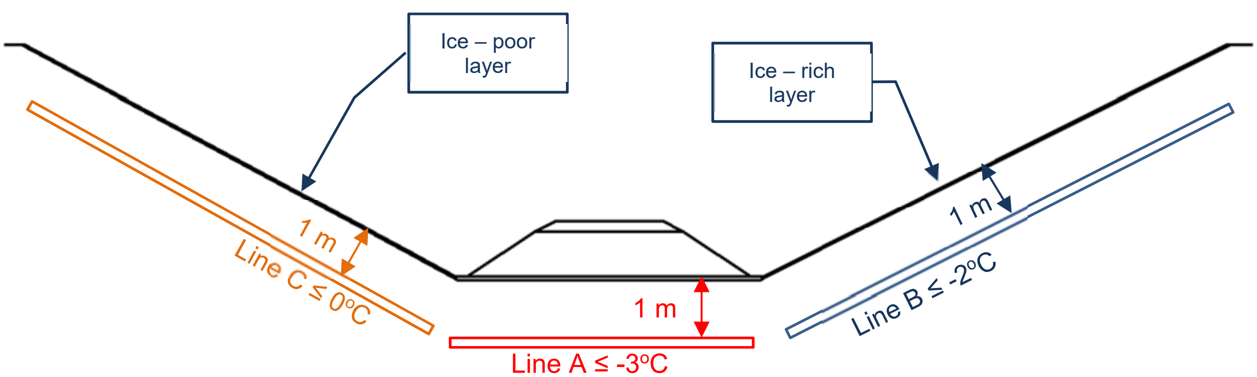


Figure 1: Temperature Threshold Zones Below Typical Railway Cut

4. Results

For each of the fourteen cases defined in this study, a transient thermal analysis was conducted for a two-year period considering the material parameters and N-factors presented in Table 2 and Table 3. The temperature profiles for the warmest ground condition are presented in Appendix C.

Table 4 summarizes the width of Lines A, B, and C with temperature <-3°C, <-2°C, and <0°C, respectively, computed for the warmest ground condition throughout the year. The results indicate that insulation is necessary to protect the foundation of the rail line from seasonal melt.

Table 4: Thermal Analysis Results

Case	Figures Appendix C	Insulation Type	Width of Line A <-3°C (m)	Width of Line B <-2°C (m)	Width of Line C < 0°C (m)
A-1	1	None	0	0	0
A-2	2	On base	8.5	0	2.6
A-3	3	On base and slopes	9	2.8	4.2
A-4	4	None	0	0	4.5
A-5	5	On base	8.1	0	3.6
A-6	6	On base and slopes	9	2.7	4.5
A-7	7	On base and crush fill on slopes	9	0	2.8
B-1	8	None	0	0	14.1
B-2	9	On base	8.4	0	12.7
B-3	10	On base and slopes	9	13.7	15.2
B-4	11	None	0	0	14.9
B-5	12	On base	8.4	0	12.5
B-6	13	On base and slopes	9	13.2	16.4
B-7	14	On base and crush fill on slopes	9	0	15.3

4.1 Climate Change Considerations

Cases B-5 and B-6 were run for a 20 year period from 2019 – 2039 to determine the risk of sloughing of the silt at the cut slopes during the operation period. The air temperature profile for this period was generated using the temperature increase increments outlined in the Design Basis and summarized in Table 5, added to the mean monthly temperature of Pond Inlet, NU from 1981 – 2010. The air temperature profile used to model the 2 week exposed cut in July 2019 and 2 year operation period starting at year 2029 is sourced from the aforementioned global warming air temperature profile.

Table 5: Temperature Increase for the Period Spanning 2010 – 2039

Period	Temperature Increase (°C)
Dec – Feb	3.8
Mar – May	2.7
Jun – Aug	1.9
Sept – Nov	3.5

The warmest temperature profiles (for Cases B-5b and B-6b) with the climate change consideration are associated with summer 2039 and are presented in Figures 15 and 16 of Appendix C. The results of this analysis are summarized in Table 6.

Table 6: Thermal Analysis Results – Climate Change Considerations

Case	Figures Appendix C	Insulation Type	Width of Line A <-3°C (m)	Width of Line B <-2°C (m)	Width of Line C < 0°C (m)
B-5b	15	On base	7.3	0	14.2
B-6b	16	On base and slopes	9	12.0	15.4

An increase in the average monthly temperatures results in a decrease in the width of Line A below -3°C and overall increase in temperature of the excavation surfaces. However, when compared to the cases run for a 2 year period starting at year 2029, the changes in the width of Lines A, B, and C are minimal for the Case B-6b in which the insulation layers were placed on the base and side slopes.

5. Conclusions and Recommendations

The conclusions and recommendations from this study are summarized below:

- This thermal analysis was performed based on some typical thermal parameters extracted from literature and historical information from the Mary River site. This analysis can be reviewed when additional data is made available with respect to thermal conditions (e.g. new data from thermocouples installed at port).
- There are a number of local factors which were not modelled in this analysis that could impact the subsurface thermal regime of any individual location. Possible local factors include elevation, slope direction, groundwater conditions, and the presence of surface water.
- Following the review of the construction schedule, for this assessment, it is assumed that the construction and installation of insulation will take place within a 2-week period in July. This will not result in excessive thawing of the permafrost and sloughing of the subsurface and foundation. However, It is recommended that special care to be taken during construction and installation of insulation in the permafrost to minimize ground disturbance and melting during the construction phase.
- For cut sections where polystyrene insulation be modelled over the base (100 mm-thick insulation), the 9 m-wide zone on Line A (1 m below the base of the cut) practically remains at a temperature below -3°C throughout the year. For uninsulated side slopes, the temperature will generally be below 0°C at 1 m below the cut surfaces. For the side slopes insulated with 50 mm-thick insulation, the temperature will practically remain below -2°C at 1m below the cut surface.

- 100 mm-thick insulation is strongly recommended beneath the railway embankment for all soil conditions (e.g. silt, and sand and gravel foundations) to avoid thawing and deformation of the embankment and foundation.
- For cut slopes in ice-poor layers, no sub-excavation or insulation layer is recommended.
- For cut slopes in ice-rich layers, a 300 mm of sub-excavation is recommended followed by placement of 300 mm of fill. A 50 mm-thick insulation layer is recommended to be placed over the slopes.
- The insulation layer should be protected and secured from uplift in winds by placement of a minimum of 200 mm-thick soil cover acting as a ballast.
- Drainage ditches are recommended at the toe of the cut slopes with a minimum longitudinal slope of 0.2% to drain the water from the toe of the slopes and, subsequently, minimize water infiltration into the permafrost.
- Further analysis should be performed if the geometries or the boundary conditions of the cut sections vary from those modelled herein, including cases where:
    - the trench base is designed wider than 9 m
    - the trench depth is greater than 7 m
    - a heat source is identified adjacent to the area; or
    - soil conditions vary from that modeled.

6. References

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Fillion, M-H, Cote, J, Konrad, J-M, 2011. Thermal radiation and conduction properties of materials ranging from sand to rock-fill, Canadian Geotechnical Journal, 48: PP 532–542.

Brown, R. J. E., Kupsch, W. O, 1974. Permafrost Terminology. National Research Council of Canada.

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Karunaratne, Kumari, 2002, N-factors and the relations between air and surface temperature in discontinuous permafrost neat Mayo, Yukon Territory, MSc Thesis, Carleton University.

Knight Piesold Ltd., 2008. Rail Infrastructure 2007 Site Investigation Summary Report, NB102-00181/8-3, Rev. 1.

Lunardini, V. J., 1978. Theory of n-factors and correlation of data. In Proc. 3rd Int. Conf. on Permafrost, Edmonton, Alberta. Ottawa: National Research Council of Canada, vol. 1, pp. 41–46.

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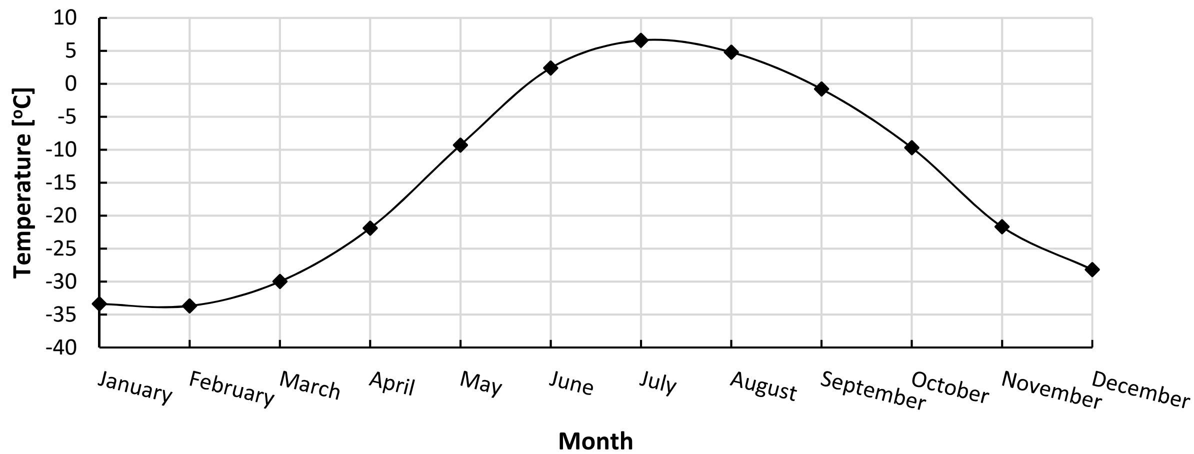
Appendices:

Appendix A – Climate Data
Appendix B – Finite Element Model Details
Appendix C – Results of Finite Element Analysis

Appendix A: Climate Data

Table A-1: Mean Monthly Temperatures - Pond Inlet, NU, 1981-2010 Climate Normals

Month	Mean Daily Average Temperature (°C)
January	-33.4
February	-33.7
March	-30.0
April	-21.9
May	-9.3
June	2.4
July	6.6
August	4.8
September	-0.8
October	-9.7
November	-21.7
December	-28.2



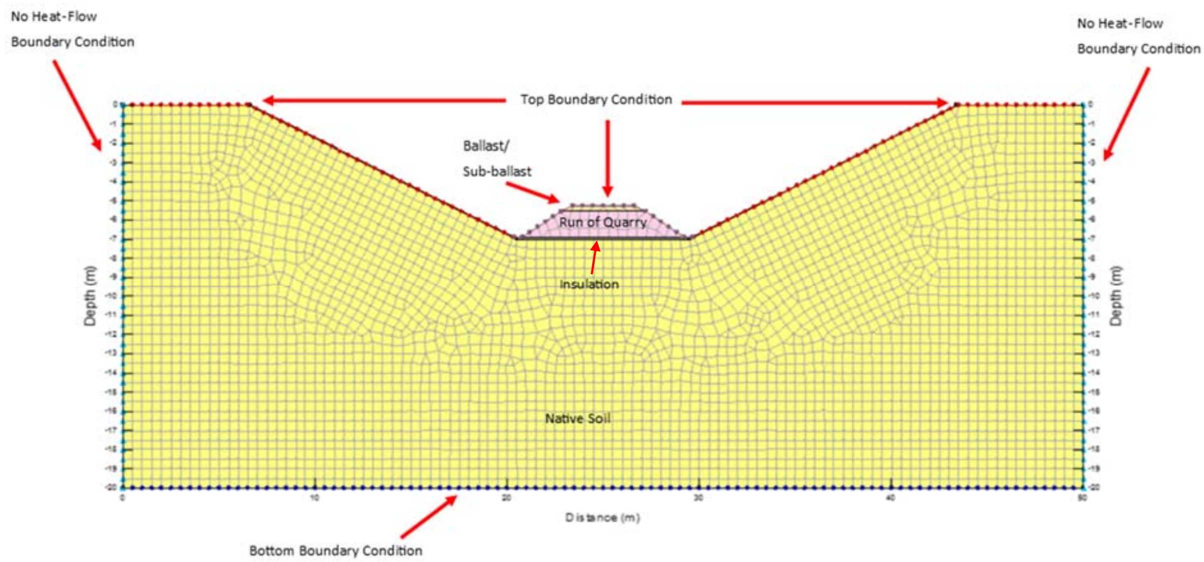
Graph-1: Mean Monthly Temperatures for Pond Inlet, NU (1981-2010)

Table A-2: Mean Monthly Temperatures from years 2029 to 2031

Year	Month	Mean Daily Average Temperature (°C)
2029	July	7.84
	August	6.04
	September	1.49
	October	-7.41
	November	-19.41
	December	-25.71
2030	January	-30.78
	February	-31.08
	March	-28.14
	April	-20.04
	May	-7.44
	June	3.71
	July	7.91
	August	6.11
	September	1.61
	October	-7.29
	November	-19.29
	December	-25.58
2031	January	-30.65
	February	-30.95
	March	-28.04
	April	-19.94
	May	-7.34
	June	3.78
	July	7.98
	August	6.18
	September	1.73

Year	Month	Mean Daily Average Temperature (°C)
	October	-7.17
	November	-19.17
	December	-25.45

Appendix B: Finite Element Model Details



Typical Model Setup, Meshing, and Boundary Conditions for FE Analyses

Appendix C: Results of Finite Element Analysis

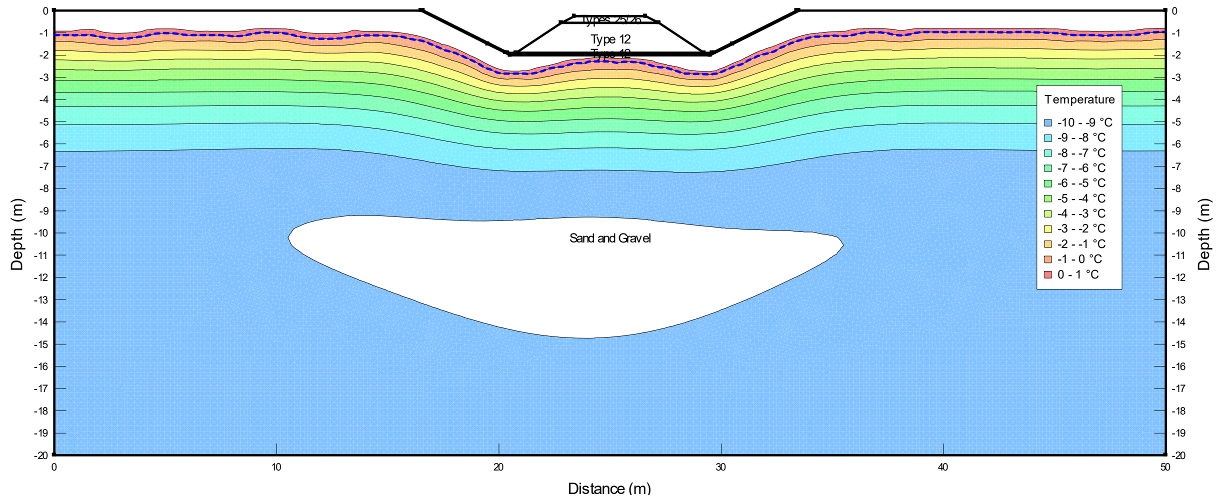


Figure 1: Results of Case A-1

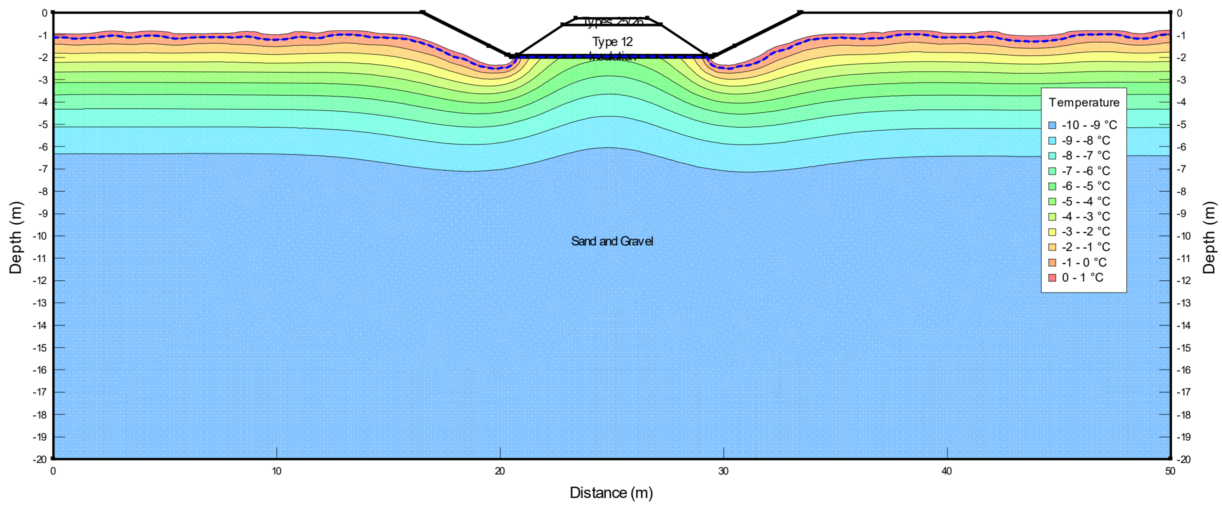


Figure 2: Results of Case A-2

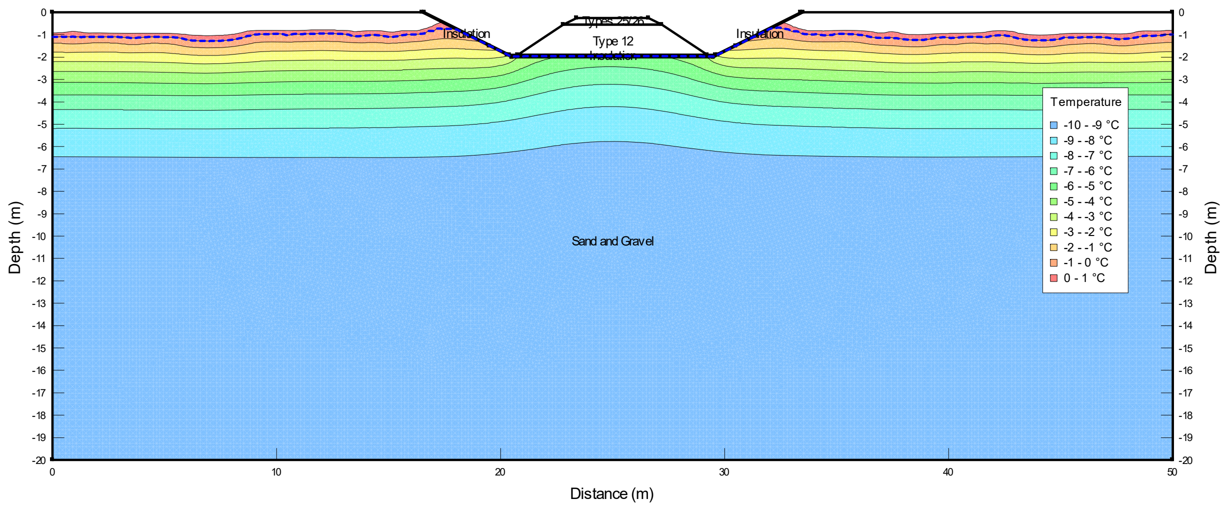


Figure 3: Results of Case A-3

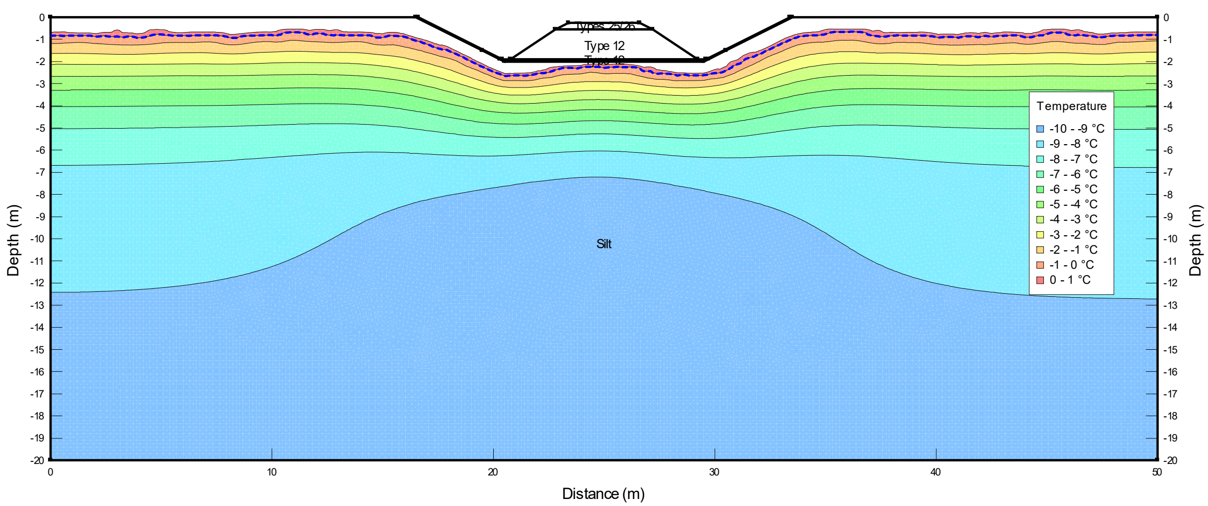


Figure 4: Results of Case A-4

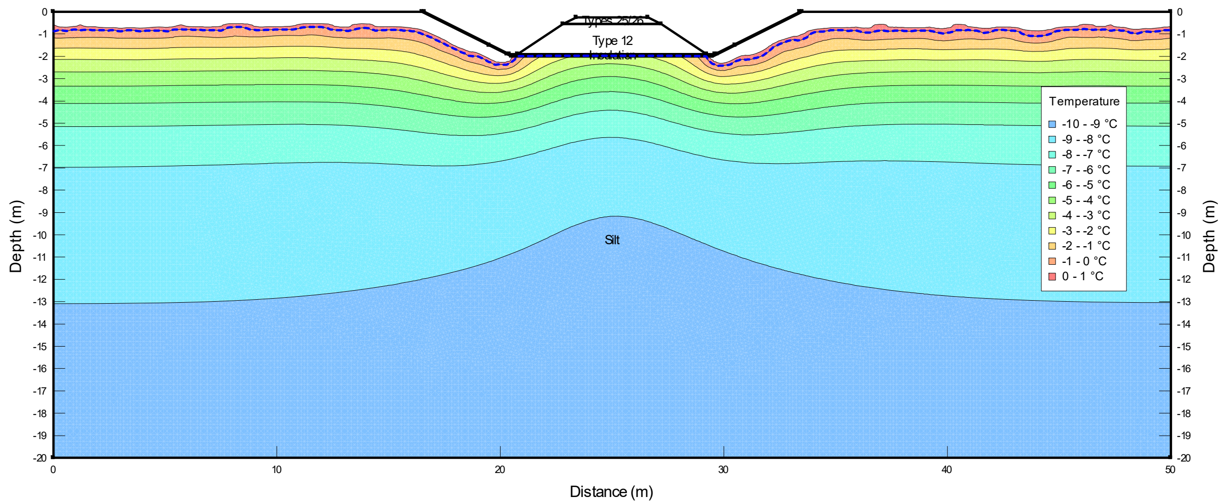


Figure 5: Results of Case A-5

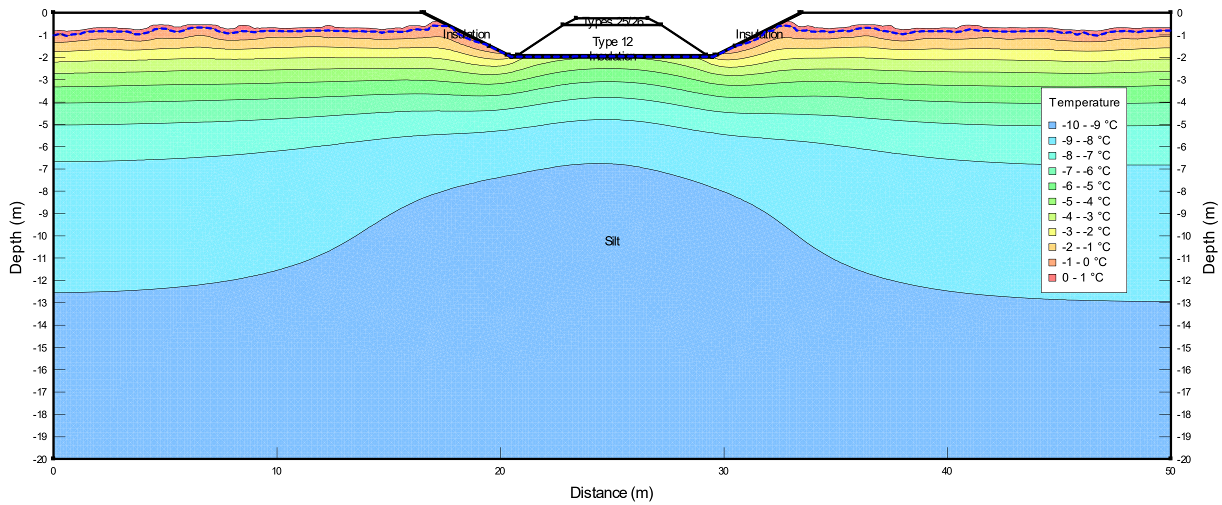


Figure 6: Results of Case A-6

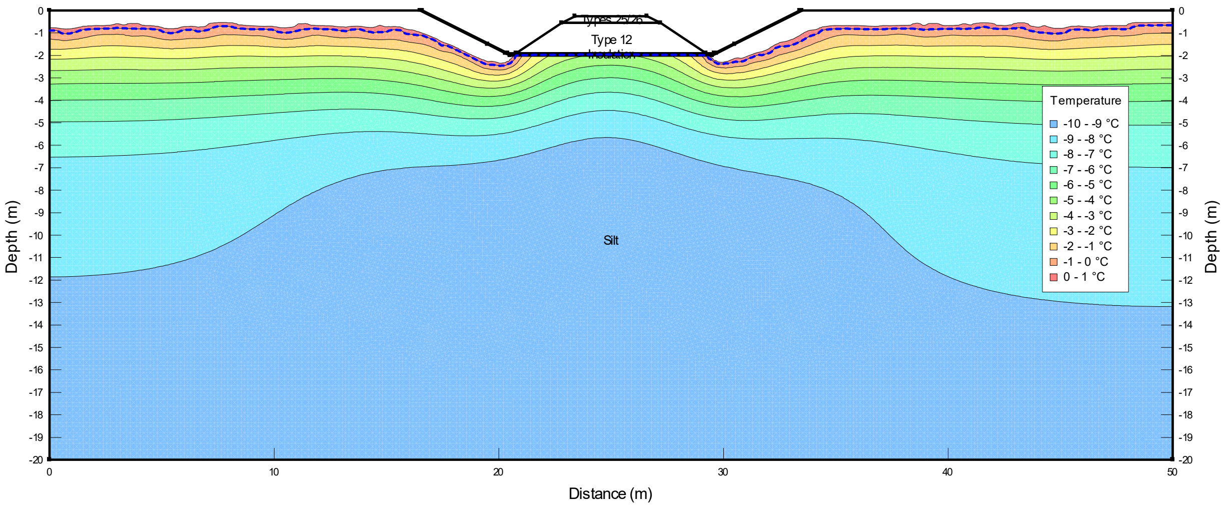


Figure 7: Results of Case A-7

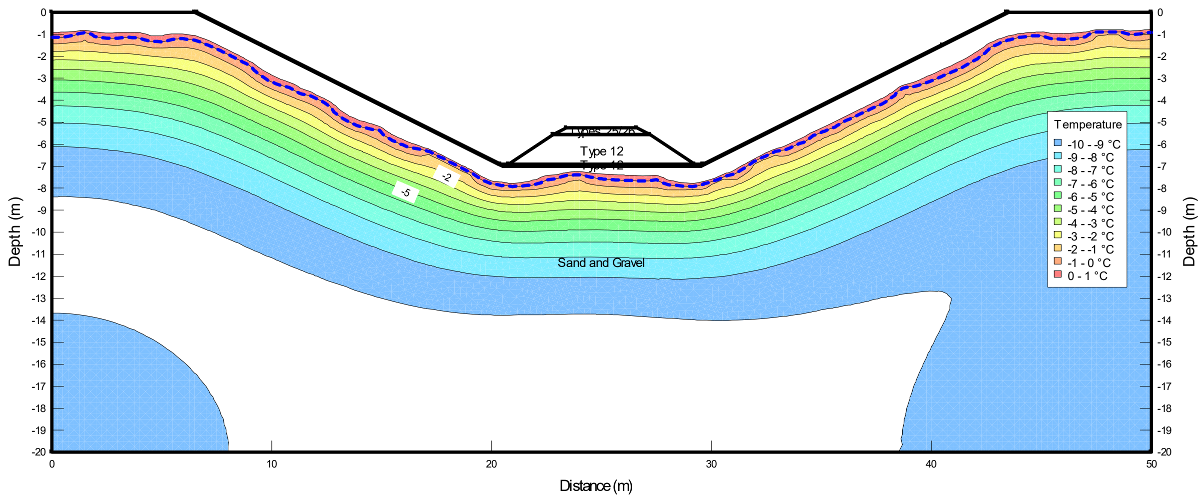


Figure 8: Results of Case B-1

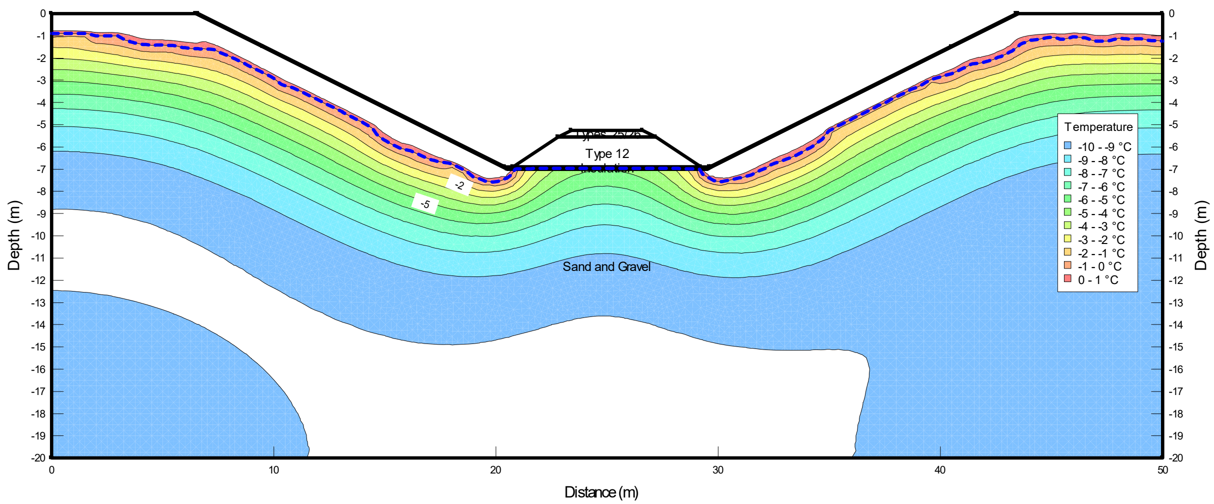


Figure 9: Results of Case B-2

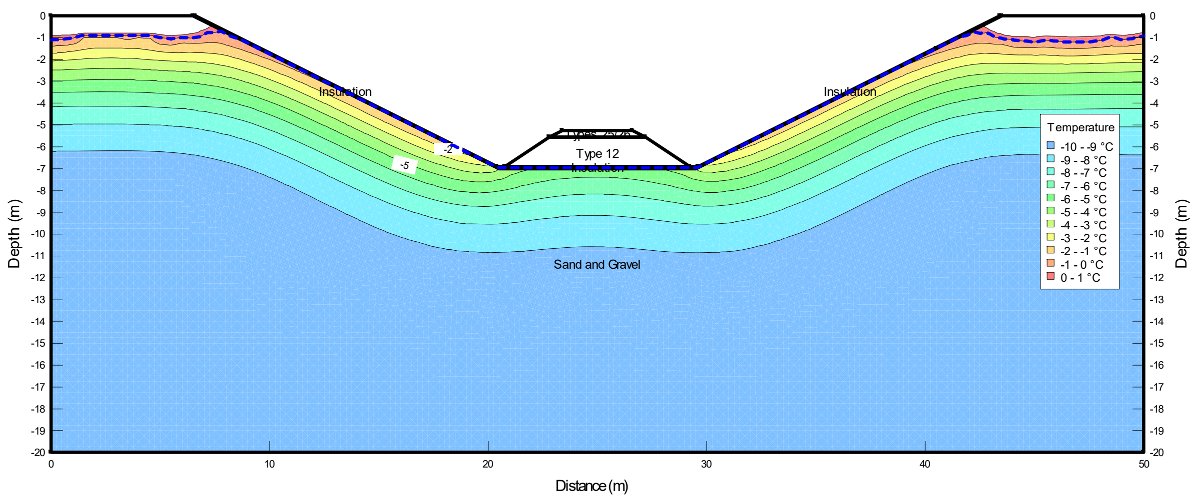


Figure 10: Results of Case B-3

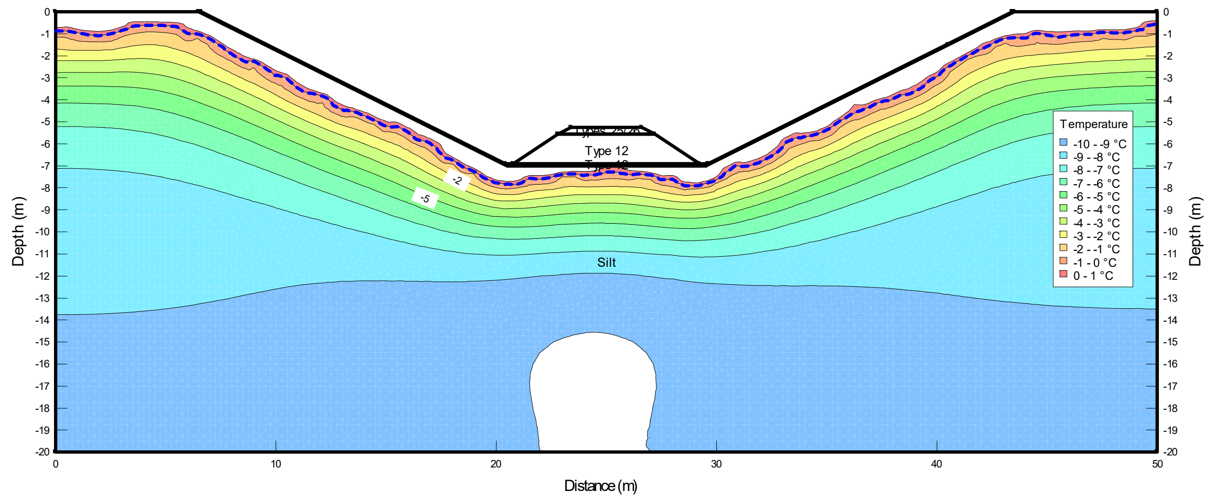


Figure 11: Results of Case B-4

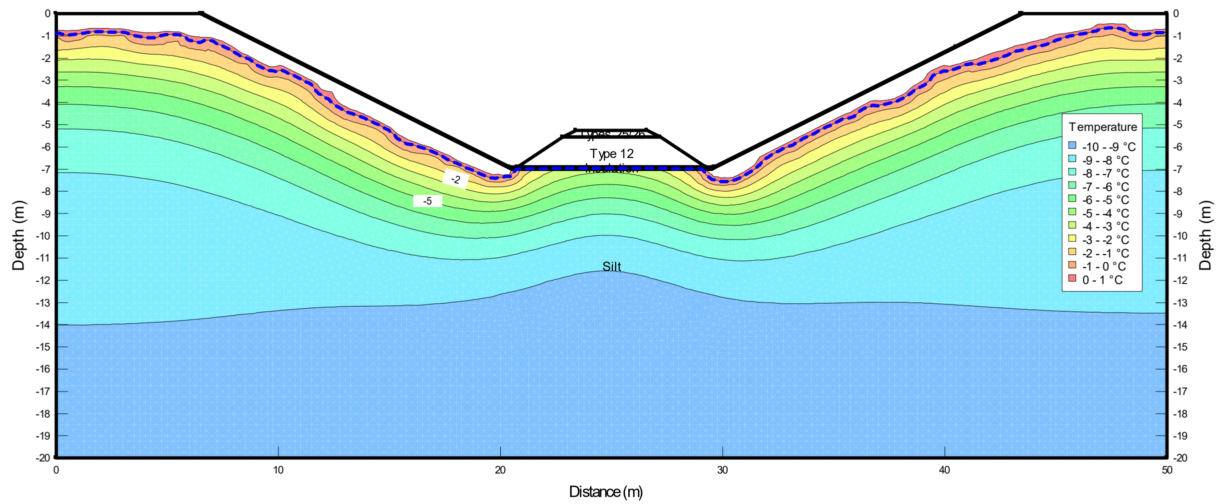


Figure 12: Results of Case B-5

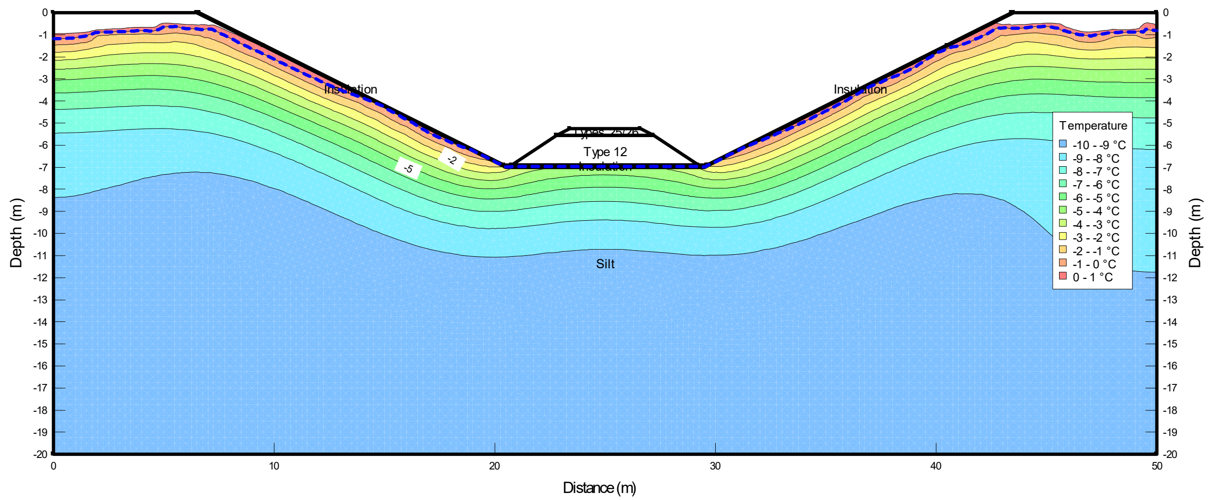


Figure 13: Results of Case B-6

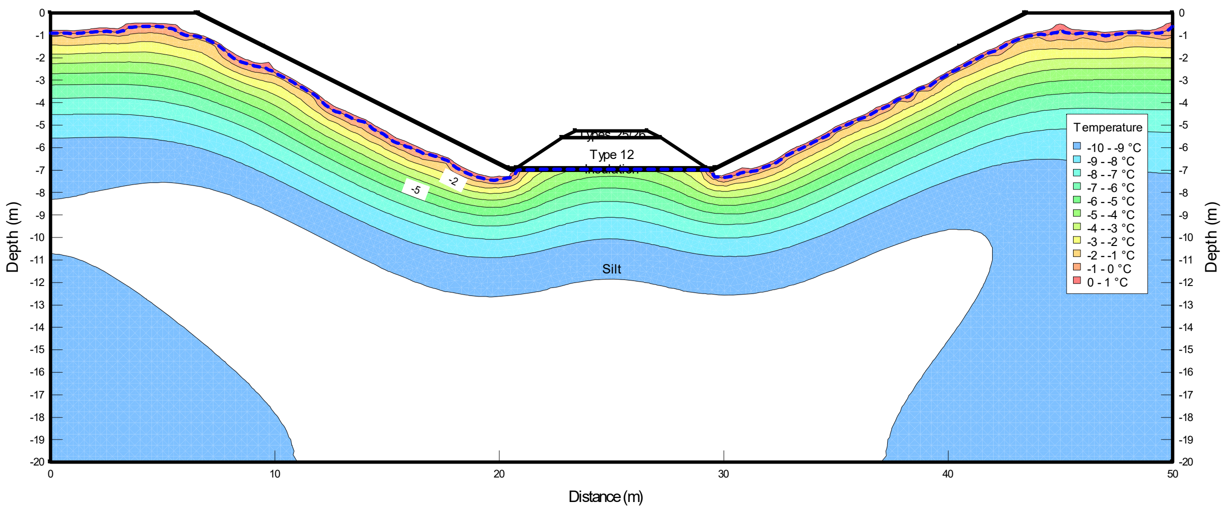


Figure 14: Results of Case B-7

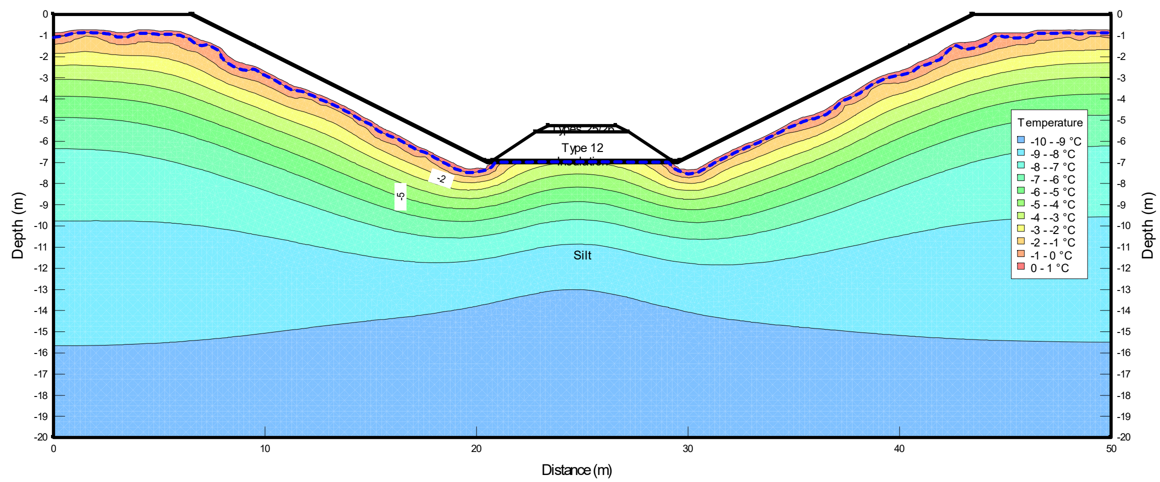


Figure 15: Results of Case B-5b – Climate Change Consideration

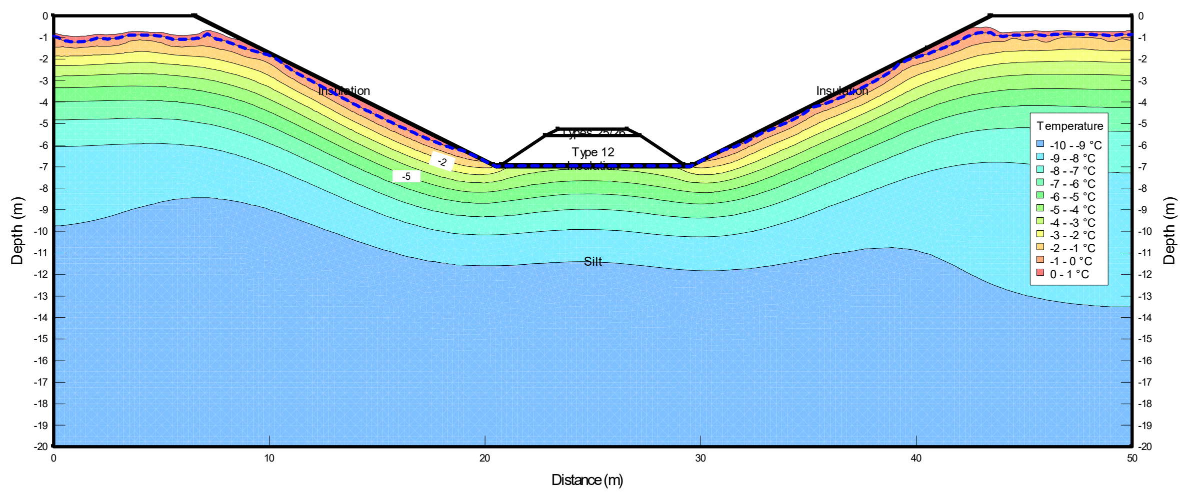


Figure 16: Results of Case B-6b – Climate Change Consideration

Appendix H

Thermal Modeling on Culverts

APPENDIX H

THERMAL MODELLING ON CULVERTS

1. Soil parameters

3 types of soils: ice-rich (silt), ice -poor (sand and gravel), Fills (Types 9,12,26, ballast/sub-ballast)

Table H1 - Assumed and Calculated Thermal Properties

Material	Frozen Thermal Conductivity (J/s/m/°C)	Unfrozen Thermal Conductivity (J/s/m/°C)	Frozen Volumetric Heat Capacity (J/m³/°C)	Unfrozen Volumetric Heat Capacity (J/m³/°C)	Insitu Water content (%)	Insitu Volumetric Water content (m³/m³)
Fill (Types 9,12 and 26, Ballast/Sub-ballast	4.5	3.0	2,400,000	3,000,000	2	3.6
Silt	2.0	1.3	2,200,000	2,200,000	30	45
Sand/Gravel	3.0	2.0	2,600,000	2,600,000	15	25.5
Insulation	0.035	0.035	37,500	37,500	0	0

2. Assumptions

Climate Change model for 20 year design life (2019 to 2039)

Culvert cases being considered as shown in Table H2.

Table H2- Definition of Cases being Modelled

Culvert Barrel Diameter (mm)	Number of Barrels	Fill Heights (m)	Subsurface
900	1	2.1, 3, 4, 5, 10	Sand and Gravel (ice-poor) and Silt (ice-rich)
	3		
1200	1	2.4, 3, 4, 5, 10	
	3		
1500	1	2.7, 3, 4, 5, 10	
	4		
1800	1	3, 4, 5, 10	
	12		

3. Thermal Modelling Output Runs

Each set of runs contain different heights of embankment and type of soil (silt representing ice-rich soils, and sand and gravel representing ice-poor soils):

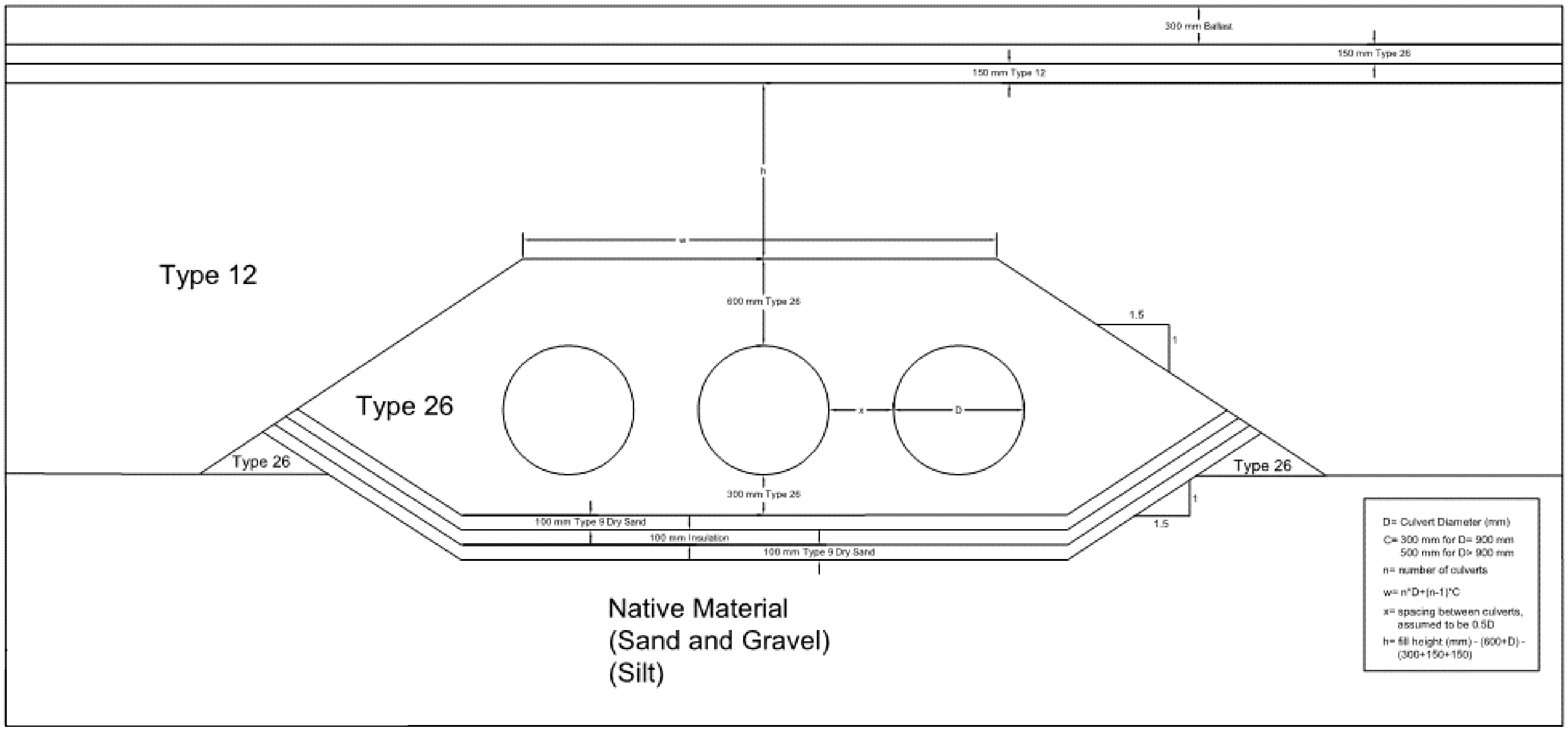


Figure H-1	**Typical Culvert Section (< 4 m Fill)**	**Project Number**	H353004	**Rev**	A	**Baffinland Iron Ore Mines**	HATCH
		By	**MY**	4/22/2019			
		Checked By	**-**	-		**Mary River Expansion Stage 3**	

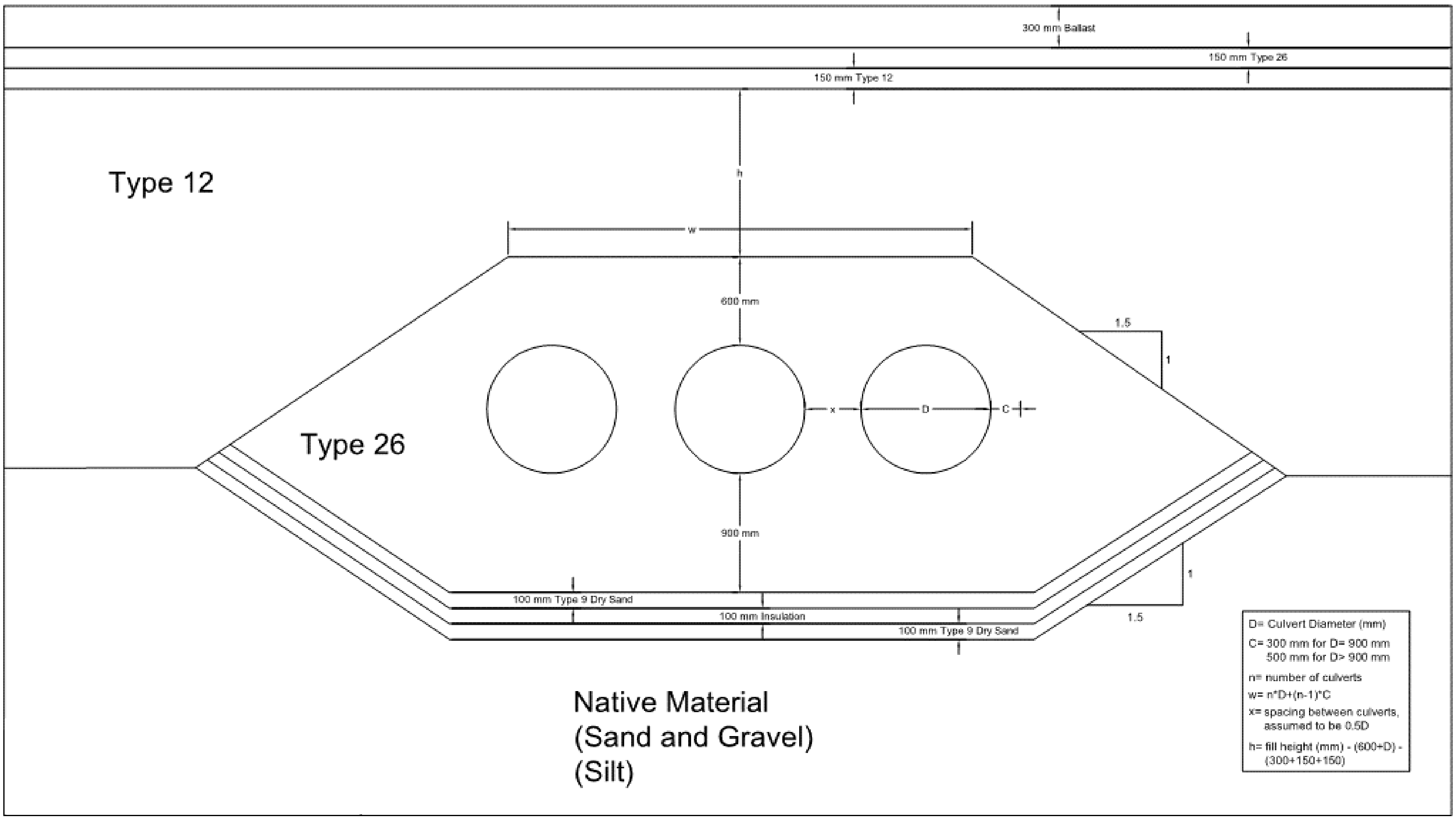


Figure H-2	**Typical Culvert Section (>4 m Fill)**	**Project Number**	H353004	**Rev**	A	**Baffinland Iron Ore Mines**	HATCH
		By	**MY**	4/22/2019			
		Checked By	**-**	-		**Mary River Expansion Stage 3**	

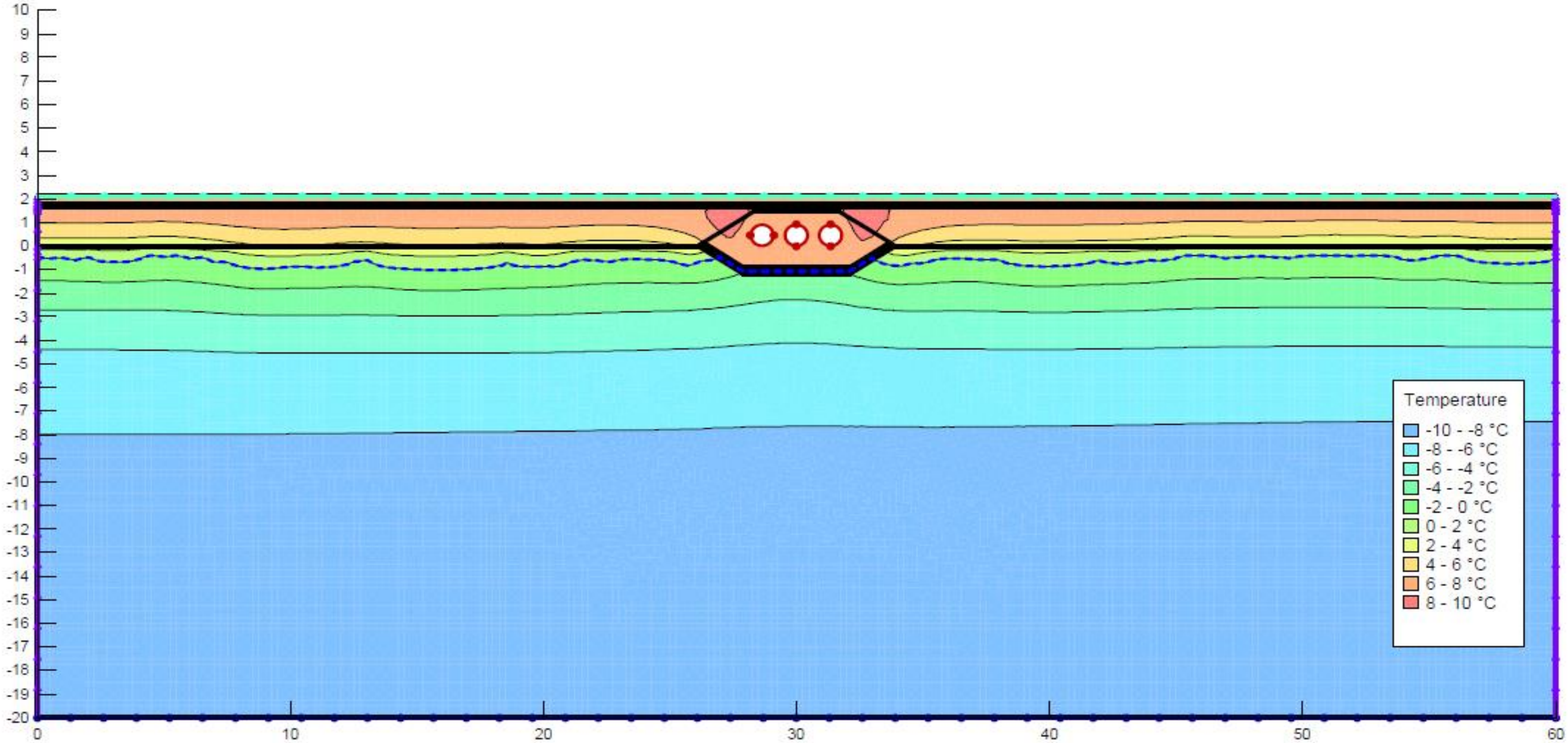


Figure H-3	**Culvert Thermal Modeling Results**	**Culvert Diamater**	900mm	**Project Number**	H353004	**Rev**		HATCH
		Fill Height	2.1m	**By**	**MY**	4/22/2019		
		Native Material	Sand and Gravel	**Checked By**	**-**	-		

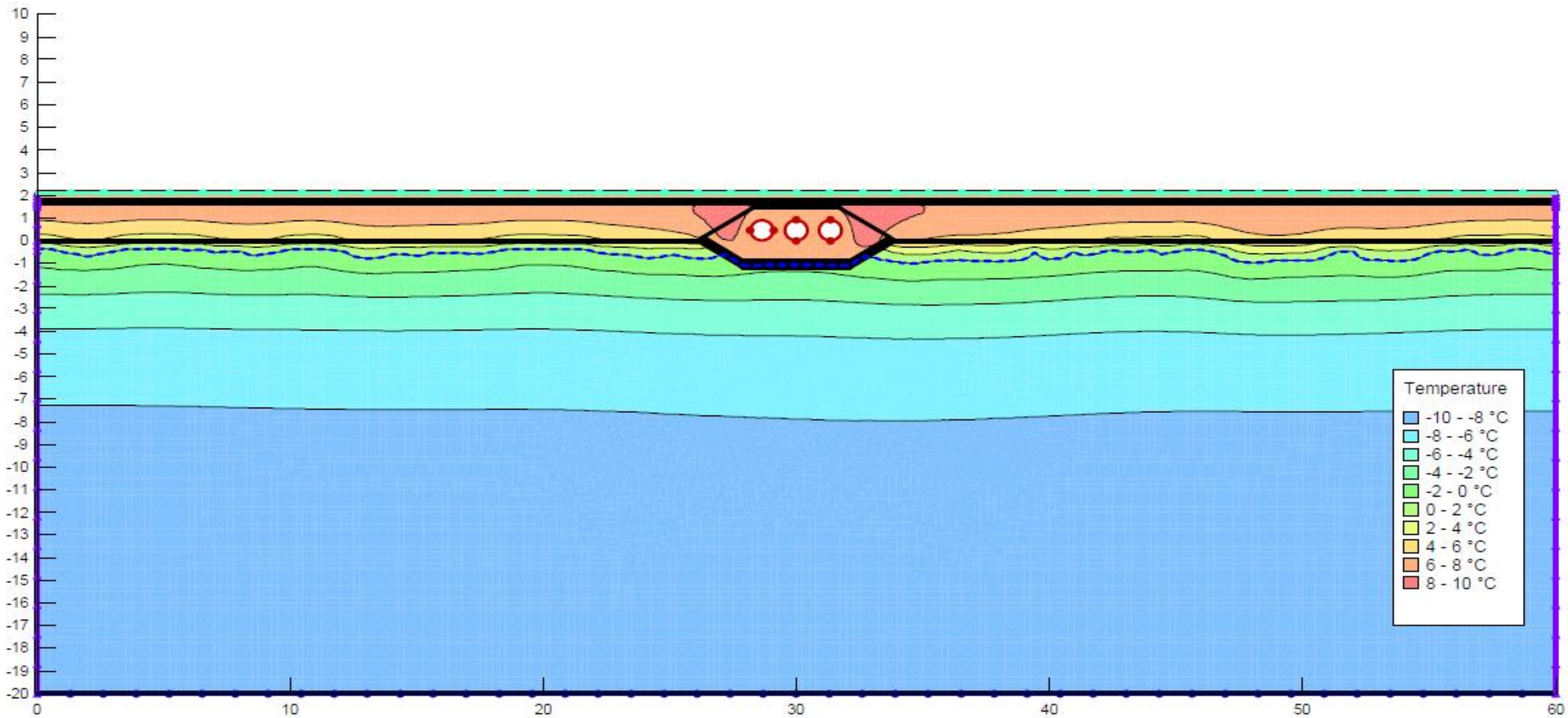


Figure H-3	**Culvert Thermal Modeling Results**	**Culvert Diamater**	900mm	**Project Number**	H353004	**Rev**	HATCH
		Fill Height	2.1m	**By**	MY	4/22/2019	
		Native Material	Silt	**Checked By**	-	-	

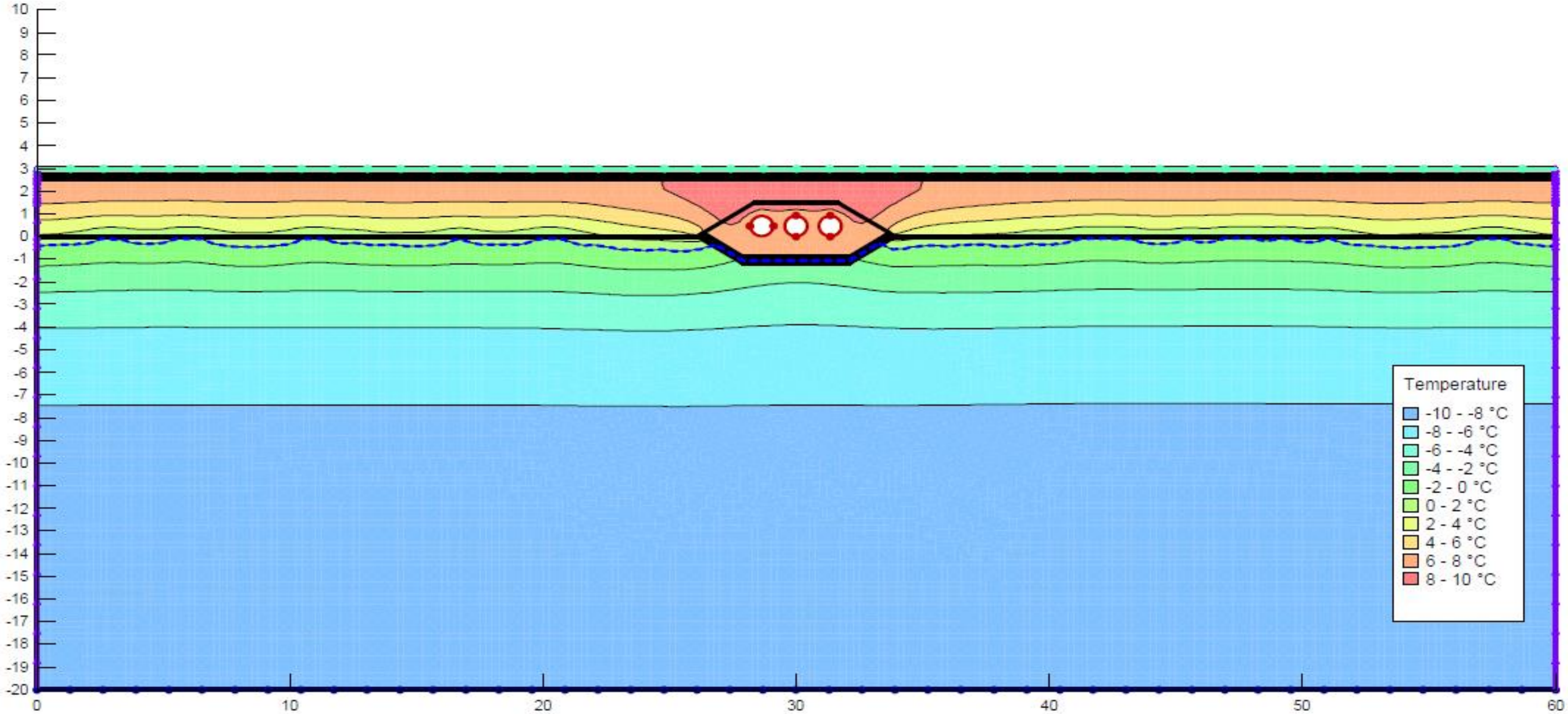


Figure H-3	**Culvert Thermal Modeling Results**	**Culvert Diamater**	900mm	**Project Number**	H353004	**Rev**	HATCH
		Fill Height	3m	**By**	MY	4/22/2019	
		Native Material	Sand and Gravel	**Checked By**	-	-	

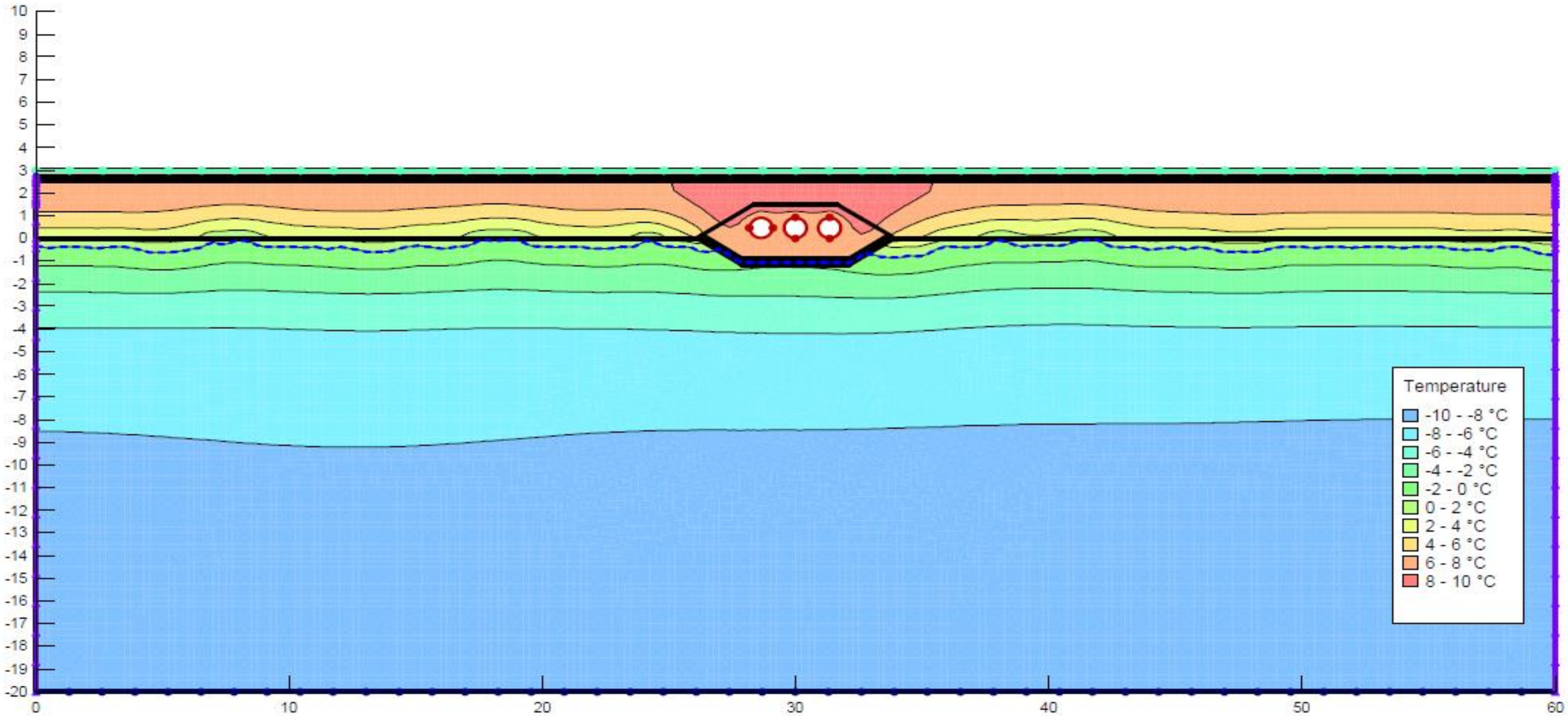


Figure H-3	Culvert Thermal Modeling Results	Culvert Diamater	900mm	Project Number	H353004	Rev	HATCH
		Fill Height	3m	By	MY	4/22/2019	
		Native Material	Silt	Checked By	-	-	

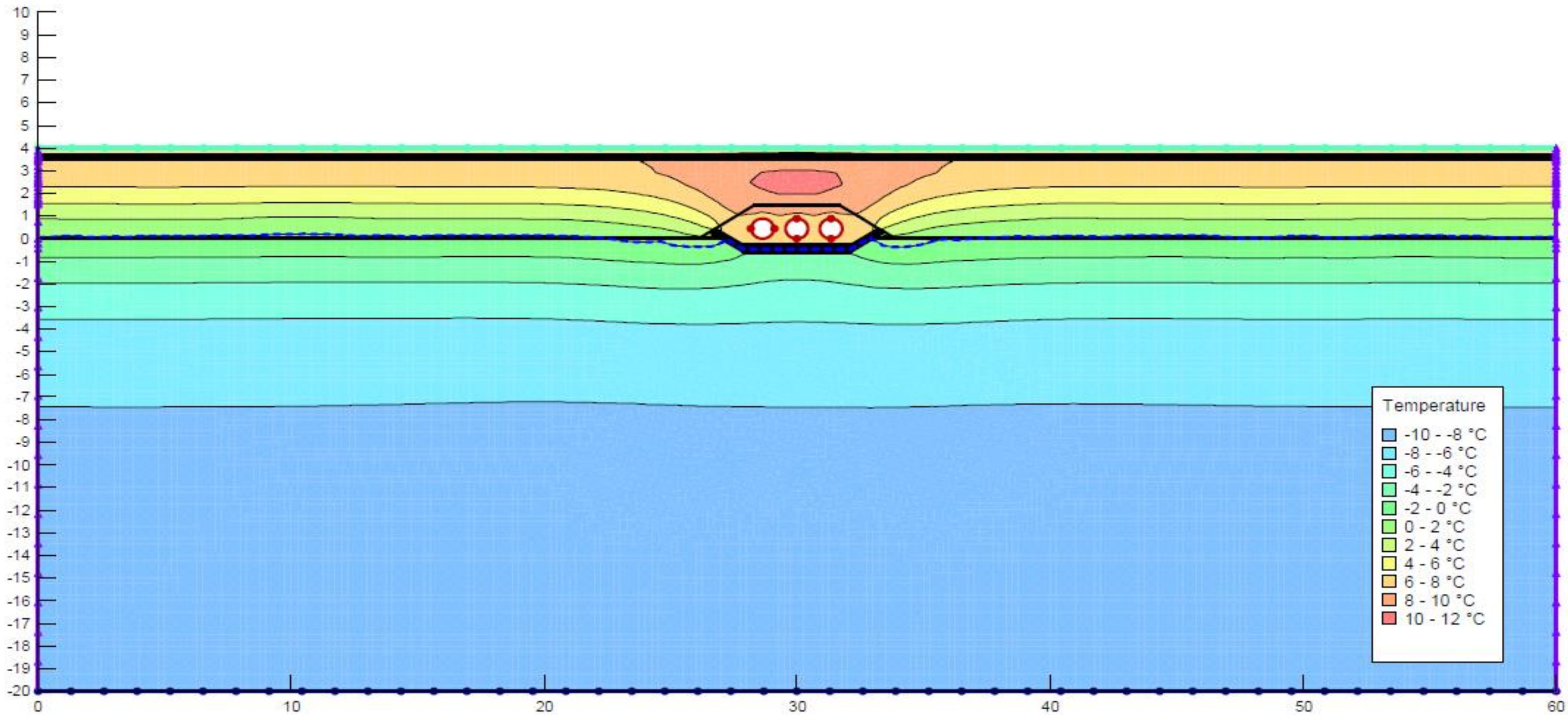


Figure H-3	Culvert Thermal Modeling Results	Culvert Diamater	900mm	Project Number	H353004	Rev	HATCH
		Fill Height	4m	By	MY	4/22/2019	
		Native Material	Sand and Gravel	Checked By	-	-	

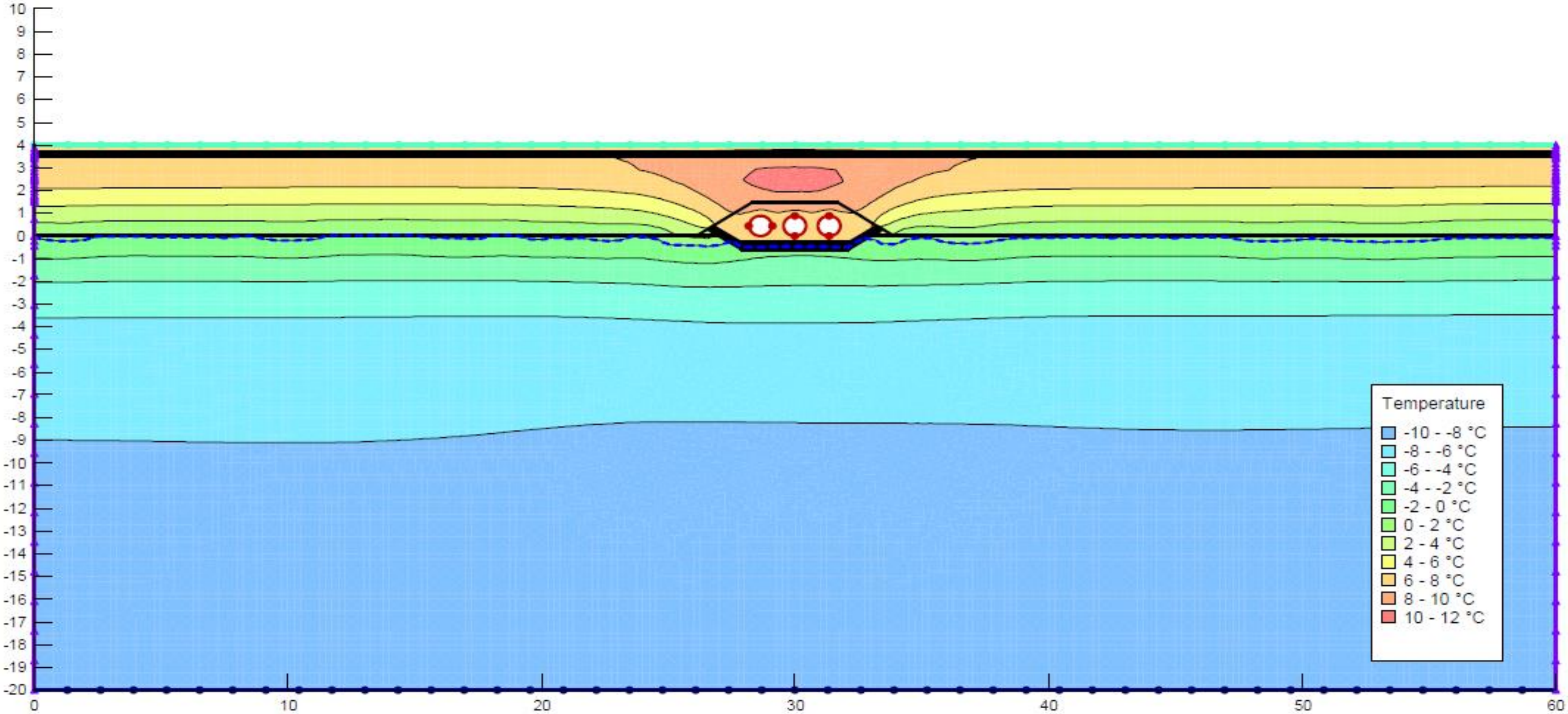


Figure H-3	**Culvert Thermal Modeling Results**	**Culvert Diamater**	900mm	**Project Number**	H353004	**Rev**	HATCH
		Fill Height	4m	**By**	MY	4/22/2019	
		Native Material	Silt	**Checked By**	-	-	

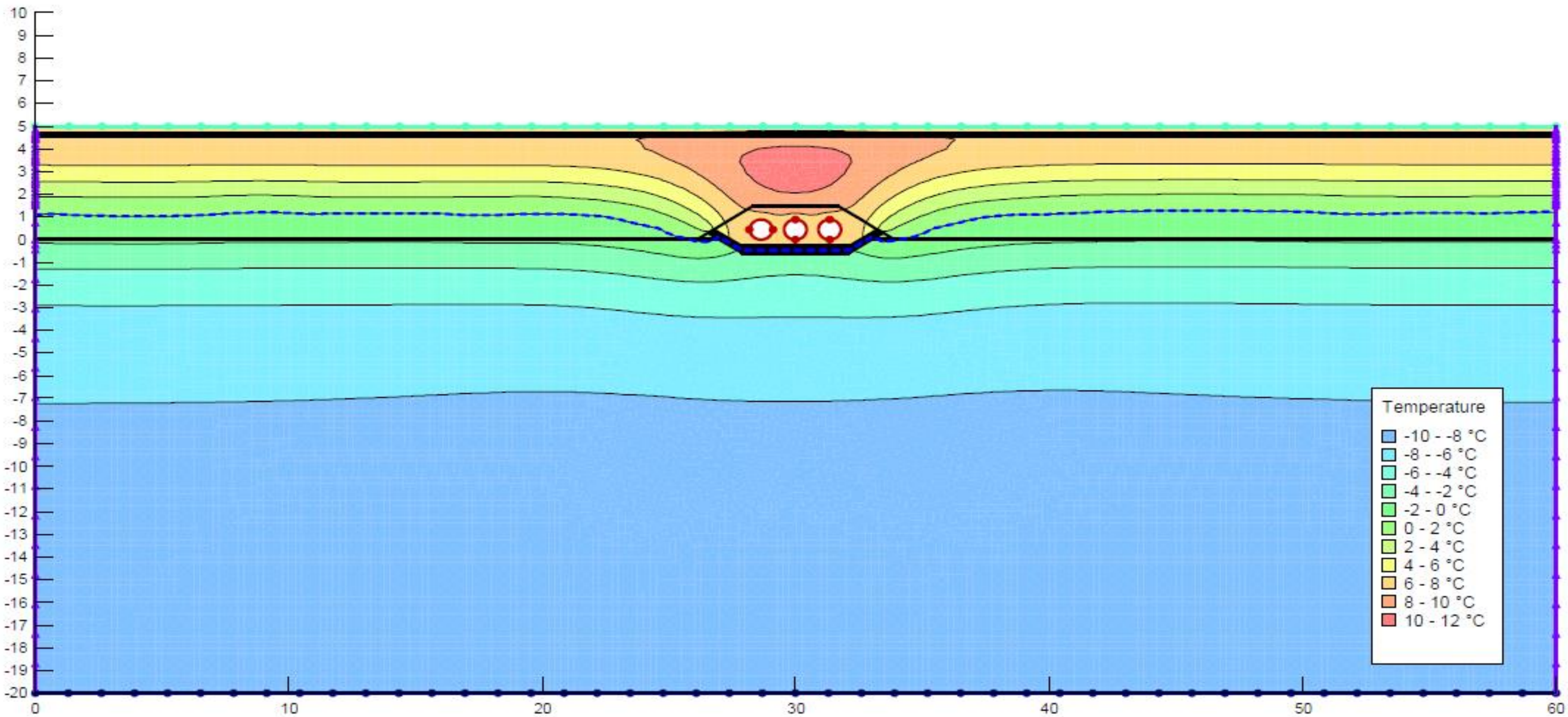


Figure H-3	**Culvert Thermal Modeling Results**	**Culvert Diamater**	900mm	**Project Number**	H353004	**Rev**	HATCH
		Fill Height	5m	**By**	**MY**	4/22/2019	
		Native Material	Sand and Gravel	**Checked By**	**-**	-	

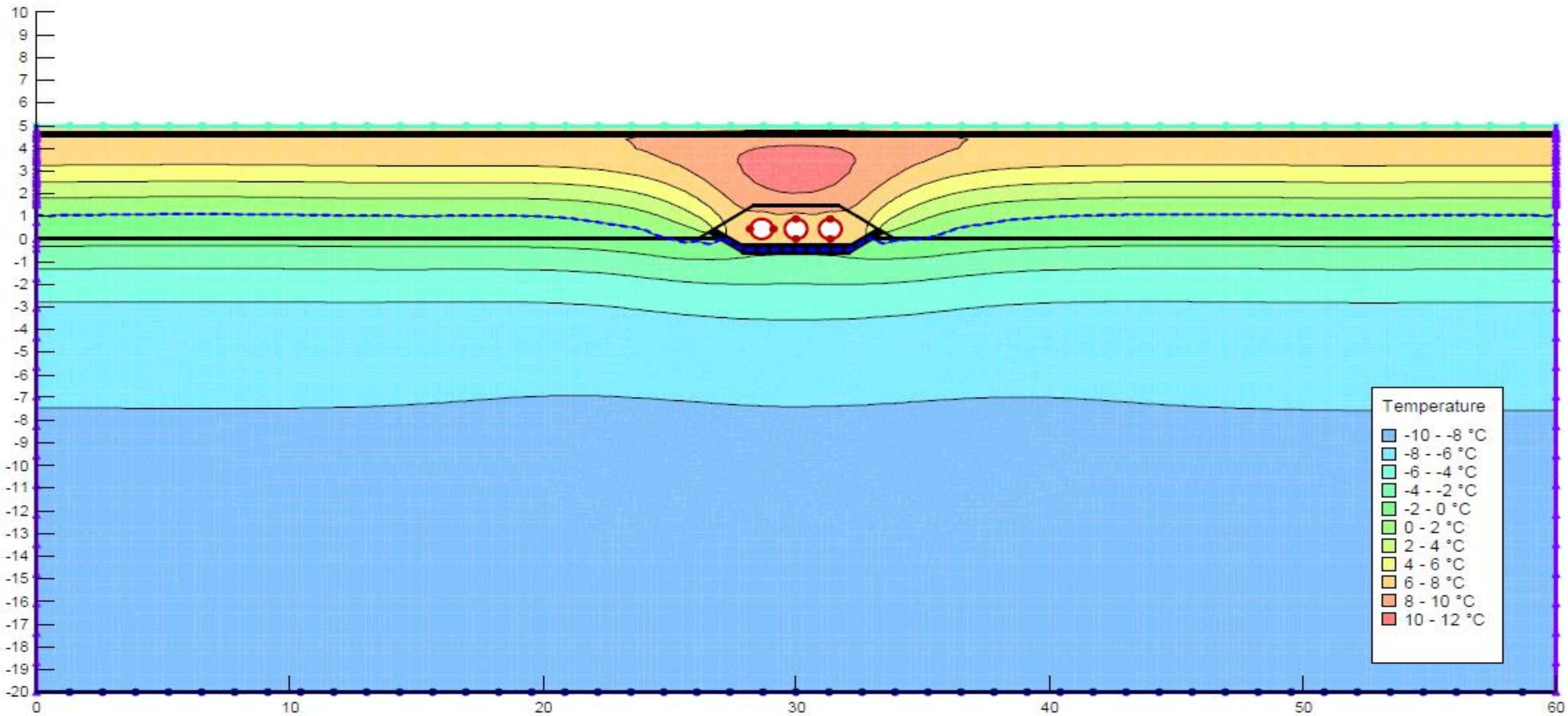


Figure H-3	Culvert Thermal Modeling Results	Culvert Diamater	900mm	Project Number	H353004	Rev	HATCH
		Fill Height	5m	By	MY	4/22/2019	
		Native Material	Silt	Checked By	-	-	

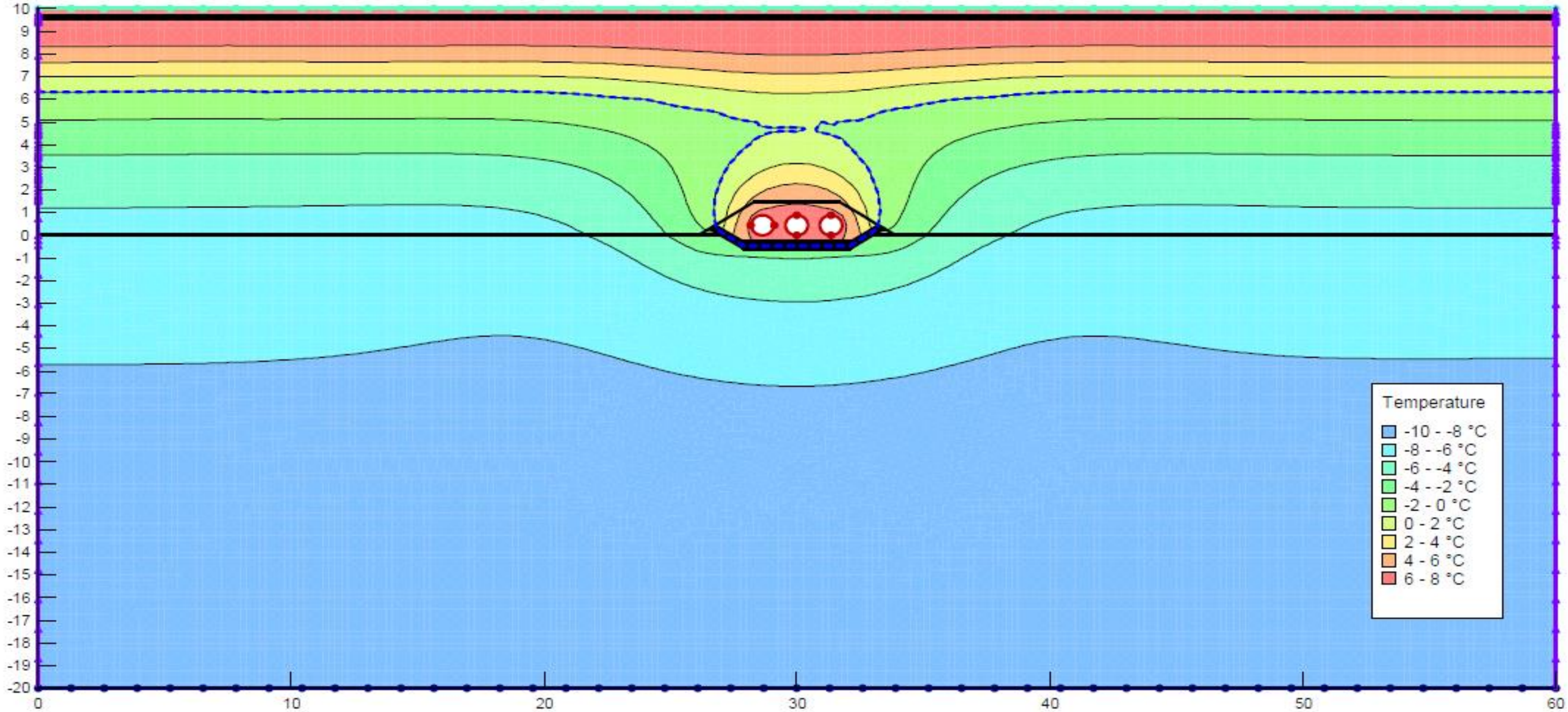


Figure H-3	Culvert Thermal Modeling Results	Culvert Diamater	900mm	Project Number	H353004	Rev	HATCH
		Fill Height	10m	By	MY	4/22/2019	
		Native Material	Sand and Gravel	Checked By	-	-	

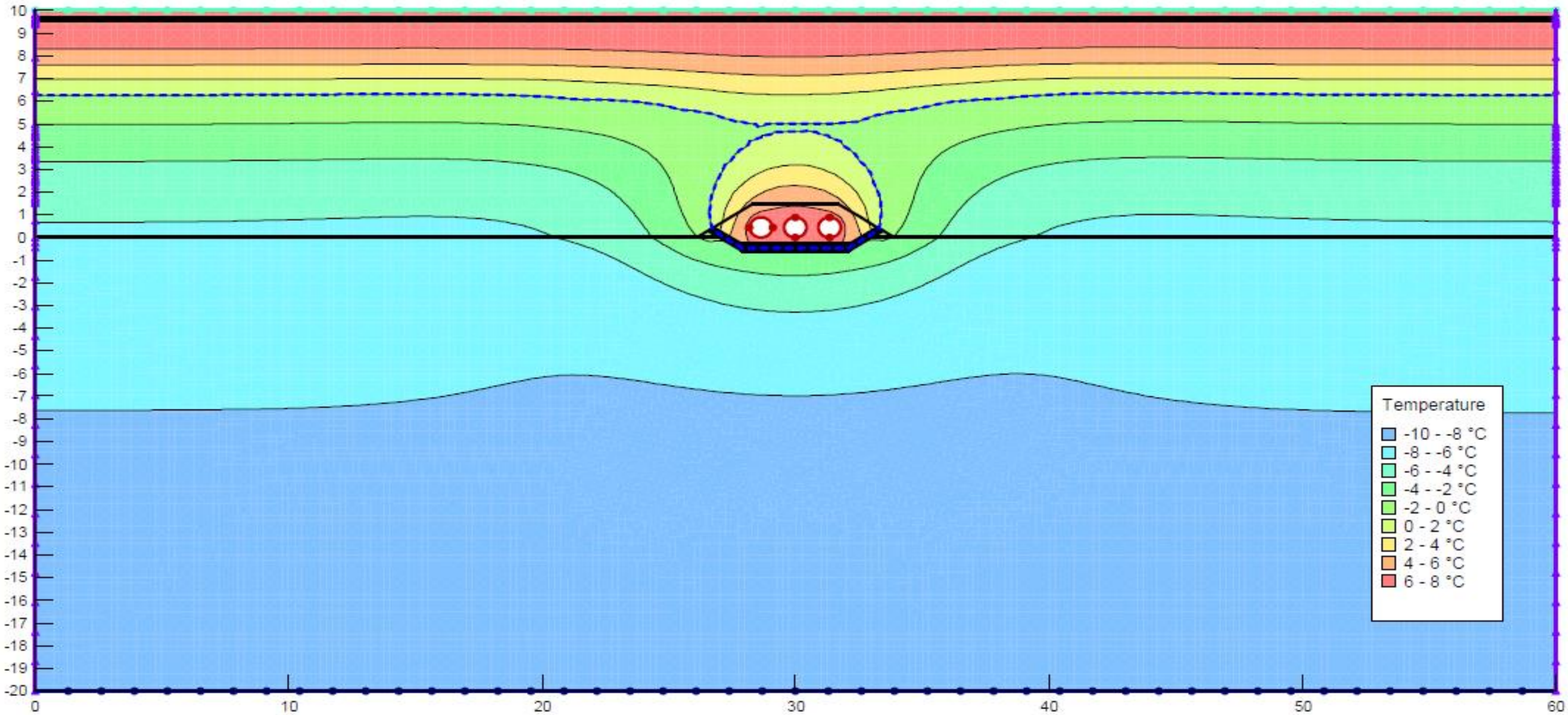


Figure H-3	**Culvert Thermal Modeling Results**	**Culvert Diamater**	900mm	**Project Number**	H353004	**Rev**	HATCH
		Fill Height	10m	**By**	MY	4/22/2019	
		Native Material	Silt	**Checked By**	-	-	

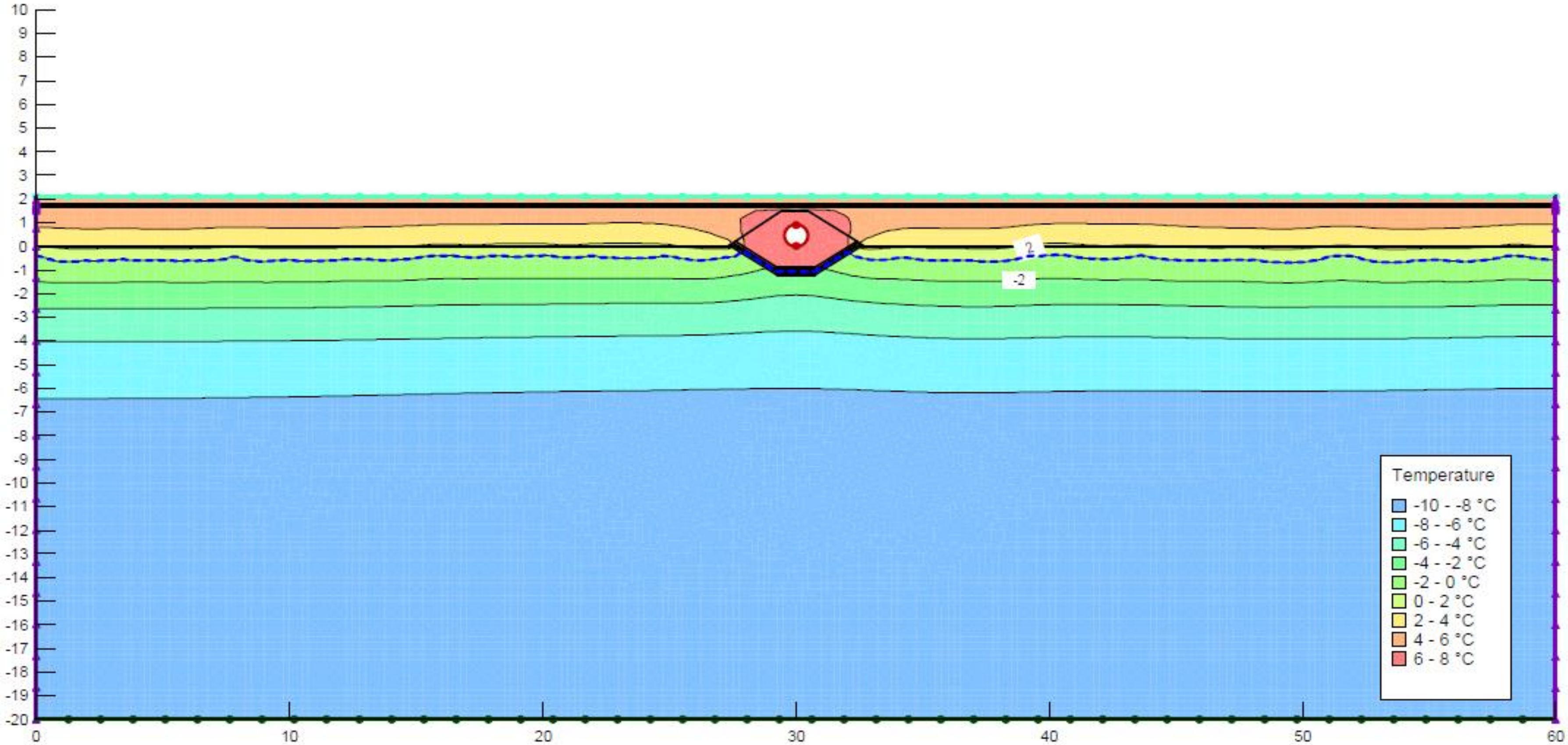


Figure H-4	Culvert Thermal Modeling Results	Culvert Diamater	900mm	Project Number	H353004	Rev	HATCH
		Fill Height	2.1m	By	MY	4/22/2019	
		Native Material	Sand and Gravel	Checked By	-	-	

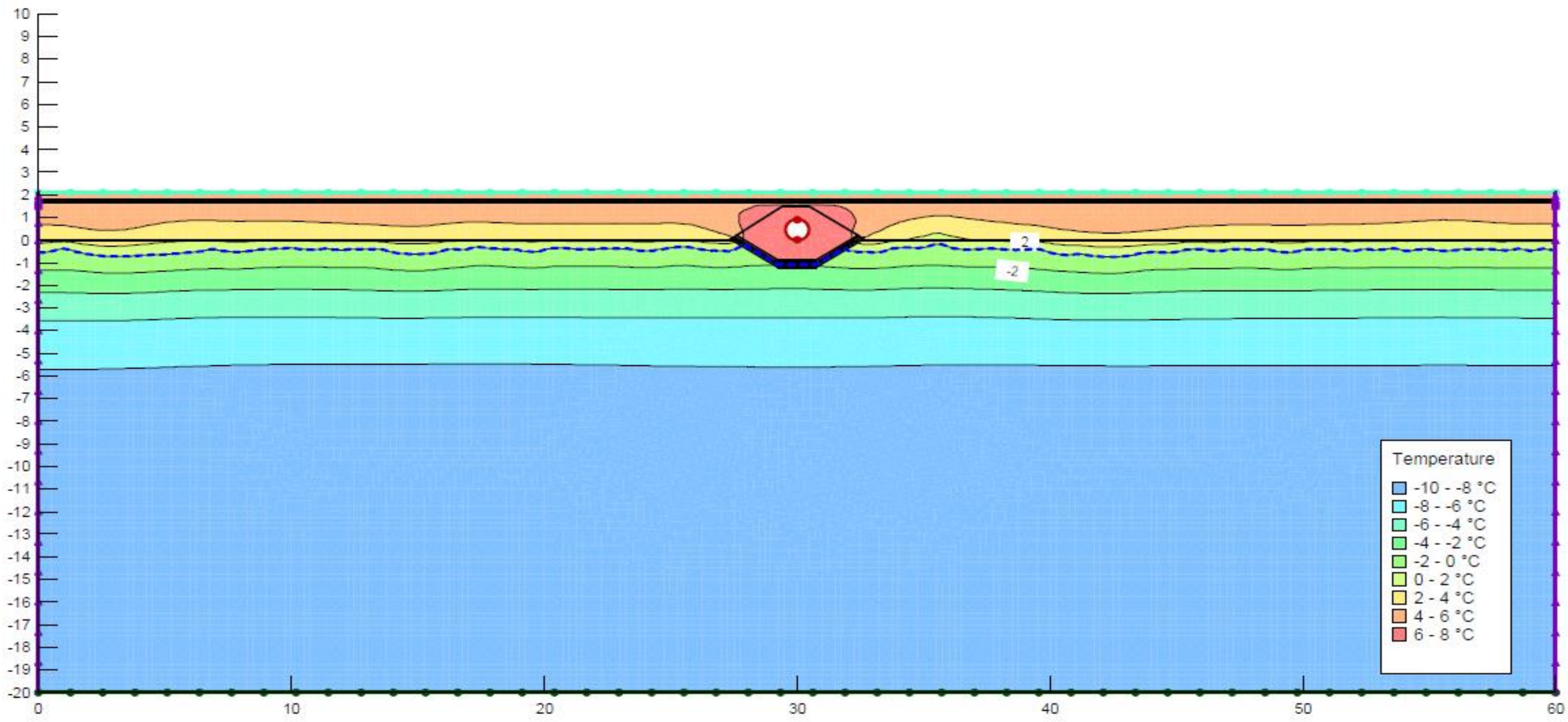


Figure H-4	Culvert Thermal Modeling Results	Culvert Diamater	900mm	Project Number	H353004	Rev		HATCH
		Fill Height	2.1m	By	MY	4/22/2019		
		Native Material	Silt	Checked By	-	-		

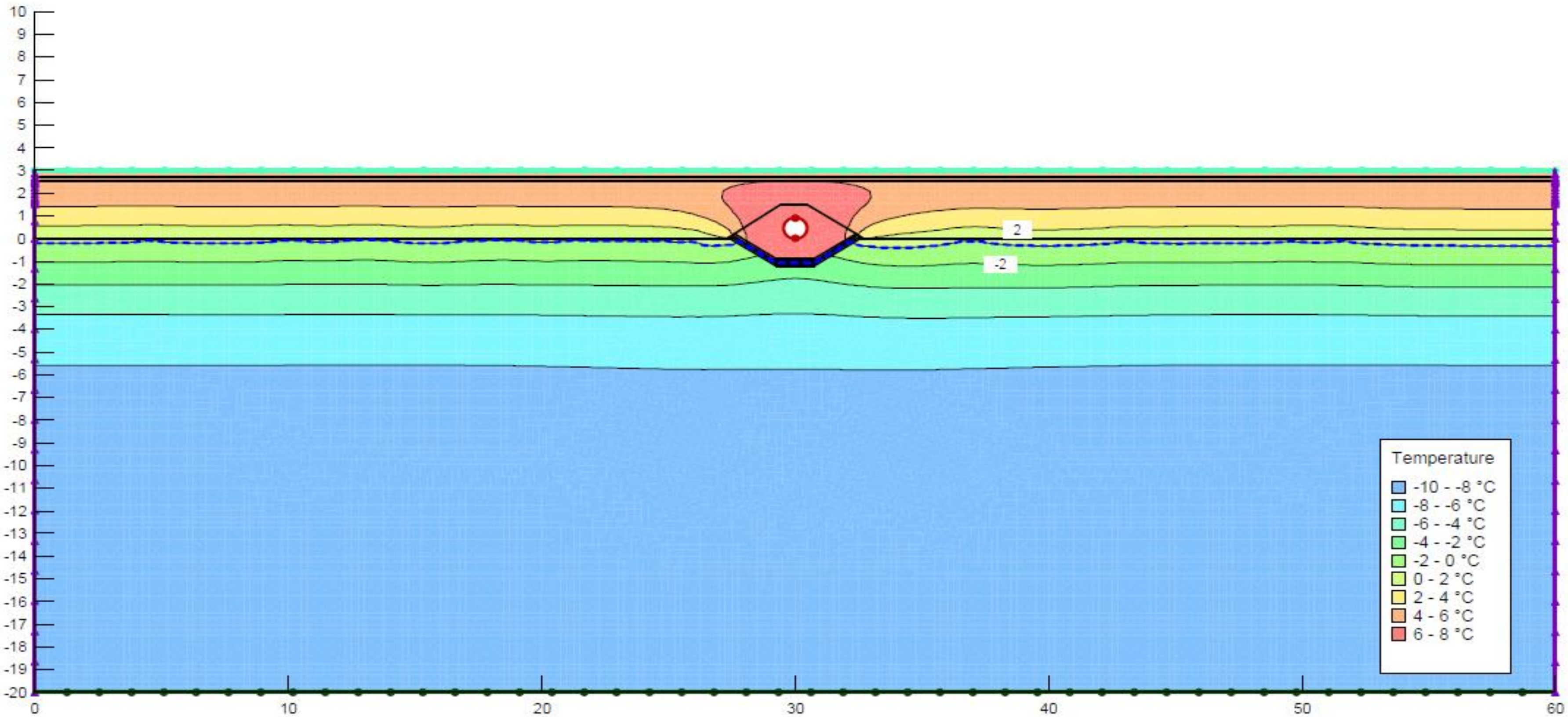


Figure H-4	**Culvert Thermal Modeling Results**	**Culvert Diamater**	900mm	**Project Number**	H353004	**Rev**	HATCH
		Fill Height	3m	**By**	MY	4/22/2019	
		Native Material	Sand and Gravel	**Checked By**	-	-	

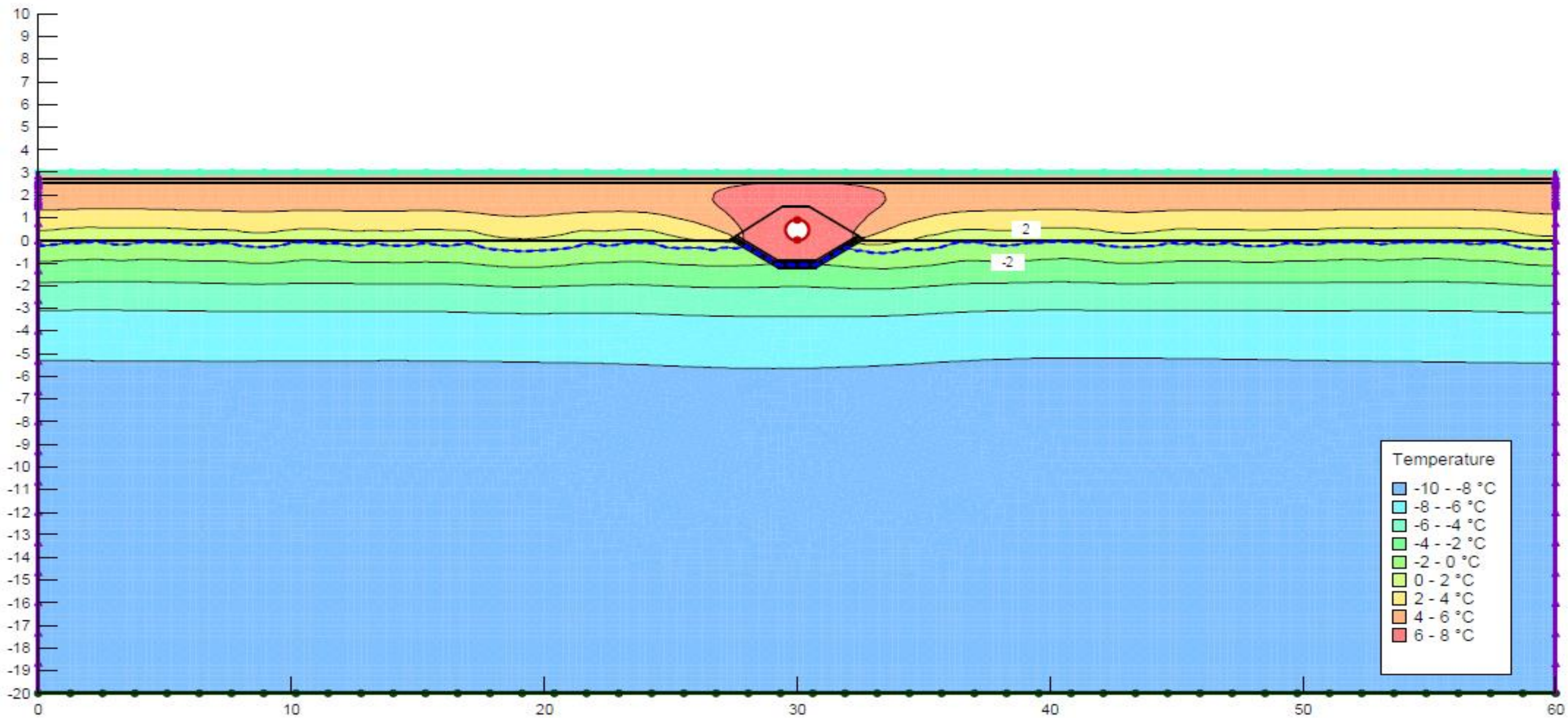


Figure H-4	Culvert Thermal Modeling Results	Culvert Diamater	900mm	Project Number	H353004	Rev		HATCH
		Fill Height	3m	By	MY	4/22/2019		
		Native Material	Silt	Checked By	-	-		

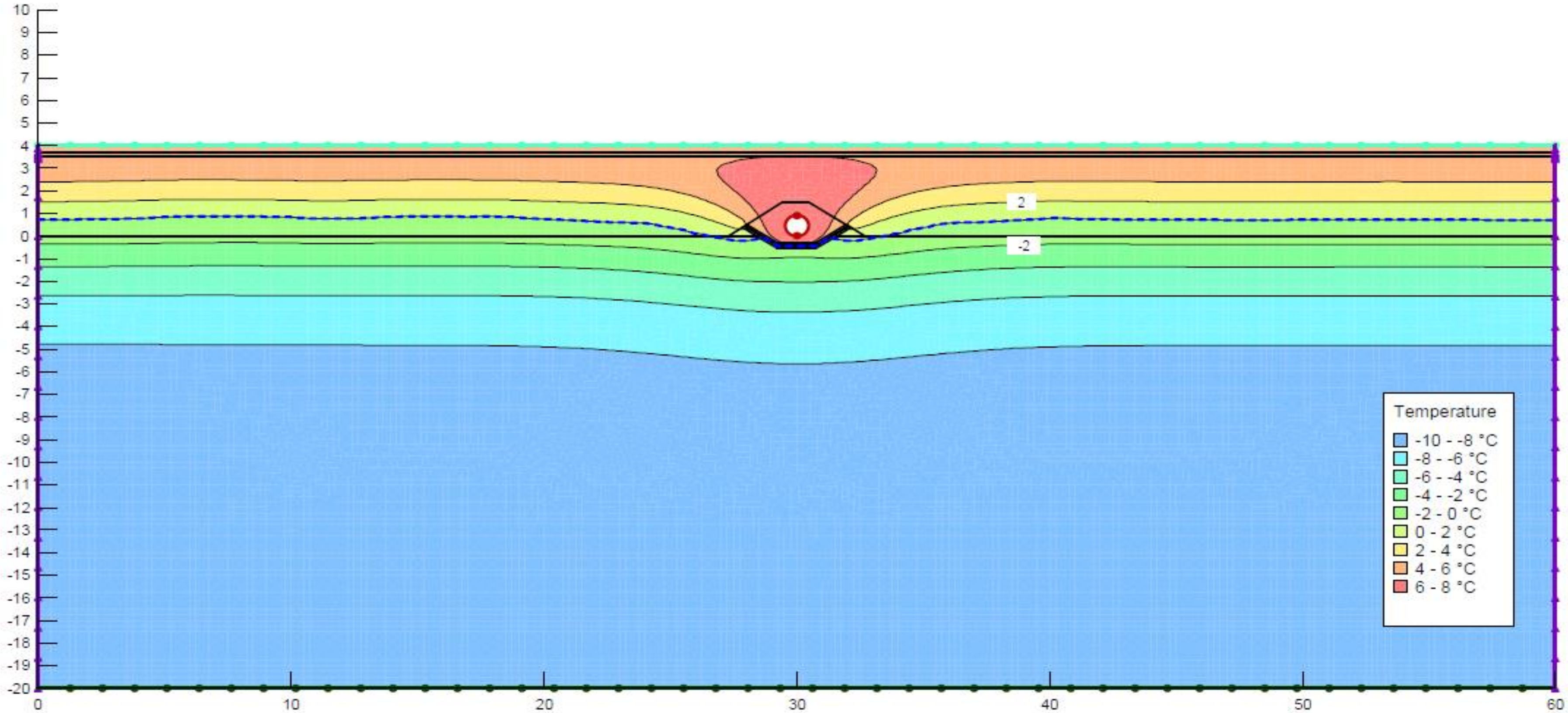


Figure H-4	Culvert Thermal Modeling Results	Culvert Diamater	900mm	Project Number	H353004	Rev	HATCH
		Fill Height	4m	By	MY	4/22/2019	
		Native Material	Sand and Gravel	Checked By	-	-	

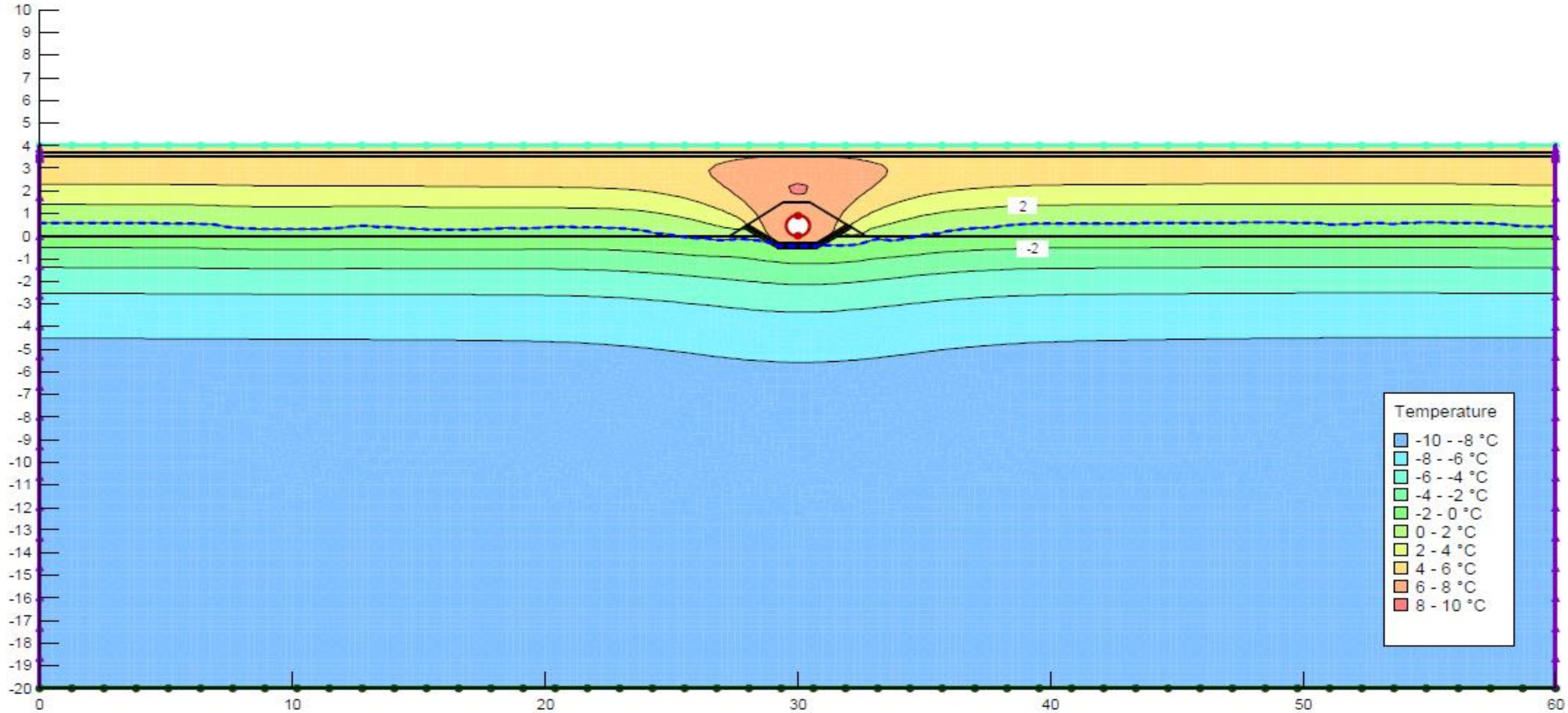


Figure H-4	**Culvert Thermal Modeling Results**	**Culvert Diamater**	900mm	**Project Number**	H353004	**Rev**		**HATCH**
		Fill Height	4m	**By**	**MY**	4/22/2019		
		Native Material	Silt	**Checked By**	**-**	-		

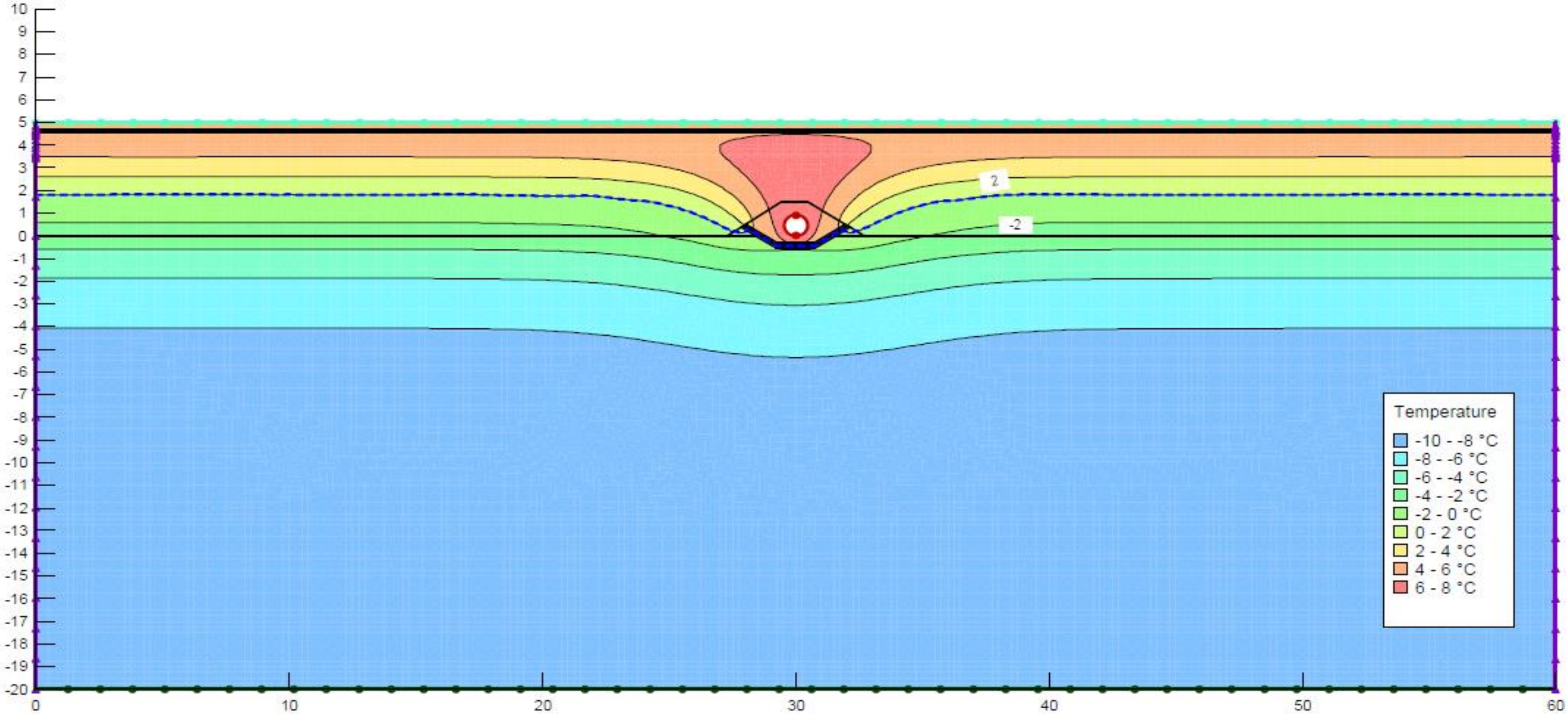


Figure H-4	Culvert Thermal Modeling Results	**Culvert Diamater**	900mm	**Project Number**	H353004	**Rev**	HATCH
		Fill Height	5m	**By**	**MY**	4/22/2019	
		Native Material	Sand and Gravel	**Checked By**	**-**	-	

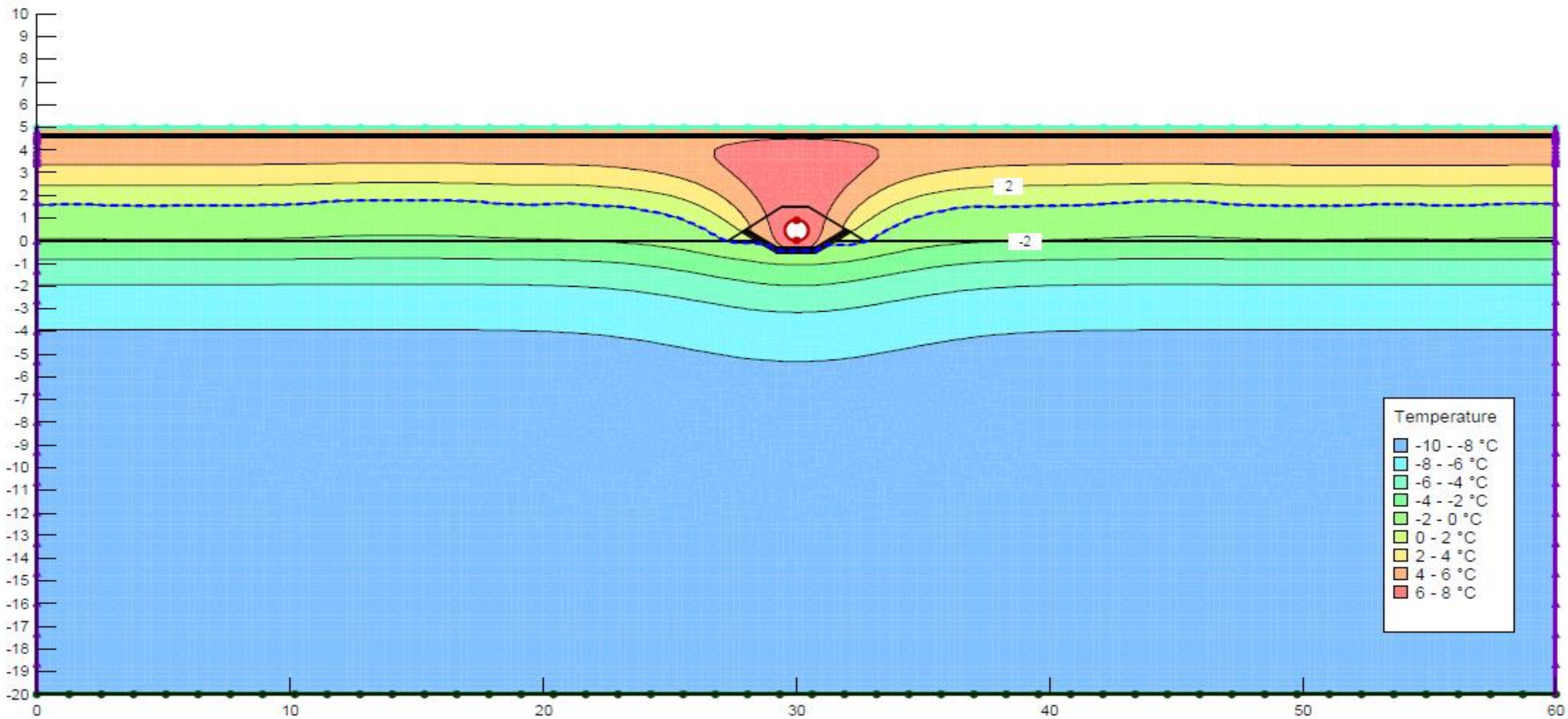


Figure H-4	**Culvert Thermal Modeling Results**	**Culvert Diamater**	900mm	**Project Number**	H353004	**Rev**	HATCH
		Fill Height	5m	**By**	**MY**	4/22/2019	
		Native Material	Silt	**Checked By**	**-**	-	

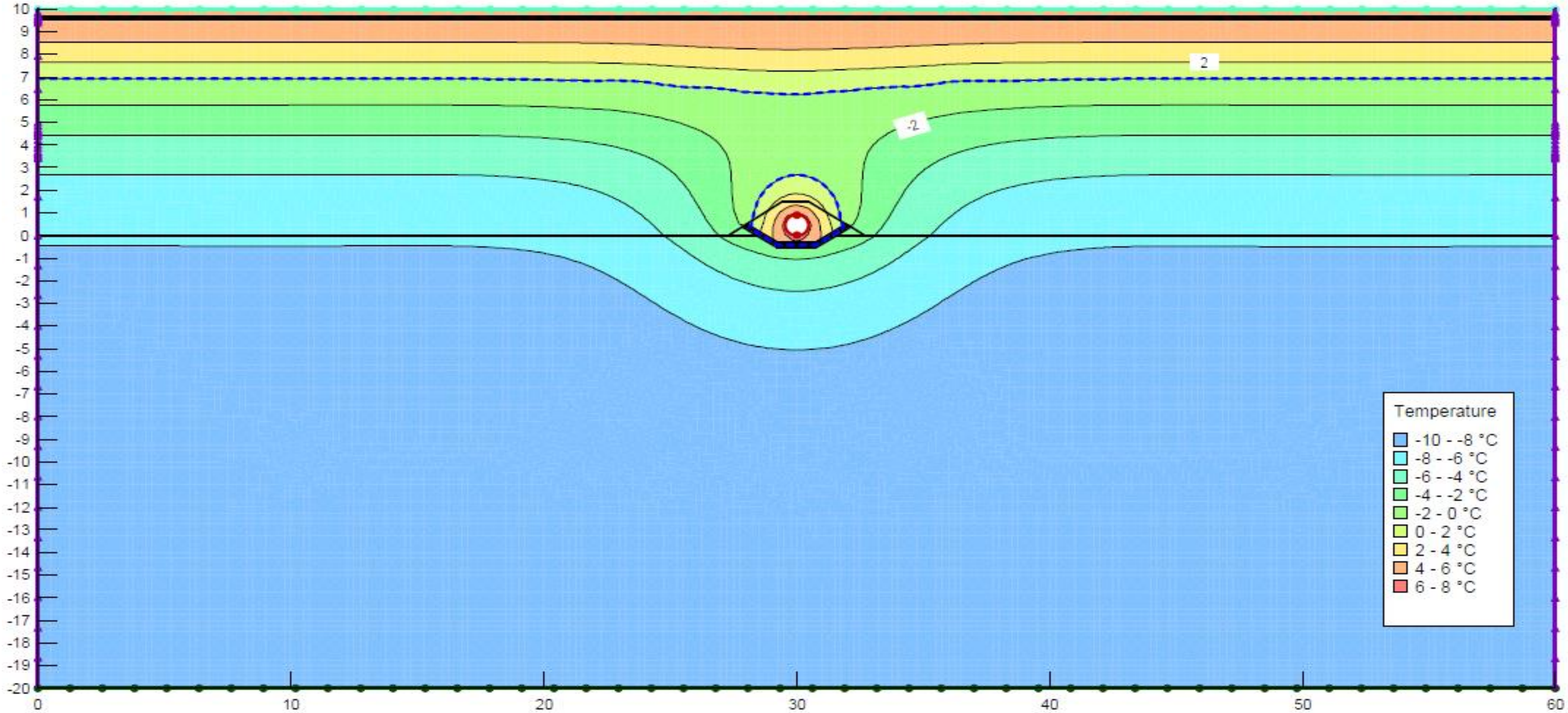


Figure H-4	**Culvert Thermal Modeling Results**	**Culvert Diamater**	900mm	**Project Number**	H353004	**Rev**	HATCH
		Fill Height	10m	**By**	MY	4/22/2019	
		Native Material	Sand and Gravel	**Checked By**	-	-	

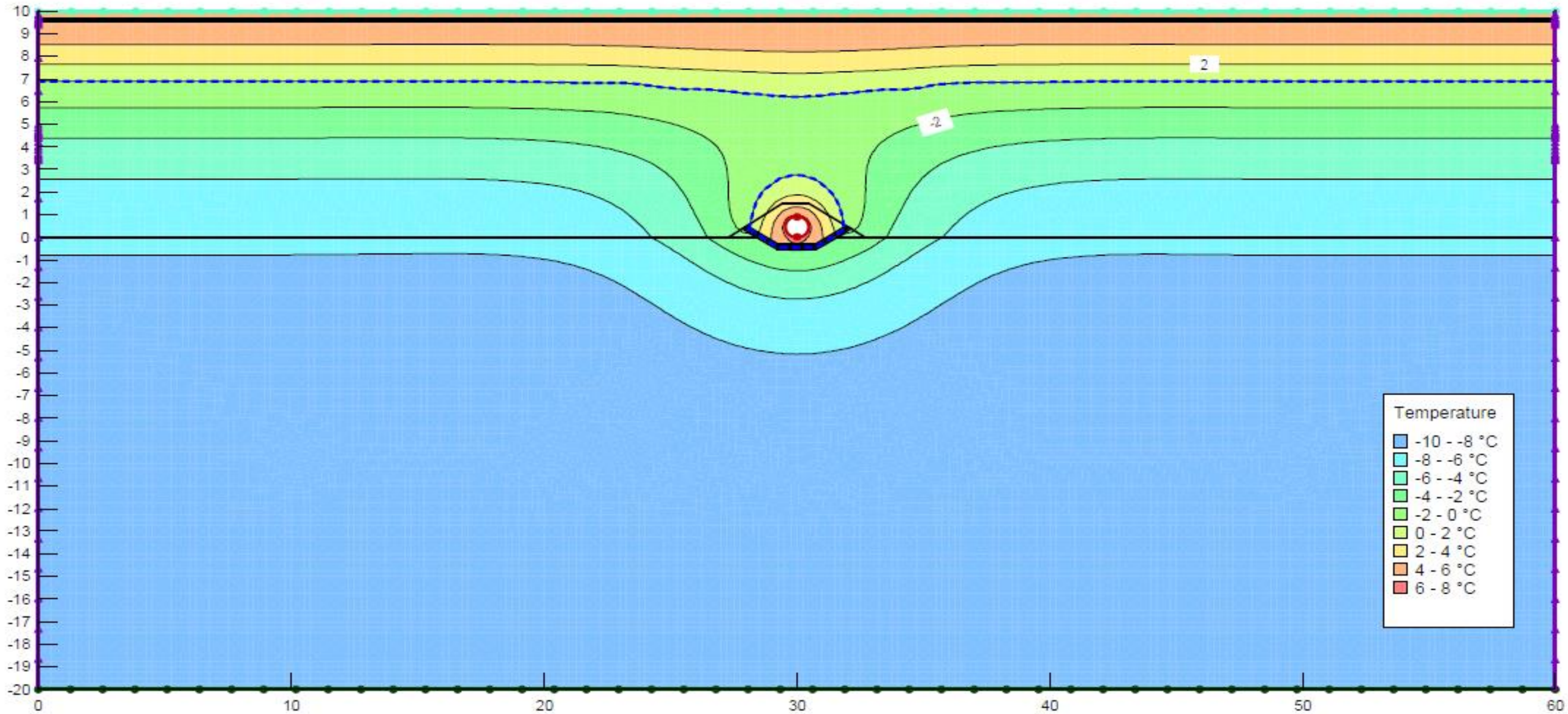


Figure H-4	Culvert Thermal Modeling Results	Culvert Diamater	900mm	Project Number	H353004	Rev	HATCH
		Fill Height	10m	By	MY	4/22/2019	
		Native Material	Silt	Checked By	-	-	

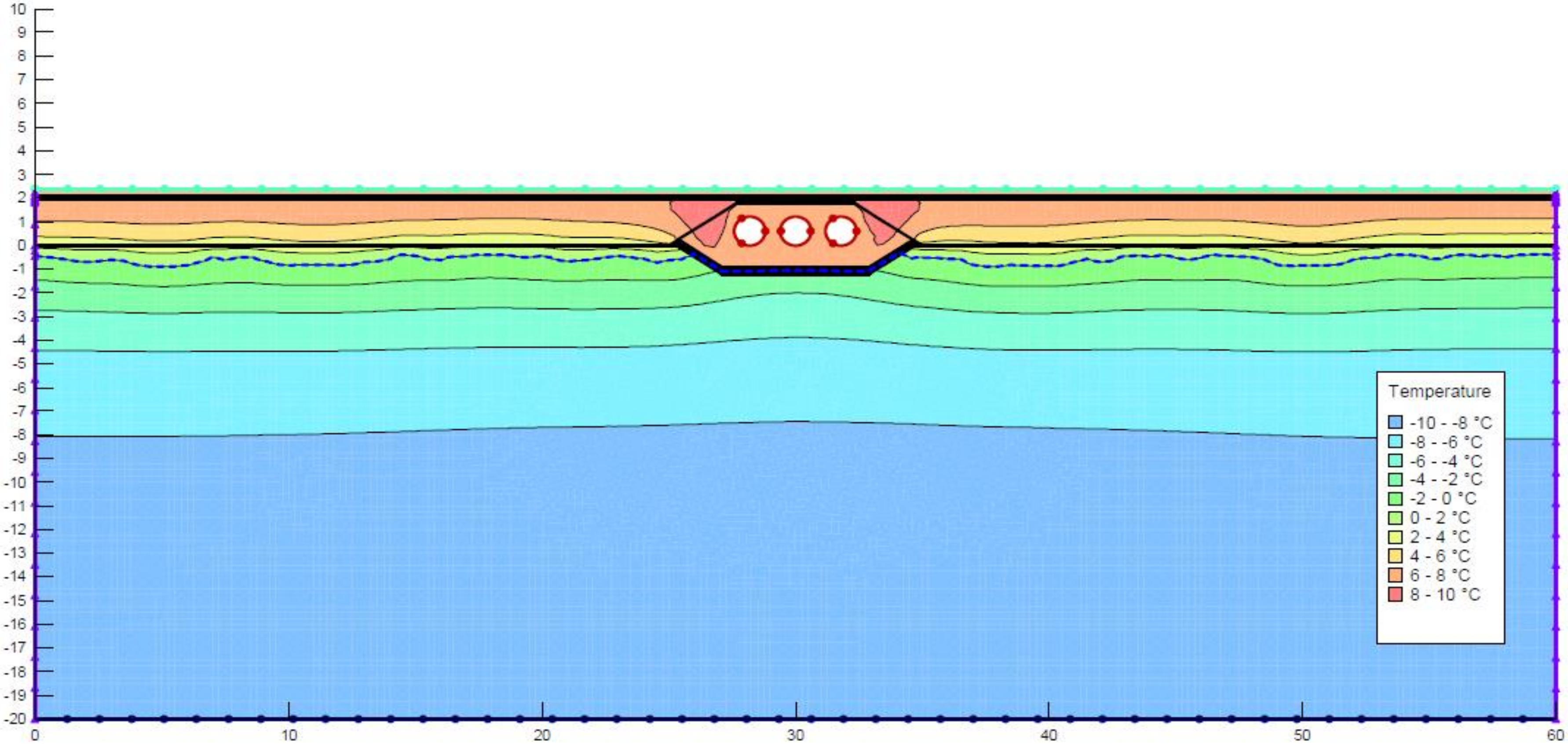


Figure H-5	**Culvert Thermal Modeling Results**	**Culvert Diamater**	1200mm	**Project Number**	H353004	**Rev**	HATCH
		Fill Height	2.4m	**By**	MY	4/22/2019	
		Native Material	Sand and Gravel	**Checked By**	-	-	

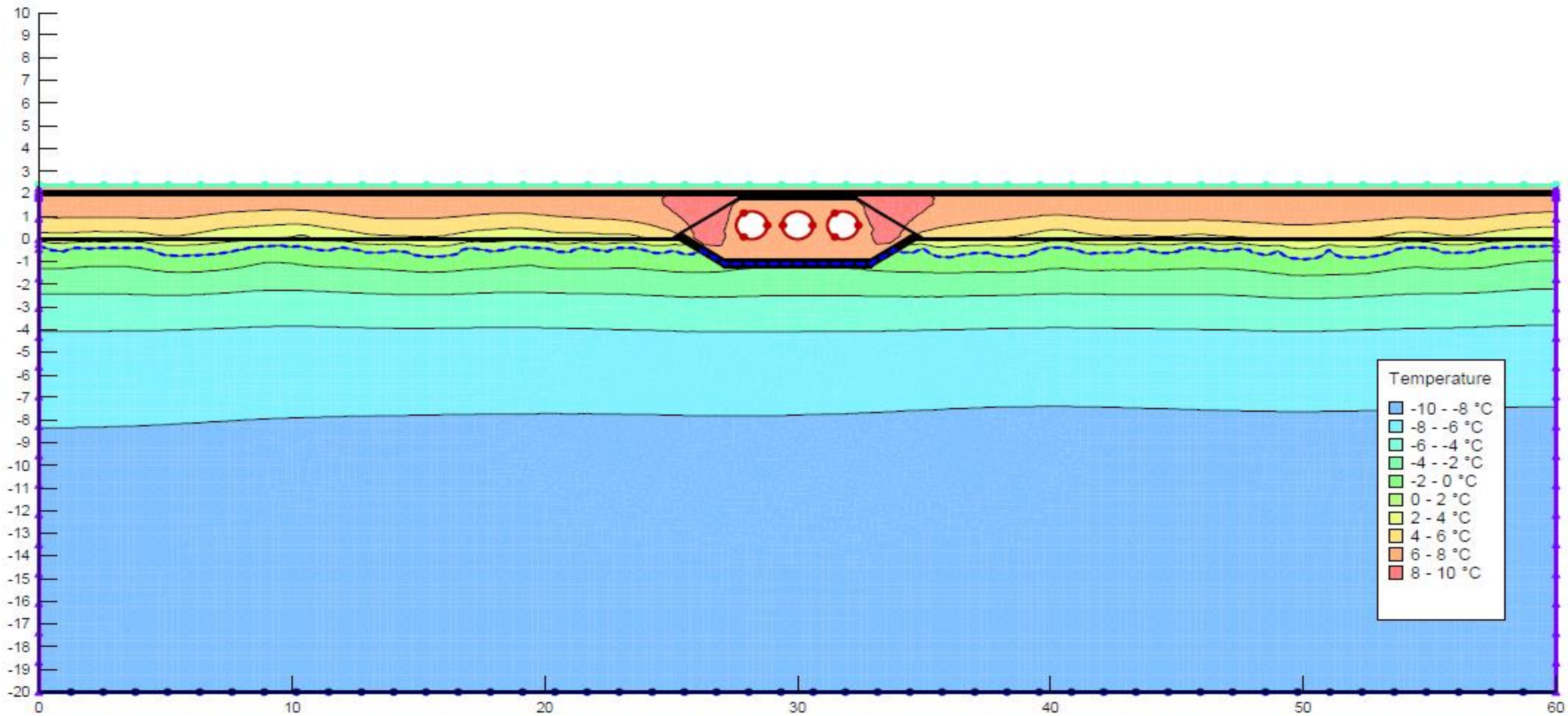


Figure H-5	**Culvert Thermal Modeling Results**	**Culvert Diamater**	1200mm	**Project Number**	H353004	**Rev**	HATCH
		Fill Height	2.4m	**By**	MY	4/22/2019	
		Native Material	Silt	**Checked By**	-	-	

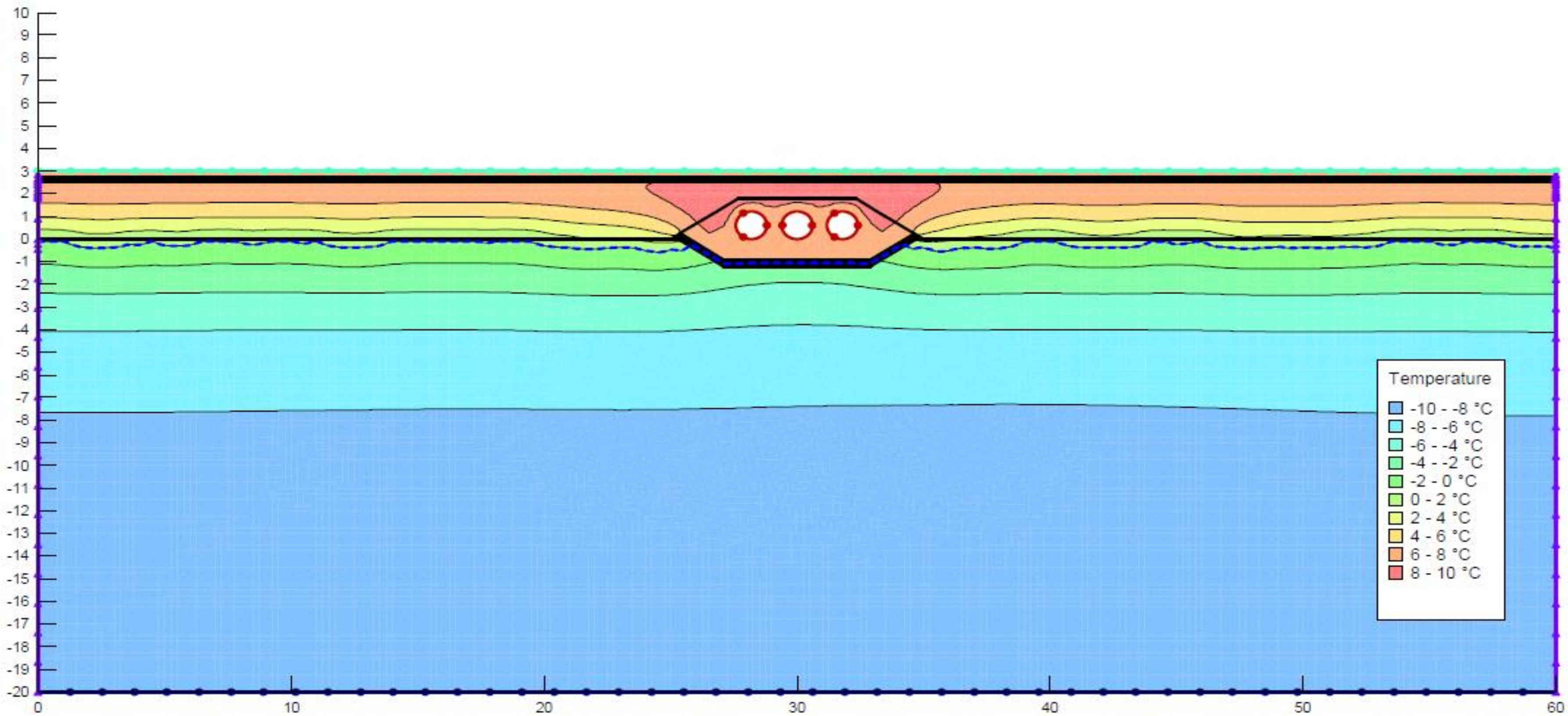


Figure H-5	**Culvert Thermal Modeling Results**	**Culvert Diamater**	1200mm	**Project Number**	H353004	**Rev**		HATCH
		Fill Height	3m	**By**	MY	4/22/2019		
		Native Material	Sand and Gravel	**Checked By**	-	-		

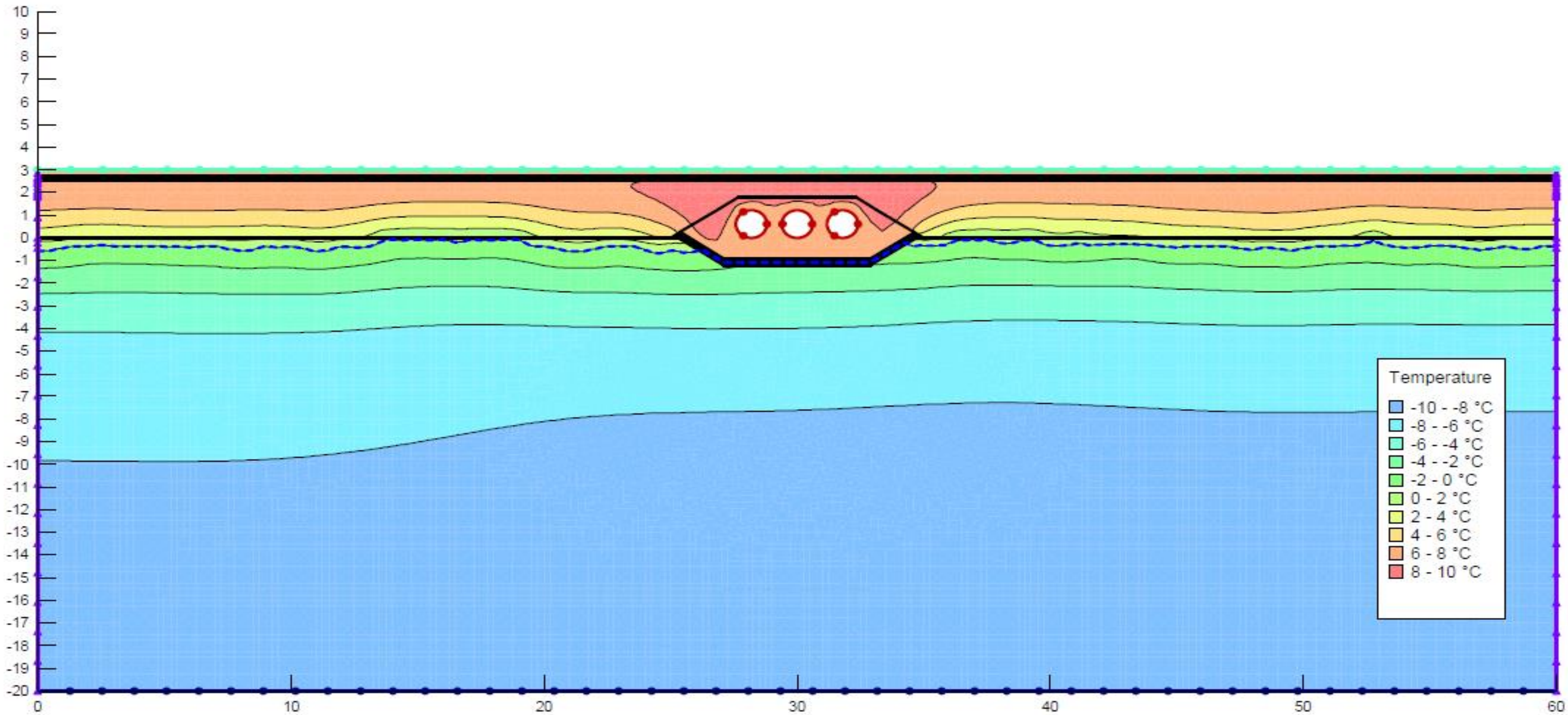


Figure H-5	Culvert Thermal Modeling Results	Culvert Diamater	1200mm	Project Number	H353004	Rev	HATCH
		Fill Height	3m	By	MY	4/22/2019	
		Native Material	Silt	Checked By	-	-	

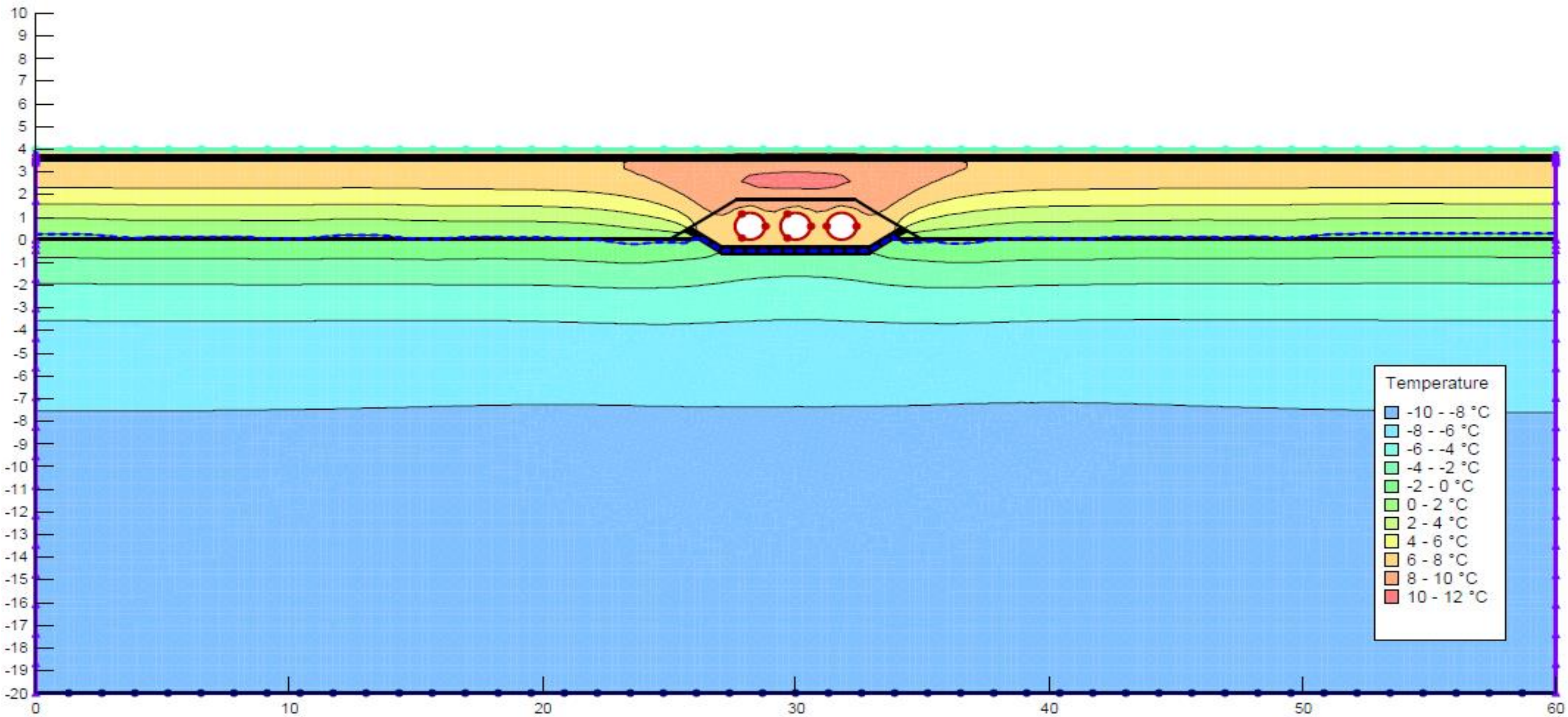


Figure H-5	**Culvert Thermal Modeling Results**	**Culvert Diamater**	1200mm	**Project Number**	H353004	**Rev**	HATCH
		Fill Height	4m	**By**	**MY**	4/22/2019	
		Native Material	Sand and Gravel	**Checked By**	**-**	-	

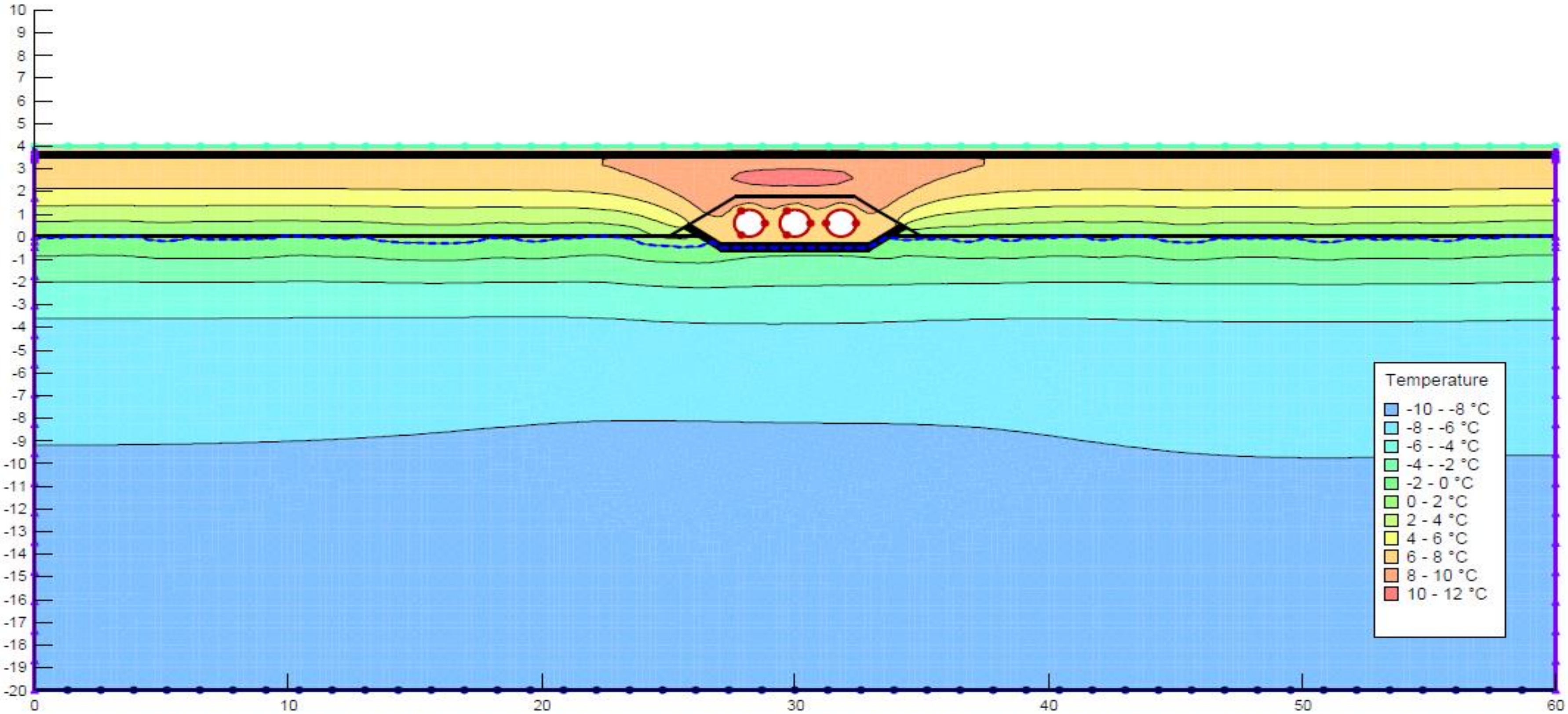


Figure H-5	**Culvert Thermal Modeling Results**	**Culvert Diamater**	1200mm	**Project Number**	H353004	**Rev**	HATCH
		Fill Height	4m	**By**	MY	4/22/2019	
		Native Material	Silt	**Checked By**	-	-	

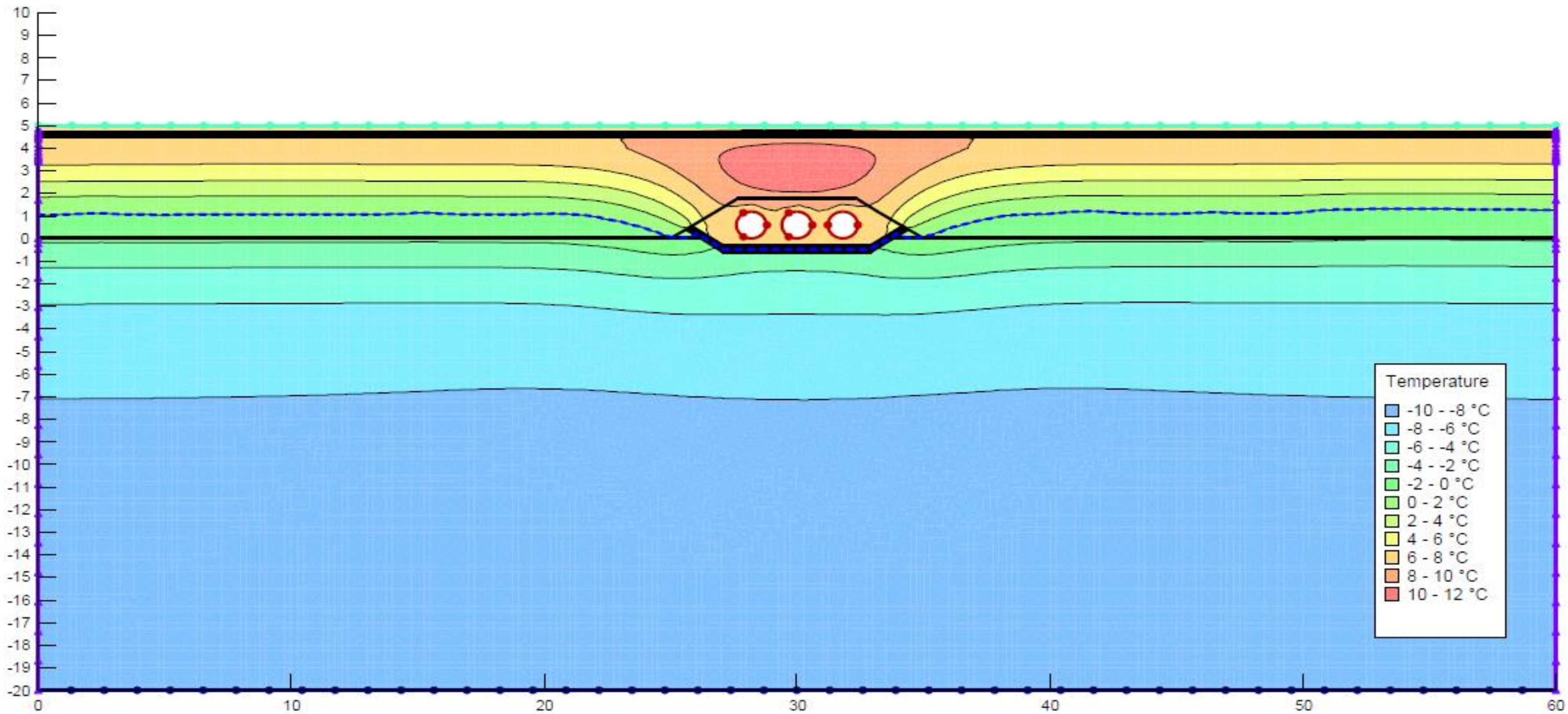


Figure H-5	**Culvert Thermal Modeling Results**	**Culvert Diamater**	1200mm	**Project Number**	H353004	**Rev**	HATCH
		Fill Height	5m	**By**	**MY**	4/22/2019	
		Native Material	Sand and Gravel	**Checked By**	**-**	-	

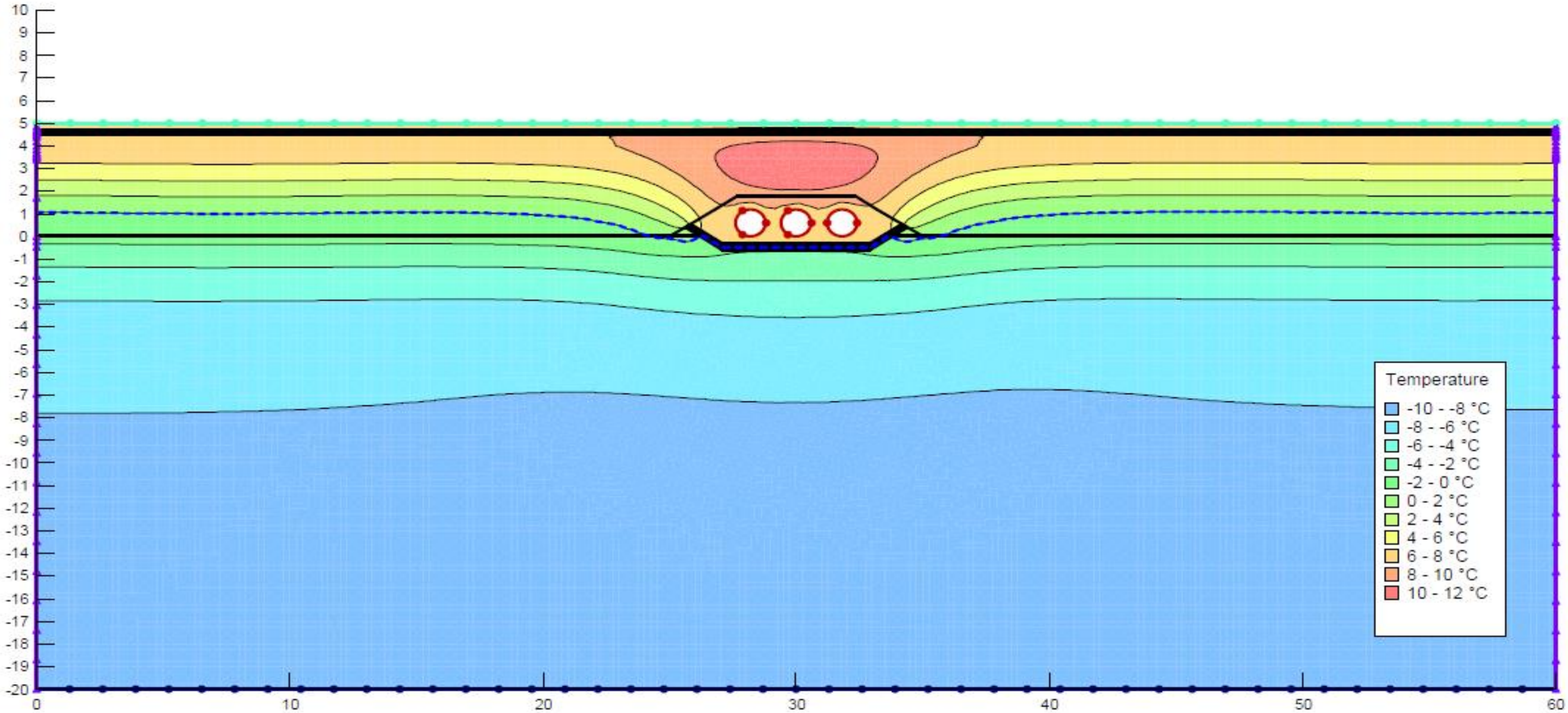


Figure H-5	**Culvert Thermal Modeling Results**	**Culvert Diamater**	1200mm	**Project Number**	H353004	**Rev**	HATCH
		Fill Height	5m	**By**	MY	4/22/2019	
		Native Material	Silt	**Checked By**	-	-	

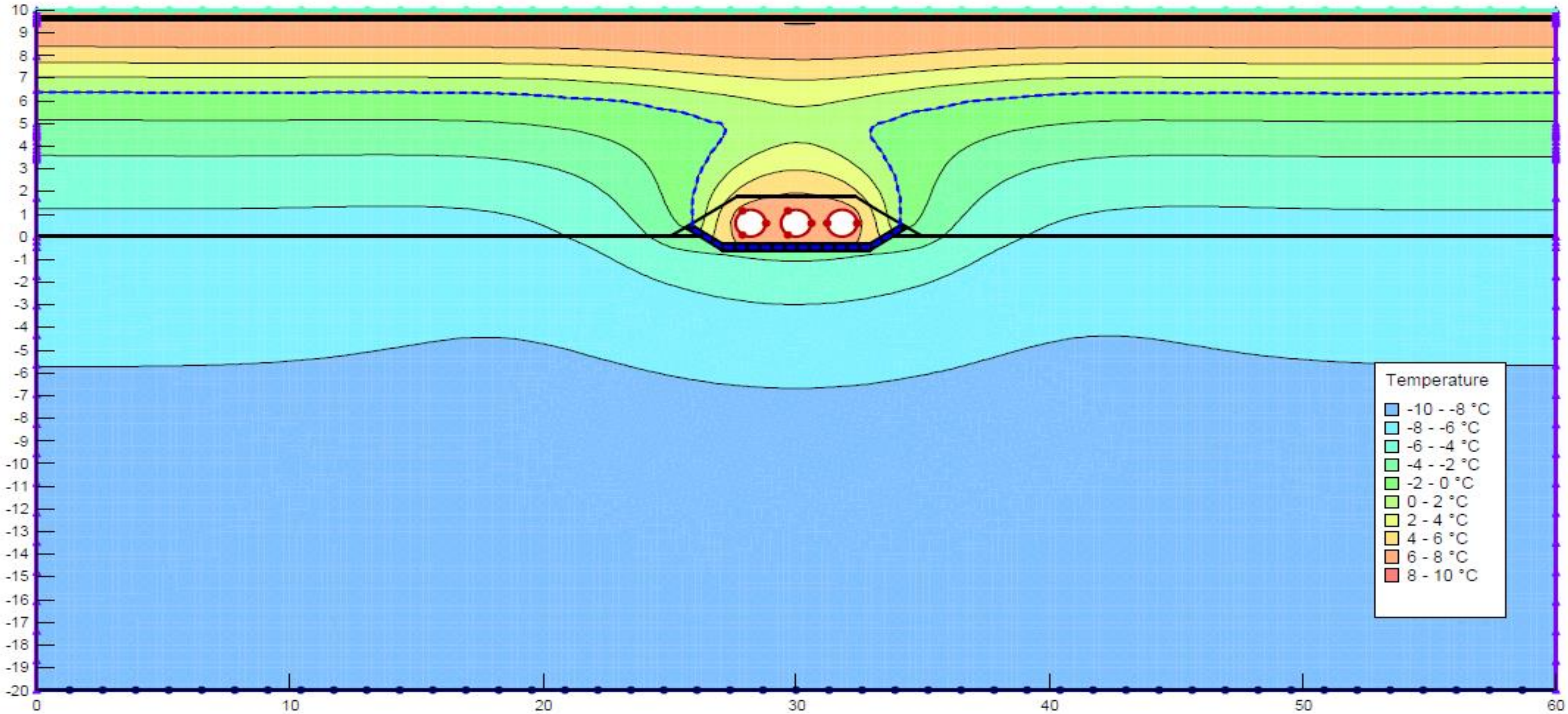


Figure H-5	**Culvert Thermal Modeling Results**	**Culvert Diamater**	1200mm	**Project Number**	H353004	**Rev**	HATCH
		Fill Height	10m	**By**	**MY**	4/22/2019	
		Native Material	Sand and Gravel	**Checked By**	**-**	-	

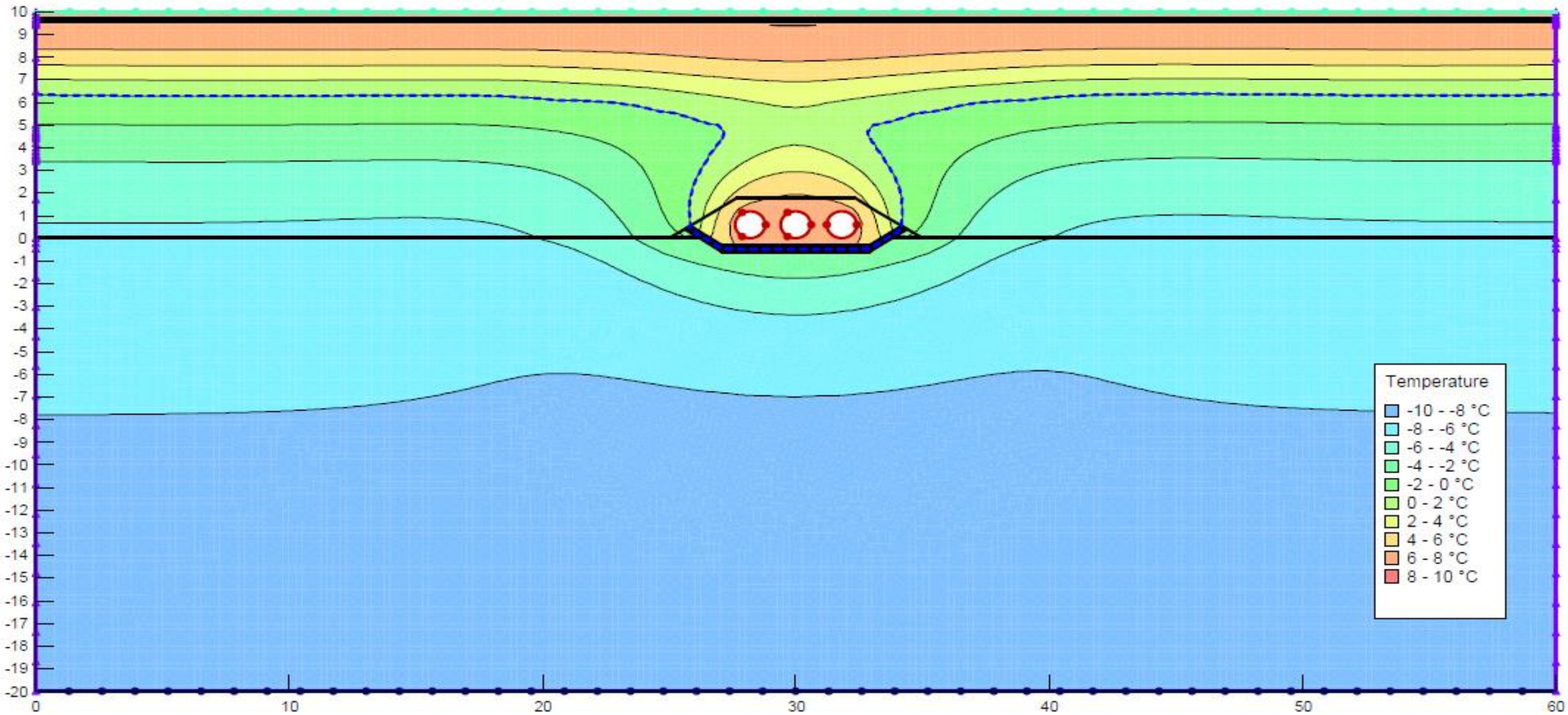


Figure H-5	Culvert Thermal Modeling Results	Culvert Diamater	1200mm	Project Number	H353004	Rev	HATCH
		Fill Height	10m	By	MY	4/22/2019	
		Native Material	Silt	Checked By	-	-	

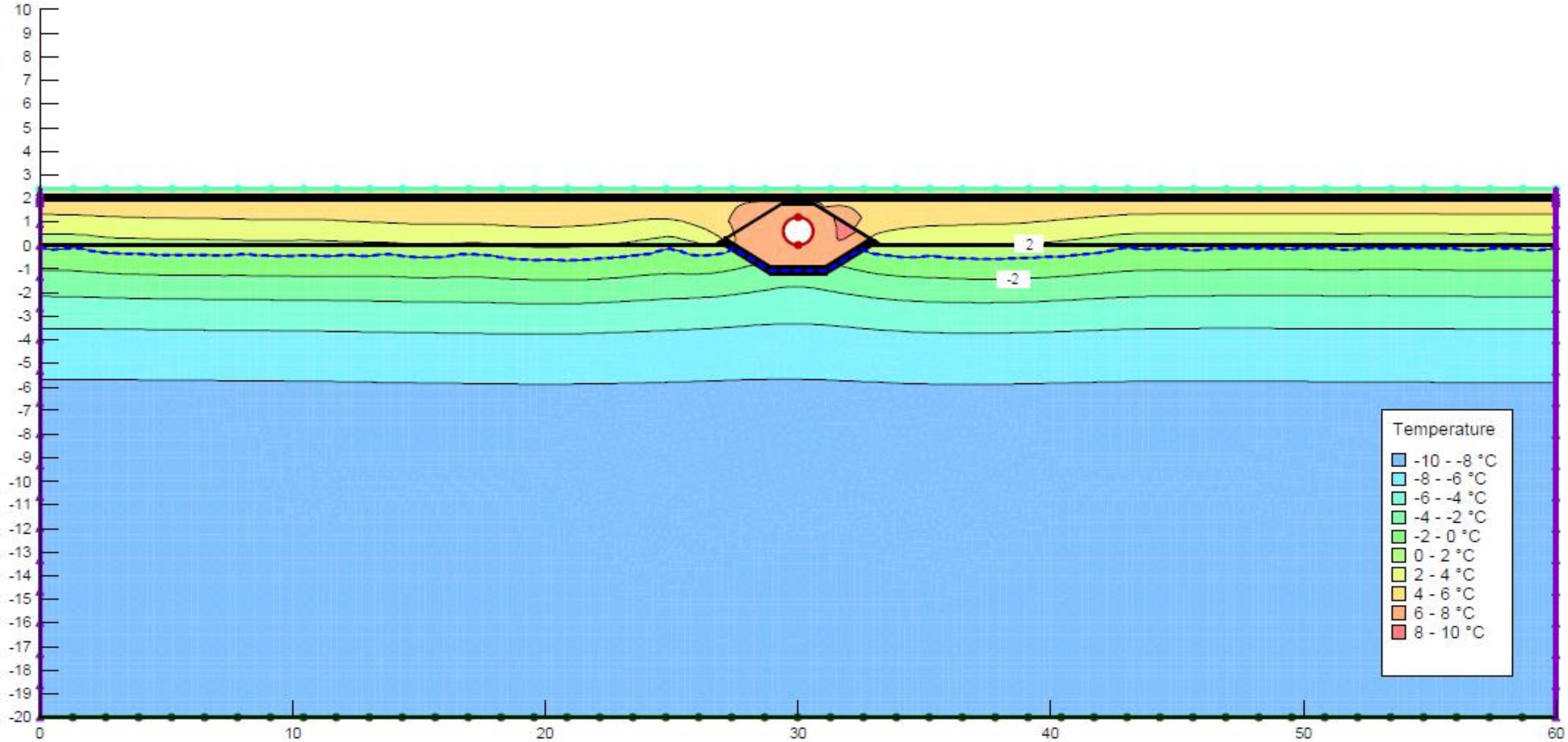


Figure H-6	**Culvert Thermal Modeling Results**	**Culvert Diamater**	1200mm	**Project Number**	H353004	**Rev**	HATCH
		Fill Height	2.4m	**By**	**MY**	4/22/2019	
		Native Material	Sand and Gravel	**Checked By**	**-**	-	

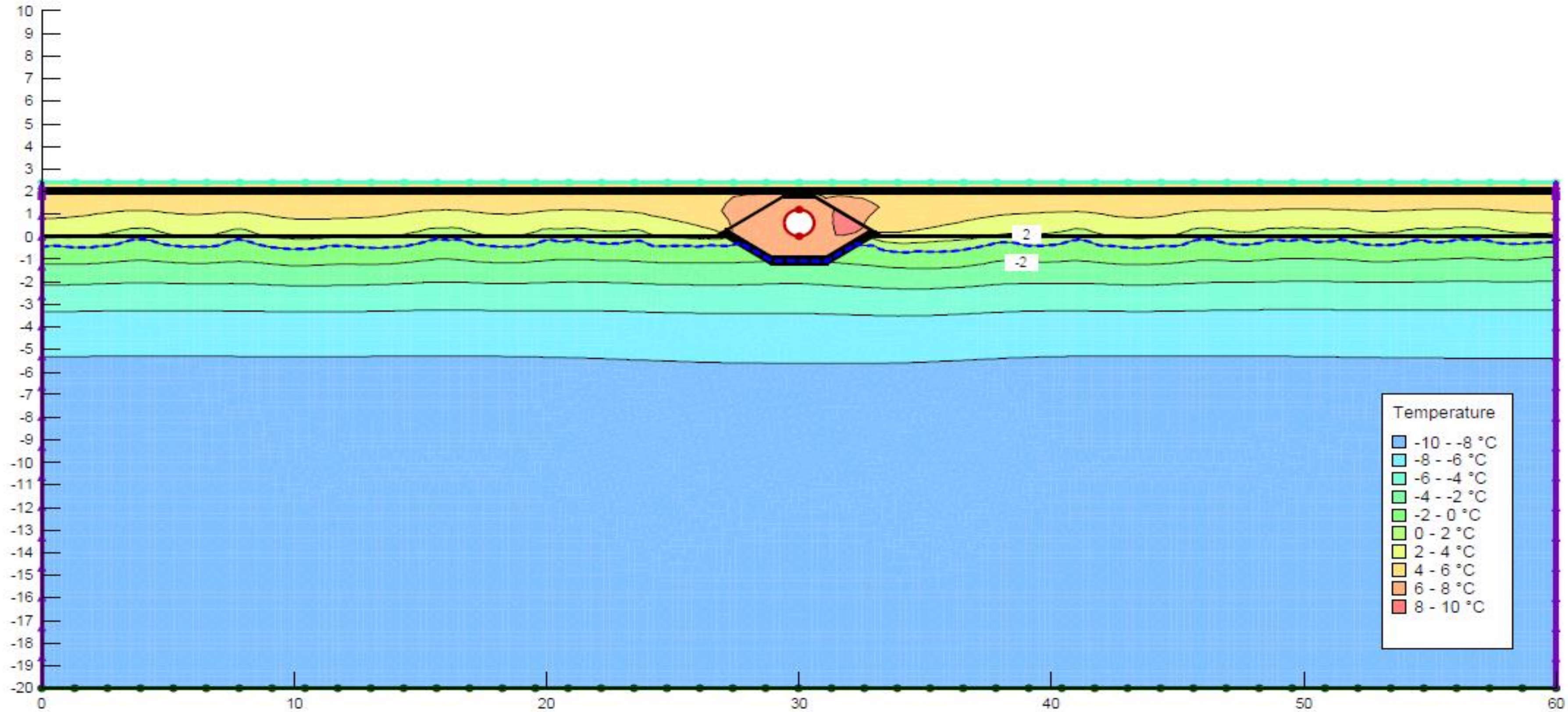


Figure H-6	Culvert Thermal Modeling Results	Culvert Diamater	1200mm	Project Number	H353004	Rev	HATCH
		Fill Height	2.4m	By	MY	4/22/2019	
		Native Material	Silt	Checked By	-	-	

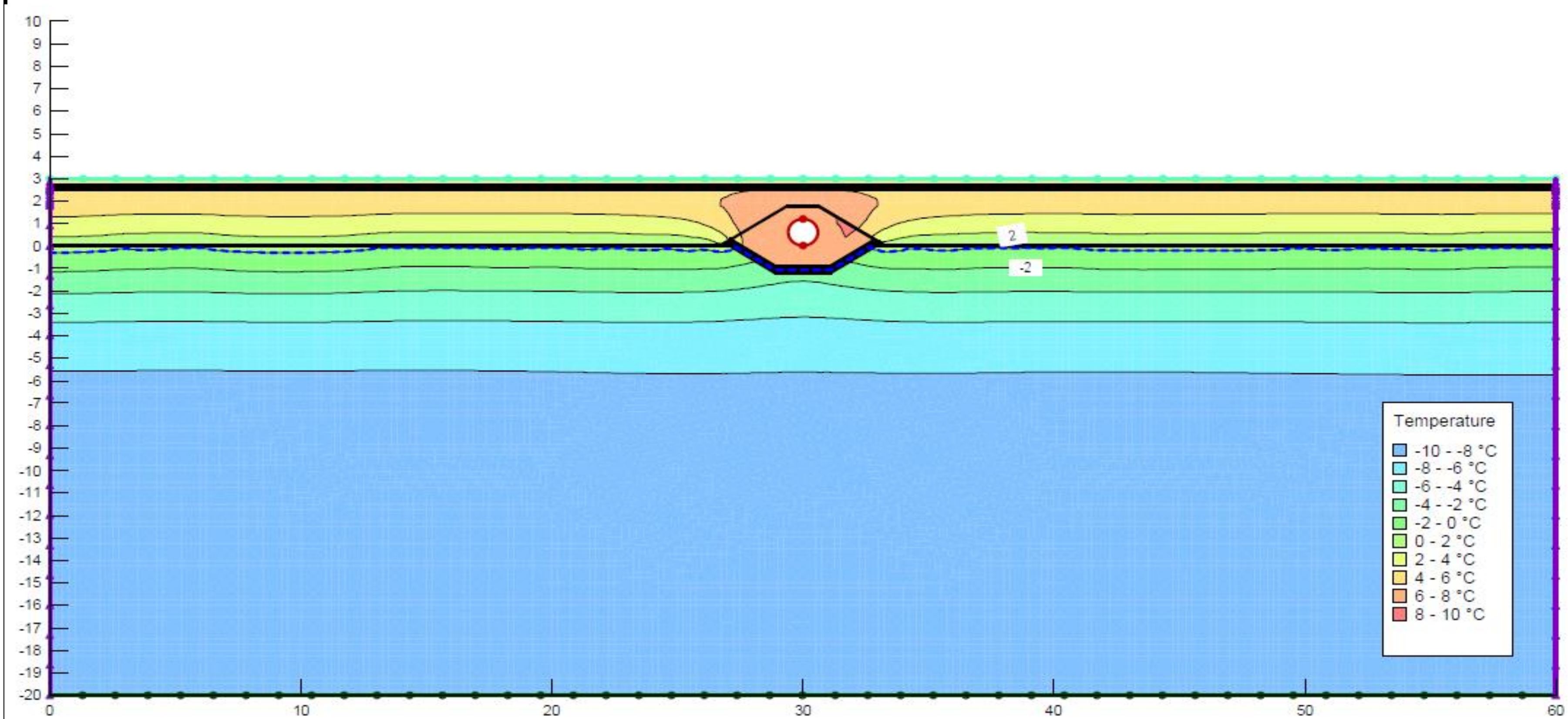


Figure H-6	**Culvert Thermal Modeling Results**	**Culvert Diamater**	1200mm	**Project Number**	H353004	**Rev**	HATCH
		Fill Height	3m	**By**	MY	4/22/2019	
		Native Material	Sand and Gravel	**Checked By**	-	-	

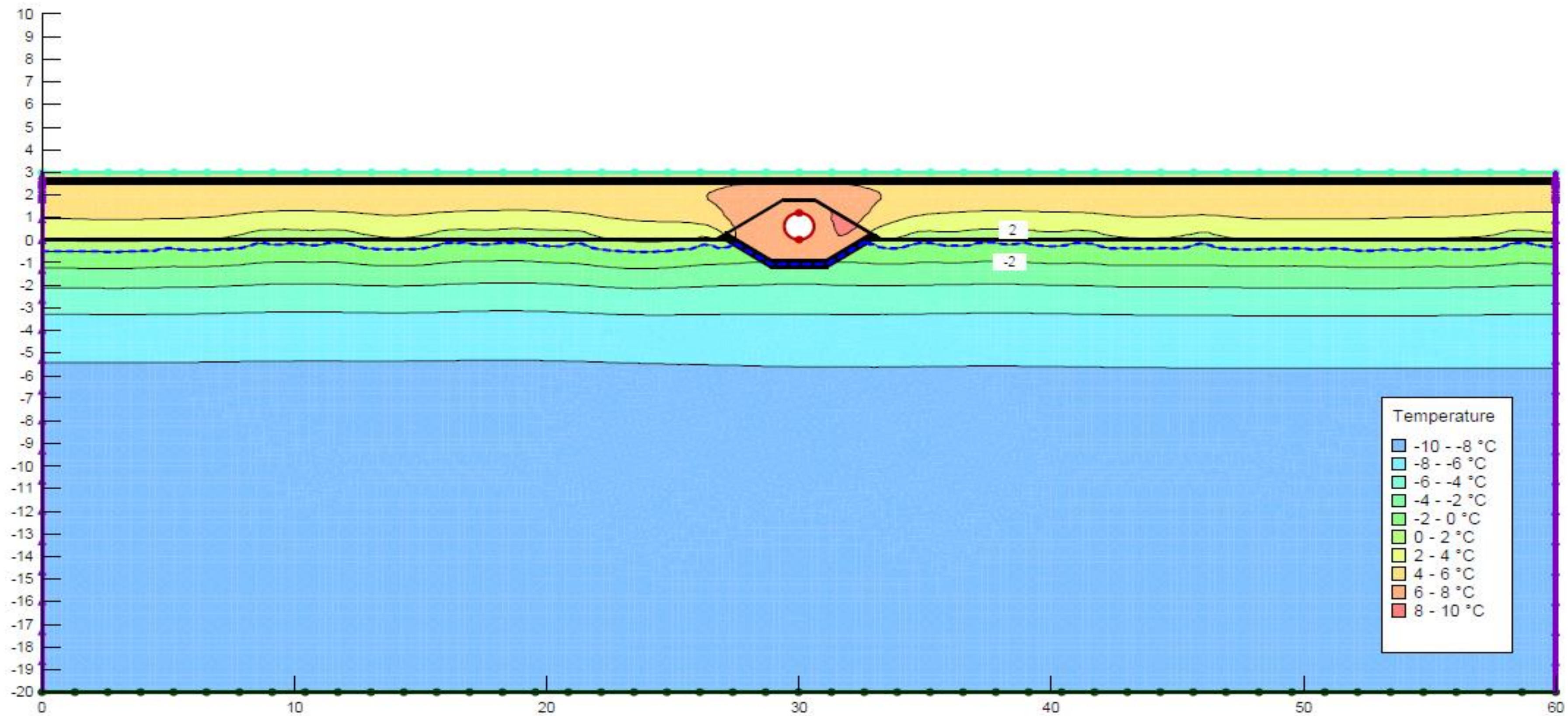


Figure H-6	**Culvert Thermal Modeling Results**	**Culvert Diamater**	1200mm	**Project Number**	H353004	**Rev**	HATCH
		Fill Height	3m	**By**	MY	4/22/2019	
		Native Material	Silt	**Checked By**	-	-	

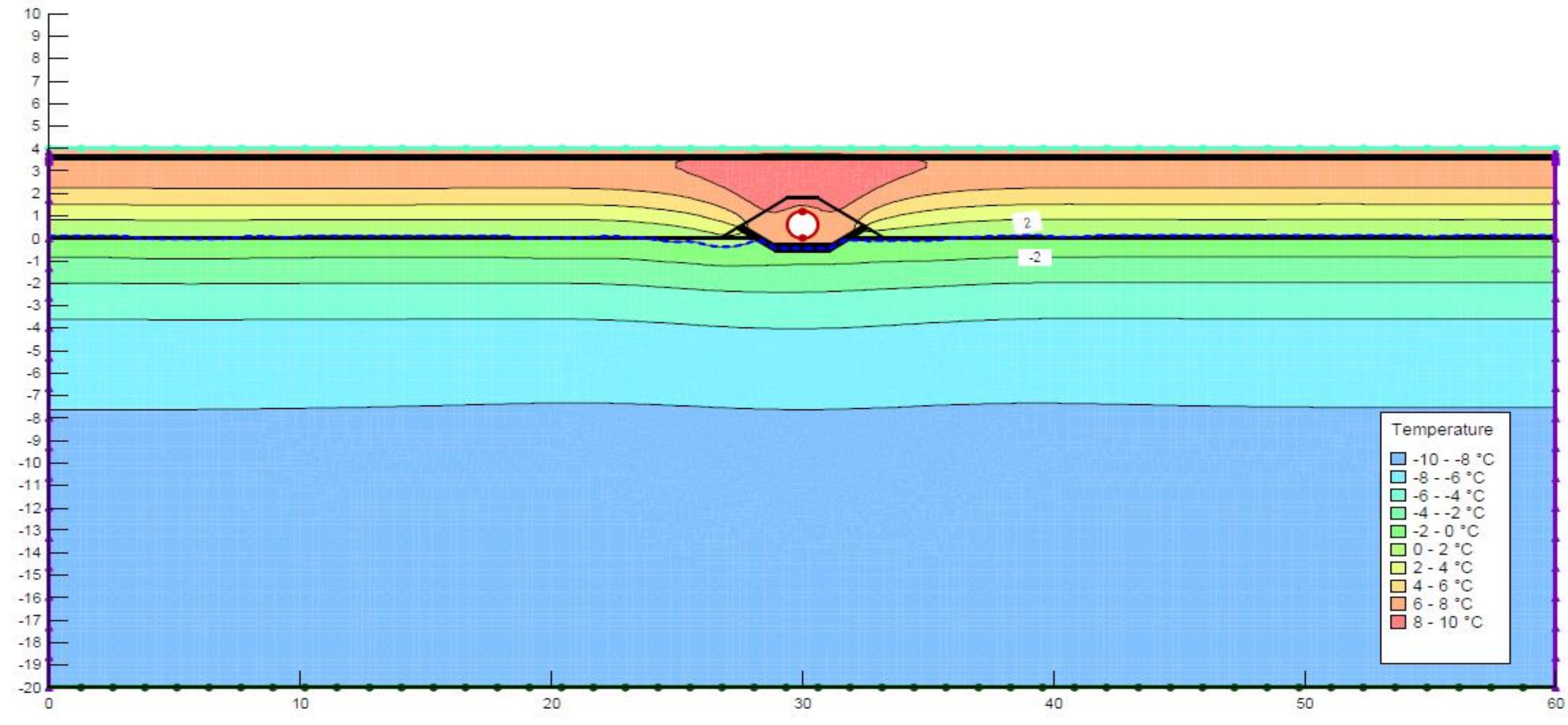


Figure H-6	**Culvert Thermal Modeling Results**	**Culvert Diamater**	1200mm	**Project Number**	H353004	**Rev**	HATCH
		Fill Height	4m	**By**	**MY**	4/22/2019	
		Native Material	Sand and Gravel	**Checked By**	**-**	-	

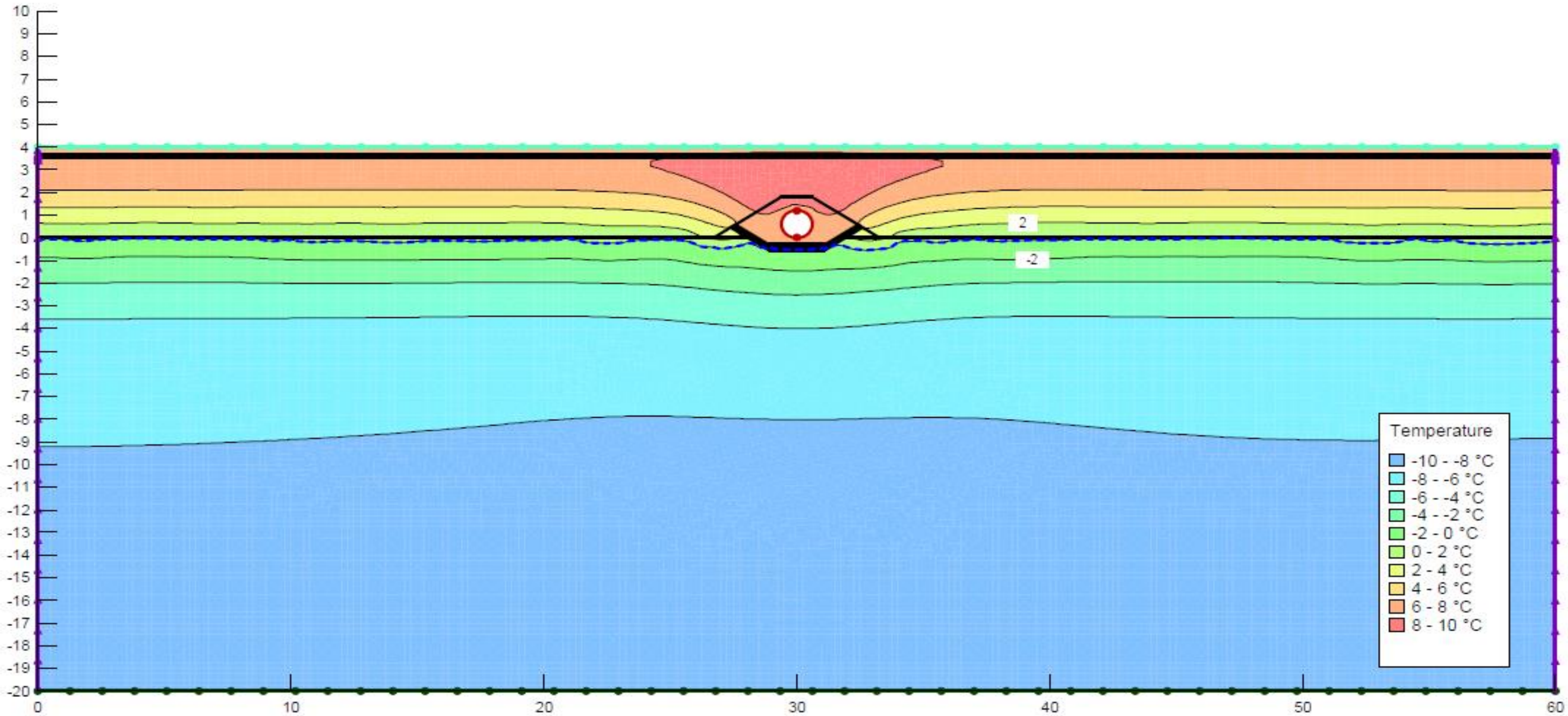


Figure H-6	**Culvert Thermal Modeling Results**	**Culvert Diamater**	1200mm	**Project Number**	H353004	**Rev**		HATCH
		Fill Height	4m	**By**	**MY**	4/22/2019		
		Native Material	Silt	**Checked By**	**-**	-		

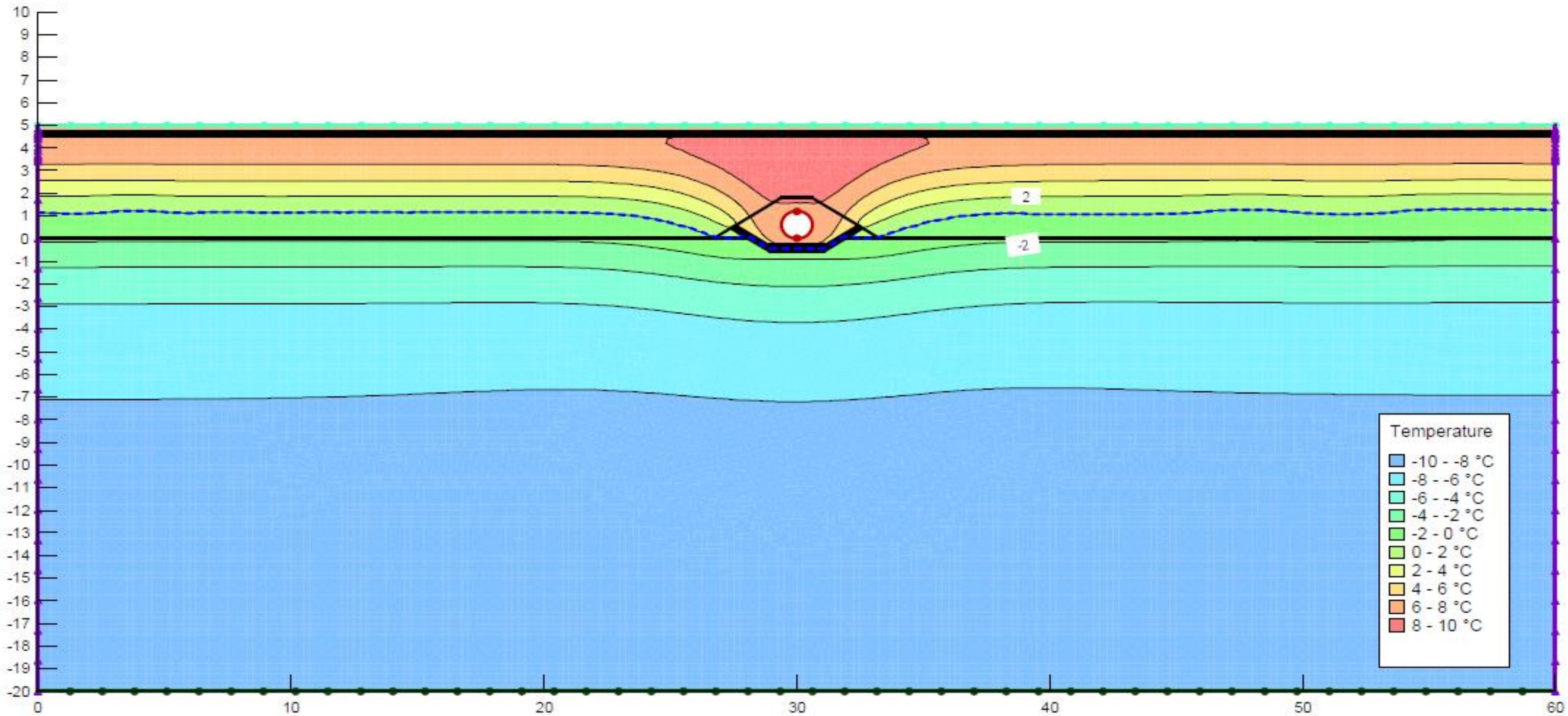


Figure H-6	**Culvert Thermal Modeling Results**	**Culvert Diamater**	1200mm	**Project Number**	H353004	**Rev**	HATCH
		Fill Height	5m	**By**	MY	4/22/2019	
		Native Material	Sand and Gravel	**Checked By**	-	-	

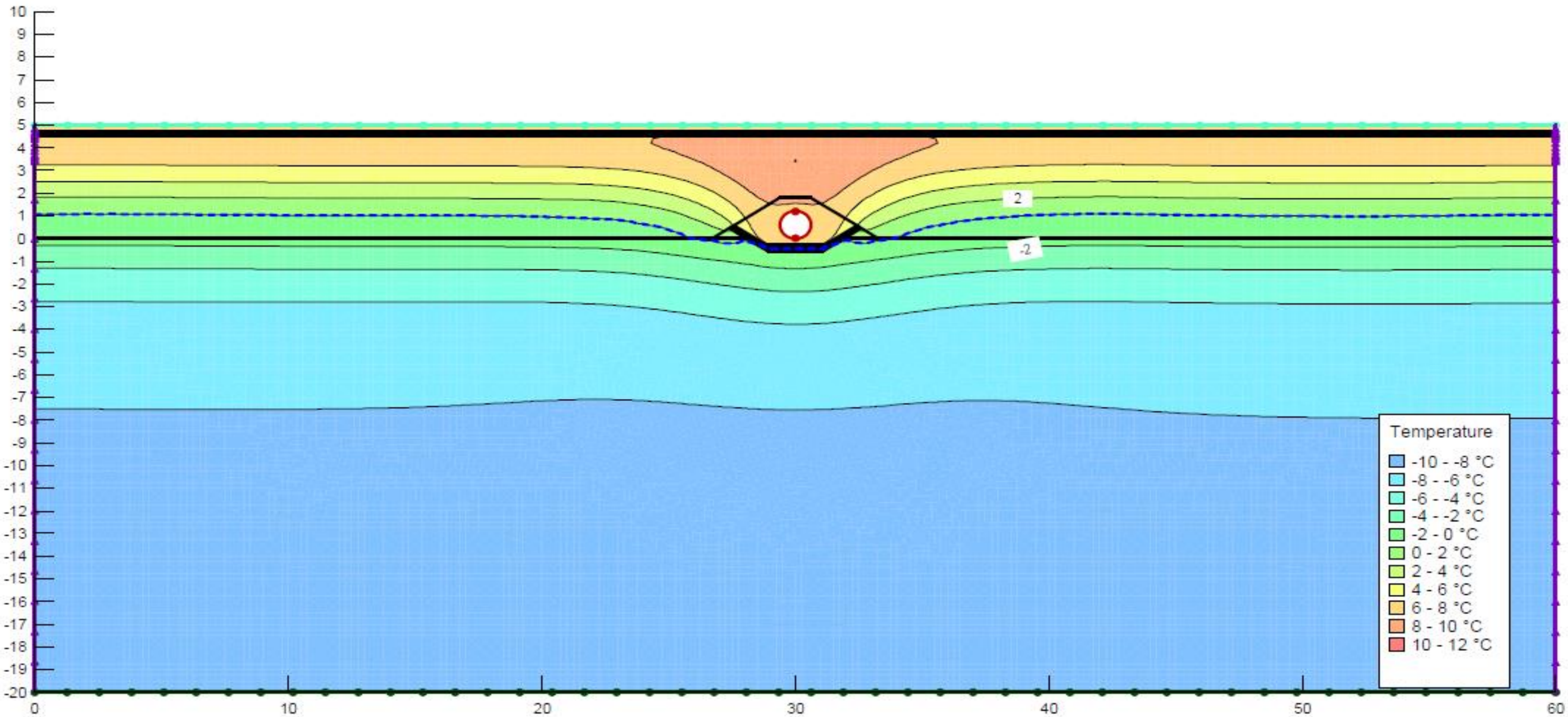


Figure H-6	Culvert Thermal Modeling Results	Culvert Diamater	1200mm	Project Number	H353004	Rev	HATCH
		Fill Height	5m	By	MY	4/22/2019	
		Native Material	Silt	Checked By	-	-	

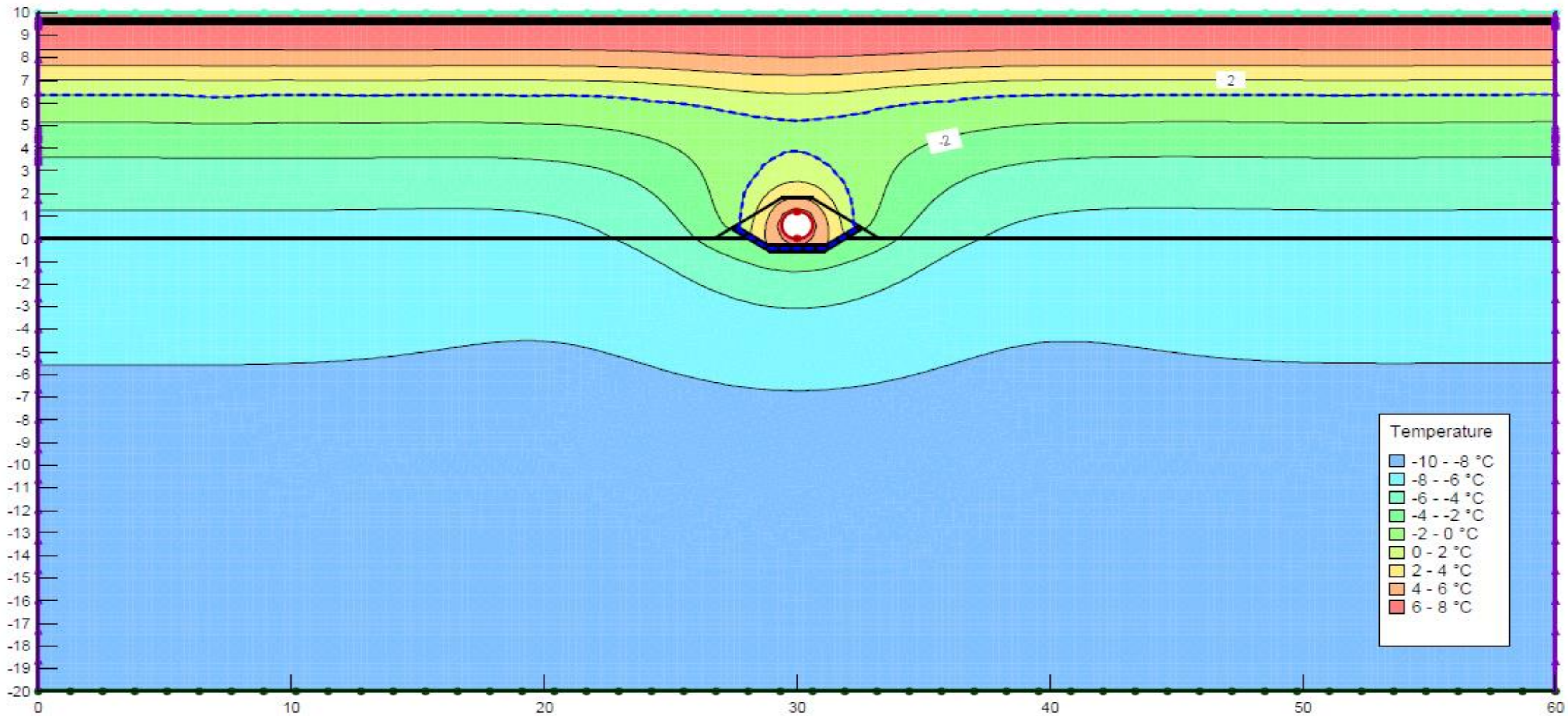


Figure H-6	**Culvert Thermal Modeling Results**	**Culvert Diamater**	1200mm	**Project Number**	H353004	**Rev**	HATCH
		Fill Height	10m	**By**	**MY**	4/22/2019	
		Native Material	Sand and Gravel	**Checked By**	-	-	

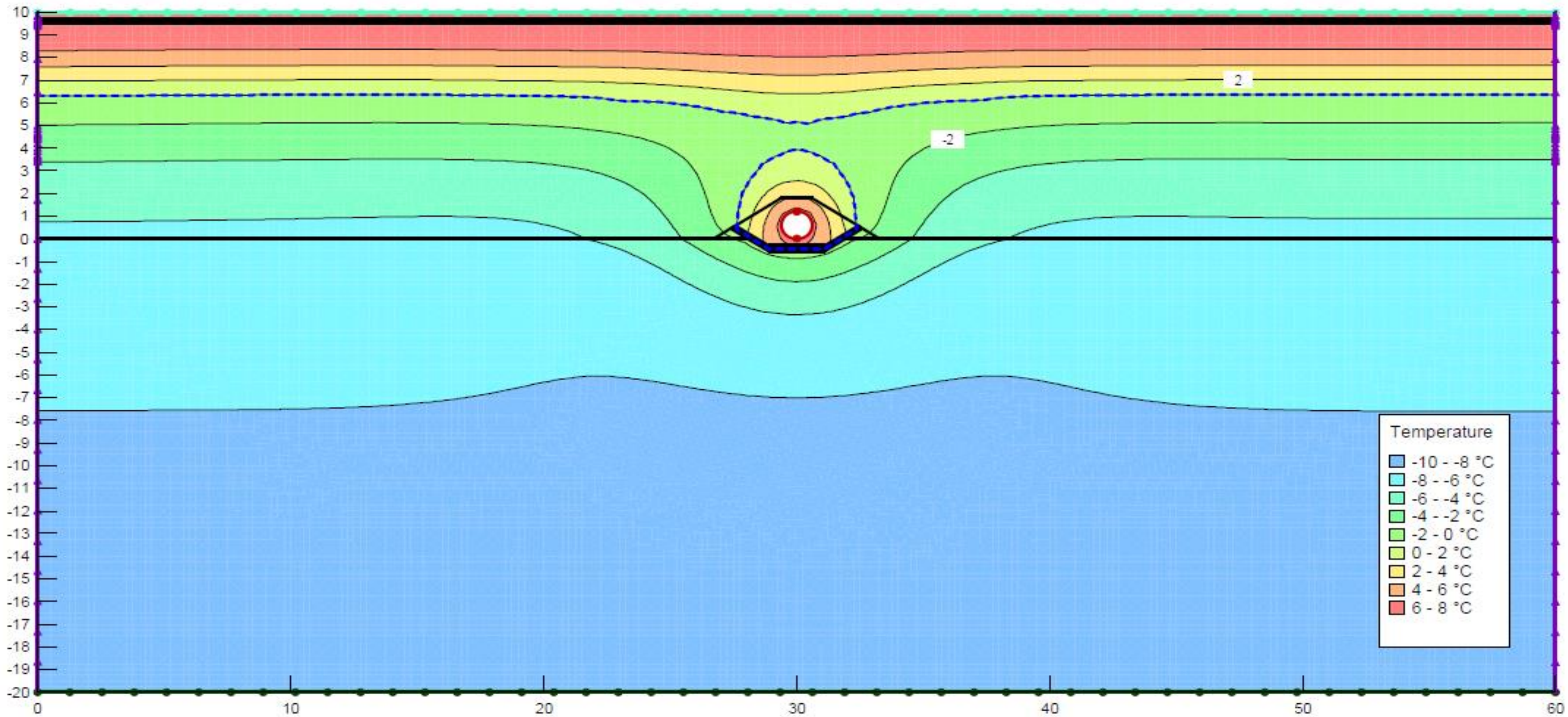


Figure H-6	Culvert Thermal Modeling Results	Culvert Diamater	1200mm	Project Number	H353004	Rev		HATCH
		Fill Height	10m	By	MY	4/22/2019		
		Native Material	Silt	Checked By	-	-		

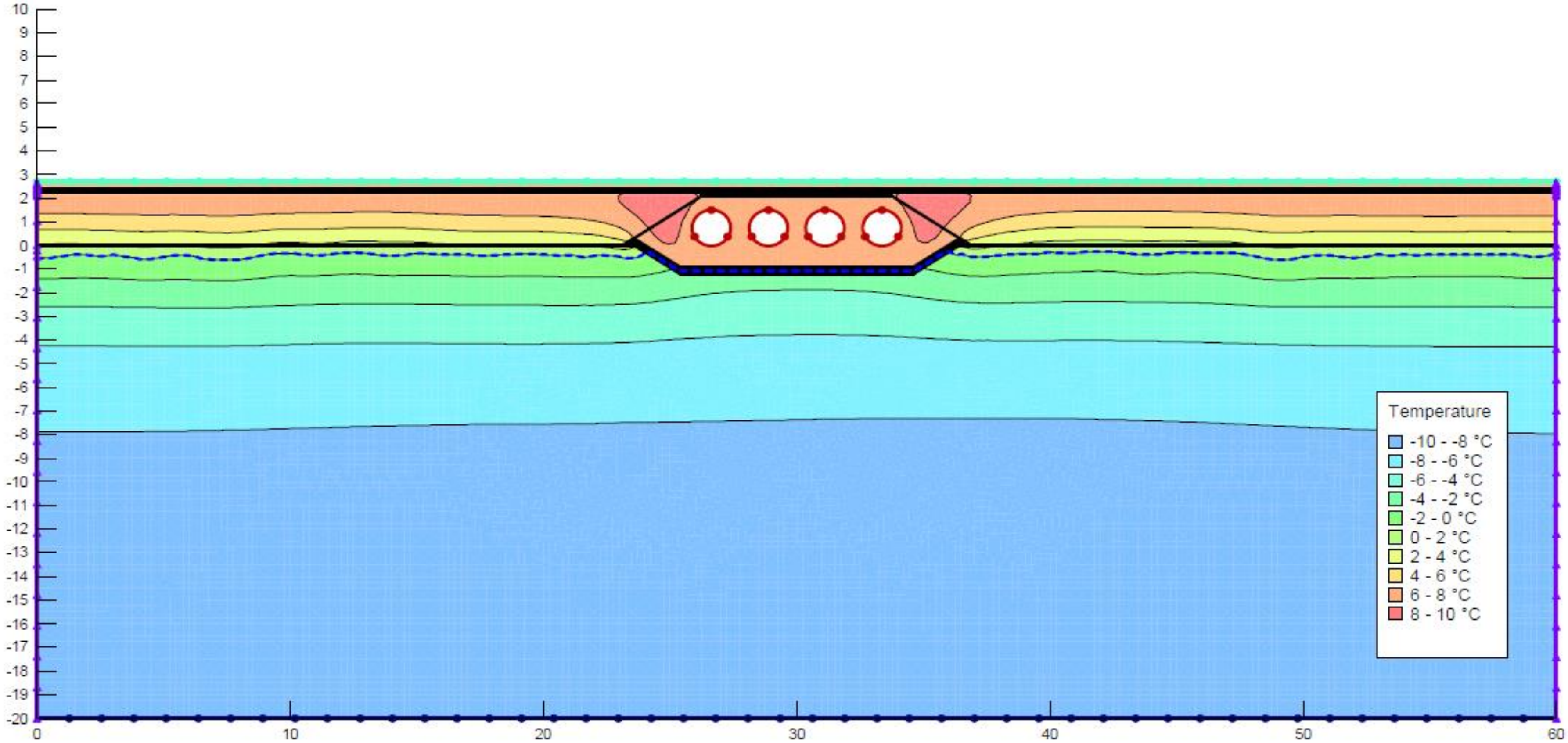


Figure H-7	**Culvert Thermal Modeling Results**	**Culvert Diamater**	1500mm	**Project Number**	H353004	**Rev**	HATCH
		Fill Height	2.7m	**By**	**MY**	4/22/2019	
		Native Material	Sand and Gravel	**Checked By**	**-**	-	

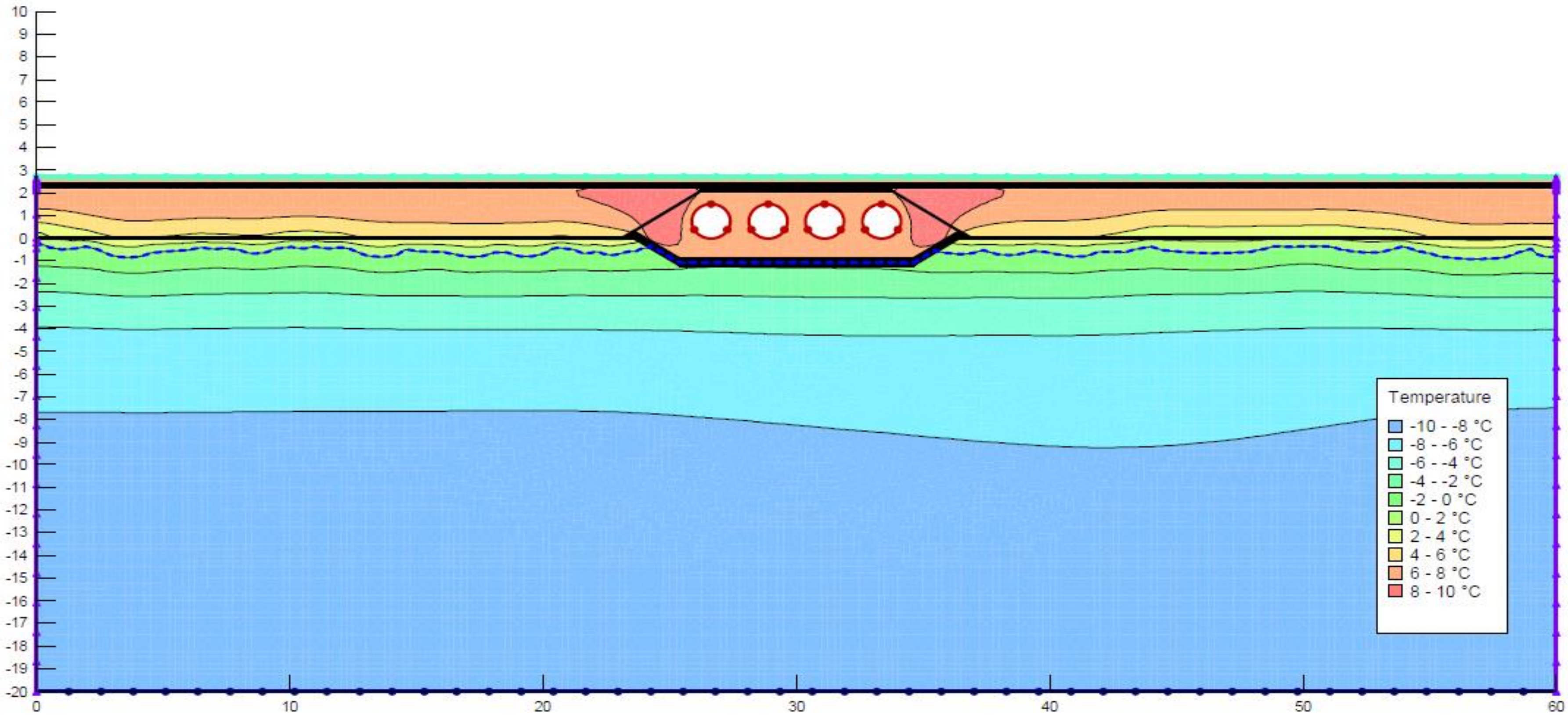


Figure H-7	**Culvert Thermal Modeling Results**	**Culvert Diamater**	1500mm	**Project Number**	H353004	**Rev**	HATCH
		Fill Height	2.7m	**By**	**MY**	4/22/2019	
		Native Material	Silt	**Checked By**	**-**	-	

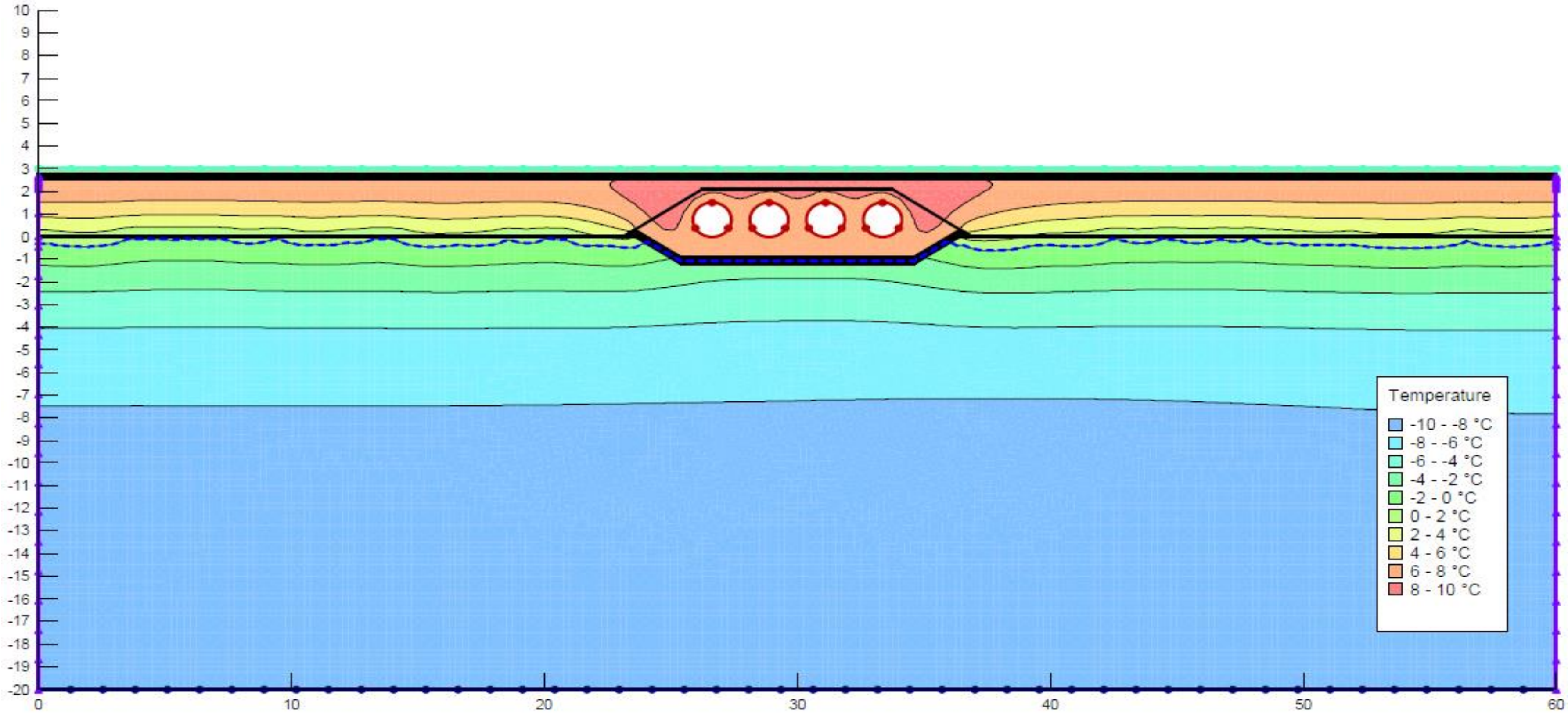


Figure H-7	Culvert Thermal Modeling Results	Culvert Diamater	1500mm	Project Number	H353004	Rev	HATCH
		Fill Height	3m	By	MY	4/22/2019	
		Native Material	Sand and Gravel	Checked By	-	-	

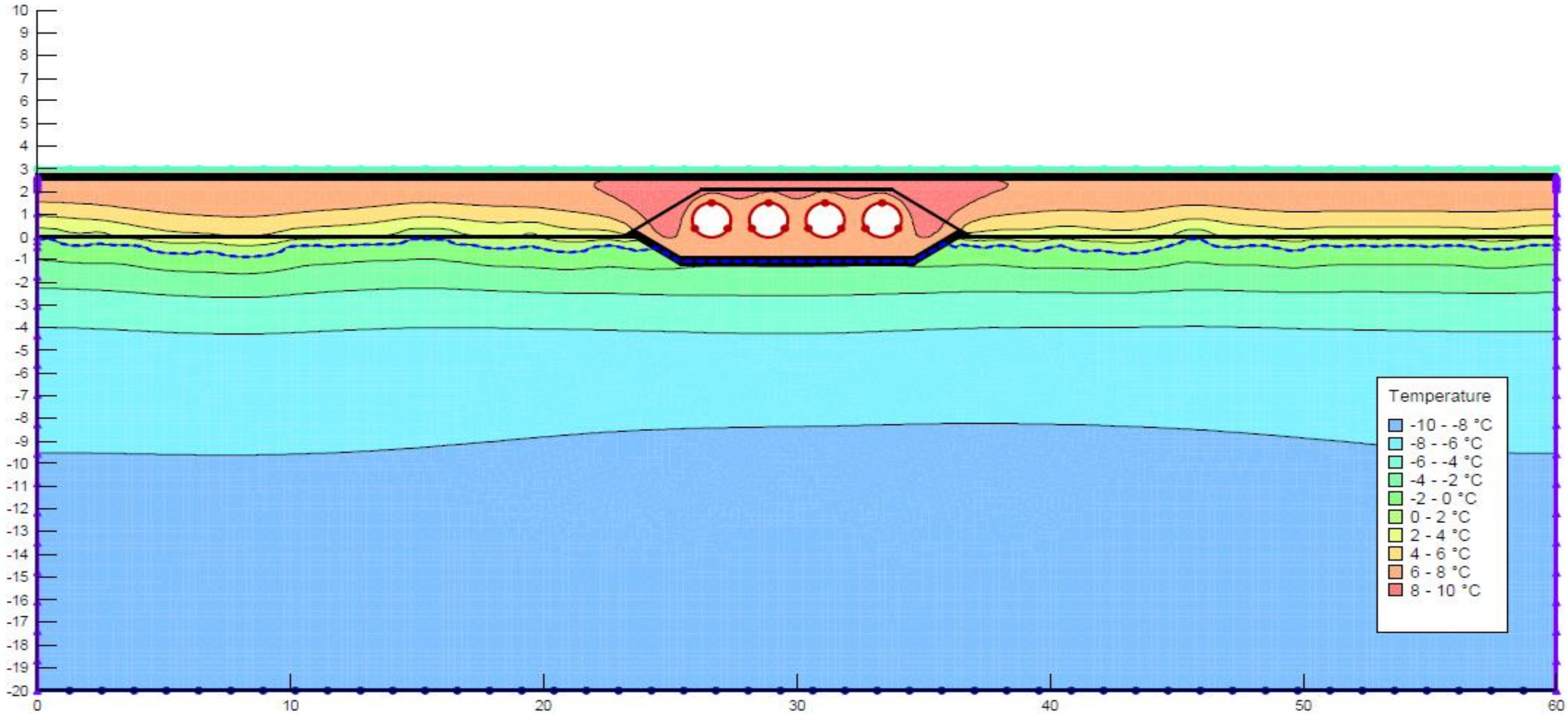


Figure H-7	Culvert Thermal Modeling Results	Culvert Diamater	1500mm	Project Number	H353004	Rev	HATCH
		Fill Height	3m	By	MY	4/22/2019	
		Native Material	Silt	Checked By	-	-	

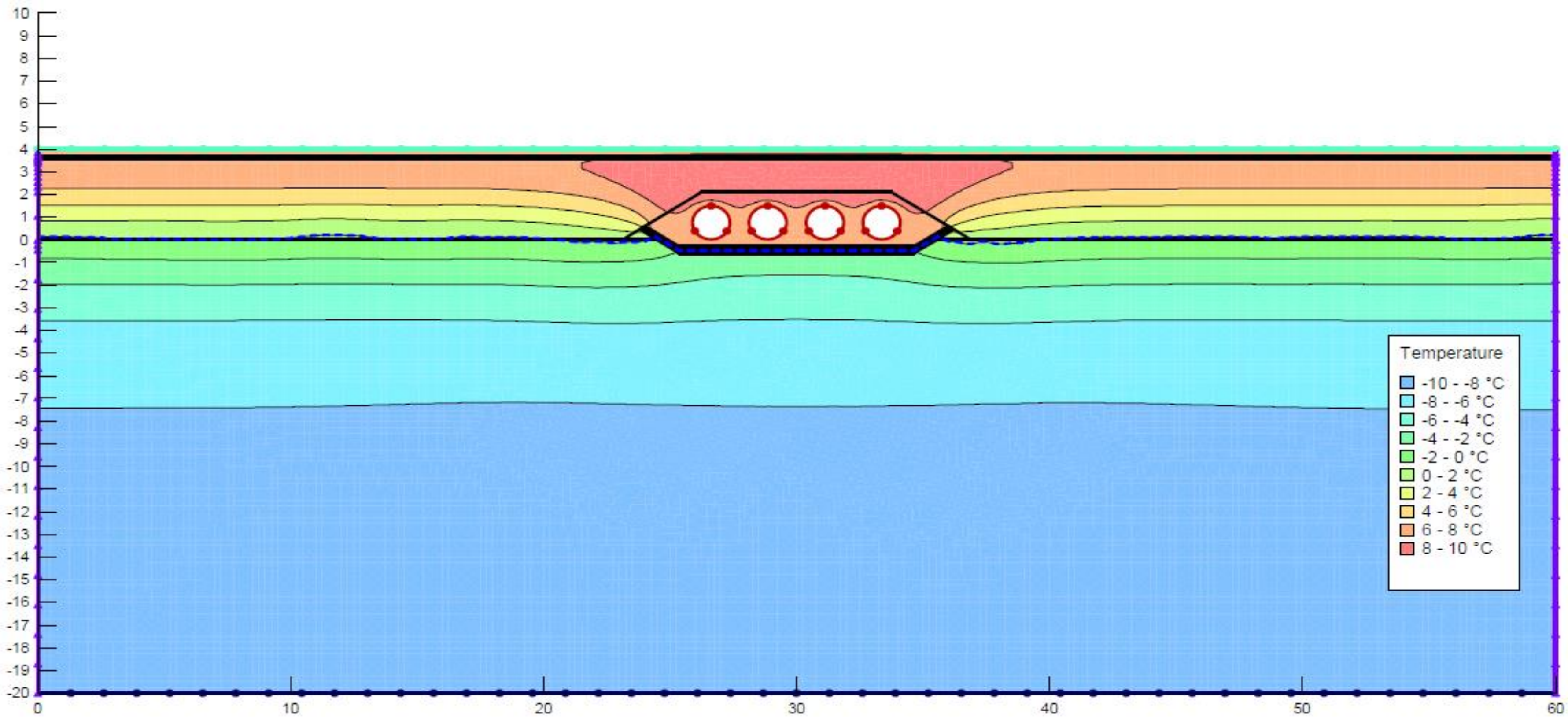


Figure H-7	**Culvert Thermal Modeling Results**	**Culvert Diamater**	1500mm	**Project Number**	H353004	**Rev**	HATCH
		Fill Height	4m	**By**	MY	4/22/2019	
		Native Material	Sand and Gravel	**Checked By**	-	-	

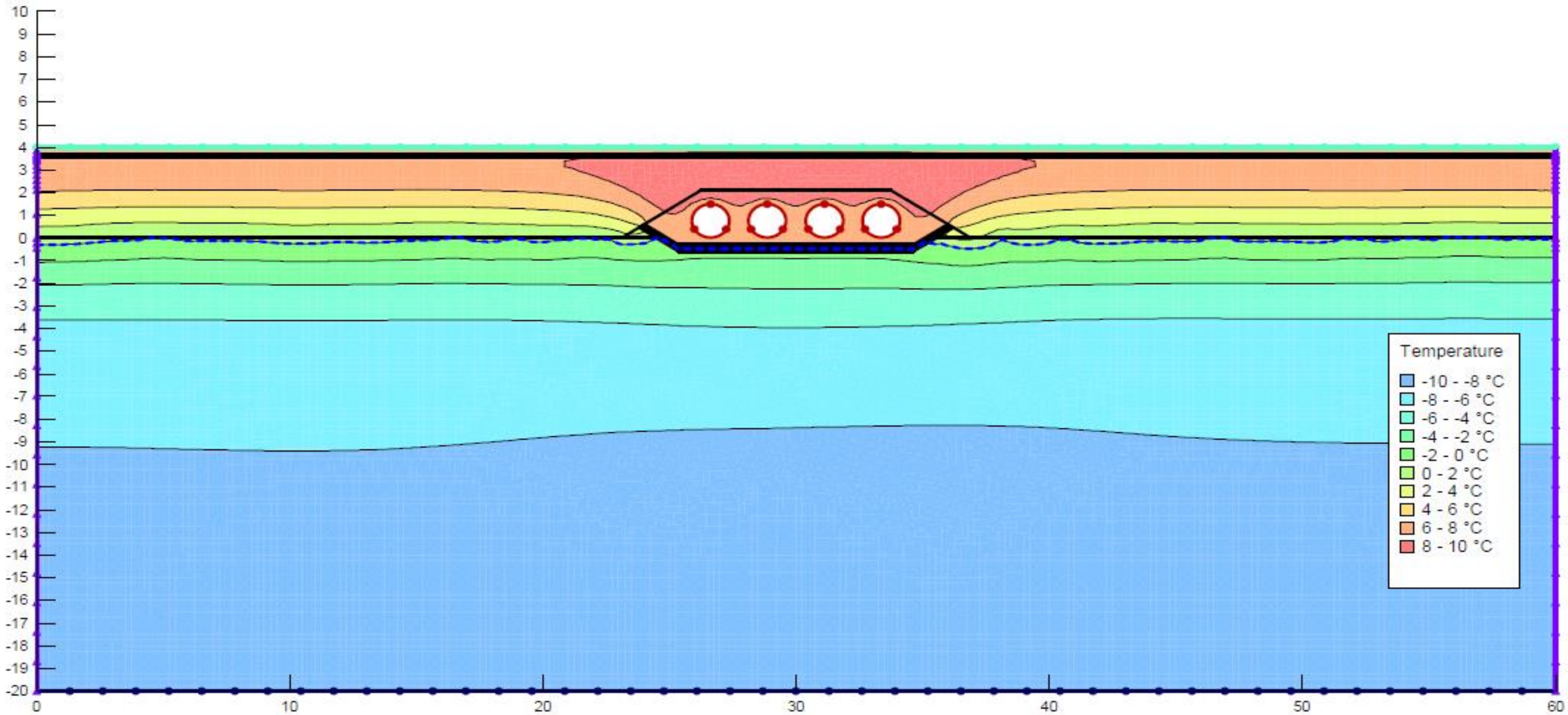


Figure H-7	**Culvert Thermal Modeling Results**	**Culvert Diamater**	1500mm	**Project Number**	H353004	**Rev**	HATCH
		Fill Height	4m	**By**	MY	4/22/2019	
		Native Material	Silt	**Checked By**	-	-	

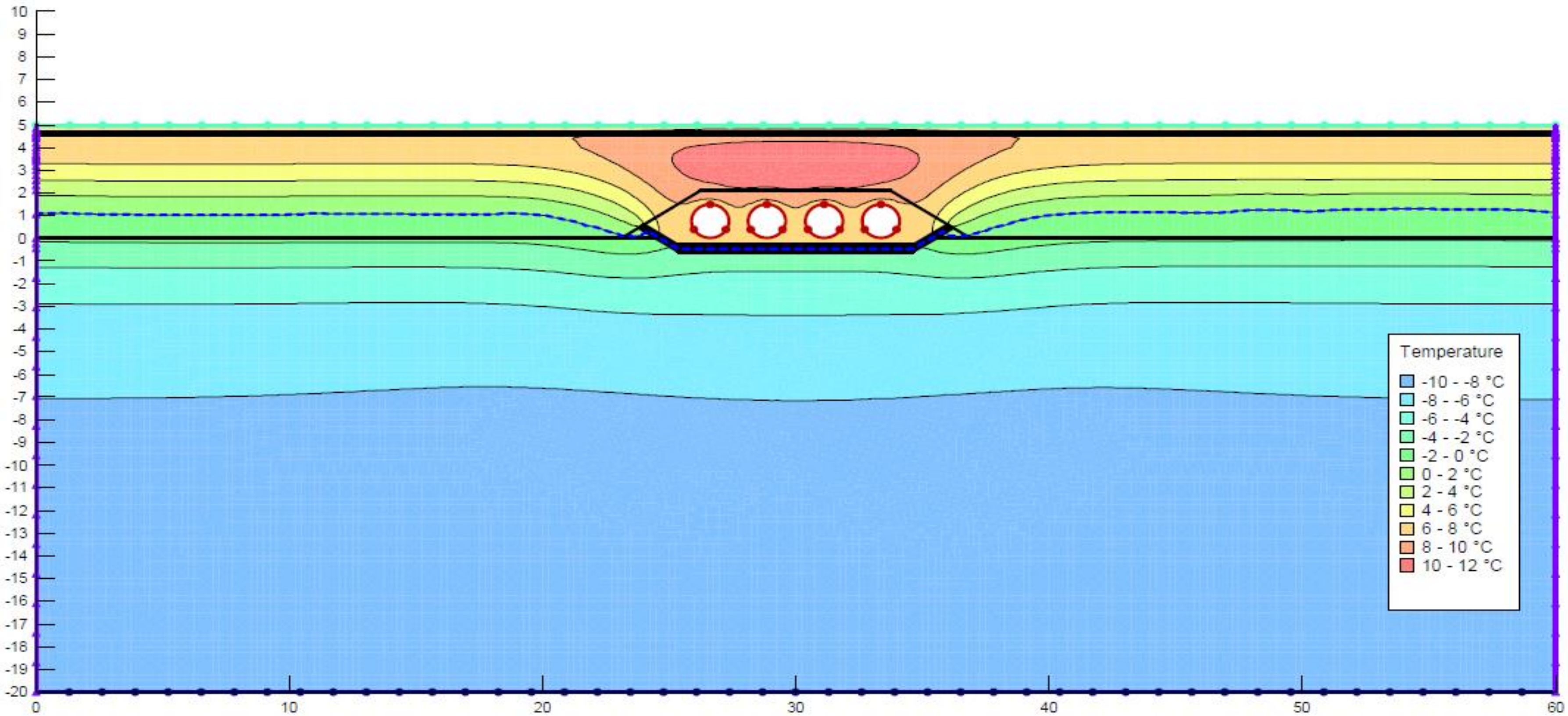


Figure H-7	**Culvert Thermal Modeling Results**	**Culvert Diamater**	1500mm	**Project Number**	H353004	**Rev**	HATCH
		Fill Height	5m	**By**	**MY**	4/22/2019	
		Native Material	Sand and Gravel	**Checked By**	**-**	-	

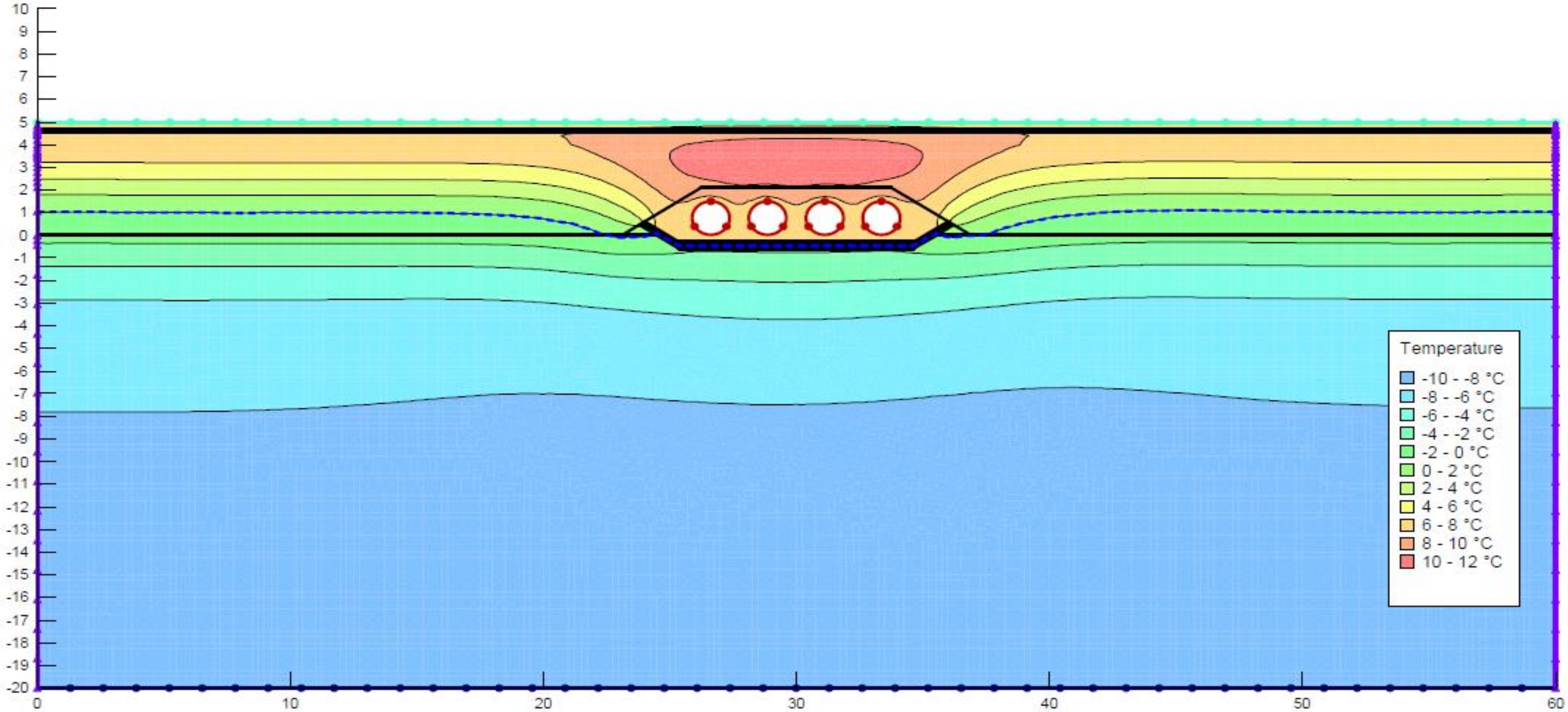


Figure H-7	**Culvert Thermal Modeling Results**	**Culvert Diamater**	1500mm	**Project Number**	H353004	**Rev**		HATCH
		Fill Height	5m	**By**	MY	4/22/2019		
		Native Material	Silt	**Checked By**	-	-		

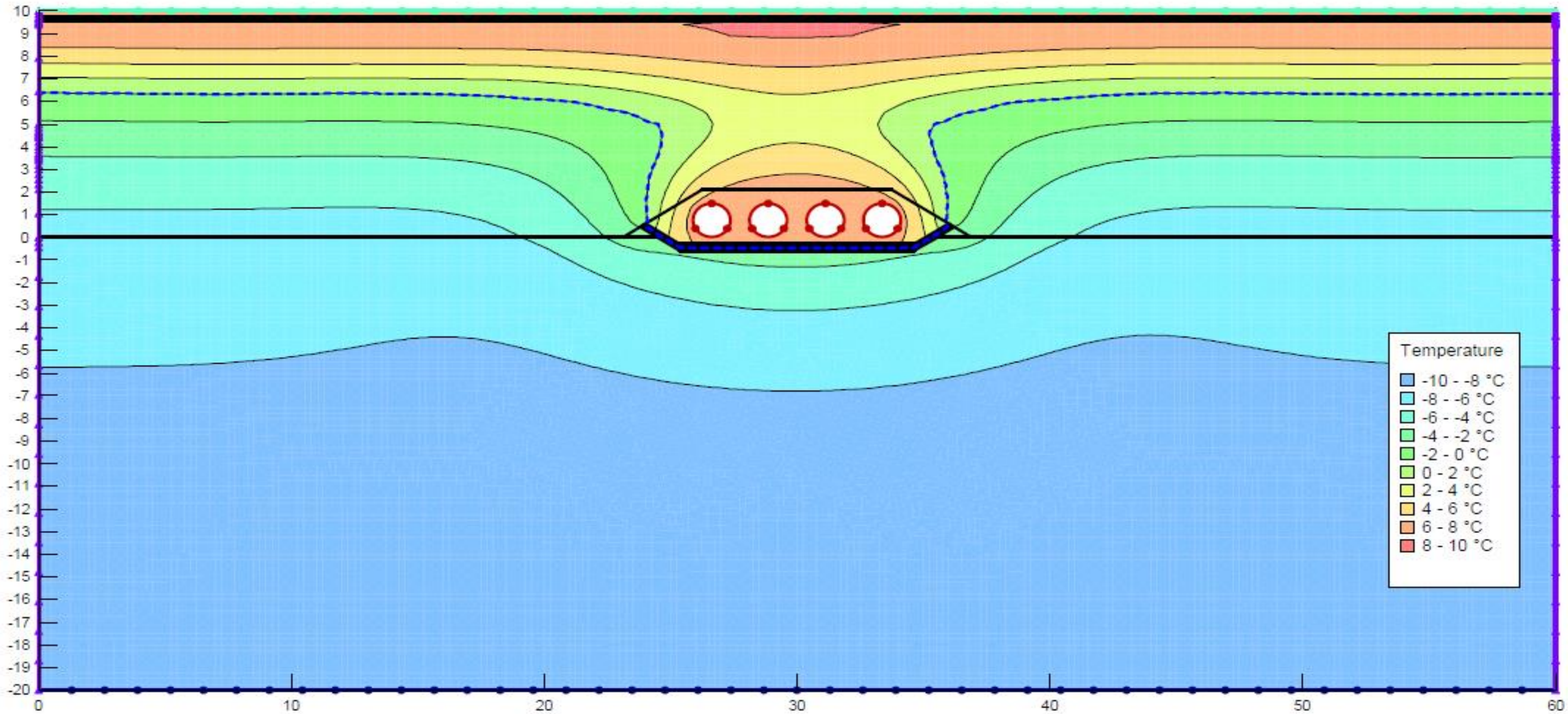


Figure H-7	**Culvert Thermal Modeling Results**	**Culvert Diamater**	1500mm	**Project Number**	H353004	**Rev**	HATCH
		Fill Height	10m	**By**	MY	4/22/2019	
		Native Material	Sand and Gravel	**Checked By**	-	-	

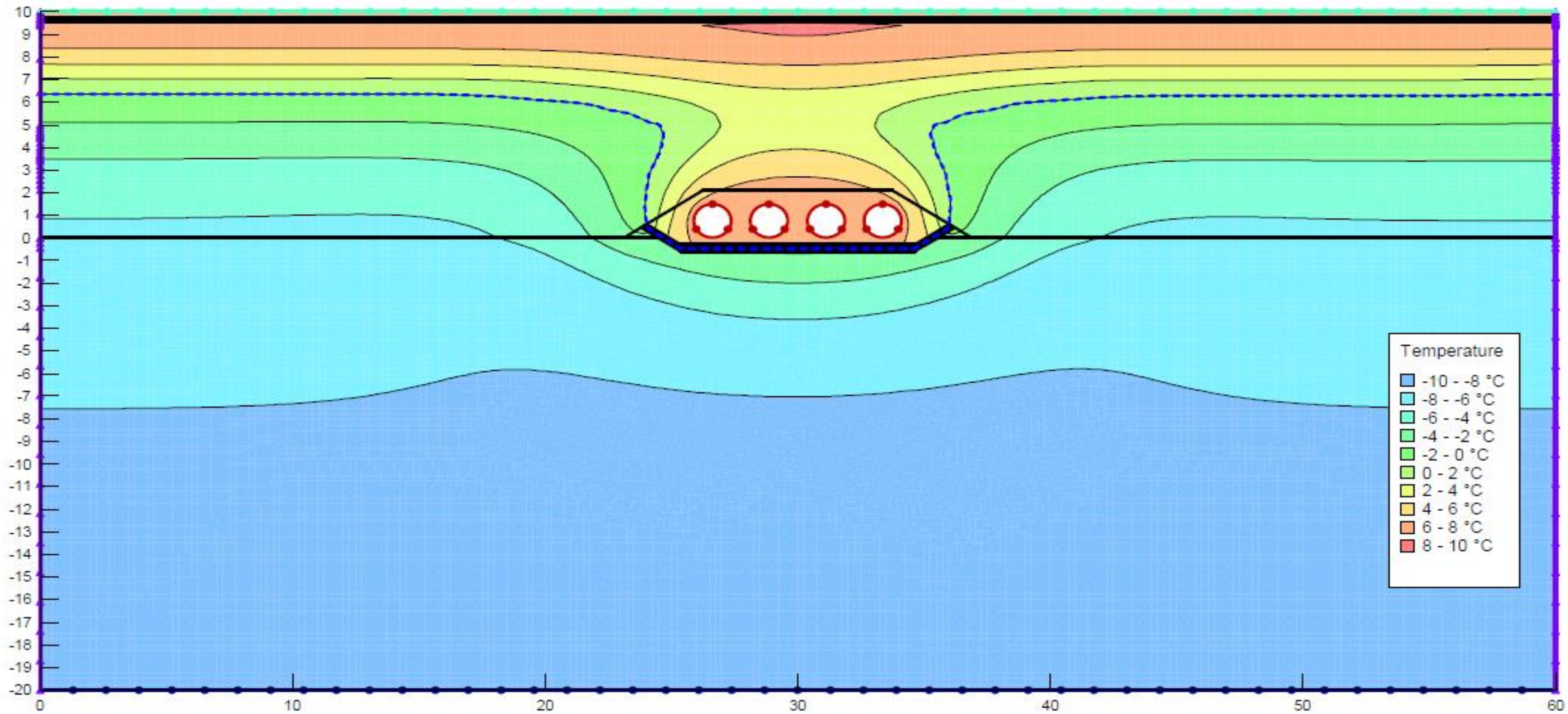


Figure H-7	Culvert Thermal Modeling Results	Culvert Diamater	1500mm	Project Number	H353004	Rev	HATCH
		Fill Height	10m	By	MY	4/22/2019	
		Native Material	Silt	Checked By	-	-	

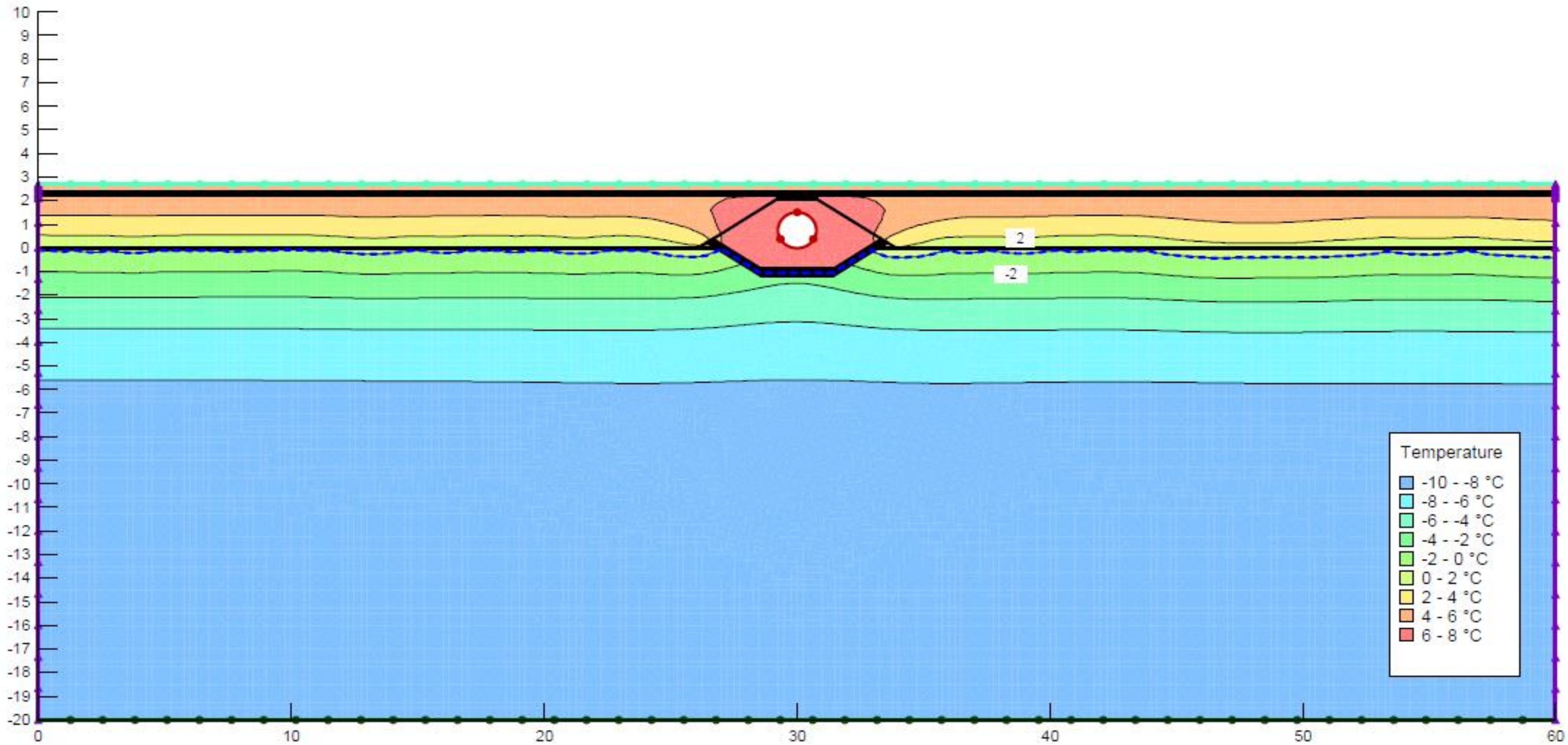


Figure H-8	Culvert Thermal Modeling Results	Culvert Diamater	1500mm	Project Number	H353004	Rev	HATCH
		Fill Height	2.7m	By	MY	4/22/2019	
		Native Material	Sand and Gravel	Checked By	-	-	

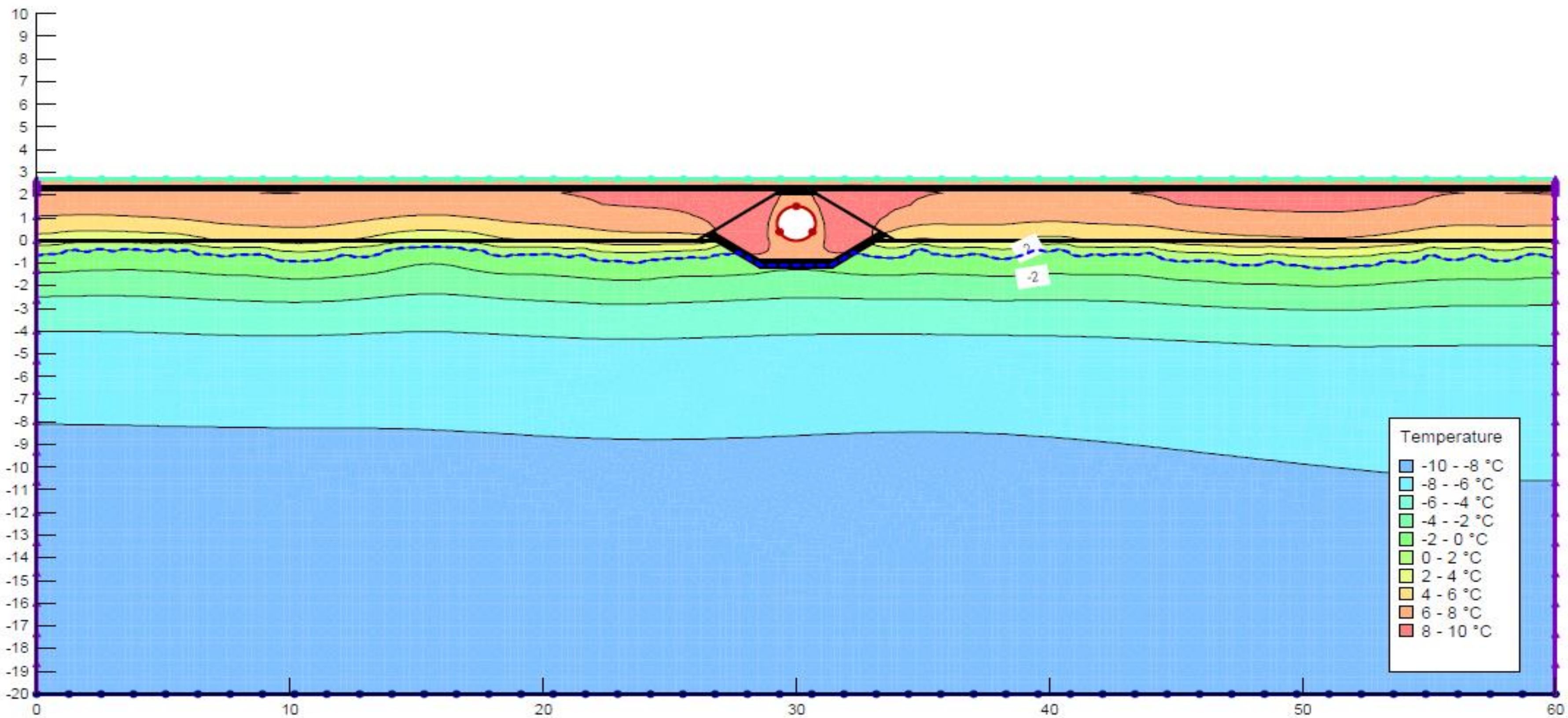


Figure H-8	**Culvert Thermal Modeling Results**	**Culvert Diamater**	1500mm	**Project Number**	H353004	**Rev**	HATCH
		Fill Height	2.7m	**By**	MY	4/22/2019	
		Native Material	Silt	**Checked By**	-	-	

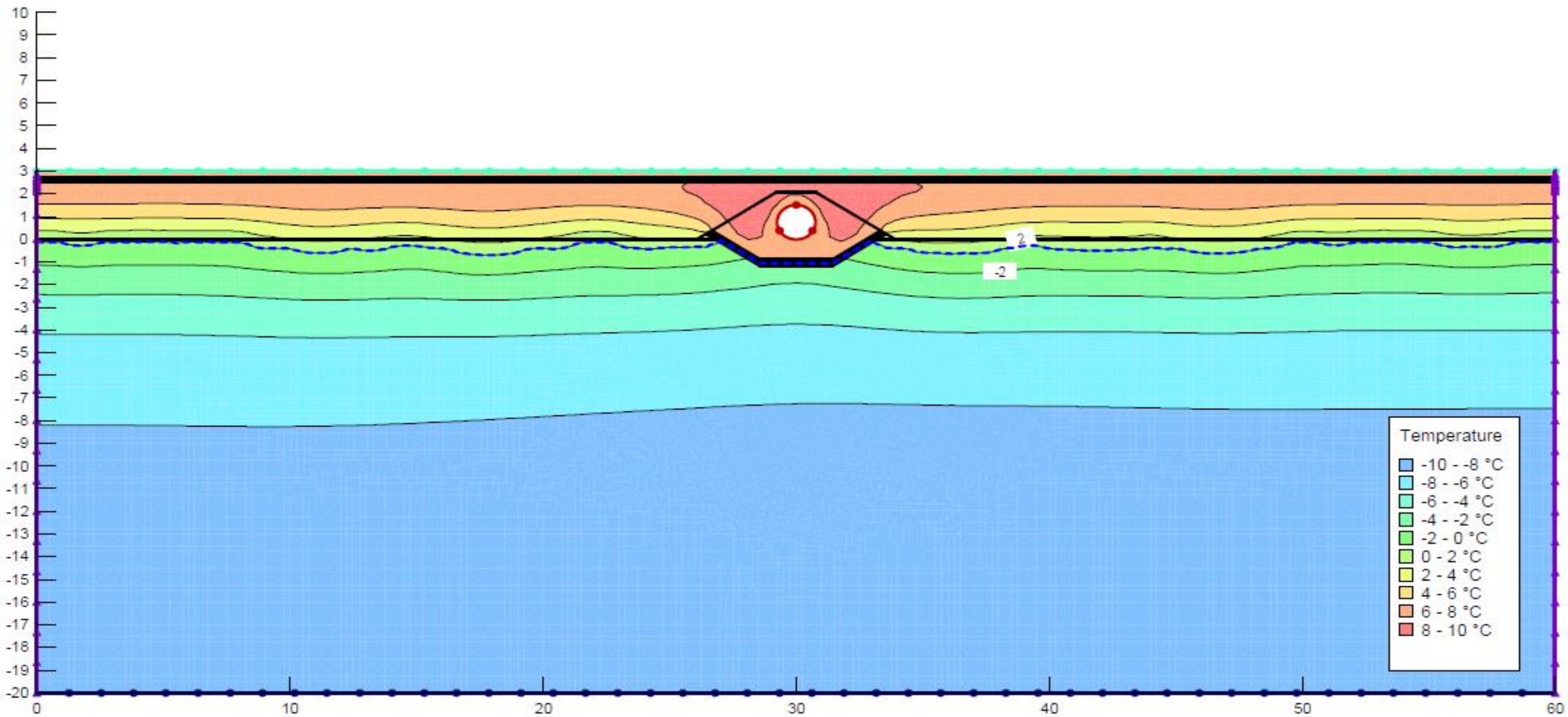


Figure H-8	**Culvert Thermal Modeling Results**	**Culvert Diamater**	1500mm	**Project Number**	H353004	**Rev**		HATCH
		Fill Height	3m	**By**	MY	4/22/2019		
		Native Material	Sand and Gravel	**Checked By**	-	-		

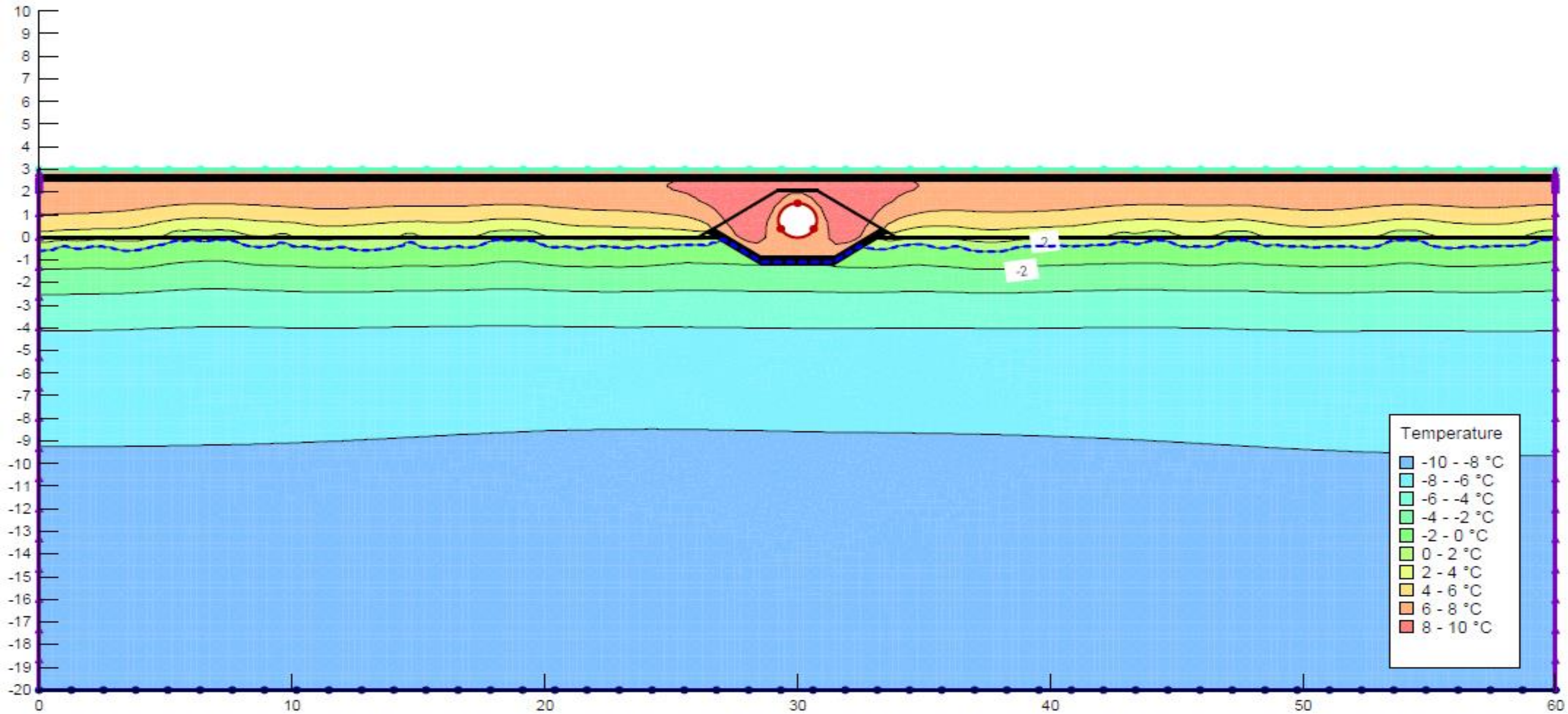


Figure H-8	Culvert Thermal Modeling Results	Culvert Diamater	1500mm	Project Number	H353004	Rev	HATCH
		Fill Height	3m	By	MY	4/22/2019	
		Native Material	Silt	Checked By	-	-	

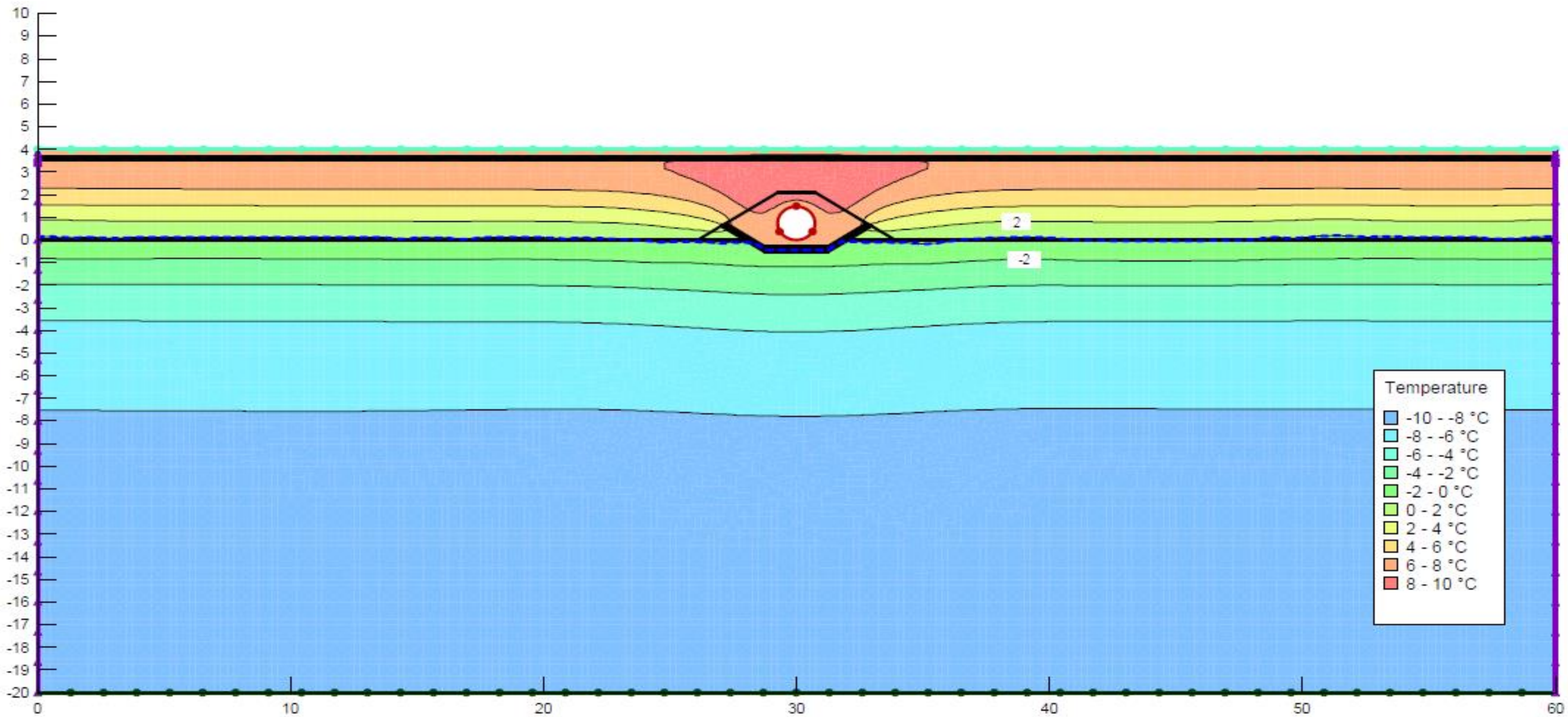


Figure H-8	Culvert Thermal Modeling Results	Culvert Diamater	1500mm	Project Number	H353004	Rev	HATCH
		Fill Height	4m	By	MY	4/22/2019	
		Native Material	Sand and Gravel	Checked By	-	-	

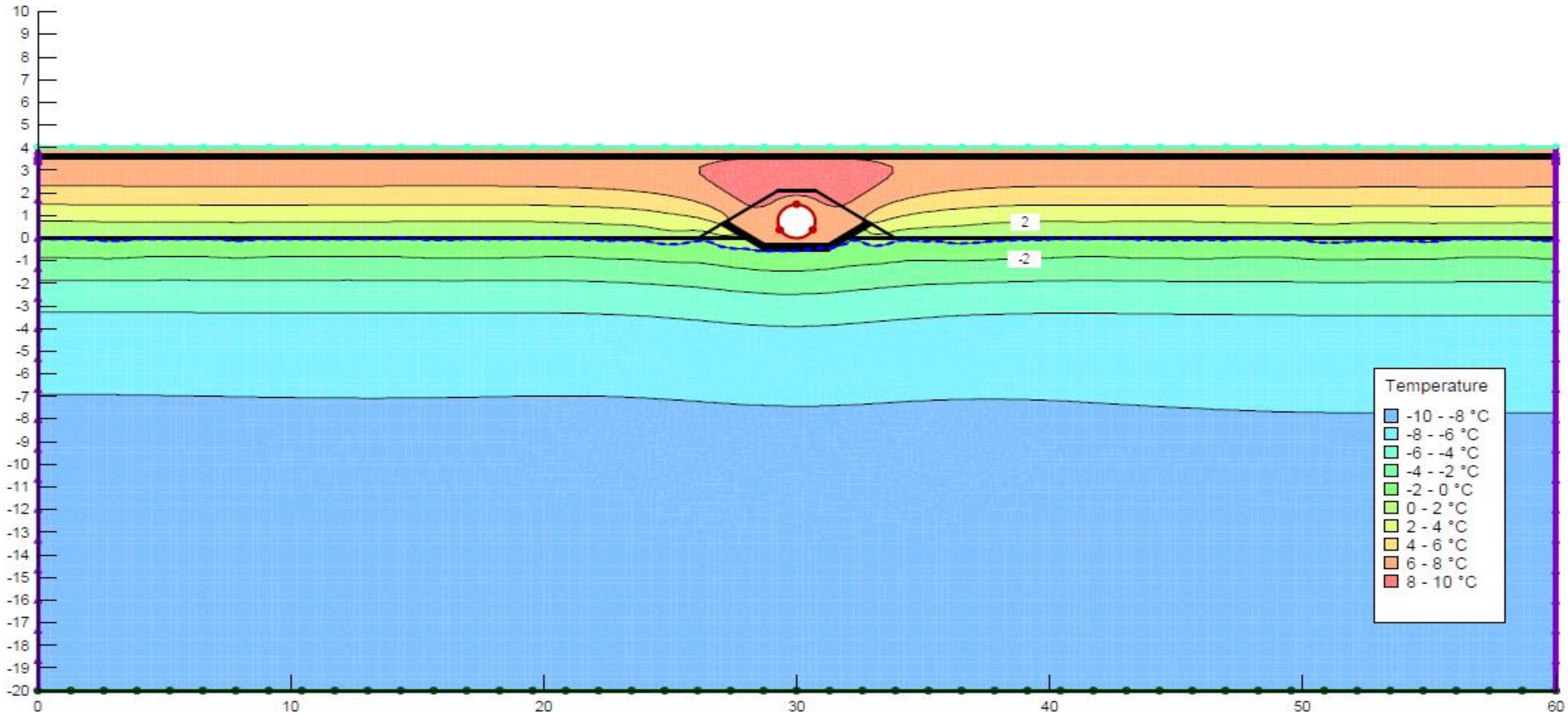


Figure H-8	**Culvert Thermal Modeling Results**	**Culvert Diamater**	1500mm	**Project Number**	H353004	**Rev**	HATCH
		Fill Height	4m	**By**	MY	4/22/2019	
		Native Material	Silt	**Checked By**	-	-	

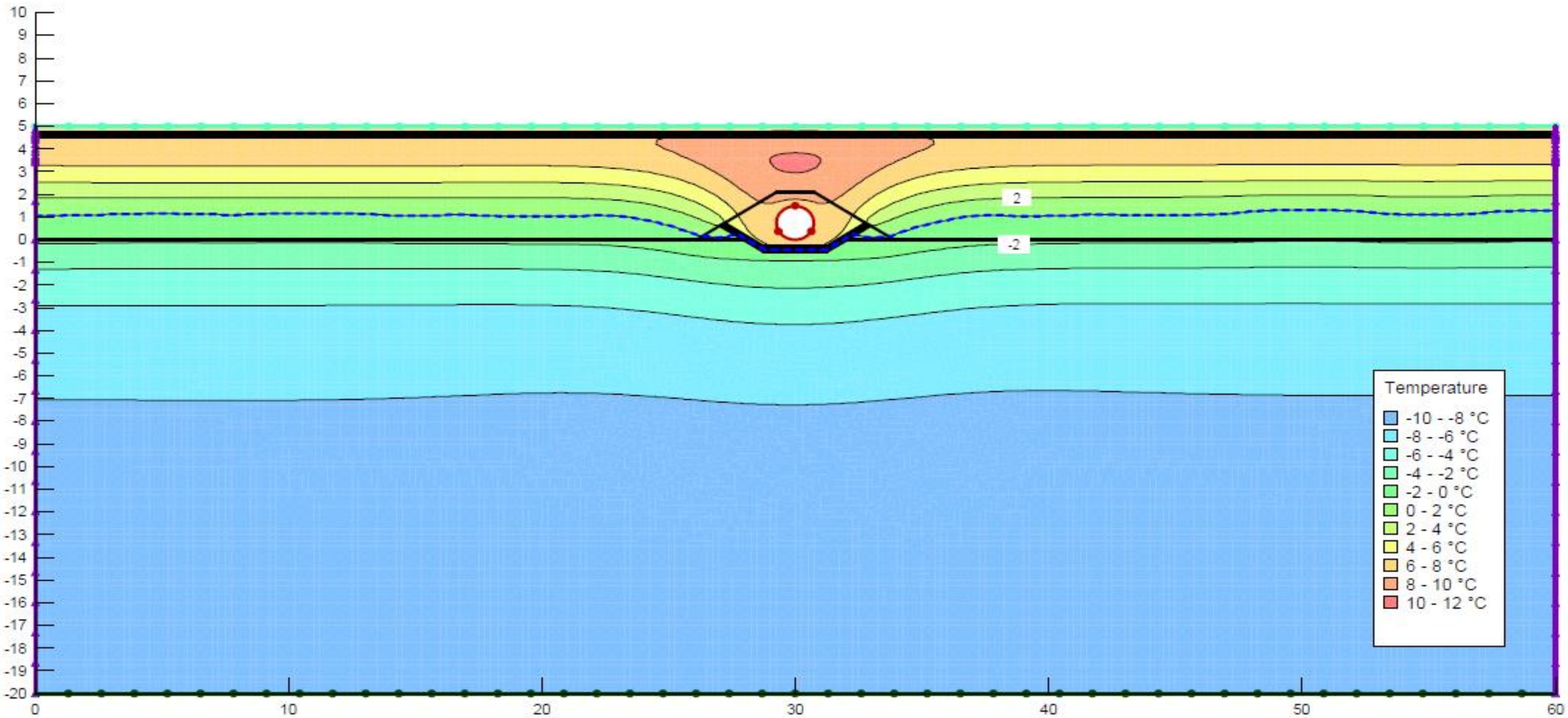


Figure H-8	**Culvert Thermal Modeling Results**	**Culvert Diamater**	1500mm	**Project Number**	H353004	**Rev**	HATCH
		Fill Height	5m	**By**	MY	4/22/2019	
		Native Material	Sand and Gravel	**Checked By**	-	-	

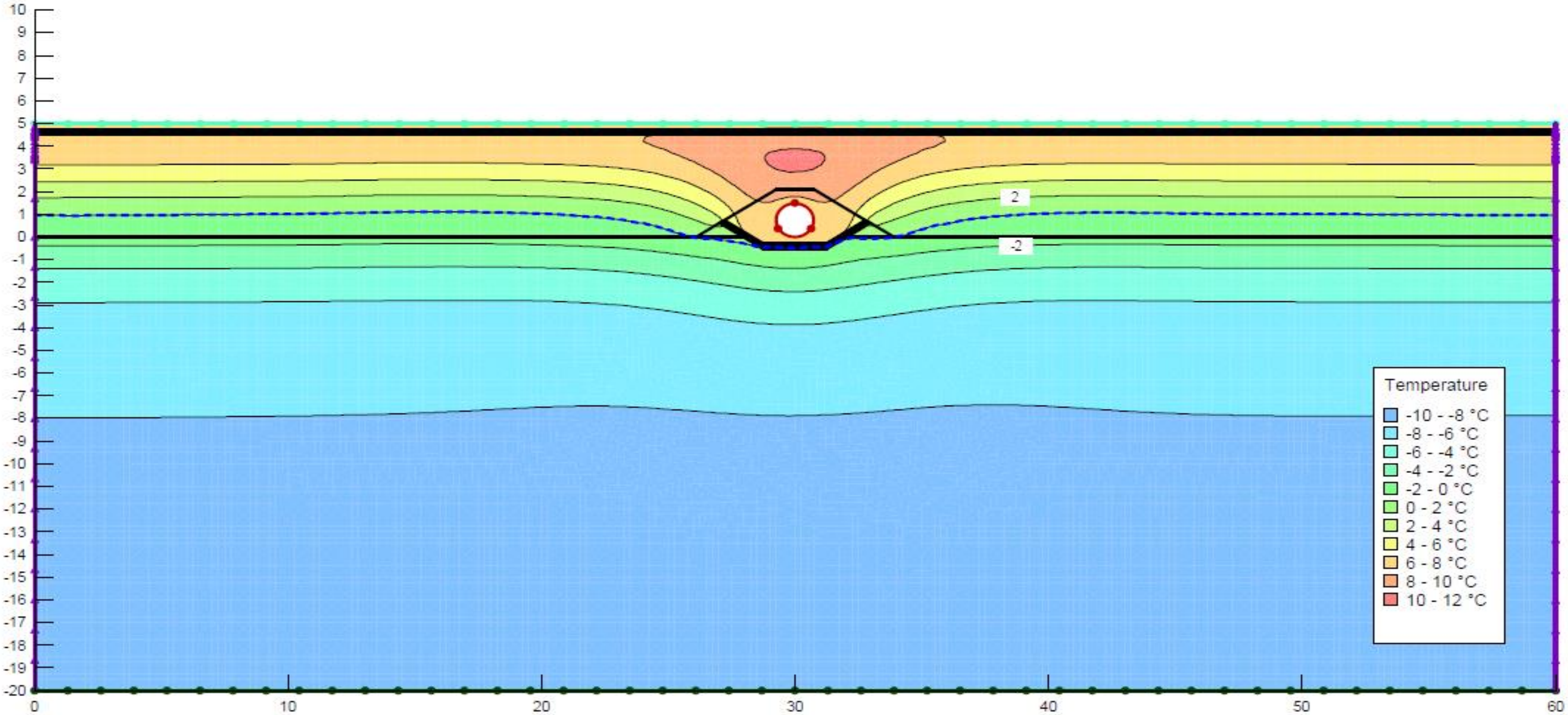


Figure H-8	**Culvert Thermal Modeling Results**	**Culvert Diamater**	1500mm	**Project Number**	H353004	**Rev**		HATCH
		Fill Height	5m	**By**	MY	4/22/2019		
		Native Material	Silt	**Checked By**	-	-		

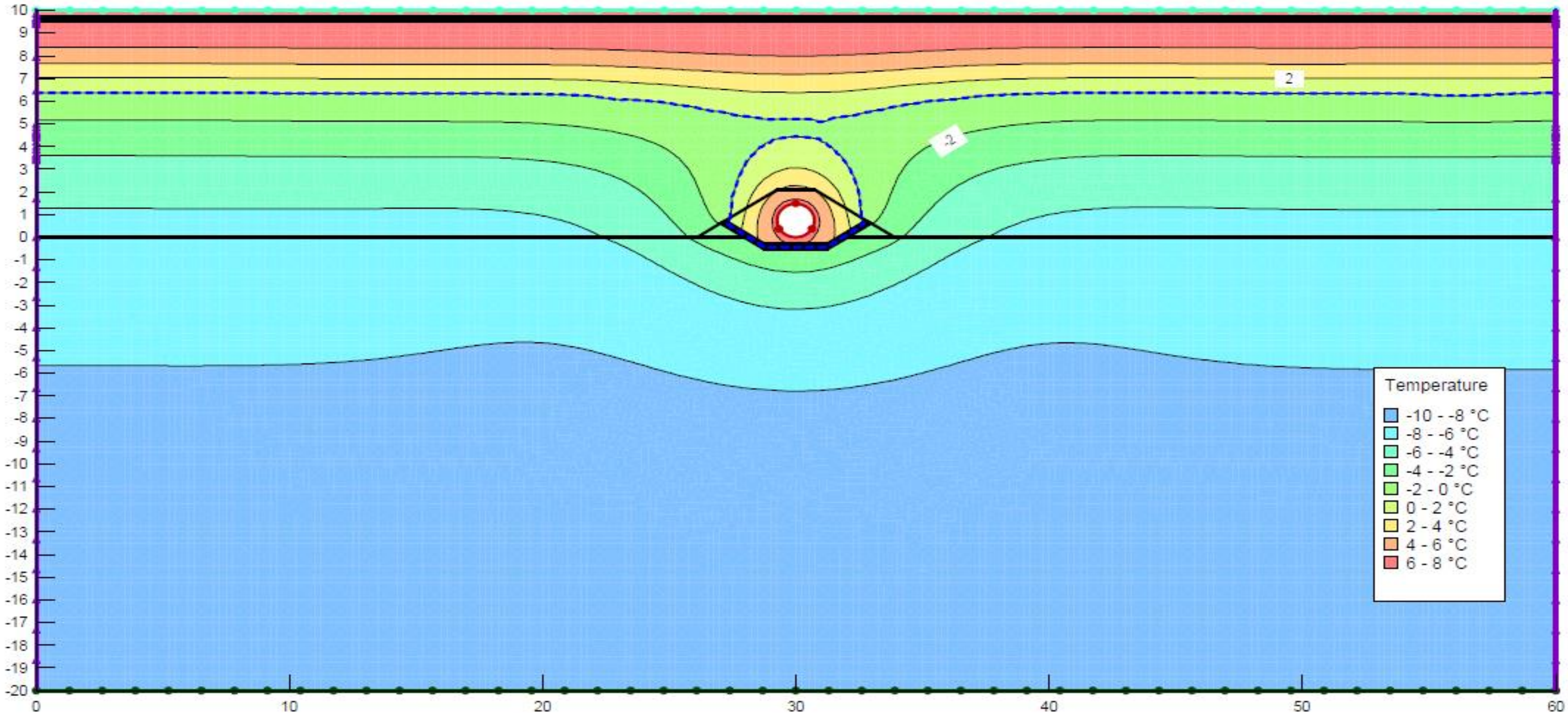


Figure H-8	**Culvert Thermal Modeling Results**	**Culvert Diamater**	1500mm	**Project Number**	H353004	**Rev**	HATCH
		Fill Height	10m	**By**	**MY**	4/22/2019	
		Native Material	Sand and Gravel	**Checked By**	**-**	-	

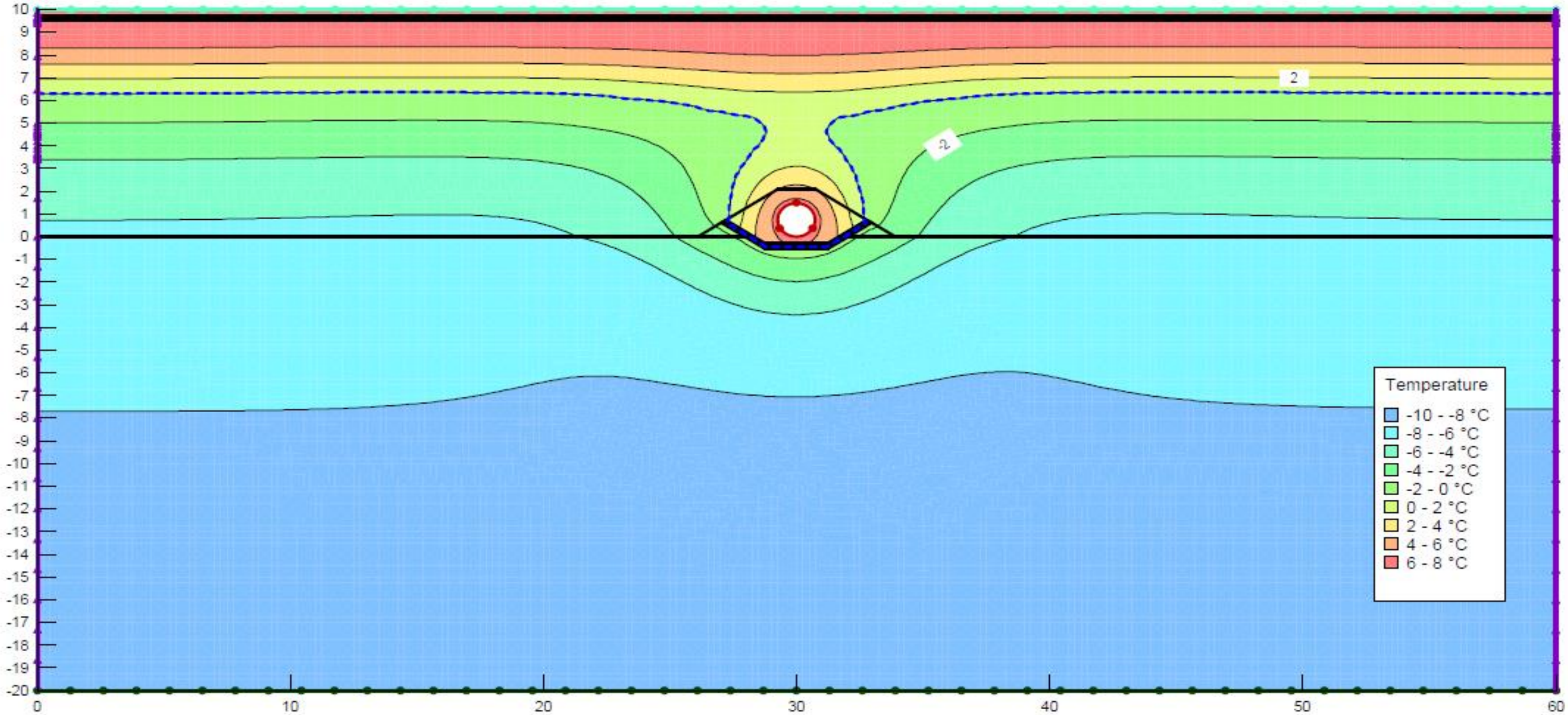


Figure H-8	**Culvert Thermal Modeling Results**	**Culvert Diamater**	1500mm	**Project Number**	H353004	**Rev**	HATCH
		Fill Height	10m	**By**	**MY**	4/22/2019	
		Native Material	Silt	**Checked By**	**-**	-	

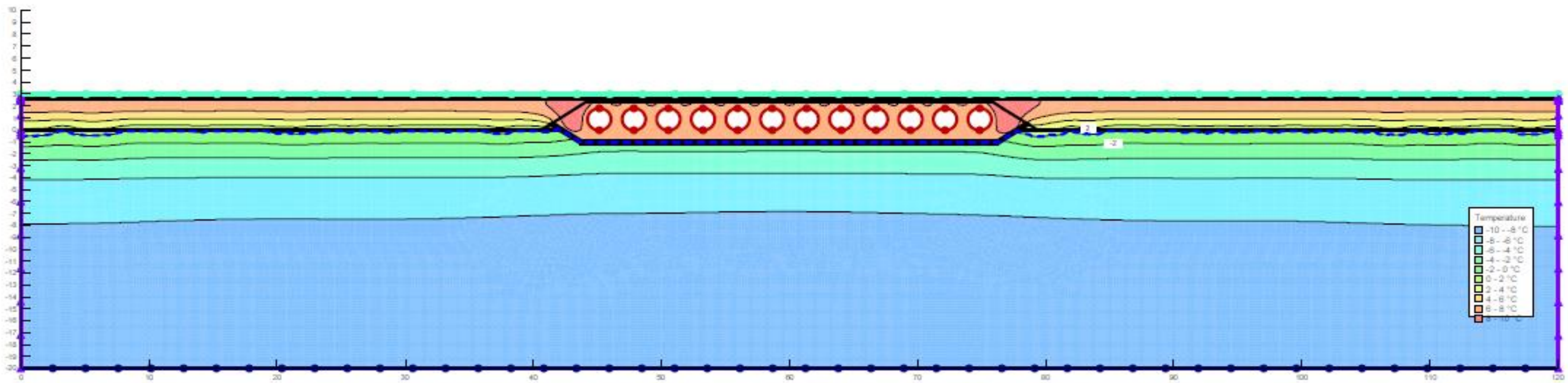


Figure H-9	**Culvert Thermal Modeling Results**	**Culvert Diamater**	1800mm	**Project Number**	H353004	**Rev**	HATCH
		Fill Height	3m	**By**	**MY**	4/22/2019	
		Native Material	Sand and Gravel	**Checked By**	**-**	-	

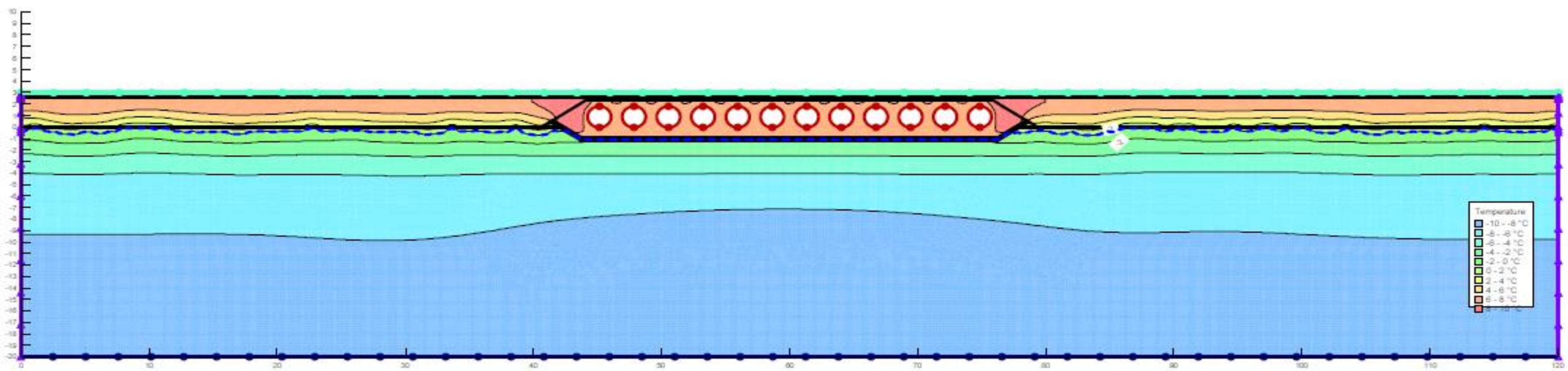


Figure H-9	Culvert Thermal Modeling Results	Culvert Diamater	1800mm	Project Number	H353004	Rev
		Fill Height	3m	By	MY	4/22/2019
		Native Material	Silt	Checked By	-	-

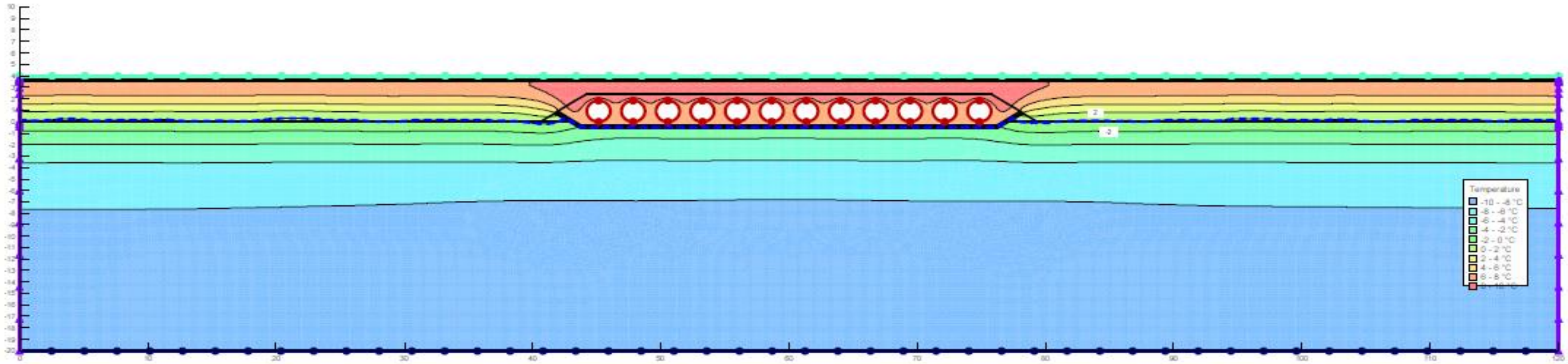


Figure H-9	**Culvert Thermal Modeling Results**	**Culvert Diamater**	1800mm	**Project Number**	H353004 **Rev**
		Fill Height	4m	**By**	MY 4/22/2019
		Native Material	Sand and Gravel	**Checked By**	- -

HATCH

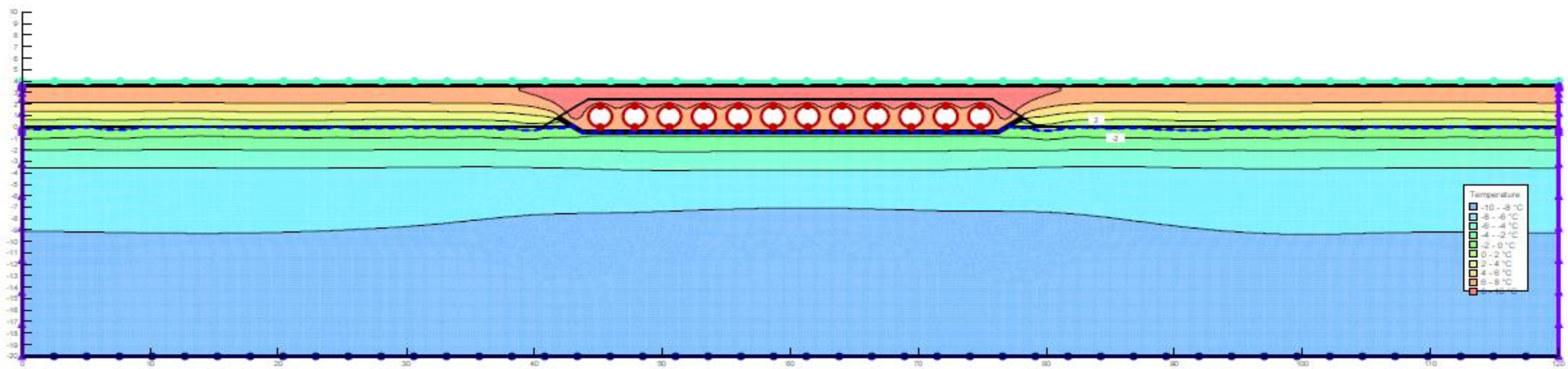


Figure H-9	**Culvert Thermal Modeling Results**	**Culvert Diamater**	1800mm	**Project Number**	H353004	**Rev**	HATCH
		Fill Height	4m	**By**	**MY**	4/22/2019	
		Native Material	Silt	**Checked By**	**-**	-	

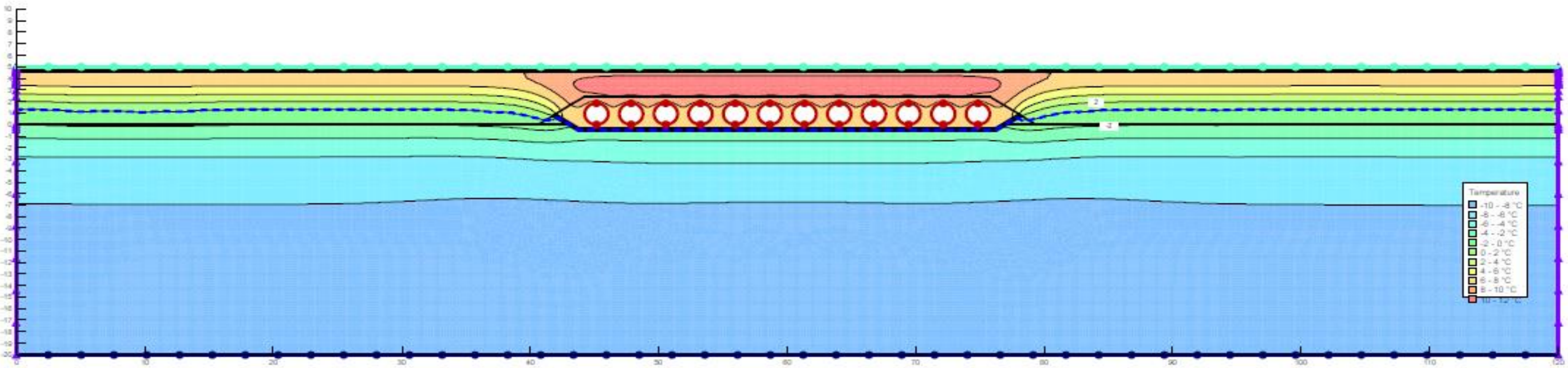


Figure H-9	**Culvert Thermal Modeling Results**	**Culvert Diamater**	1800mm	**Project Number**	H353004	**Rev**
		Fill Height	5m	**By**	MY	4/22/2019
		Native Material	Sand and Gravel	**Checked By**	-	-

HATCH

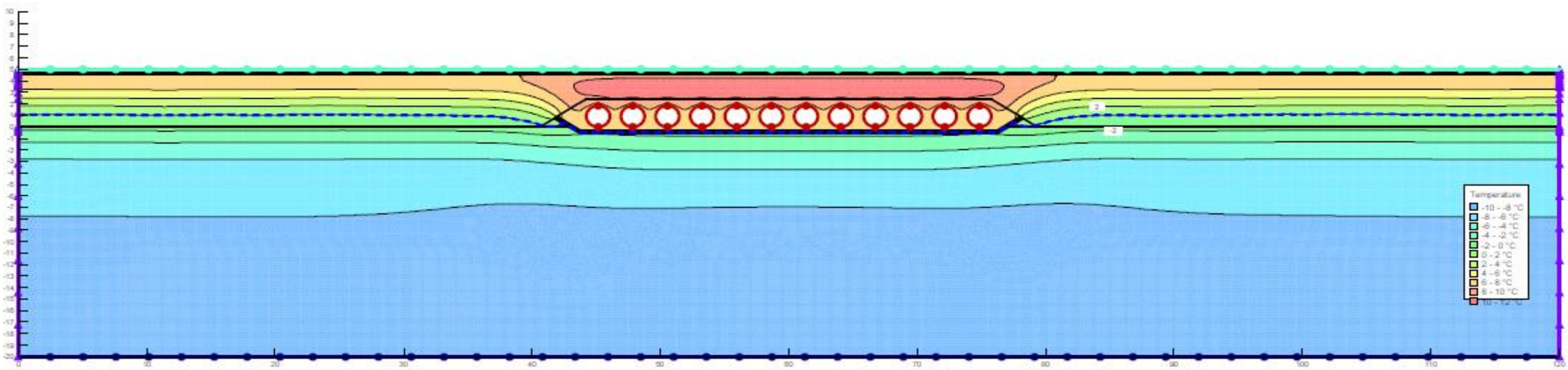


Figure H-9	**Culvert Thermal Modeling Results**	**Culvert Diamater**	1800mm	**Project Number**	H353004	**Rev**	HATCH
		Fill Height	5m	**By**	**MY**	4/22/2019	
		Native Material	Silt	**Checked By**	**-**	-	

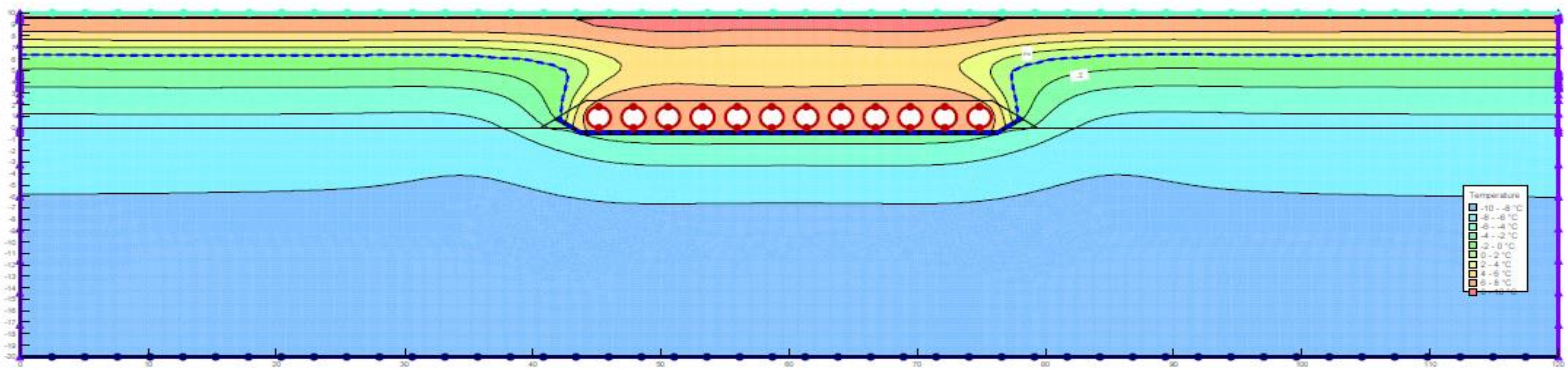


Figure H-9	Culvert Thermal Modeling Results	Culvert Diamater	1800mm	Project Number	H353004	Rev	HATCH
		Fill Height	10m	By	MY	4/22/2019	
		Native Material	Sand and Gravel	Checked By	-	-	

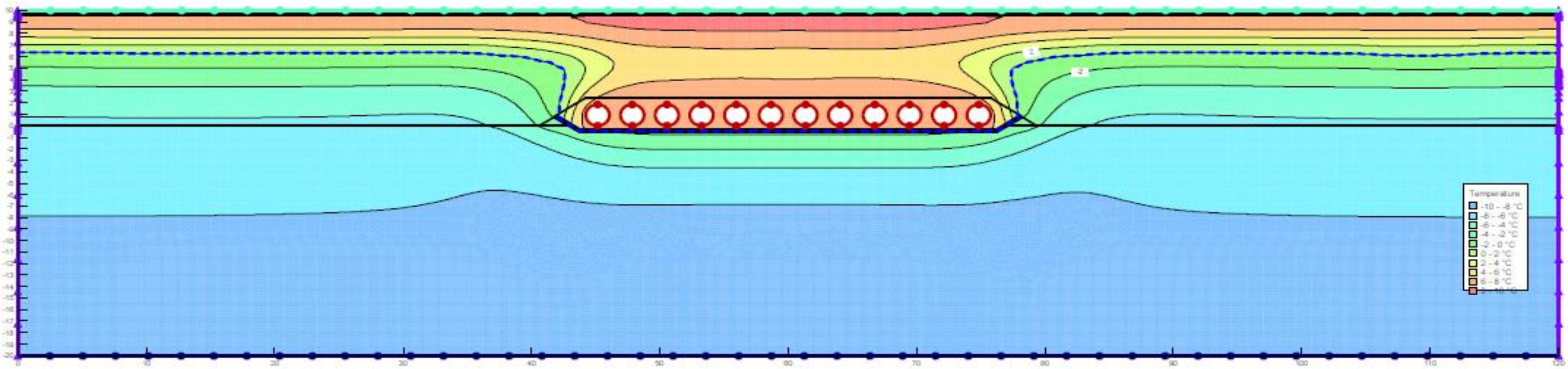


Figure H-9	**Culvert Thermal Modeling Results**	**Culvert Diamater**	1800mm	**Project Number**	H353004	**Rev**	HATCH
		Fill Height	10m	**By**	**MY**	4/22/2019	
		Native Material	Silt	**Checked By**	**-**	-	

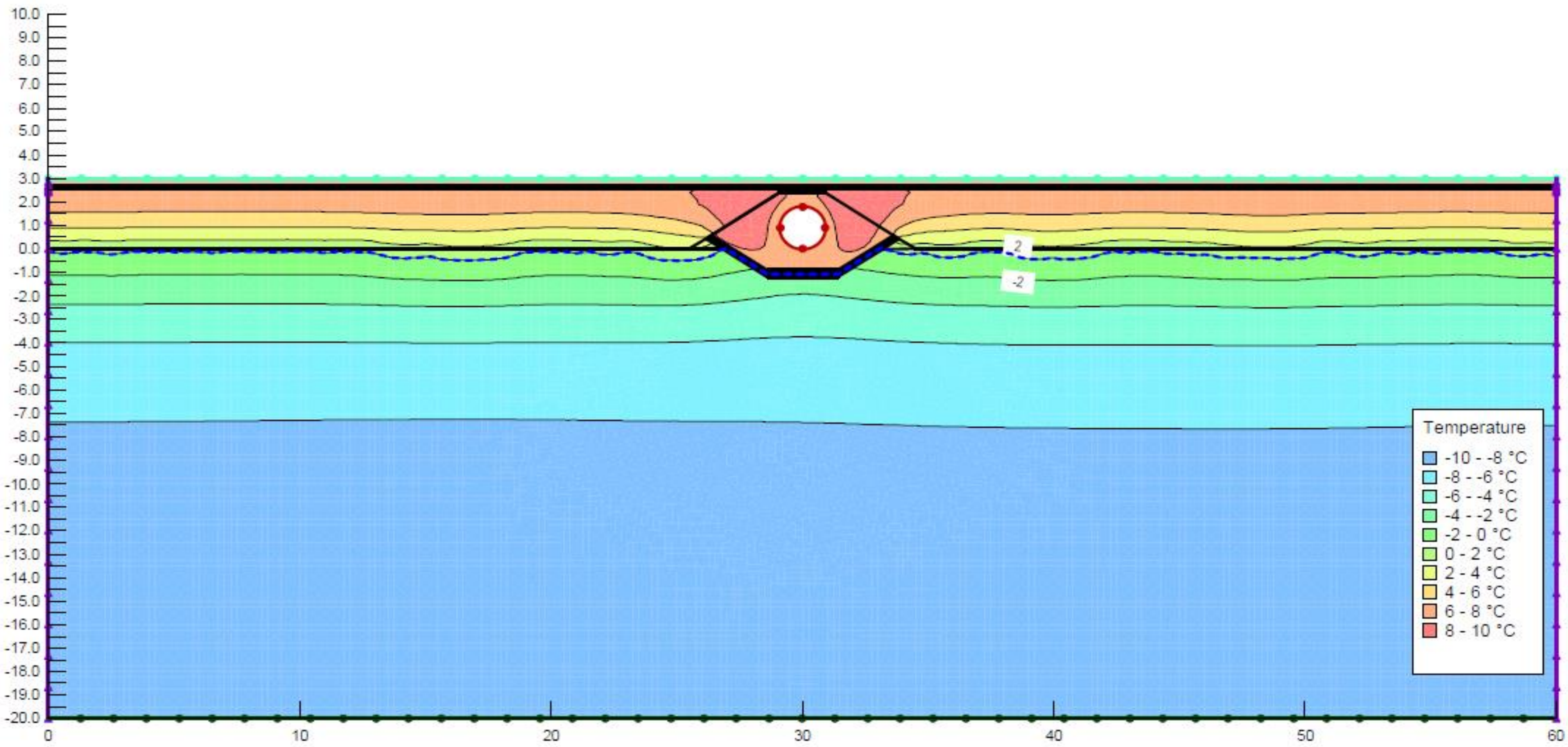


Figure H-10	Culvert Thermal Modeling Results	Culvert Diamater	1800mm	Project Number	H353004	Rev	HATCH
		Fill Height	3m	By	MY	4/22/2019	
		Native Material	Sand and Gravel	Checked By	-	-	

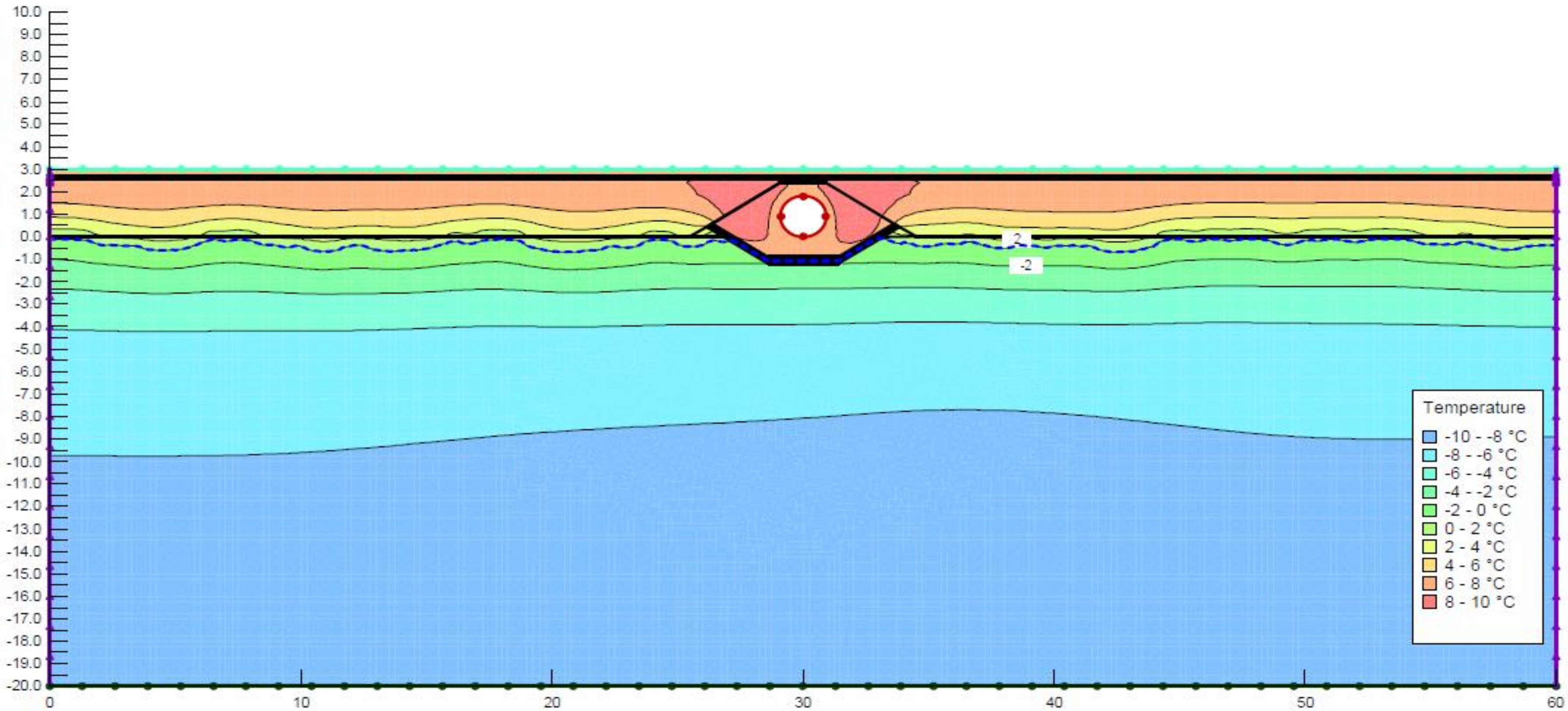


Figure H-10	Culvert Thermal Modeling Results	Culvert Diamater	1800mm	Project Number	H353004	Rev	HATCH
		Fill Height	3m	By	MY	4/22/2019	
		Native Material	Silt	Checked By	-	-	

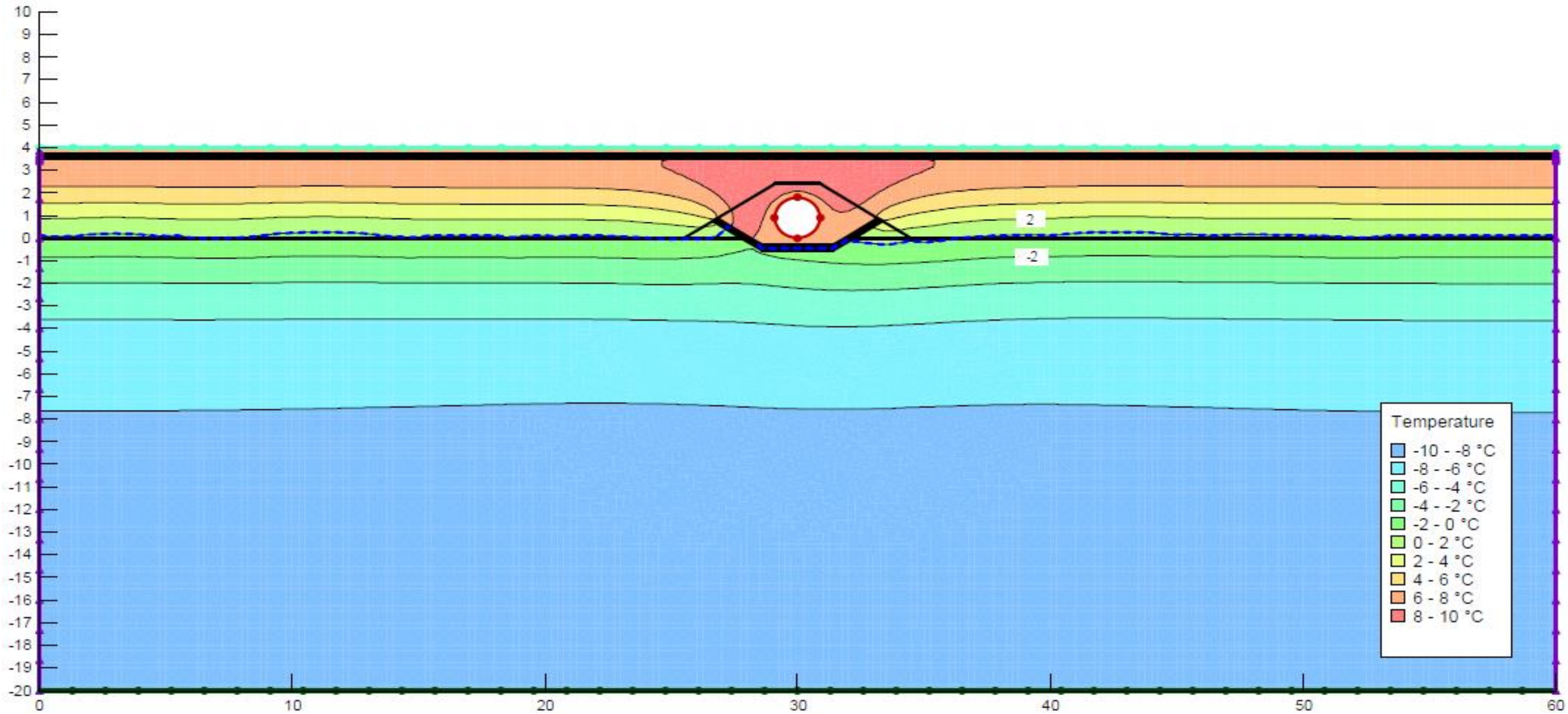


Figure H-10	**Culvert Thermal Modeling Results**	**Culvert Diamater**	1800mm	**Project Number**	H353004	**Rev**
		Fill Height	4m	**By**	MY	4/22/2019
		Native Material	Sand and Gravel	**Checked By**	-	-

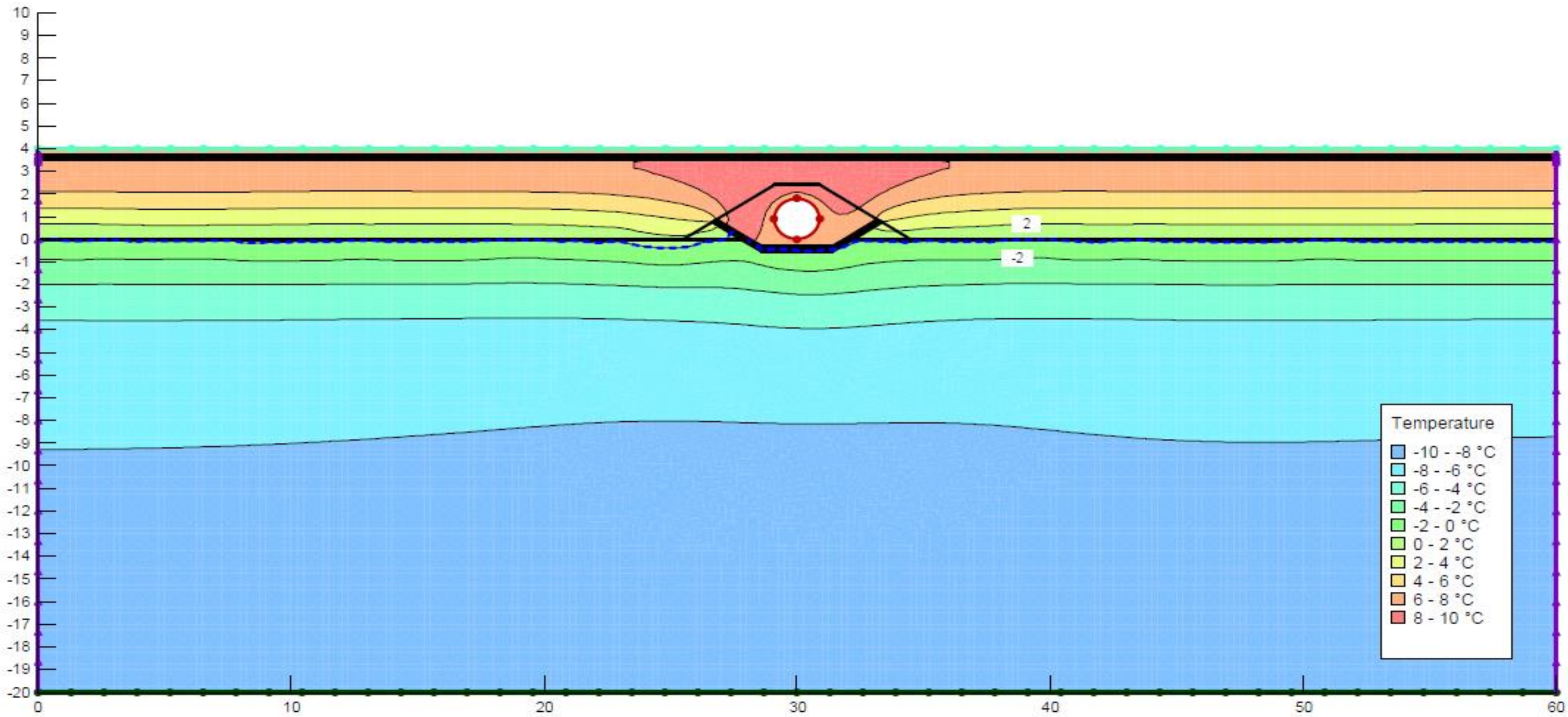


Figure H-10	Culvert Thermal Modeling Results	Culvert Diamater	1800mm	Project Number	H353004	Rev	HATCH
		Fill Height	4m	By	MY	4/22/2019	
		Native Material	Silt	Checked By	-	-	

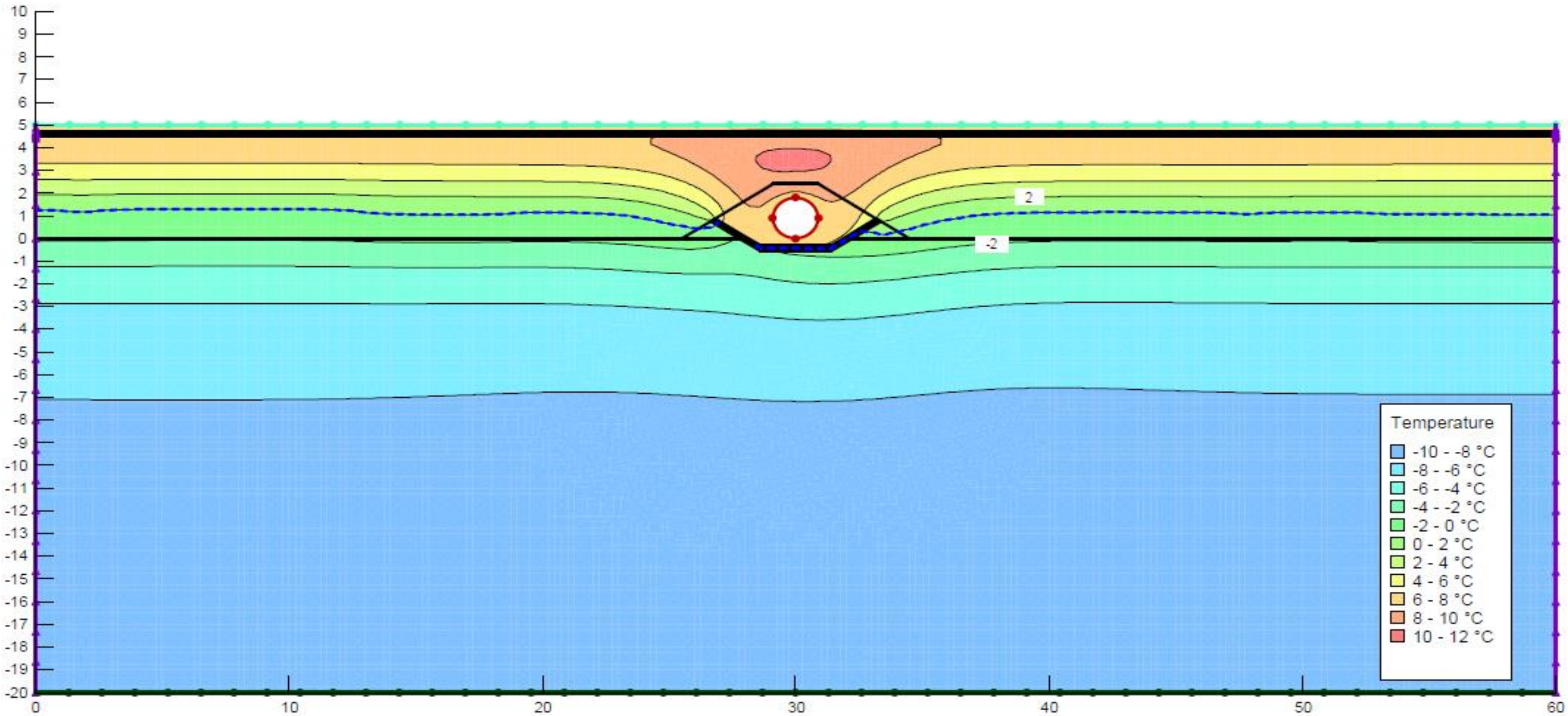


Figure H-10	Culvert Thermal Modeling Results	**Culvert Diamater**	1800mm	**Project Number**	H353004	**Rev**		HATCH
		Fill Height	5m	**By**	**MY**	4/22/2019		
		Native Material	Sand and Gravel	**Checked By**	**-**	-		

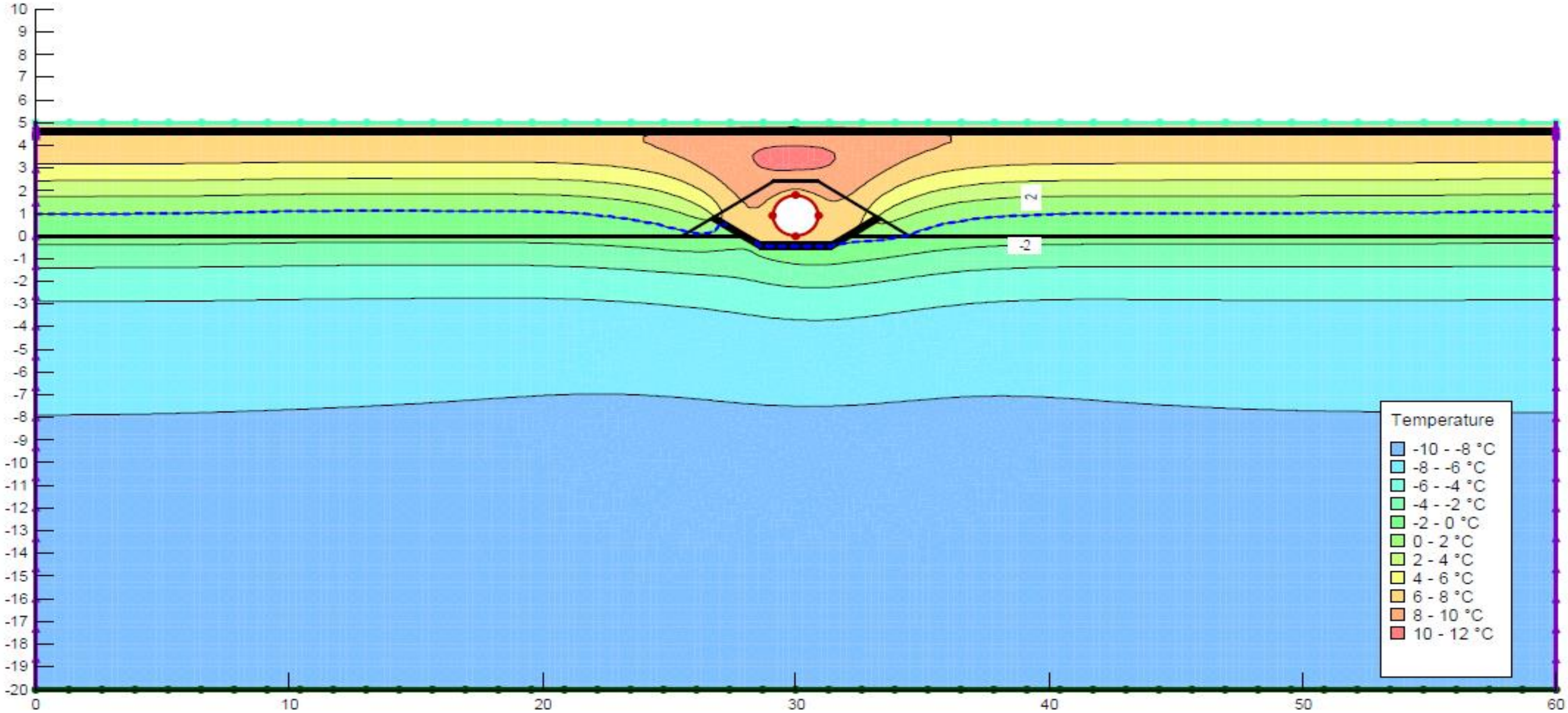


Figure H-10	Culvert Thermal Modeling Results	Culvert Diamater	1800mm	Project Number	H353004	Rev	HATCH
		Fill Height	5m	By	MY	4/22/2019	
		Native Material	Silt	Checked By	-	-	

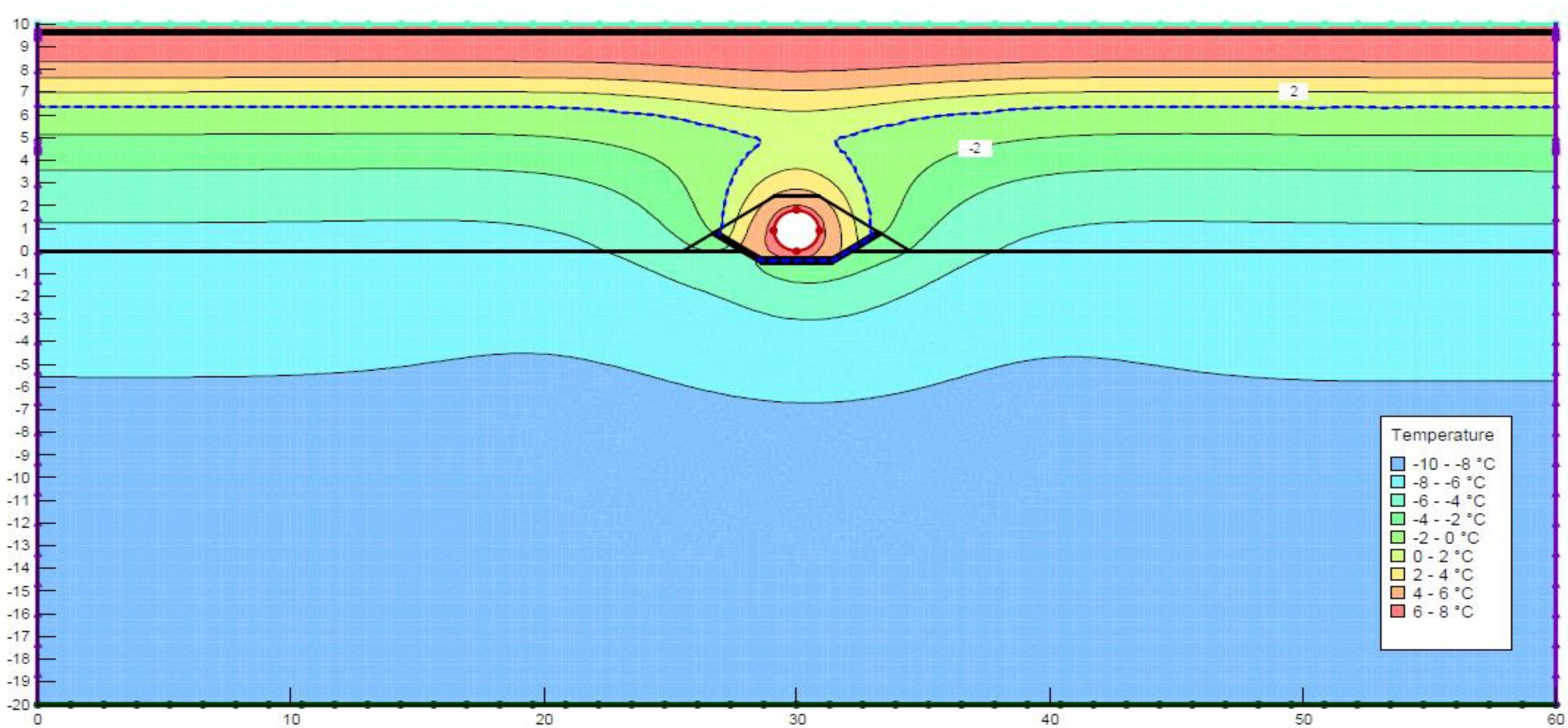


Figure H-10	Culvert Thermal Modeling Results	Culvert Diamater	1800mm	Project Number	H353004	Rev	HATCH
		Fill Height	10m	By	MY	4/22/2019	
		Native Material	Sand and Gravel	Checked By	-	-	

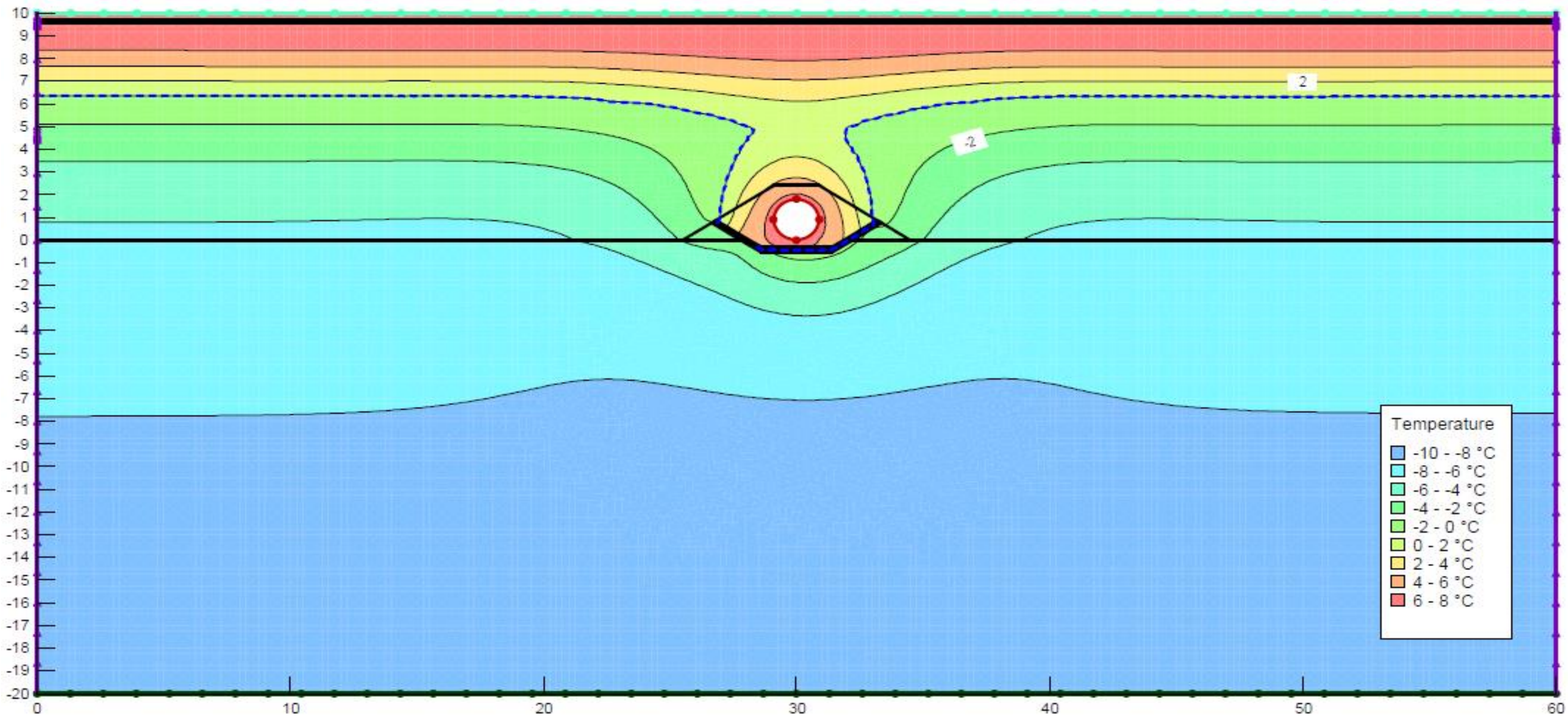


Figure H-10	Culvert Thermal Modeling Results	**Culvert Diamater**	1800mm	**Project Number**	H353004	**Rev**		HATCH
		Fill Height	10m	**By**	MY	4/22/2019		
		Native Material	Silt	**Checked By**	-	-		