Alaska Gold Company

A NovaGold Subsidiary

ROCK CREEK MINE
PLAN OF OPERATIONS
VOLUME 6
Thermal and Seepage Evaluation
May, 2006

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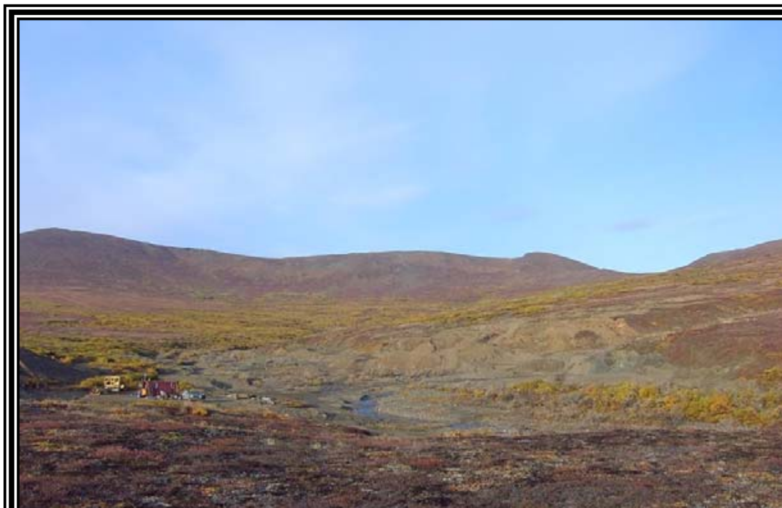
Placer mining on the Rock Creek deposit, 1902



NovaGold

Appendix C
Thermal and Seepage Evaluation

THERMAL AND SEEPAGE EVALUATION

for the proposed

ROCK CREEK GOLD MINE
TAILINGS STORAGE FACILITY DAM
NOME, ALASKA

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April 2006

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Executive Summary

Northern Geotechnical Engineering, Inc. was contracted by Smith Williams Consultants, Inc. to conduct a thermal and fluid seepage analysis for a rock fill tailings retention dam to be constructed as part of the proposed Rock Creek Gold Mine located north of Nome, Alaska. The focus of the evaluation was to determine the approximate seepage flow under the dam and to assess alternative designs for minimizing the seepage volume. Alternatives included 1) lining the upper face of the dam, 2) incorporating thermosyphons to create a frozen barrier to water flow and 3) extending the liner system into the weathered bedrock foundation.

The Rock Creek Project is a gold ore mining and extraction operation proposed to be constructed along the southwestern flank of Mt. Brynteson, approximately 6 miles north of Nome, Alaska. The project facilities will be constructed along both sides of Rock Creek and will consist of an open pit mine, ore processing and extraction facilities, tailings storage facility, and associated operation/administrative facilities.

Several subsurface exploration programs have been conducted at the site, and the subsurface conditions at the site have been characterized through the installation of multiple core holes, boreholes, and test pits located across the extent of the site. Data obtained from these exploration studies were used to develop material properties and subsurface profiles used for the modeling effort. Thermal data collected was used to calibrate the model material properties and boundary condition functions.

Numerical modeling of the tailing storage facility was conducted using thermal and fluid seepage analysis software applications (TEMP/W & SEEP/W) developed and produced by GeoSlope International, Ltd. TEMP/W and SEEP/W are two-dimensional, finite-element analysis software applications which can model (predict) thermal and hydraulic changes in specified materials due to environmental changes, construction, and/or demolition of structures which may alter the thermal and hydraulic regimes of the materials modeled. TEMP/W and SEEP/W can perform time-step analyses in concert with one another effectively modeling convective heat transfer to predict the real-time impact that groundwater seepage has on the freeze-thaw interface of specified materials,

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and to predict the volume of water that will seep through the dam and underling native materials over the course of time.

A scaled model of the proposed tailings storage facility and surrounding/underlying materials was first constructed in the software program's graphical user interface using the available design tools. A layered model was constructed which depicts the tailings stockpile and dam, as well as the underlying soils/bedrock. The model was constructed in a manner which incorporates all three phases of the proposed dam construction into one model. This design method allowed the thermal/seepage analysis to be executed in three separate phases corresponding to the three proposed phases of dam construction.

Once a functional and reasonable analysis procedure had been developed, several different scenarios were generated and analyzed which allowed for the investigation of the effects that differing material properties, boundary conditions, and heat removal systems could have on the thermal and hydraulic conditions of the tailing storage facility and native materials during and after tailings placement within the storage area. A total of seven different scenarios were analyzed using the fundamental three-phase model.

All seven scenarios were analyzed by the modeling software, and the results were then compared to one another to determine what effect differing material properties, boundary conditions, and heat removal systems would have on the tailings storage facility and surrounding native materials.

Flux sections, which are used to determine the amount of discharge occurring thorough individual elements within the model, were placed at the upstream and downstream toes of the dam to calculate the discharge rate that is predicted to occur in each phase of the analyses. A vertical flux section was placed across the elements through which subsurface flow is predicted to occur to calculate the instantaneous horizontal flow rates which occur through each of the specified elements within the models. The instantaneous flow rates for each time step in the analysis were obtained from the flux sections and averaged together to obtain an average discharge rate for each year-long analysis.

From the modeling analysis it appears that with a liner on the rock fill dam, the seepage flow is governed by the properties of the weathered bedrock. During the period of time that tails are being added to the system, the heat added to the system cannot be controlled by passive artificial cooling. Decreasing the flow volume through the dam by cutting off the top 2/3 of the weathered bedrock significantly reduces the seepage flow from the tails.

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Passive cooling of the upstream toe of the dam has little effect on the annual seepage flows if there is no cut off into the weathered bedrock. With a cutoff extending 2/3 of the way through the weathered bedrock, passive cooling is not necessary.

In itself, thawing of the permafrost will have no effect on the stability of the Tailing storage facility. Controlling seepage to control the transport of contaminants is needed from an environmental standpoint. The annual average temperature suggests that with passive cooling, a permafrost barrier could be achieved. Due to the seepage flow and thermal input from the warm tails, it appears to not be practical to achieve a frozen barrier with thermosyphons. As ambient air temperatures rise, the ability to sustain a frozen barrier is reduced. Seepage flow can be effectively controlled using an HDPE cutoff barrier than extends most of the way through the weathered bedrock.

A cutoff trench in the weathered bedrock is recommended to control seepage from the tails to the downstream toe of the dam. The dam and cutoff trench can be constructed in the summer or winter. Additionally, the cutoff trench should be allowed to freeze prior to placement of tails over the trench.

We greatly appreciate the opportunity to be of service to you. If you have any questions regarding the material presented in this report, please contact our office at your convenience.

Sincerely,

NORTHERN GEOTECHNICAL ENGINEERING, INC.

ACS

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1.0 INTRODUCTION

Northern Geotechnical Engineering, Inc (NGE) was contracted by Smith Williams Consultants, Inc. (SWC) to conduct a thermal and fluid seepage analysis for a rock fill tailings retention dam to be constructed as part of the proposed Rock Creek Gold Mine located north of Nome, Alaska. The focus of the evaluation was to determine the approximate seepage flow under the dam and to assess alternative designs for minimizing the seepage volume. Alternatives included 1) lining the upper face of the dam, 2) incorporating thermosyphons to create a frozen barrier to water flow and 3) extending the liner system into the weathered bedrock foundation.

The proposed dam design calls for a rock fill structure to be constructed at the mine site on top of frozen bedrock. The upstream side of the dam will be lined with a high density polyethylene (HDPE) geomembrane, which will inhibit the migration of fluids through the upstream face of the dam. The initial design proposed that the foundation of the dam would be maintained in a frozen state (possibly through the use of thermosyphons) which would further limit the amount of fluids which could be transmitted through the dam and native materials to the downstream toe of the dam. The goals of the thermal and fluid seepage analysis were to: 1) evaluate the impact that the introduction of the tailings slurry will have on the native frozen materials; 2) determine if (and where) any heat removal devices will need to be installed to maintain frozen ground conditions at upstream toe of the dam; and 3) estimate the amount of fluid flow-through that may occur beneath and/or through the dam over time.

The various evaluations conducted on several scenarios using thermosyphons indicated that the fluid flow through and under the dam was not significantly reduced by the extra cooling provided. The distribution of the fluid flow was altered however the total fluid flow on an annual basis was not significantly reduced. Based on these results, a second model was developed to simulate extending the HDPE liner part way through the weathered bedrock where the fluid flow was concentrated.

The thermal and ground water seepage analysis was conducted using numerical modeling software applications developed by Geo-Slope International (TEMP/W and SEEP/W). A scaled model of the proposed dam and underlying strata was constructed in the software application using material properties measured at the site, as well as documented values for similar materials. Climatological and geographical data for the region were also acquired and incorporated into analysis. The model was constructed in three separate phases to correspond with the three proposed phases of dam construction. The analysis results of each preceding phase were subsequently applied as initial conditions in the analysis for each succeeding phase to effectively model the long-term effects of the dam and stored tailings on the frozen ground. Heat removal requirements were also examined in the analysis, and thermosyphon placement and size were estimated to maintain the frozen regime of the upstream toe of the dam.

Results of the analyses indicate that the use of thermosyphons is not cost effective and that extending the cutoff liner through 2/3 of the weathered bedrock significantly reduces fluid flow. It is apparent that the introduction of warm tails (above freezing at the time they are pumped into the reservoir area) impacts the permafrost foundation area. The permeability of the weathered bedrock and the fluid flow with its accompanying heat transfer are high enough to prevent the thermosyphons from creating a complete barrier to fluid flow. As the flow section decreases during the winter, the fluid flow velocity increases with an increased head. This increased velocity increases the thermal erosion rate, transferring the cooled fluid downstream where it is ineffective for developing a permanent barrier.

The modeling effort was conducted in metric units to match the previous and continuing work being completed for the project. Table 1 presents conversions for all of the units used within the model.

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2.0 PROJECT LOCATION AND DESCRIPTION

The Rock Creek Project is a gold ore mining and extraction operation proposed to be constructed along the southwestern flank of Mt. Brynteson, approximately 6 miles north of Nome, Alaska (Figure 1). The proposed project site is located within Sections 14, 15, 22, 23, 24, 25, 26, and 33, T10N, R34W, Kateel River Meridian, Alaska. The project facilities will be constructed along both sides of Rock Creek (a drainage of Mt. Brynteson and a tributary of the Snake River), and will consist of an open pit mine, ore processing and extraction facilities, tailings storage facility, and associated operation/administrative facilities. The base of the site sits at an approximate elevation of 100 meters above mean sea level (msl) with approximately 135 meters of relief across the site. The terrain is gently sloping to near vertical and is vegetated with low lying grasses and shrubs, muskeg, and riparian alders. Figure 2 presents a map of the TSF portion of the project site as it is currently planned.

Nome is located in area of discontinuous permafrost. Areas that have been disturbed by mining activities, larger stream beds and lakes are typically underlain with thawed ground. Undisturbed areas typically are underlain with permafrost that extends from a few to about 100 feet below the surface. Permafrost temperatures are typically quite warm and usually greater than -3°C. Annual temperature/precipitation values range from -15°C to 10°C with an average of 42 cm of rainfall equivalent precipitation (including snowfall) falling each year (Norwest, 2003). The average annual temperature is below 0°C thus barely maintaining the existing permafrost.

Approximately 7.5 million tons of gold ore (approx. 6,000 tons per day) is projected to be removed from the Rock Creek mine over the projected operational life of the mine (approx. 3-4 years). The Rock Creek processing and extraction facility will also accommodate and additional 1000 tons of gold ore per day which will be transported to the site from the Big Hurrah open pit gold mine located approximately 30 miles east of Nome.

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The tailings produced from the gold extraction process will be in paste form (very thick slurry), with the majority of the processing solution/water removed to be reused in the extraction process prior to placing the tails in the reservoir area. A Tailing Storage Facility (TSF) will be constructed south of Rock Creek, and will consist of a homogenous rock-fill dam with a 60-mil HDPE geomembrane lining the upstream face of the dam. The Tailing Storage Facility Dam (TSFD) will be constructed in three stages to minimize initial construction costs. Figure 3 shows a cross section of the dam with the three phases indicated. Figure 4 shows the modified cross-section for the extended liner analysis. The tailings will be placed behind the TSFD using a gravity-fed HDPE pipeline distribution system which will place the tailings from bottom to top using a series of distribution towers, and proceed up slope as tailing placement continues. Once mining operations have ended and tailings placement ceased, the TSF surface will be reclaimed and have permanent surface drainage features emplaced.

3.0 PREVIOUS WORK

3.1 Preliminary Economic Study

(Norwest Corporation - August 2003)

NovaGold Resources Inc. (NovaGold) contracted Norwest Corporation (Norwest) to conduct a preliminary economic study, mine plan, and cost estimate for the Rock Creek Project in the spring of 2003. The report provides a general description of the project site and project objectives. It also provides a fairly detailed account of the regional and local geology, mineral resource, and evaluates the potential recoverable gold based on a series of cores drilled across the extent of the site. The report provides recommendations for pit and rock dump dimensions, and initial recommendations for the TSF and impoundment dam construction. The report concludes the need for an in-depth geotechnical assessment of the site, and recommends additional core holes, boreholes, and test pits be installed across the site to better characterize the subsurface materials and aid in the refinement of the designs for the pit walls, rock dump foundations, TSF and TSFD, drainage system, and processing facility foundations.

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3.2 Draft Geotechnical Site Investigation
(Golder Associates - February 2004)

NovaGold contracted Golder Associates (Golder) to conduct geotechnical explorations at the Rock Creek Project site in the fall of 2003. The explorations were aimed at characterizing the subsurface conditions which exist beneath the proposed mine pit, TSF, processing facility site, and rock waste dumps. The explorations consisted of the installation of multiple core holes, boreholes, and test pits across the site (graphical logs were provided in the appendix of the Golder report). Appropriate rock and soil samples were collected and submitted for a suite of geotechnical analyses. The report details the subsurface conditions at each respective location, and provides a brief description of the permafrost and ground water conditions encountered across the site.

3.3 Geotechnical Site Investigation
(Smith Williams Consultants - April 2005)

Alaska Gold Company (Alaska Gold) contracted Smith Williams Consultants, Inc. (SWC) to conduct geotechnical explorations at the Rock Creek Project site in the summer and fall of 2004. The explorations were conducted in two phases due to issues which arose regarding equipment availability, site access, and facility design reconfigurations. Phase I was conducted in August of 2004 and consisted of the advancement of four core holes along the extent of the proposed TSFD and the excavation of a total of 34 test pits at selected locations across the site corresponding to proposed facility locations. Representative rock and soil samples were collected and submitted for a suite of geotechnical analyses. Grab samples of existing placer tailings located along Glacier Creek were also collected for geotechnical analyses to determine their suitability for use as drainage and bedding materials. Vibrating-wire piezometers and thermister strings were installed into all four of the core holes drilled during phase one of the explorations.

Phase two of the explorations were conducted in November of 2004 and consisted of excavating a total of 28 additional test pits at areas located across the site which either: 1) encountered refusal during phase one of the explorations due to frozen conditions; 2)

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were inaccessible during phase one of the explorations due to thawed surface conditions; or 3) which corresponded to facility design reconfigurations which were enacted after phase one of the explorations were completed. Representative rock and soil samples were collected and submitted for a suite of geotechnical analyses.

A summary of the subsurface conditions encountered at each of the facility sites and recommendations concerning building foundations and retaining structures is provided within. Graphical logs for the core holes and test pits installed during both phases of the explorations, results of the laboratory analyses, and data recorded from the thermister strings were all included in the appendices of the SWC report.

3.4 Feasibility Design Study
(Smith Williams Consultants - June 2005)

SWC completed a feasibility design study for the Rock Creek Project following the geotechnical explorations they conducted at the site in the fall of 2004 for Alaska Gold. The study accounts for all of the available information collected from the previous explorations conducted at the site, as well as all of the design changes enacted since the conception of the project, and presents a comprehensive evaluation of the existing site conditions and present comprehensive design recommendations for all of the proposed project facilities.

As part of the study, SWC conducted a preliminary seepage analysis for the proposed TSF using SEEP/W finite seepage analysis software) to estimate seepage flows, head distribution, and water levels within the TSFD. Estimates obtained from the preliminary analysis indicate that approximately 120,000 m^3 of fluid seepage may occur each year through the TSFD. The analysis also indicated that the stability of the TSFD should not be affected by the volume of fluids which is predicted to exist within the TSFD under normal operating procedures and average climatic conditions. The analysis indicated that even with total liner failure, the stability of the TSFD should not be compromised.

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To this date, this is the most current and comprehensive report detailing the existing conditions identified at the site and the proposed design for the project. This study is the basis for the all of the design dimensions and subsurface conditions used to construct the model of the TSFD used in our thermal and fluid seepage analyses.

4.0 SUBSURFACE CONDITIONS

As mentioned in Section 3.0, several subsurface exploration programs have been conducted at the site, and the subsurface conditions at the site have been characterized through the installation of multiple core holes, boreholes, and test pits located across the extent of the site. A complete description of the subsurface conditions encountered across the site is not included in this report, and the focus will only be on the subsurface conditions observed beneath the proposed TSF and TSFD. For a complete description of the subsurface conditions across the remaining portion of the site, please refer to the reports listed in Section 3.0.

The entire TSF footprint is overlain by a thin organic mat ranging from 0.05 meters to 0.15 meters in thickness. Low-lying areas and drainages located within the limits of the proposed TSF are typically underlain by differing thicknesses of sand, silt and gravel mixtures overlying which overlie fractured bedrock. These areas are typically characterized at the surface by shrub and willow thickets and represent thawed soil zones with subsurface water flow. The remaining portions of the proposed TSF footprint are underlain by finer-grained silts and sandy silts which are saturated, ice-rich, and overlay frozen bedrock. The ice-rich materials display moisture contents up to, and exceeding 100 percent of the total sample mass. These areas are characterized at the surface by low-lying sedge and tundra.

The footprint of the TSFD is also overlain by a thin tundra mat ranging from 0.09 meters to 0.12 meters in thickness. It is subsequently underlain by a 0.5 meter thick layer of saturated silts, which in turn is underlain by zero to six meters of silt and sandy silt which are saturated and ice-rich (permafrost). The ice-rich materials display moisture contents up to, and exceeding 100 percent of the total sample mass. The surficial sediments are

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underlain by a graphic schist bedrock containing visible sulfides, significant quartz veining, and substantial evidence of calcite. The condition of the schist ranges from decomposed or rubblized to competent at depths of 0.6 to 6.1 meters. The weathered bedrock material is frozen to depth, except along the Rock Creek drainage, where the material is thawed. Core samples reveal that the bedrock is moderately to highly fractured at depth. Data collected from thermister strings placed in core holes located along the centerline of the proposed TSFD indicate that temperatures within the bedrock range from -1/7°C to -1.2 °C at the bedrock surface (5-6 meters bgs) to -1.3°c to -1.2°C at a depth of 25 meters bgs. Permeability testing conducted in the four boreholes located along the centerline of the TSFD indicates that the bedrock has permeabilities ranging from 1.2×10^{-3} to 4.1×10^{-6} m/s, with higher permeabilities observed near the Rock Creek drainage and along the southern extent of the TSFD. The increased permeabilities are thought to represent areas of highly fractured bedrock, and where the fractures are relatively open and ice-free.

Based on the subsurface information derived from the several previous studies, a generalized cross-section was developed as shown in Figures 3 and 4. As with all sites, there was a range of material parameters for each unit, details of which are presented in the following Section 5.2.3.

5.0 COMPUTER ANALYSIS

5.1 Brief Overview of Numerical Modeling

Numerical modeling is a technique which utilizes mathematics to simulate actual physical processes. Numerical modeling has only recently become a viable industry tool with the advent of high-speed microprocessors and advanced software design, which can efficiently process the complex calculations involved. While computers and associated numerical modeling software have made the modeling process a more accessible and less expensive alternative to physical modeling and actual field testing, they have not eliminated the need for user understanding and expertise. The modeling program is only a glorified calculator; the model design, material properties, and analysis settings and

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results must still be evaluated and deemed reasonable by a competent and knowledgeable user.

Numerical modeling is a non-invasive and relatively expeditious technique which allows the user to manipulate initial site conditions and forecast (predict) future site conditions. However, because the model analysis is based on user defined material properties, the results generated are only as accurate as the data that is initially input. Furthermore, averaged values for material properties are often used in the modeling process to limit the complexity of the model, and allow for a more manageable data set. These generalizations do not account for the small-scale variations (both vertical and lateral) which often occur in earth materials. Therefore, results obtained from numerical models should not be viewed as real-world solutions, but should instead be used along with other site-specific data to help guide future site design.

5.2 Modeling Procedure

Numerical modeling of the TSFD was conducted using thermal and fluid seepage analysis software applications (TEMP/W & SEEP/W) developed and produced by GeoSlope International, Ltd. TEMP/W & SEEP/W are two-dimensional, finite-element analysis software applications which can model (predict) thermal and hydraulic changes in specified materials due to environmental changes, construction, and/or demolition of structures which may alter the thermal and hydraulic regimes of the materials modeled. Furthermore, TEMP/W & SEEP/W can perform time-step analyses in concert with one another effectively modeling convective heat transfer to predict the real-time impact that groundwater seepage has on the freeze-thaw interface of specified materials, and to predict the volume of water that will seep through the dam and underling native materials over the course of time.

For this project 2 models were developed because the model using thermosyphons to restrict water flow under the dam appeared to be relatively ineffective. The second model was created to assess the effectiveness of extending the HDPE liner part way through the weathered bedrock. A total of 7 scenarios were run. Details of each are presented in Section 5.4.

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5.2.1 Model Generation

A scaled model of the proposed TSFD (and surrounding/underlying materials) was first constructed in the software program's graphical user interface using the available design tools. A layered model was constructed which depicts the tailings stockpile and associated TSFD, as well as the underlying soils/bedrock depicted in Figures 3 and 4. The model was constructed in a manner which incorporates all three phases of the proposed TFSD construction into one model. This design method allowed the thermal/seepage analysis to be executed in three separate phases corresponding to the three proposed phases of dam construction (Phases I-III). Figure 5 presents a flow chart of the analysis procedures used for each of the 7 scenarios.

Furthermore, the three phase model allowed for the calculation of site conditions predicted to exist at the scheduled initiation of Phases II and III of dam construction. The three-phase model addresses this concern since the TSF (as well as the TSFD and surrounding/underlying materials) will not have reached equilibrium by the scheduled initiation of succeeding phases of dam construction.

Therefore, the results of the analysis for each preceding phase of the model were subsequently incorporated as initial conditions for each succeeding phase of dam construction to effectively model the impact of the changing configuration. Long-term effects of the TSF following completion of the mining operations could then be modeled using the final configuration and applying the boundary conditions for multiple years.

5.2.2 Mesh Configuration

Before any thermal/seepage analysis could be performed, the model had to be divided into individual units known as "regions". The region dimensions are designated by the user, and allow the user to assign material properties to the model (Discussion of material properties is provided in Section 5.2.3). Figure 6 shows the regions used for the thermosyphon analysis and Figure 7 shows the regions used for the extended liner analysis. The regions are subsequently divided into smaller units known as "elements" during a process known as "meshing. The software application generates an "element mesh" (a.k.a. grid), which allows the program to relate information contained within each

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element to the surrounding elements during the temporal analyses. Each element is composed of the most basic model units known as "nodes" (i.e. corner points), which link each element to one another within each region, and between surrounding regions.

The physical configuration of the element mesh generated for all three phases of the thermosyphon model is displayed in Figure 8. Figure 9 shows a detail of the thermosyphon node placement. A similar mesh was developed for the extended liner and is shown in Figure 10. The comprehensive model (Phase III) of the thermosyphon analysis included a total of 8803 nodes comprising a total of 8513 elements which were arranged in both structured and unstructured quad meshes across a total of 86 regions. The liner extension model was similar in size.

All of the elements located along the vertical downstream extent of the model were assigned as "infinite elements", and extended laterally to infinity (Figures 8 and 10). Infinite elements allow the user to extend the effective influence of the boundary conditions (in either the X or Y direction, or both) without actually extending the mesh. Thus reducing the number of nodes/elements that would otherwise be required to extend the model to a distance far enough away from the TSFD so as not to influence the results of the analysis near the area of interest.

5.2.3 Material Properties

The model generated for the proposed TSFD is comprised of six different materials which represent the five earth materials and the HDPE liner that are proposed to be used in the construction of the TSF (See Sections 2.0 and 4.0). The six materials include: 1) Fractured bedrock; 2) Weathered/decomposed bedrock; 3) Native topsoil; 4) Mine tailings (paste); 5) Rock fill used for dam construction; and 6) HDPE geomembrane used to line the upstream face of the TSFD.

The two natural processes simulated in this study are: 1) the transfer of heat energy through earth materials (thermal analysis); and 2) the movement of water through earth materials (seepage analysis). These processes are evaluated based on certain physical properties inherent to each earth material. The thermal and hydraulic properties for each

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of the six materials comprising the model were obtained and/or derived from a combination of: 1) site specific field data; 2) established values documented in existing literature for similar materials; and 3) from previously defined material properties listed in the TEMP/W & SEEP/W. Table 2 summarizes the material properties used.

Appendix A defines and presents the thermal functions used in the modeling effort (Thermal Conductivity and Unfrozen Water Content). Similarly Appendix B defines and presents the hydraulic functions used (Hydraulic Conductivity and Volumetric Water Content).

5.2.4 Boundary Conditions

Boundary conditions are used to define the external conditions that affect the temperature and seepage within the model, and are in essence what define the direction that energy or fluids will move within the system. Boundary conditions are used by the program to calculate the gradient within a problem set, whether it be heat energy flux into or out of a system, or ground water flow through a system. Boundary conditions are user defined, and are usually based on real-world data (i.e. climate data, elevation data, geothermal data, etc.).

The boundary conditions used for this model included air temperature coupled with modifiers, precipitation, and wind. Details of these functions are presented in Appendix C.

5.2.5 Thermosyphons

Thermosyphons are gas filled sealed tubes that through phase change in the gas are capable of transferring heat from a warm location to a colder location. Typically the tubes are filled with pressurized Carbon Dioxide (CO_2). The pressure used defines the temperature at which the CO_2 changes from a gas to a liquid. To maintain permafrost, the liquid needs to boil and change to a gas at a temperature below the freezing temperature of water. The gas will then revert to a liquid at a lower temperature. Within a sealed tube, the gas will rise to the top where a radiator is located. When the air temperature is low enough to remove the latent heat of the gas, it turns into a liquid and flows back down the

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tube. The warm earth temperatures then boil the liquid absorbing heat from the ground. The gas then floats to the radiator, repeating the cycle.

To model the thermosyphon function, the model needs to assess the temperature difference between the ground adjacent to the thermosyphon (See Figure 9 for locations) and the air temperature. The amount of heat that can be removed is a function of the radiator size in relation to the thermosyphon pipe size (length) and the efficiency of the radiator. The radiator efficiency is a function of the wind speed, air temperature and configuration of the piping in the ground.

The efficiency of the thermosyphon configuration in the ground was developed from data provided by the manufacturer and input into the model. The configuration used for the model represents nearly the minimum efficiency for thermosyphons due to the nearly flat configuration of the piping in the ground. The model does not represent the extreme length or flatness of thermosyphons that have been installed and function.

For this model, the thermosyphon length and ground configuration are constants and the air temperature and wind speed functions are input. For this design, it was assumed that the thermosyphon would run along the base of the dam with radiators at both ends. The length input was taken as ½ of the total length of the dam at the end of Phase III. The only remaining variable is the size of the radiator, which is measured in surface area of the fins. Two different sizes were modeled, 1) a radiator size of 50 m^2 being a normal large radiator consisting of 3 or 4 fin sets attached to the top of each thermosyphon, and 2) a radiator size of 200m^2 representing a likely extreme size radiator set on each end of the thermosyphon.

5.3 Analysis Procedure

As discussed in the model set up in section 5.1, the analysis uses a multi-step procedure to account for the anticipated out-of-equilibrium conditions that exist at the beginning of each Phase of construction. Figure 5 presents the flow chart used for the analysis of each phase.

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Seven different scenarios were analyzed to assess different conditions. These scenarios can be grouped into 3 sets based on the initial conditions assumed. They are:

- Group 1, Current Conditions
    1. Scenario 1. Current conditions, no thermosyphons
    2. Scenario 3. Current conditions with small thermosyphons
    3. Scenario 4. Current conditions with large thermosyphons
- Group 2, Elevated Conditions
    1. Scenario 5. Elevated boundary conditions without thermosyphons
    2. Scenario 6. Elevated boundary conditions with small thermosyphons
    3. Scenario 7. Elevated boundary conditions with large thermosyphons
- Group 3, Current Conditions with an extended liner

Details of the phase analyses are presented in the sections below. The scenario analysis discussions are presented in Section 5.4

5.3.1 Phase I

Before any transient analyses could be performed, an initial conditions file had to be generated (through a steady state analysis) which established the subsurface thermal and hydraulic conditions of the native materials located within the footprint of the proposed TSF. The steady-state analysis was performed to establish the initial thermal and hydraulic conditions of the native materials at equilibrium (as measured in the field), prior to the addition or removal of any materials at the surface of the model (i.e. addition of dam material, tailings, or removal of native overburden). This was accomplished by applying a series of lateral thermal boundary conditions which defined the thermal gradient of the native materials prior to TSFD construction. The boundary condition temperatures were adjusted until the vertical thermal gradient produced by the steady state analysis effectively represented the actual subsurface conditions measured at the site (i.e. thermistor values from core holes along the TSFD centerline).

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The initial hydraulic conditions of the native materials were defined by applying pressure head boundary conditions to each node along the surface of the weathered bedrock layer (which is where ground water table is reported to exist). This boundary condition essentially assigns a hydraulic head pressure to each node based on the Y-coordinate of the node (*i.e.* node elevation above msl).

The results of these steady state analyses represent the initial thermal and hydraulic conditions predicted to exist at the TSF site at the proposed start of TSFD construction in January of 2006 (designated as Jan:01).

The results of the steady state analyses (thermal and hydraulic) were then used as the initial conditions for a transient thermal analysis aimed at predicting the thermal and hydraulic conditions of the TSFD and underlying native materials during construction of Phase I of the TSFD, but prior to initial tailings placement. Results of the analyses for the three groups are presented in Appendix D.

Before the transient analysis was performed, the regions within the model which represent the fist phase of the TSFD were activated, and each node within these regions was assigned a thermal boundary condition equal to -5.8°C (the average air temperature between January and August), estimated temperature of rock fill used to construct the TSFD. A transient analysis then was run for one, 24-hour time step to establish the initial thermal and hydraulic conditions of the TSFD. The results were then saved as the initial conditions for the following transient analysis which predicts the impact of the TSFD on the thermal and hydraulic conditions of the native materials the course of the following 8 months. (Jan:01 to Aug:01).

A transient analysis (using connective heat transfer analysis w/ SEEP/W) was then initiated which ran from January (of the first year of TSFD construction – designated Jan:01) to August (of the first year of TSFD construction – designated as Aug:01), using an individual time-step of 24 hours. The result of the transient analysis is the predicted thermal and hydraulic conditions of the first phase of TSFD construction (and underlying native materials) prior to tailings placement. The results of this analysis were then saved as the initial conditions for the following the transient analysis which analyzes the impact

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of Phase I of tailings placement on the thermal and hydraulic conditions of the TSFD and native materials.

Results of the analyses prior to placement of the Phase I tails are presented in Appendix D.

The regions representing Phase I of tailings placement were then activated within the model. Each node within these regions was assigned a constant thermal boundary condition of 2°C (assumed average temperature of tailings as they are placed behind the TSFD). Also, a hydraulic boundary condition was placed along all of the nodes which define the bottom of the tailings (i.e. the tailings interface w/ the underlying native materials and the upstream face of the TSFD) which assigned a potential head to all of the selected nodes equal to the maximum height of the tailings along the TSFD face (i.e. maximum potential head of water stored within the tailings). A transient analysis then was run for one, 24-hour time step to establish the initial thermal and hydraulic conditions of the tailings. The results were then saved as the initial conditions for the following transient analysis which predicts the impact of the stored tailings on the thermal and hydraulic conditions of the native materials and TSFD over the course of the next 365 days. (Aug:01 to Aug:02).

The ensuing transient analysis was run for 365 days with 24 hours time steps. The results of this transient analysis display the predicted thermal and hydraulic conditions of the TSFD and native materials after one year of operation (Aug:02). The results of this year-long analysis then subsequently saved as the initial conditions for Phase II of TSF construction/operation.

Results of the Phase I analysis for the 7 scenarios are presented in Appendix E.

5.3.2 Phase II

The results of the year-long, Phase I transient analysis (Aug:01 to Aug:02) were subsequently applied as the initial conditions for a transient analysis of Phase II of TSFD construction and tailings placement. The regions representing Phase II of the TSFD and

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tailings placement were then activated within the model (as was performed in Phase I) and every node located within the newly activated TSFD regions was assigned a boundary condition equal to 2.2°C, and every node within Phase II of the tailings was assigned a thermal boundary condition of 2°C (See Section 5.3.1). A transient analysis was then executed for one, 24-hour time step to establish the thermal and hydraulic conditions of the second phase of TSFD construction and tailings placement. The results were then saved as the initial conditions for a transient analysis which predicts the impact of the stored tailings on the thermal and hydraulic conditions of the TSFD and native materials over the course of the ensuing 365 days (up to Aug:03). The transient analysis was carried out for 365 days with 24 hours time steps. The results of this transient analysis display the predicted thermal and hydraulic conditions of the TSFD and native materials after two years of operation.

Results of the Phase II analyses for the seven scenarios are presented in Appendix F.

5.3.3 Phase III

The results of the year-long, Phase II transient analysis (Aug:02 to Aug:03) were subsequently applied as the initial conditions for a transient analysis of Phase III of TSFD construction and tailings placement. The regions representing Phase III of the TSFD and tailings placement were then activated within the model (as was performed in Phase I and II) and every node located within the newly activated TSFD regions was again assigned a boundary condition equal to 2.2°C, and every node within Phase II of the tailings was assigned a thermal boundary condition of 2°C. A transient analysis was then executed for one, 24-hour time step to establish the thermal and hydraulic conditions of the third and final phase of TSFD construction and tailings placement. The results were then saved as the initial conditions for a transient analysis which predicts the impact of the stored tailings on the thermal and hydraulic conditions of the TSFD and native materials over the course of the ensuing 365 days (up to Aug:04). The transient analysis was carried out for 365 days with 24 hours time steps. The results of this transient analysis display the calculated predicted thermal and hydraulic conditions of the TSFD and native materials after three years of operation.

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Results of the analyses at the end of Phase III are presented in Appendix G for all seven scenarios.

5.3.4. Extended Analysis (9 year)

The results of the Phase III analysis were then saved as the initial conditions for a final transient analysis which predicts the impact of the stored tailings on the thermal and hydraulic conditions of the TSFD and native materials over an extended period of time after TSF closure has occurred (up to Aug:13). The transient analysis was carried out for a total of 3290 days (9 years) using 24 hour time steps. The results of this transient analysis display the predicted thermal and hydraulic conditions of the TSFD and native materials nine years after TSF operations cease.

Results of the extended analyses for the seven scenarios are presented in Appendix H.

5.4 Analysis Scenarios

Once a functional and reasonable analysis procedure had been developed, several different scenarios were generated and analyzed which allowed for the investigation of the effect(s) that differing material properties, boundary conditions, and heat removal systems could have on the thermal and hydraulic conditions of the TSFD and native materials during and after tailings placement within the TSF. A total of seven different scenarios were analyzed using the fundamental three-phase model described in Section 5.3.

5.4.1 Scenario 1

Current Site Conditions

Scenario 1 analyzes the fundamental three-phase model of the TSFD using material property functions derived from data obtained from the site and from published values for similar materials. Appendices A and B along with Table 2 list the material property functions for all 6 materials used in Scenario 1. The climatic boundary condition function used Scenario 1 is based on recent average ambient air temperatures and precipitation for the Nome area (Appendix C).

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The material properties and boundary conditions used for this scenario were used without alteration for scenarios 2, 3, and 4.

5.4.2 Scenario 2

Current Site Conditions w/ Extended Liner

Scenario 2 analyzes the fundamental three-phase model of the TSFD using the material property functions for scenario 1. Results from scenario 1 showed that most of the water flow from the tails toward the downstream toe went through the weathered bedrock. To reduce this flow, the liner used to prevent fluid flow through the rock fill dam was extended about 2/3 of the way through the weathered bedrock.

5.4.3 Scenario 3

Current Site Conditions w/ Heat Removal System (50 m^2 Radiator)

Scenario 3 is based off scenario 1 and analyzes the potential effect that a heat removal system could have on the thermal and hydraulic conditions of the TSFD and native materials. The heat removal system consists of two thermosyphons which were placed at two nodes, just downstream of the upstream toe of the TSFD, and immediately beneath the geomembrane liner material as shown in Figure 9. The heat removal capacity of each thermosyphon is based on a total condenser radiator area of 50 square meters (average maximum size for condenser radiators used in similar applications) per thermosyphon. All other boundary conditions and material property functions remain unchanged from Scenario 1.

5.4.4. Scenario 4

Current Site Conditions w/ Heat Removal System (200 m^2 Radiator)

Scenario 4 applies the same conditions as Scenario 3 (See Section 5.4.3.) except that the total condenser radiator area was increased to 200 square meters per thermosyphon. All other material property functions remain unchanged. The results of this analysis were compared with the results from Scenario 3 to determine the effect that increased

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condenser radiator size would have on the thermal and hydraulic conditions of the TSFD and native materials.

5.4.5. Scenario 5

Elevated Temperatures and Hydraulic Conductivity

Scenario 5 analyzes the potential effect that a five-fold increase in the hydraulic conductivity function for the native weathered bedrock material would have and the thermal and hydraulic conditions of the TSFD and native materials. The average annual air temperature was increased by 3°C, representing a major increase in global temperature. Appendix C discusses the boundary conditions used. All other boundary conditions and other material property functions remain unchanged from Scenario 1.

5.4.6. Scenario 6

Elevated Temperature and Hydraulic Conductivity and Heat Removal System ($50m^2$ Radiator)

Scenario 6 applies the same boundary conditions used in Scenario 5 with a thermosyphon system equal to that used in scenario 3. All other material property functions remain unchanged. The results of this analysis were compared with the results from Scenario 3 to determine the effect that increased permeability values would have on the thermal and hydraulic conditions of the TSFD and native materials. Scenario 5 was also compared to scenario 4 to assess the effect of the thermosyphons on the increased flow.

5.4.7. Scenario 7

Elevated Temperature and Hydraulic Conductivity Heat Removal System ($200m^2$ Radiator)

Scenario 7 applies the same conditions as in Scenario 5 (See Section 5.4.5.) and applying the extreme thermosyphon system used in scenario 4. All other boundary conditions remain unchanged. The results of this analysis were compared with the results from Scenario 5 to determine the effect that the thermosyphons have and to scenario 4 to assess the effects of the increased temperature and hydraulic conductivity.

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5.5 Analysis Results

All seven scenarios were analyzed by the modeling software, and the results were then compared to one another to determine what effect differing material properties, boundary conditions, and heat removal systems would have on the TSFD and surrounding native materials.

The first stage of analysis was to evaluate the mass balance of the fluids within the system. Figure 11 presents a schematic of the mass balance elements for the modeled system. Flux sections, which are used to determine the amount of discharge occurring thorough individual elements within the model, were placed at the upstream and downstream toes of the TSFD to calculate the discharge rate (Q) in cubic meters/hour that is predicted to occur in each phase of the analyses. A vertical flux section was placed across the elements through which subsurface flow is predicted to occur (i.e. the elements located above the frozen bedrock and below the geomembrane liner material and ground surface) to calculate the instantaneous horizontal flow rates which occur through each of the specified elements within the models. The instantaneous flow rates for each time step in the analysis were obtained from the flux sections and averaged together to obtain an average discharge rate for each year-long analysis.

Next, the cumulative hydraulic boundary flux for each node along the top and downstream face of the TSFD (which occurred over the course of each analysis) was calculated using the software. Using the flux volume and the total calculated precipitation volume, the amount of runoff and infiltration could be determined.

Ice melt and thaw was determined by calculating the change in the volumetric water content at each node. These changes were summed for the TSFD cross section, including the region of weathered bedrock between the flux sections. The ice melt includes changes in moisture content above the saturated region which also affects the water balance.

The water balance calculations for each phase of each scenario are presented in Table 3. The water balance and subsequent water outflow calculations are further complicated by the fact that all of the tails does not enter the facility at the beginning of each phase as

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modeled. Nor does the entire dam have a cross section equal to the maximum cross section modeled. To compensate for the actual conditions of continuous inflow of tails and variable dam height, the model calculated flows were adjusted. Figure 12 presents a schematic of the averaging scheme used.

It should be noted that the averaging factors for the precipitation, inflow, outflow and ice melt are not constant with each other or for each phase due to differences in the flux boundary geometries for each variable of the water balance. This was corrected by first calculating an approximate factor based on geometry and inputting the factors into all seven scenarios for each phase of analysis. The factors were then adjusted, with the largest adjustments going to the ice melt (as this factor was the least certain in our model data calculations) such that the difference between inflow and outflow for the seven scenarios combined was minimized.

Prior to adjustment, most of the calculated water balances were within 10% of each other, with the larger variations occurring in the late phases of the analysis. Based on the numerous assumptions made in developing the model, this variation was considered within the limits of the analysis. Following adjustments, the water balances between inflow and outflow were generally within about 5 percent.

From the calculations above, the predicted outflow from the base of the dam was calculated. The results are presented in Table 4. The calculated data also allowed calculation of the approximate percent volume of the outflow that is derived from infiltrated precipitation and ice melt. Where ice melt percentages are not tabulated on Table 4, the ice volume was either balanced or there was a net ice accumulation, resulting in no outflow component. Ice accumulation occurs when the inflow to the flux section exceeds the net outflow.

Due to temperature changes the monthly flow distribution is not uniform with most of the outflow occurring in August, September and October. The thermosyphons tended to grow ice in the winter months which then melted out in the summer further concentrating the flow. Table 5 presents the percent of flow per month for the different scenarios. Where

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the flow distributions were similar, the scenarios were lumped together into one set of data.

The seven scenarios were compared to each other. The end result of each phase was compared for the seven scenarios. Plots of the temperature and hydraulic conditions were grouped by phase and are presented in Appendices D through H. A discussion for each scenario is presented below.

Additional review was completed for each scenario by reviewed intermediate time steps throughout the 3 phases and extended analysis. Time step plots for scenario 2 Phase III are presented in Appendix I. All of the phases and scenarios could have time step plots made.

5.5.1. Scenario 1

Scenario 1 represents the base conditions assumed for the model. These assumptions were made based on the field data, existing environmental data base, published literature and initial calibration runs used to establish a pre-construction equilibrium for the model. During the year for all of the phases (See 5.5.2 for detailed discussion of analysis of Appendix I data) of scenario 1, some ice growth was observed in the winter with subsequent thawing the following year. Introduction of the tails into the system increased temperatures throughout the system with water seepage carrying heat downstream.

Water accumulation was observed on the liner during the initial third of the phase. This water eventually flowed to the toe of the liner and into the weathered bedrock. Ice erosion was noticed, especially in the early summer while the winter ice accumulation still had the flow path somewhat restricted, which increased the flow velocities by keeping the upstream head high.

Each addition of tails for each new phase increased the water supply into the system. Because the water was generally warmer than the tails below and under the dam, a thermal plume could be seen. During the winter months, the water in the dam foundation started to freeze back, loosing its heat to warm up, but not thaw the ice below the dam.

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After completion of the tails impoundment at the end of Phase III, a general cooling of the tails and dam foundation was observed. Additionally, with no additional water derived from the tails, water flow decreased. Eventually, the water flow would approximate the precipitation input to the TSF. This equilibrium was not achieved in the two year extended analysis.

5.5.2. Scenario 2

Scenario 2 was developed following review of the model results from the thermosyphon analyses (Scenarios 3 and 4). It is clear from the results of scenario 1 that a vast majority of water seeping under the dam flows through the weathered bedrock. To reduce the water flow, an artificial cutoff was modeled with the liner extending about 2/3 of the way through the modeled weathered bedrock zone. See Figures 4 and 7.

Cutting off the majority of the water flow in the weathered bedrock had a significant effect on the total outflow measured downstream. This in turn resulted in cooler temperatures within the permafrost below the dam, higher retained moisture within the tails and less ice melt.

In the long-term runs (See Appendix H), the differences between scenario 1 and 2 become less, although it is apparent that there is more water remaining in the tails in scenario 2.

5.5.3. Scenario 3

Scenario 3 uses the material properties and boundary conditions from Scenario 1 with thermosyphons added at the upstream toe of the dam. Cooling of the soil below the liner was evident in the fall and winter months, however the fluid flow was never cut off completely. Heat carried from the tails through the weathered bedrock flowed over the frozen section up into the dam rock fill material. The majority of the head loss realized was due to the rise in elevation to flow over the frozen bulb.

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In the spring when the thermosyphons were no longer active (the ground temperature immediately surrounding the thermosyphon was lower than the air temperature), the frozen bulb that had developed over the winter begins to shrink. By the beginning of August, the increased flow from the thawing tails, the thawing freeze bulb, and thermal erosion from the fluid flow combine to greatly increase the outflow at the toe of the dam.

By the time the thermosyphons again become active in late September, the thermal regime is essentially the same as the previous year. Following the phase III addition of tails, the flow rate begins to drop off as the heat and water supply diminish. The thermosyphons then begin to build a frozen bulb that increases each cooling season. It is expected that within several years the flow corridor through the weathered bedrock would seal off with a frozen barrier.

5.5.4. Scenario 4

Scenario 4 is similar to scenario 3 with additional cooling capacity. The additional cooling capacity was evident in the annual development of a frozen bulb. Each year the bulb would be slightly larger than that developed in Scenario 3. Each thawing season, the frozen bulb would melt out completely.

It appears that the decreased flow area increased the flow velocity, canceling the effect of freezing the weathered bedrock. Similar to Scenario 3, following the final tails placement, the flow area trended toward freezing a blockage. The growth of the frozen bulb is slightly faster than noted in Scenario 3. It appears that the cooling rate at the thaw/frozen interface of the bulb is governed by the thermal conductivity of the frozen weathered bedrock surrounding the thermosyphon.

5.5.5. Scenario 5

Increasing the permeability of the weathered bedrock had a significant effect on the water flow at the downstream toe of the dam. The tails drained faster which also tended to erode the upstream permafrost under the tails. The increased temperature had less of an impact on the model. The thaw season was lengthened and the freezing season shortened, however at depth within the model, the material temperatures changed very little.

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The average annual temperature for the raised conditions is still below freezing. Discounting solar radiation gains, the permafrost would still be maintained by the ambient air conditions. With the solar gain it is possible that there will be a gradual degradation of the permafrost.

The increased flow through the weathered bedrock increases the thaw rate of the permafrost under the dam. Below the weathered bedrock there is slight rise in temperature although through the modeled time frame, the bedrock remains frozen.

5.5.6. Scenario 6

Scenario 6 is similar to scenario 3 but uses the model parameters developed for scenario 5. Cooling of the soil below the liner was evident in the fall and winter months, however the fluid flow was never cut off completely. As expected the cutoff was slightly less than that achieved in scenario 3. Heat carried from the tails through the weathered bedrock flowed over the frozen section up into the dam rock fill material. The majority of the head loss realized was due to the rise in elevation to flow over the frozen bulb.

In the spring when the thermosyphons were no longer active (the ground temperature immediately surrounding the thermosyphon was lower than the air temperature), the frozen bulb that had developed over the winter begins to shrink. By late July or the beginning of August, the increased flow from the thawing tails, the thawing freeze bulb, and thermal erosion from the fluid flow combine to greatly increase the outflow at the toe of the dam.

By the time the thermosyphons again become active in late September, the thermal regime is essentially the same as the previous year. Following the phase III addition of tails, the flow rate begins to drop off as the heat and water supply diminish. The thermosyphons then begin to build a frozen bulb that increases each cooling season. It is expected that within several years the flow corridor through the weathered bedrock would seal off with a frozen barrier.

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5.5.7. Scenario 7

Scenario 7 is similar to scenario 4 but uses the model parameters developed for scenario 5. The additional cooling capacity was evident in the annual development of a frozen bulb. Each year the bulb would be slightly larger than that developed in Scenario 6. Each thawing season, the frozen bulb would melt out completely.

It appears that the decreased flow area increased the flow velocity, canceling the effect of freezing the weathered bedrock. Similar to Scenario 6, following the final tails placement, the flow area trended toward freezing a blockage. The growth of the frozen bulb is slightly faster than noted in Scenario 6. It appears that the cooling rate at the thaw/frozen interface of the bulb is governed by the thermal conductivity of the frozen weathered bedrock surrounding the thermosyphon.

6.0 ANALYSIS CONCLUSIONS

Based on the results of the modeling effort several conclusions can be made regarding the control of seepage flow under the dam and out of the downstream toe.

- From the modeling analysis it appears that with a liner on the rock fill dam, the seepage flow is governed by the properties of the weathered bedrock.
- During the period of time that tails are being added to the system, the heat added to the system cannot be controlled by passive artificial cooling.
- Winter construction of the dam would likely have little effect on the seepage volumes, however allowing the cutoff trench to freeze before placement of tails on the dam face would likely have a long-term benefit for limiting seepage flow.
- Decreasing the flow volume through the dam by cutting off the top 2/3 of the weathered bedrock significantly reduces the seepage flow from the tails.
- Passive cooling of the upstream toe of the dam has little effect on the annual seepage flows if there is no cut off into the weathered bedrock.
- With a cutoff extending 2/3 of the way through the weathered bedrock, passive cooling is not necessary.

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- Thermosyphons alter the flow regime of the tails seepage and increase the thaw rate of existing ice present in the weathered bedrock.

7.0 ENGINEERING CONCLUSIONS

Disturbance of permafrost in the Nome area, particularly in areas where there is significant water flow has invariably resulted in a complete disappearance of the permafrost. It appears from the modeling effort that control of seepage volumes is key to reducing the permafrost degradation rate.

In itself, thawing of the permafrost will have no effect on the stability of the TSF. The dam itself will be founded on weathered bedrock which has sufficient strength to support the dam when thawed. Additional seepage will also have no effect on the dam stability.

Controlling seepage to control the transport of contaminants is needed from an environmental standpoint. Although the annual average temperature suggests that with passive cooling, a permafrost barrier could be achieved. Due to the seepage flow and thermal input from the warm tails, it appears to not be practical to achieve a frozen barrier. As ambient air temperatures rise, the ability to sustain a frozen barrier is reduced. Seepage flow can be effectively controlled using an HDPE cutoff barrier that extends most of the way through the weathered bedrock.

8.0 ENGINEERING DESIGN RECOMMENDATIONS

The design of the dam for the tailing storage facility as presented to NGE at the beginning of the modeling analysis is suitable for the proposed containment of paste tails. Thermosyphons used to cool the upstream toe have little to no effect on the control of seepage from the tails. A cutoff liner through the bedrock is effective and should be incorporated into the design. Allowing the cutoff region to freeze prior to placement of tails directly on the cutoff will likely have a long-term benefit controlling the downstream seepage.

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Due to inherent variability of the weathered bedrock, an experienced geotechnical engineer should be on site to evaluate the cutoff trench. It is expected that the trench depth required to inhibit seepage flow under the dam will vary considerably, especially if zones of highly fractured rock are encountered.

Placement of tails the first winter should be designed such that the tails are placed away from the dam face. This will leave the cutoff trench exposed to cooling and freezing. Allowing some water to flow into the trench area during the freezing period will be beneficial in forming a frozen barrier. The accumulated water depth should be limited to avoid forming a lake that will not completely freeze. A similar effect can be achieved by introducing excess water into the cutoff trench backfill during or shortly after construction. This recommendation may be overridden by the compaction and construction requirements for the trench backfill.

9.0 CLOSURE

Northern Geotechnical Engineering Inc. prepared this report exclusively for the use of *Smith Williams Consultants* for use in design of the proposed Tailings Storage Facility Dam. *Northern Geotechnical Engineering, Inc.* should be notified if significant changes are to occur in the nature, design, or location of the proposed structures in order that the conclusions presented in this report may be reviewed and, if necessary, modified to satisfy the proposed changes.

Due to the natural variability of earth materials, variations in material properties most likely exist across the project site. However, for modeling purposes, established material values were applied to the models, and therefore do not reflect any large scale variations in material properties which may occur across the site. It is therefore recommended that a qualified geotechnical engineer be on-site during construction activities to provide corrective recommendations for any unexpected conditions revealed during construction. Furthermore, the construction budget should allow for any unanticipated conditions which may be encountered during construction activities.

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Northern Geotechnical Engineering Inc. conducted this investigation following the standard of care expected of professionals undertaking similar work in the State of Alaska under similar conditions. No warranty expressed or implied is made.

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TABLES

Table 1
Unit Conversion Table

Parameter	Measurement	English Units	SI Units	Conversion Factor (SI to English)
Length	L	Feet (ft)	Meter (m)	1 m = 3.28 ft
Time	T	Hour (hr)	Hour (hr)	Same units
Force	F	Pound (lb)	KiloNewton (kN)	1 kN = 224.8 lb
Pressure	F/L^2	Pounds per Square Foot (PSF)	KiloPascal (kPa)	1 kPa = 20.89 psf
Unit Wt. of Water	F/L^3	Pounds per Cubic Foot (pcf)	kN/m^3	9.807 kN/m^3 = 62.4 pcf
Unit Wt.	F/L^3	Pounds per Cubic Foot (pcf)	kN/m^3	1 kN/m^3 = 6.363 pcf
Hydraulic Conductivity	L/t	ft/hr	m/hr	1 m/hr = 3.28 ft/hr
Hydraulic Head	L	ft	m	1 m = 3.28 ft
Hydraulic Nodal Flux	$Q=L^3/t$	ft^3/hr	m^3/hr	1 m^3/hr = 35.288 ft^3/hr
Hydraulic Flux Boundary	q=L/t	ft/hr	m/hr	1 m/hr = 3.28 ft/hr
Hydraulic Flux Section	L^3/t	ft^3/hr	m^3/hr	0.028 m^3/hr = 1 ft^2/hr
Volume	L^3	ft^3	m^3	1 m^3 = 35.288 ft^3
Heat	H	British Thermal Unit (BTU)	KiloJoules (kJ)	1.055 kJ = 1 BTU
Temperature	T	Degrees Farenheight (°F)	Degrees Celcius (°C)	1 °C = 1.6 °F
Latent Heat	H/L^3	BTU/ft^3	kJ/m^3	37.229 kJ/m^3 = 1 BTU/ft^3
Thermal Conductivity	H/(t)(L)(T)	BTU/hr ft °F	kJ/hr m °C	6.229 kJ/ hr m °C = 1 BTU/ hr ft °F
Volumetric Heat Capacity	$H/(L^3)(T)$	BTU/ft^3 °F	kJ/m^3 °C	67.07 kJ/m^3 °C = 1 BTU/ft^3 °F
Total Heat Flow	Q=H/t	BTU/hr	kJ/hr	1 kJ/hr = 0.948 BTU/hr
Unit Heat Flow	$Q=H/(t)(L^2)$	BTU/hr ft^2	kJ/hr m^2	11.35 kJ/hr m^2 = 1 BTU/hr ft^2

Table 2

Material Properties Used for Numerical Modeling of Rock Creek TSFD

Material	Volumetric Heat Capcity (frozen) kJ/m^3 ^{o}C	Volumetric Heat Capcity (unfrozen) kJ/m^3 ^{o}C	Volumetric Water Content	Hydraulic Conductivity at Saturation
Fractured Bedrock	1.88E+03	2.00E+03	5.00E-02	3.60E-02
Weathered Bedrock	1.88E+03	2.22E+03	1.50E-01	1.69E+01
Native Soils	1.91E+03	3.16E+03	5.00E-01	9.80E-01
Tailing Slurry	1.88E+03	3.10E+03	5.40E-01	2.40E-03
Rock Fill for TSFD	1.94E+03	1.94E+03	1.50E-01	6.67E+01
HPDE Liner	1.88E+03	3.10E+03	5.40E-01	5.00E-15

Table 3

Water Balance Calculations

Scenario #	PHASE I (AUG:01 to AUG:02)		PHASE II (AUG:02 to AUG:03)		PHASE III (AUG:03 to AUG:04)		EXTENDED RUN (AUG:04 to AUG:05)		EXTENDED RUN (AUG:05 to AUG:06)	
1	Instantaneous Inflow Rate (m^3/hr)	0.0177	Instantaneous Inflow Rate (m^3/hr)	0.0092	Instantaneous Inflow Rate (m^3/hr)	0.0138	Instantaneous Inflow Rate (m^3/hr)	0.0153	Instantaneous Inflow Rate (m^3/hr)	0.0054
	Instantaneous Outflow Rate (m^3/hr)	0.0159	Instantaneous Outflow Rate (m^3/hr)	0.0123	Instantaneous Outflow Rate (m^3/hr)	0.031	Instantaneous Outflow Rate (m^3/hr)	0.0262	Instantaneous Outflow Rate (m^3/hr)	0.0075
	Avg. Inflow Rate (m^3/yr)	155	Inflow (m^3/yr)	81	Inflow (m^3/yr)	121	Inflow (m^3/yr)	134	Inflow (m^3/yr)	47
	Avg. Outflow Rate (m^3/yr)	139	Outflow (m^3/yr)	108	Outflow (m^3/yr)	272	Outflow (m^3/yr)	230	Outflow (m^3/yr)	66
	Cum. Bound Flux (m^3/yr)	22	Cum. Bound Flux (m^3/yr)	33	Cum. Bound Flux (m^3/yr)	45	Cum. Bound Flux (m^3/yr)	45	Cum. Bound Flux (m^3/yr)	45
	Avg. Vol. Water Content Change (w/in Dam)	0.0222	Avg. Vol. Water Content Change (w/in Dam)	-0.0016	Avg. Vol. Water Content Change (w/in Dam)	-0.0174	Avg. Vol. Water Content Change (w/in Dam)	-0.0046	Avg. Vol. Water Content Change (w/in Dam)	0.0014
	Avg. Vol. Water Content Change (Below Dam)	N/A	Avg. Vol. Water Content Change (Below Dam)	N/A	Avg. Vol. Water Content Change (Below Dam)	-0.0242	Avg. Vol. Water Content Change (Below Dam)	-0.0041	Avg. Vol. Water Content Change (Below Dam)	0.0015
	Amount of Water Stored as Ice (m^3)	24	Amount of Water Stored as Ice (m^3)	-4	Amount of Water Stored as Ice (m^3)	-112	Amount of Water Stored as Ice (m^3)	-26	Amount of Water Stored as Ice (m^3)	8
	% Difference Between Inflow & Outflow	8	% Difference Between Inflow & Outflow	9	% Difference Between Inflow & Outflow	4	% Difference Between Inflow & Outflow	12	% Difference Between Inflow & Outflow	20
2	Instantaneous Inflow Rate (m^3/hr)	0.0005	Instantaneous Inflow Rate (m^3/hr)	0.0003	Instantaneous Inflow Rate (m^3/hr)	0.0002	Instantaneous Inflow Rate (m^3/hr)	0.0002	Instantaneous Inflow Rate (m^3/hr)	0
	Instantaneous Outflow Rate (m^3/hr)	0.0028	Instantaneous Outflow Rate (m^3/hr)	0.008	Instantaneous Outflow Rate (m^3/hr)	0.0137	Instantaneous Outflow Rate (m^3/hr)	0.0201	Instantaneous Outflow Rate (m^3/hr)	0.0027
	Avg. Inflow Rate (m^3/yr)	4	Inflow (m^3/yr)	3	Inflow (m^3/yr)	2	Inflow (m^3/yr)	2	Inflow (m^3/yr)	0
	Avg. Outflow Rate (m^3/yr)	25	Outflow (m^3/yr)	70	Outflow (m^3/yr)	120	Outflow (m^3/yr)	176	Outflow (m^3/yr)	24
	Cum. Bound Flux (m^3/yr)	22	Cum. Bound Flux (m^3/yr)	33	Cum. Bound Flux (m^3/yr)	45	Cum. Bound Flux (m^3/yr)	45	Cum. Bound Flux (m^3/yr)	45
	Avg. Vol. Water Content Change (w/in Dam)	0.0049	Avg. Vol. Water Content Change (w/in Dam)	-0.0074	Avg. Vol. Water Content Change (w/in Dam)	-0.0105	Avg. Vol. Water Content Change (w/in Dam)	-0.0113	Avg. Vol. Water Content Change (w/in Dam)	0.0015
	Avg. Vol. Water Content Change (Below Dam)	N/A	Avg. Vol. Water Content Change (Below Dam)	N/A	Avg. Vol. Water Content Change (Below Dam)	-0.0111	Avg. Vol. Water Content Change (Below Dam)	-0.0136	Avg. Vol. Water Content Change (Below Dam)	0.0019
	Amount of Water Stored as Ice (m3)	5	Amount of Water Stored as Ice (m3)	-18	Amount of Water Stored as Ice (m3)	-63	Amount of Water Stored as Ice (m3)	-70	Amount of Water Stored as Ice (m3)	9
	% Difference Between Inflow & Outflow	12	% Difference Between Inflow & Outflow	31	% Difference Between Inflow & Outflow	18	% Difference Between Inflow & Outflow	56	% Difference Between Inflow & Outflow	27
3	Instantaneous Inflow Rate (m^3/hr)	0.0178	Instantaneous Inflow Rate (m^3/hr)	0.0082	Instantaneous Inflow Rate (m^3/hr)	0.0095	Instantaneous Inflow Rate (m^3/hr)	0.007	Instantaneous Inflow Rate (m^3/hr)	0.0047
	Instantaneous Outflow Rate (m^3/hr)	0.0163	Instantaneous Outflow Rate (m^3/hr)	0.0144	Instantaneous Outflow Rate (m^3/hr)	0.0356	Instantaneous Outflow Rate (m^3/hr)	0.0236	Instantaneous Outflow Rate (m^3/hr)	0.0046
	Avg. Inflow Rate (m^3/yr)	156	Inflow (m^3/yr)	72	Inflow (m^3/yr)	83	Inflow (m^3/yr)	61	Inflow (m^3/yr)	41
	Avg. Outflow Rate (m^3/yr)	143	Outflow (m^3/yr)	126	Outflow (m^3/yr)	312	Outflow (m^3/yr)	207	Outflow (m^3/yr)	40
	Cum. Bound Flux (m^3/yr)	22	Cum. Bound Flux (m^3/yr)	33	Cum. Bound Flux (m^3/yr)	45	Cum. Bound Flux (m^3/yr)	45	Cum. Bound Flux (m^3/yr)	45
	Avg. Vol. Water Content Change (w/in Dam)	0.0228	Avg. Vol. Water Content Change (w/in Dam)	-0.003	Avg. Vol. Water Content Change (w/in Dam)	-0.018	Avg. Vol. Water Content Change (w/in Dam)	-0.0115	Avg. Vol. Water Content Change (w/in Dam)	0.0048
	Avg. Vol. Water Content Change (Below Dam)	N/A	Avg. Vol. Water Content Change (Below Dam)	N/A	Avg. Vol. Water Content Change (Below Dam)	0	Avg. Vol. Water Content Change (Below Dam)	-0.0134	Avg. Vol. Water Content Change (Below Dam)	0.0068
	Amount of Water Stored as Ice (m3)	25	Amount of Water Stored as Ice (m3)	-7	Amount of Water Stored as Ice (m3)	-116	Amount of Water Stored as Ice (m3)	-71	Amount of Water Stored as Ice (m3)	31
	% Difference Between Inflow & Outflow	6	% Difference Between Inflow & Outflow	12	% Difference Between Inflow & Outflow	35	% Difference Between Inflow & Outflow	22	% Difference Between Inflow & Outflow	17
4	Instantaneous Inflow Rate (m^3/hr)	0.0176	Instantaneous Inflow Rate (m^3/hr)	0.0062	Instantaneous Inflow Rate (m^3/hr)	0.0114	Instantaneous Inflow Rate (m^3/hr)	0.0059	Instantaneous Inflow Rate (m^3/hr)	0.0022
	Instantaneous Outflow Rate (m^3/hr)	0.0157	Instantaneous Outflow Rate (m^3/hr)	0.0137	Instantaneous Outflow Rate (m^3/hr)	0.037	Instantaneous Outflow Rate (m^3/hr)	0.0235	Instantaneous Outflow Rate (m^3/hr)	0.0048
	Avg. Inflow Rate (m^3/yr)	154	Inflow (m^3/yr)	54	Inflow (m^3/yr)	100	Inflow (m^3/yr)	52	Inflow (m^3/yr)	19
	Avg. Outflow Rate (m^3/yr)	138	Outflow (m^3/yr)	120	Outflow (m^3/yr)	324	Outflow (m^3/yr)	206	Outflow (m^3/yr)	42
	Cum. Bound Flux (m^3/yr)	22	Cum. Bound Flux (m^3/yr)	33	Cum. Bound Flux (m^3/yr)	45	Cum. Bound Flux (m^3/yr)	45	Cum. Bound Flux (m^3/yr)	45
	Avg. Vol. Water Content Change (w/in Dam)	0.0219	Avg. Vol. Water Content Change (w/in Dam)	-0.0058	Avg. Vol. Water Content Change (w/in Dam)	-0.017	Avg. Vol. Water Content Change (w/in Dam)	-0.0118	Avg. Vol. Water Content Change (w/in Dam)	-0.0026
	Avg. Vol. Water Content Change (Below Dam)	N/A	Avg. Vol. Water Content Change (Below Dam)	N/A	Avg. Vol. Water Content Change (Below Dam)	0	Avg. Vol. Water Content Change (Below Dam)	-0.0138	Avg. Vol. Water Content Change (Below Dam)	-0.0039
	Amount of Water Stored as Ice (m3)	24	Amount of Water Stored as Ice (m3)	-14	Amount of Water Stored as Ice (m3)	-107	Amount of Water Stored as Ice (m3)	-72	Amount of Water Stored as Ice (m3)	-17
	% Difference Between Inflow & Outflow	9	% Difference Between Inflow & Outflow	17	% Difference Between Inflow & Outflow	33	% Difference Between Inflow & Outflow	28	% Difference Between Inflow & Outflow	61

Table 3 - Continued

Water Balance Calculations

Scenario #	PHASE I (AUG:01 to AUG:02)		PHASE II (AUG:02 to AUG:03)		PHASE III (AUG:03 to AUG:04)		EXTENDED RUN (AUG:04 to AUG:05)		EXTENDED RUN (AUG:05 to AUG:06)	
5	Instantaneous Inflow Rate (m^3/hr)	0.0259	Instantaneous Inflow Rate (m^3/hr)	0.0525	Instantaneous Inflow Rate (m^3/hr)	0.0743	Instantaneous Inflow Rate (m^3/hr)	0.0695	Instantaneous Inflow Rate (m^3/hr)	0.0226
	Instantaneous Outflow Rate (m^3/hr)	0.0268	Instantaneous Outflow Rate (m^3/hr)	0.0492	Instantaneous Outflow Rate (m^3/hr)	0.0744	Instantaneous Outflow Rate (m^3/hr)	0.0502	Instantaneous Outflow Rate (m^3/hr)	0.0185
	Avg. Inflow Rate (m^3/yr)	227	Inflow (m^3/yr)	460	Inflow (m^3/yr)	651	Inflow (m^3/yr)	609	Inflow (m^3/yr)	198
	Avg. Outflow Rate (m^3/yr)	235	Outflow (m^3/yr)	431	Outflow (m^3/yr)	652	Outflow (m^3/yr)	440	Outflow (m^3/yr)	162
	Cum. Bound Flux (m^3/yr)	22	Cum. Bound Flux (m^3/yr)	33	Cum. Bound Flux (m^3/yr)	45	Cum. Bound Flux (m^3/yr)	45	Cum. Bound Flux (m^3/yr)	45
	Avg. Vol. Water Content Change (w/in Dam)	-0.001	Avg. Vol. Water Content Change (w/in Dam)	0.0277	Avg. Vol. Water Content Change (w/in Dam)	0.0025	Avg. Vol. Water Content Change (w/in Dam)	0.0042	Avg. Vol. Water Content Change (w/in Dam)	-0.0001
	Avg. Vol. Water Content Change (Below Dam)	N/A	Avg. Vol. Water Content Change (Below Dam)	N/A	Avg. Vol. Water Content Change (Below Dam)	0.007	Avg. Vol. Water Content Change (Below Dam)	0.0076	Avg. Vol. Water Content Change (Below Dam)	0.0008
	Amount of Water Stored as Ice (m3)	-1	Amount of Water Stored as Ice (m3)	68	Amount of Water Stored as Ice (m3)	21	Amount of Water Stored as Ice (m3)	30	Amount of Water Stored as Ice (m3)	1
	% Difference Between Inflow & Outflow	6	% Difference Between Inflow & Outflow	1	% Difference Between Inflow & Outflow	3	% Difference Between Inflow & Outflow	28	% Difference Between Inflow & Outflow	33
5	Instantaneous Inflow Rate (m^3/hr)	0.0244	Instantaneous Inflow Rate (m^3/hr)	0.0618	Instantaneous Inflow Rate (m^3/hr)	0.077	Instantaneous Inflow Rate (m^3/hr)	0.0754	Instantaneous Inflow Rate (m^3/hr)	0.0207
	Instantaneous Outflow Rate (m^3/hr)	0.0274	Instantaneous Outflow Rate (m^3/hr)	0.0644	Instantaneous Outflow Rate (m^3/hr)	0.0784	Instantaneous Outflow Rate (m^3/hr)	0.0656	Instantaneous Outflow Rate (m^3/hr)	0.0188
	Avg. Inflow Rate (m^3/yr)	214	Inflow (m^3/yr)	541	Inflow (m^3/yr)	675	Inflow (m^3/yr)	661	Inflow (m^3/yr)	181
	Avg. Outflow Rate (m^3/yr)	240	Outflow (m^3/yr)	564	Outflow (m^3/yr)	687	Outflow (m^3/yr)	575	Outflow (m^3/yr)	165
	Cum. Bound Flux (m^3/yr)	22	Cum. Bound Flux (m^3/yr)	33	Cum. Bound Flux (m^3/yr)	45	Cum. Bound Flux (m^3/yr)	45	Cum. Bound Flux (m^3/yr)	45
	Avg. Vol. Water Content Change (w/in Dam)	-0.0015	Avg. Vol. Water Content Change (w/in Dam)	-0.0027	Avg. Vol. Water Content Change (w/in Dam)	-0.011	Avg. Vol. Water Content Change (w/in Dam)	0.0046	Avg. Vol. Water Content Change (w/in Dam)	-0.0009
	Avg. Vol. Water Content Change (Below Dam)	N/A	Avg. Vol. Water Content Change (Below Dam)	N/A	Avg. Vol. Water Content Change (Below Dam)	-0.0155	Avg. Vol. Water Content Change (Below Dam)	0.0082	Avg. Vol. Water Content Change (Below Dam)	-0.0005
	Amount of Water Stored as Ice (m3)	-2	Amount of Water Stored as Ice (m3)	-7	Amount of Water Stored as Ice (m3)	-71	Amount of Water Stored as Ice (m3)	32	Amount of Water Stored as Ice (m3)	-5
	% Difference Between Inflow & Outflow	1	% Difference Between Inflow & Outflow	3	% Difference Between Inflow & Outflow	14	% Difference Between Inflow & Outflow	14	% Difference Between Inflow & Outflow	29
7	Instantaneous Inflow Rate (m^3/hr)	0.0235	Instantaneous Inflow Rate (m^3/hr)	0.0184	Instantaneous Inflow Rate (m^3/hr)	0.0882	Instantaneous Inflow Rate (m^3/hr)	0.0816	Instantaneous Inflow Rate (m^3/hr)	0.0046
	Instantaneous Outflow Rate (m^3/hr)	0.0258	Instantaneous Outflow Rate (m^3/hr)	0.0285	Instantaneous Outflow Rate (m^3/hr)	0.0907	Instantaneous Outflow Rate (m^3/hr)	0.0922	Instantaneous Outflow Rate (m^3/hr)	0.008
	Avg. Inflow Rate (m^3/yr)	206	Inflow (m^3/yr)	161	Inflow (m^3/yr)	773	Inflow (m^3/yr)	715	Inflow (m^3/yr)	40
	Avg. Outflow Rate (m^3/yr)	226	Outflow (m^3/yr)	250	Outflow (m^3/yr)	795	Outflow (m^3/yr)	808	Outflow (m^3/yr)	70
	Cum. Bound Flux (m^3/yr)	22	Cum. Bound Flux (m^3/yr)	33	Cum. Bound Flux (m^3/yr)	45	Cum. Bound Flux (m^3/yr)	45	Cum. Bound Flux (m^3/yr)	45
	Avg. Vol. Water Content Change (w/in Dam)	-0.0035	Avg. Vol. Water Content Change (w/in Dam)	-0.0198	Avg. Vol. Water Content Change (w/in Dam)	-0.0135	Avg. Vol. Water Content Change (w/in Dam)	-0.0138	Avg. Vol. Water Content Change (w/in Dam)	-0.0012
	Avg. Vol. Water Content Change (Below Dam)	N/A	Avg. Vol. Water Content Change (Below Dam)	N/A	Avg. Vol. Water Content Change (Below Dam)	0	Avg. Vol. Water Content Change (Below Dam)	-0.0217	Avg. Vol. Water Content Change (Below Dam)	-0.0011
	Amount of Water Stored as Ice (m3)	-4	Amount of Water Stored as Ice (m3)	-49	Amount of Water Stored as Ice (m3)	-95	Amount of Water Stored as Ice (m3)	-92	Amount of Water Stored as Ice (m3)	-7
	% Difference Between Inflow & Outflow	2	% Difference Between Inflow & Outflow	3	% Difference Between Inflow & Outflow	14	% Difference Between Inflow & Outflow	6	% Difference Between Inflow & Outflow	26

Table 4
Predicted Water Outflow

Annual Flow Calcs
cubic meters per year

	Base Conditions Scenario 1			Extended Liner Scenario 2			Thermosyphons Scenarios 3, 4			High Perm and Temp Scenario 5		
	Outflow	% rain	% ice melt	Outflow	% rain	% ice melt	Outflow	% rain	% ice melt	Outflow	% rain	% ice melt
Phase I	68000	21		12000	98		68000	21		121000	11	1
Phase II	96000	26	3	45000	63	17	96000	30	13	368000	7	
Phase III	275000	13	34	121000	29	66	275000	13	30	693000	5	
Year 4	219000	18	12	108000	32	30	189000	22	40	559000	5	
Year 5	72000	51		44000	79		45000	81		207000	18	

Table 5
Monthly Flow Distribution

Monthly Seepage Flow, No heat pipes
Percent of total flow for phase

Scenarios 1, 2, 5

	Phase 1	Phase 2	Phase 3
Jan			7
Feb			2
Mar			
Apr			
May	4	2	1
Jun	6	2	1
Jul	8	4	2
Aug	17	32	39
Sep	37	24	19
Oct	27	18	10
Nov	1	12	10
Dec		6	9

Monthly Seepage Flow, heat pipes 50 square meter radiators
Percent of total flow for phase

Scenarios 3, 6

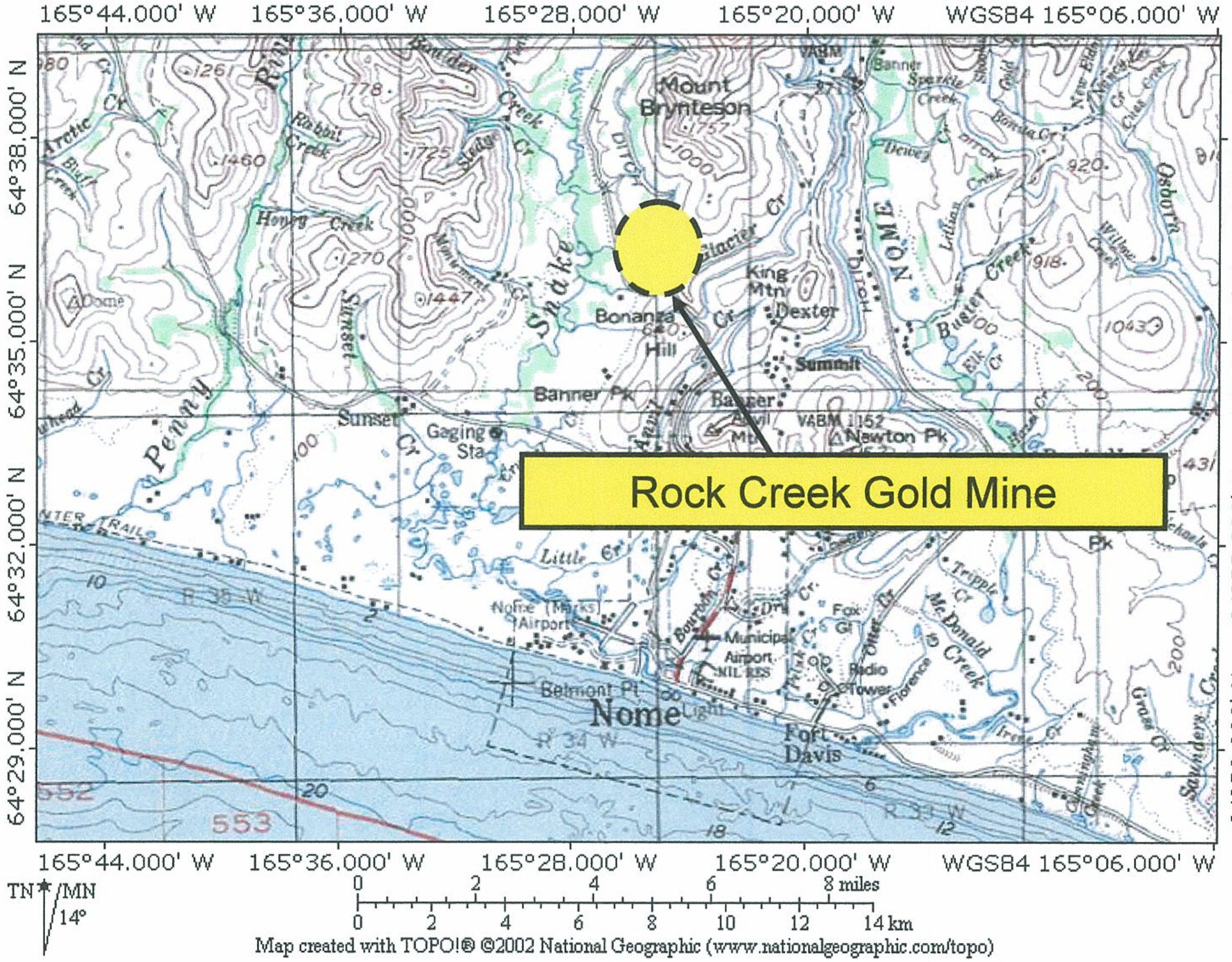
	Phase 1	Phase 2	Phase 3
Jan			2
Feb			
Mar			
Apr			
May	5		
Jun	3		
Jul	5		1
Aug	14	44	53
Sep	39	18	13
Oct	29	22	13
Nov	5	11	9
Dec		5	9

Monthly Seepage Flow, heat pipes 200 square meter radiators
Percent of total flow for phase

Scenarios 4, 7

	Phase 1	Phase 2	Phase 3
Jan		1	3
Feb			1
Mar			
Apr			
May	3		
Jun	5		
Jul	5	2	2
Aug	14	41	53
Sep	42	17	12
Oct	30	22	11
Nov	2	11	9
Dec		7	9

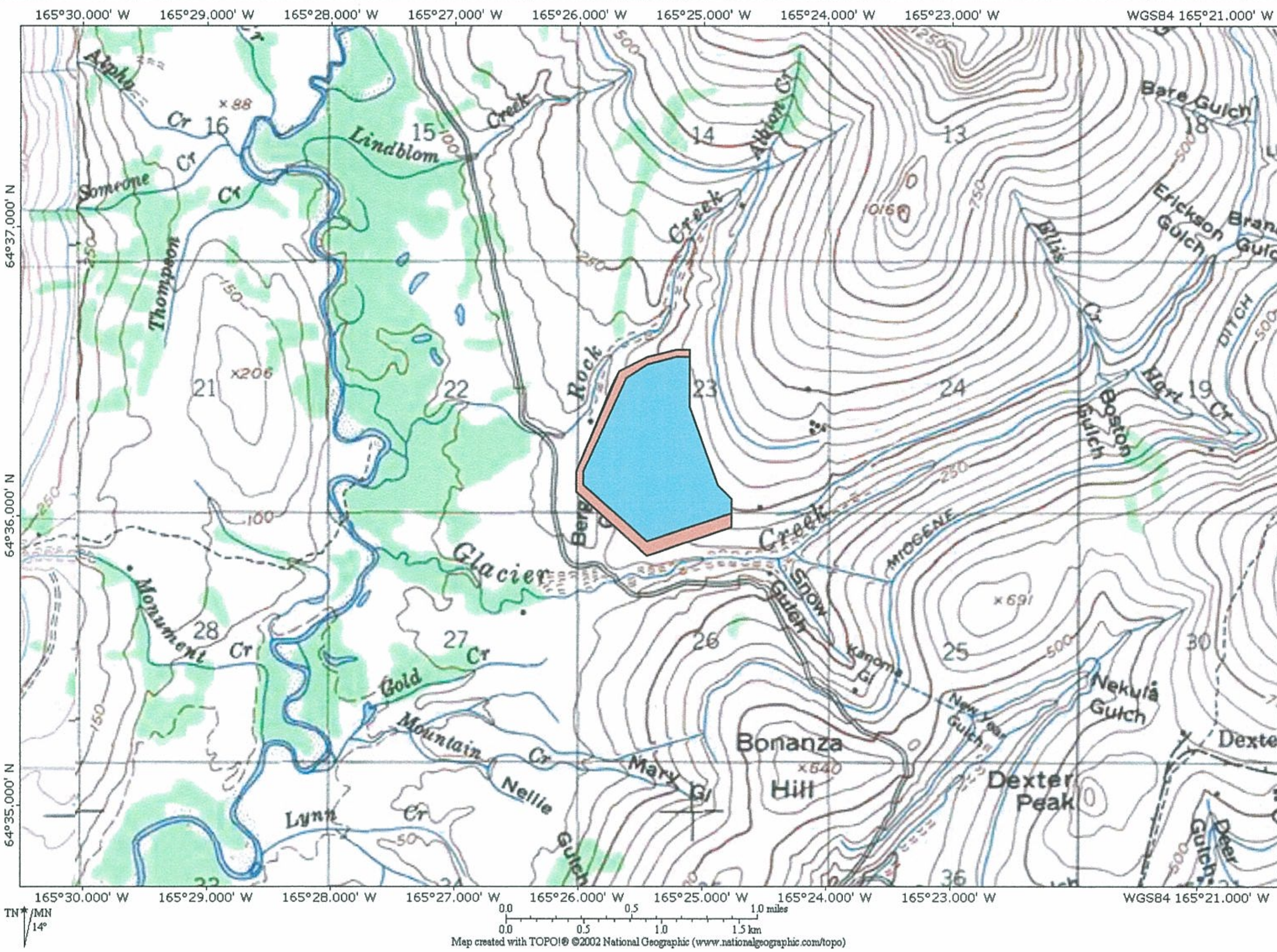
FIGURES



REGION LOCATION MAP

Rock Creek Dam,
Nome, Alaska

FIG 1



= Tailings Storage Facility Dam

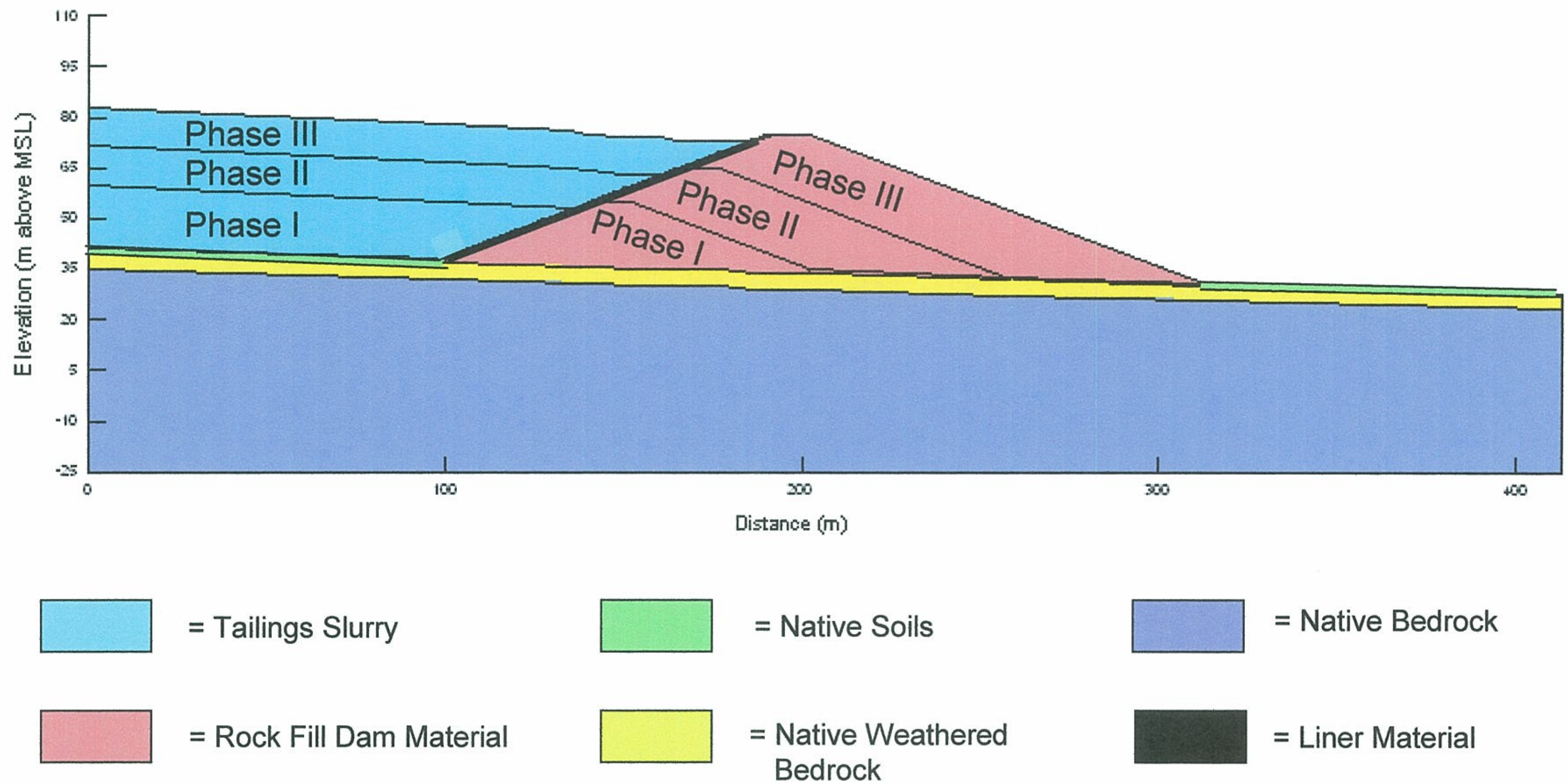
= Tailings

*Approximate size and location

SITE LOCATION MAP

Rock Creek Dam,
Nome, Alaska

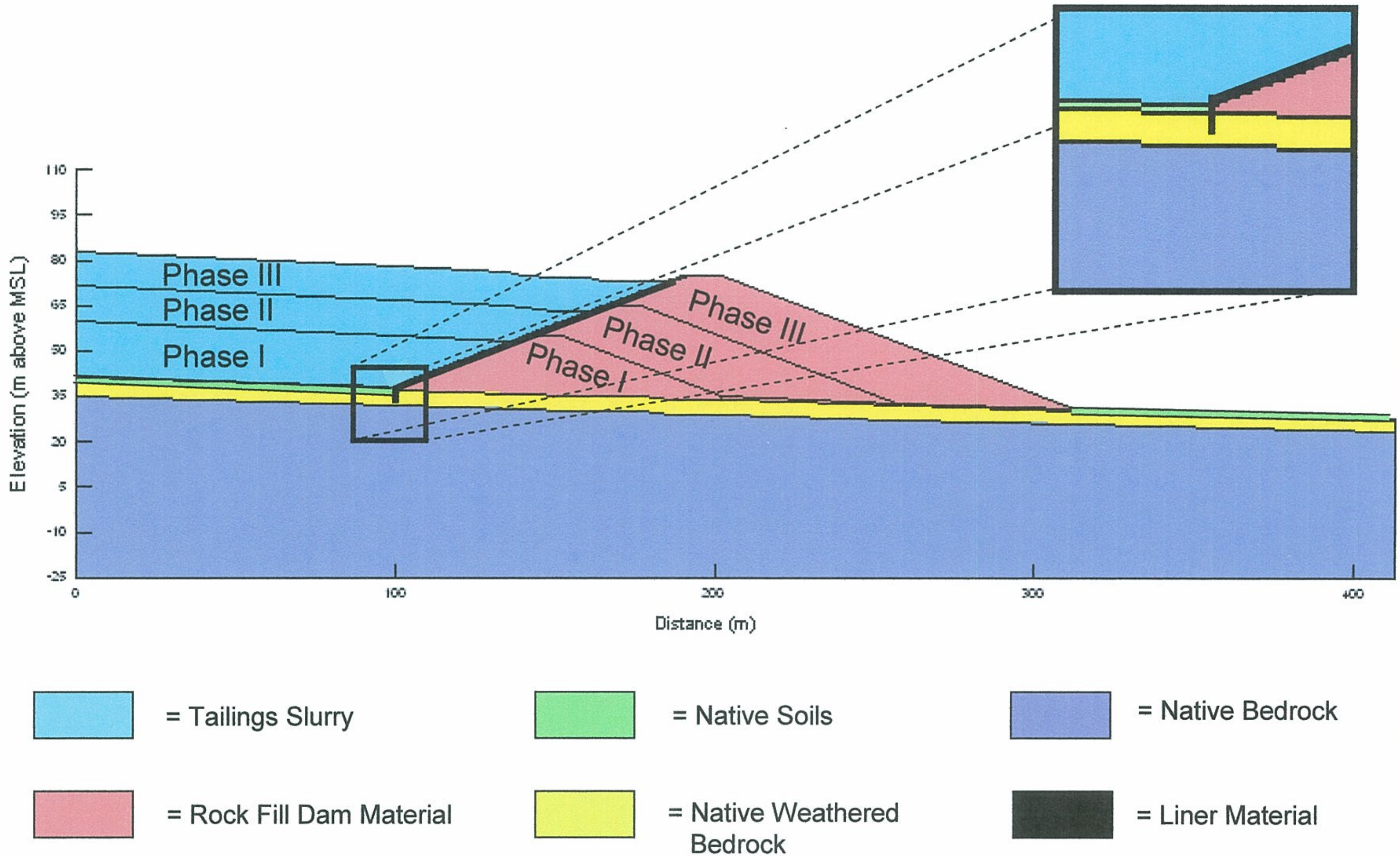
FIG 2



CROSS-SECTION OF COMPUTER MODEL SHOWING ALL THREE PHSES OF TSF CONSTRUCTION

Rock Creek Dam,
Nome, Alaska

FIG 3

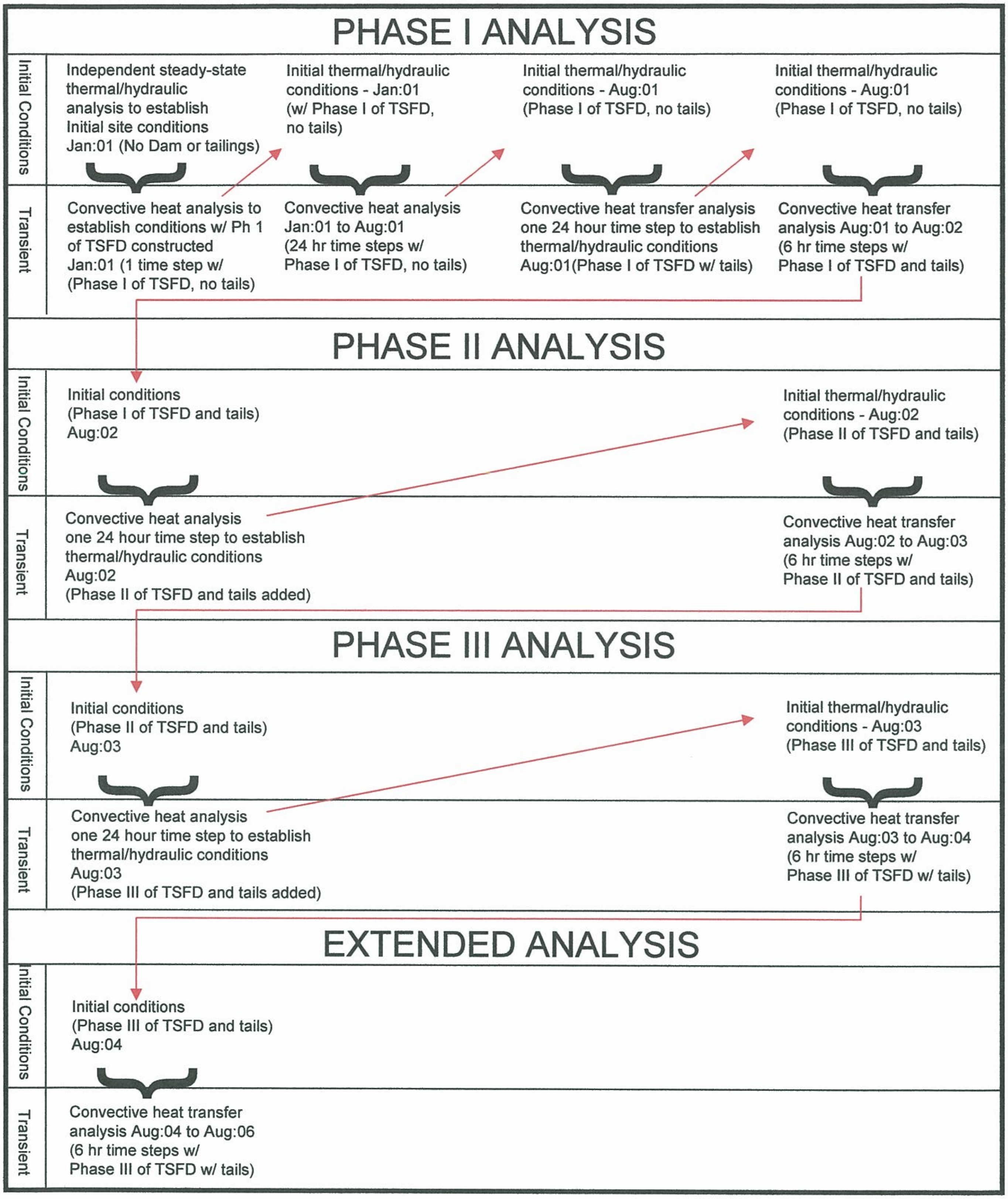


CROSS-SECTION OF COMPUTER MODEL SHOWING SCENARIO 2 W/ LINER EXTENDED INTO THE WEATEHRED BEDROCK

Rock Creek Dam,
Nome, Alaska

FIG 4

NORTHERN GEOTECHNICAL ENGINEERING, INC. TERRA FIRMA TESTING



→ = Analysis results saved as initial conditions for ensuing analysis

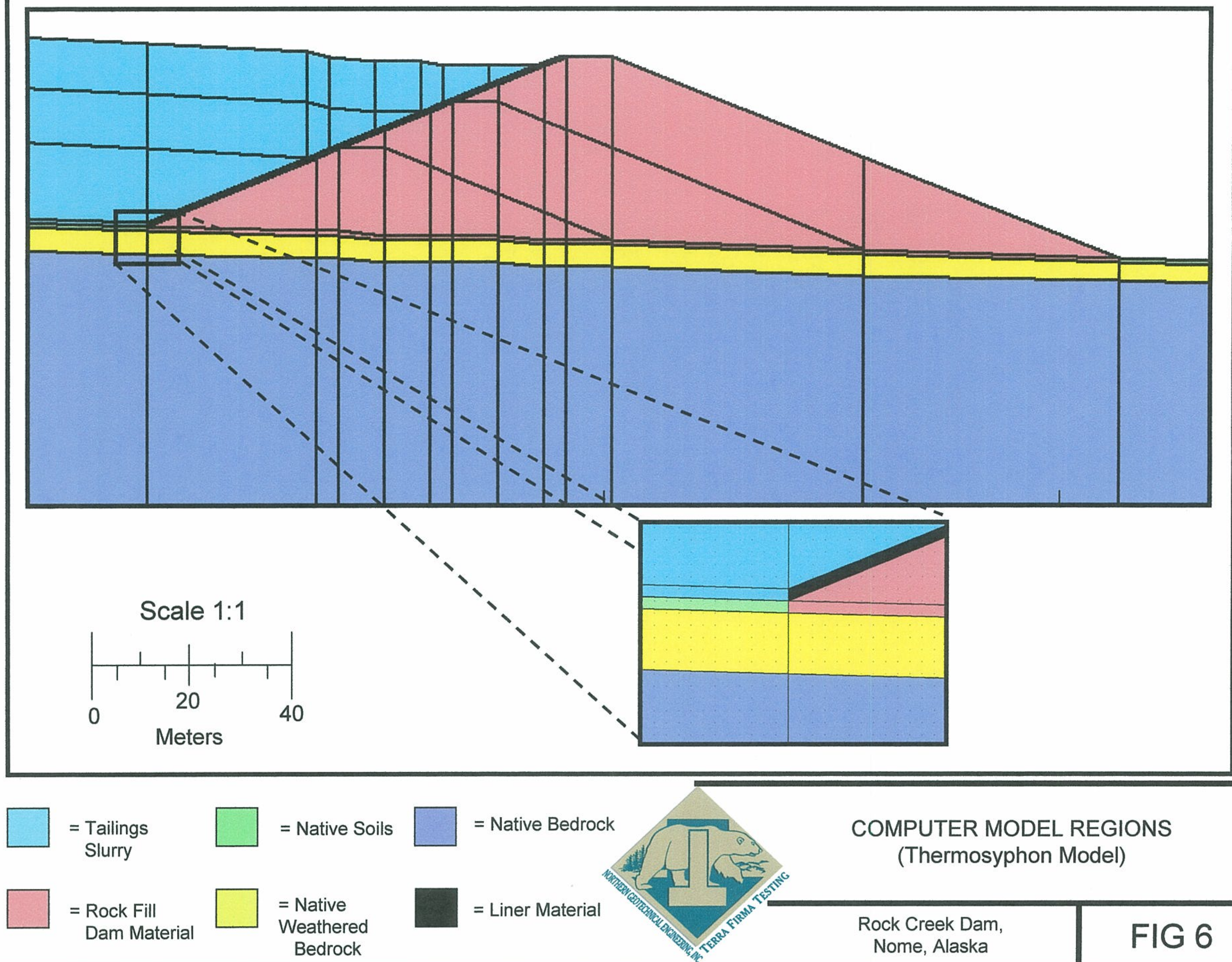
} = Initial conditions used for transient analysis

NORTHERN GEOTECHNICAL ENGINEERING, INC. TERRA FIRMA TESTING

THERMAL/SEEPAGE ANALYSIS FLOW CHART

Rock Creek TSFD
Nome, Alaska

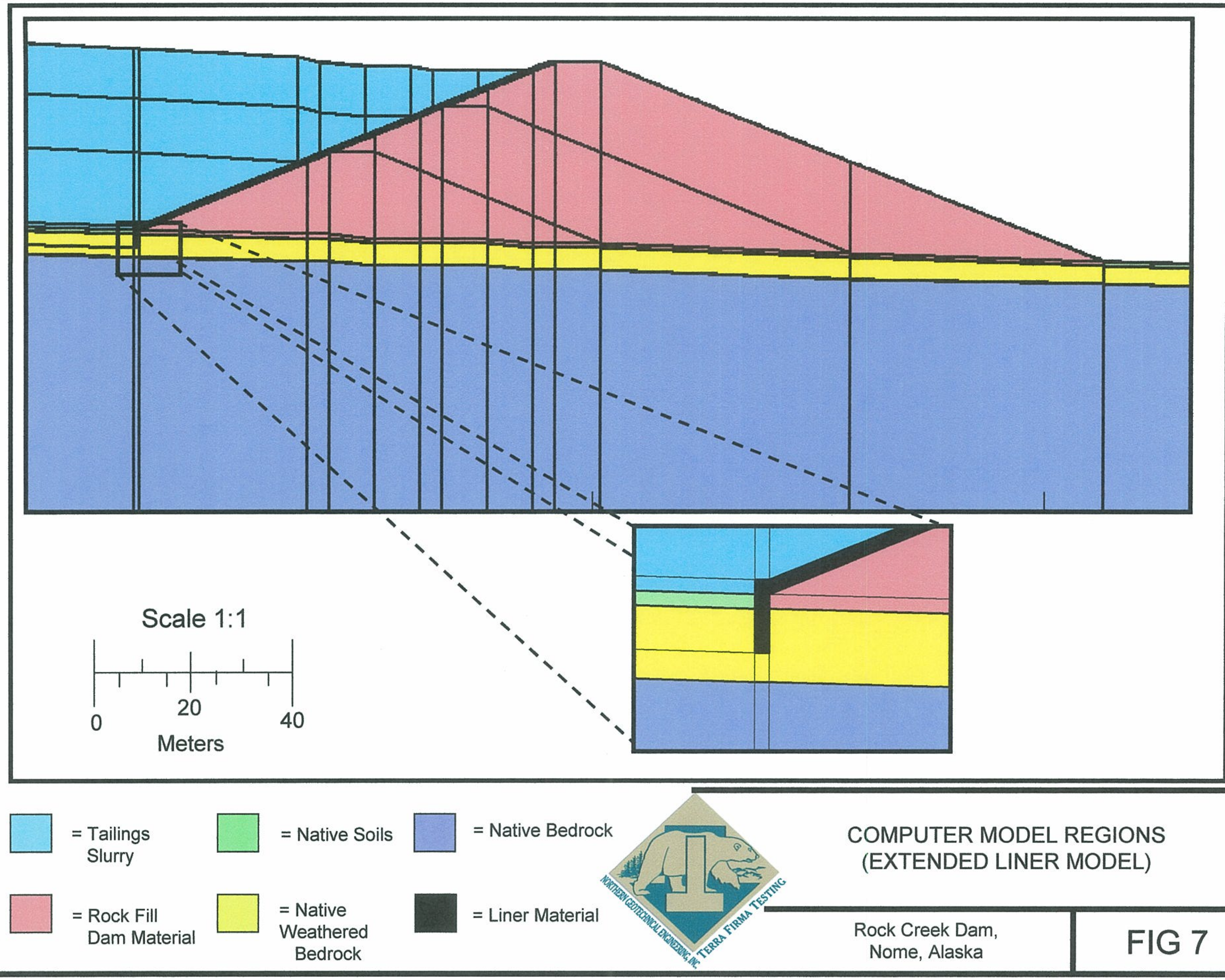
FIG 5



COMPUTER MODEL REGIONS
(Thermosyphon Model)

Rock Creek Dam,
Nome, Alaska

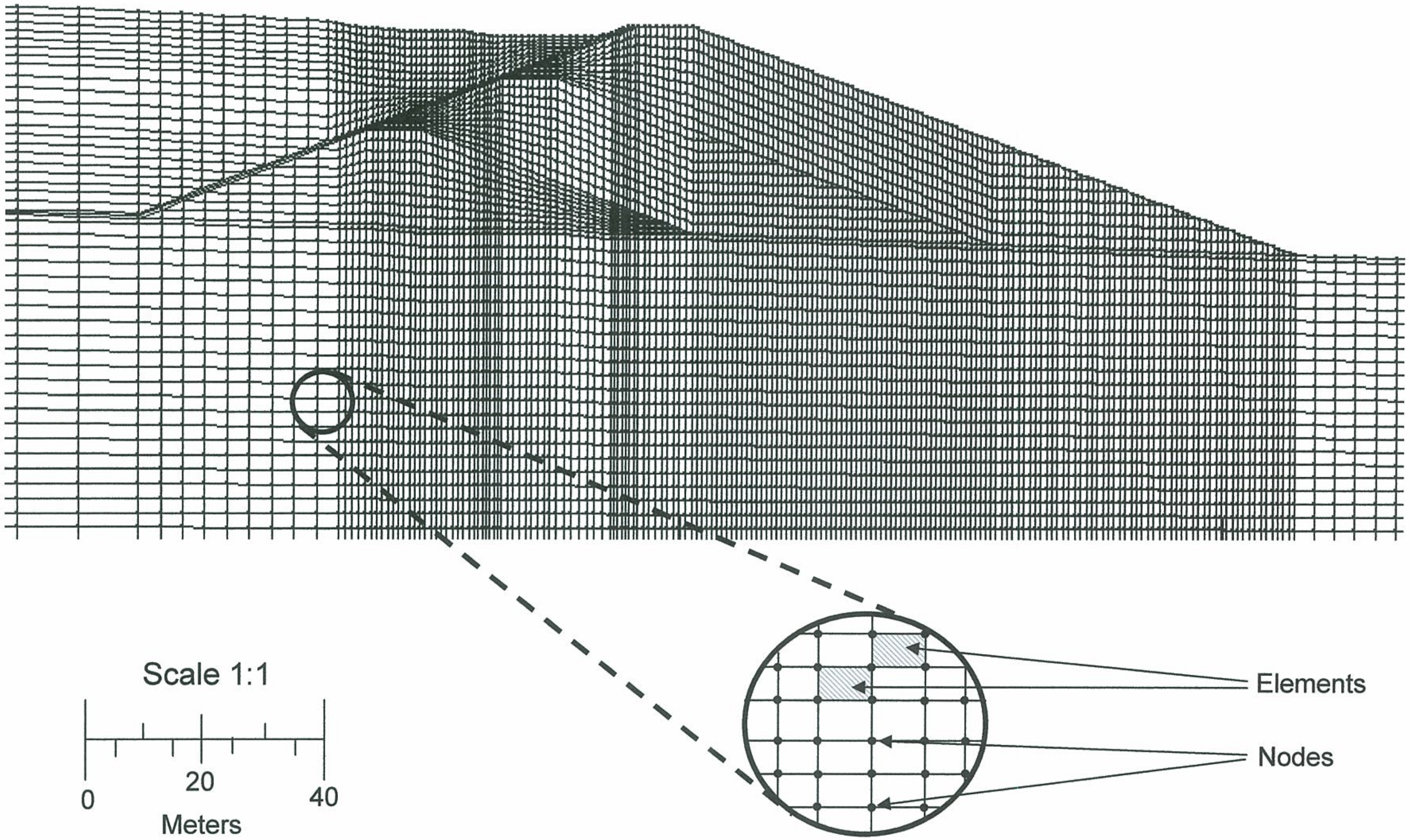
FIG 6



COMPUTER MODEL REGIONS
(EXTENDED LINER MODEL)

Rock Creek Dam,
Nome, Alaska

FIG 7

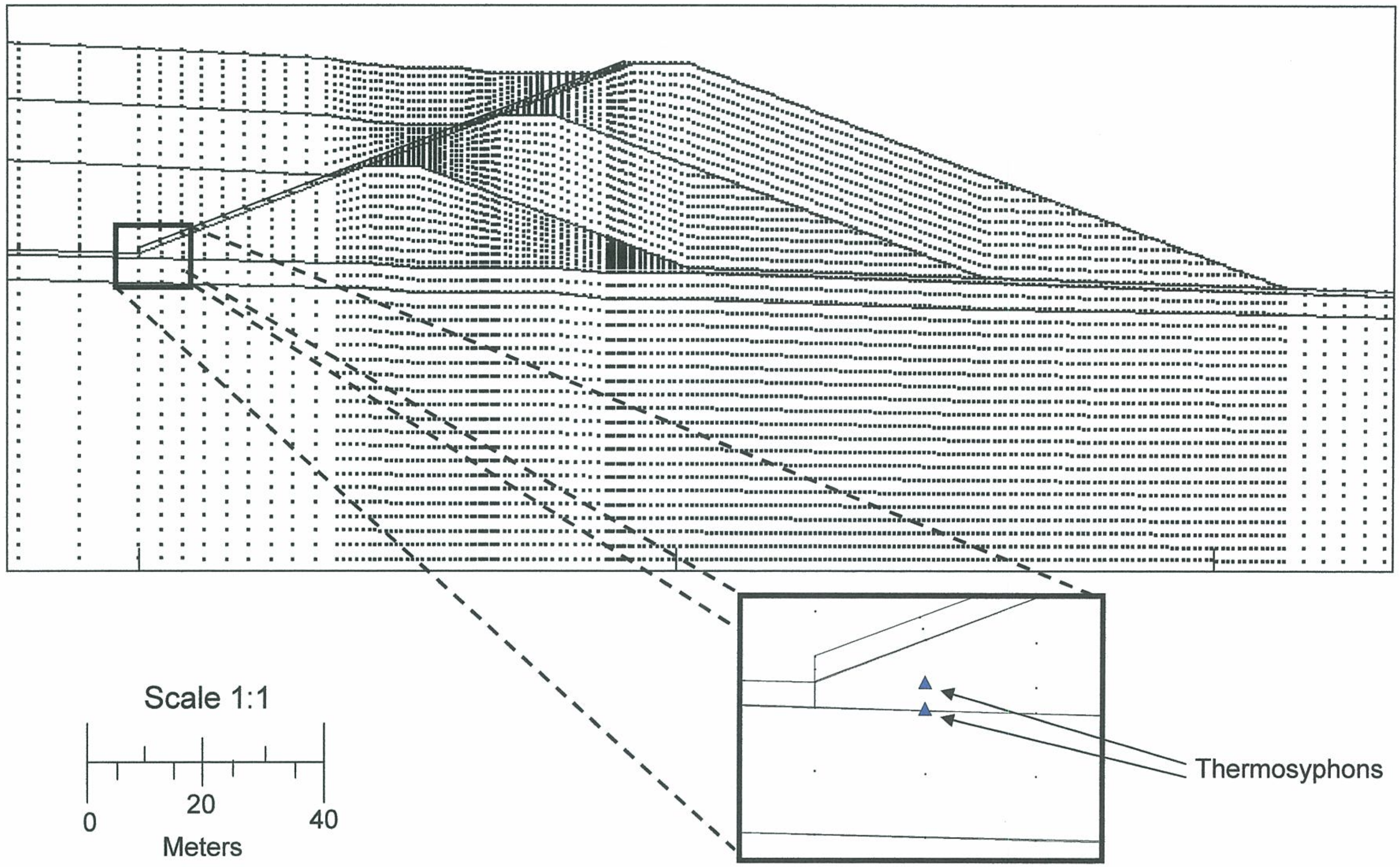


COMPUTER MODEL ELEMENTS AND NODES

Rock Creek Dam, Nome, Alaska

FIG 8

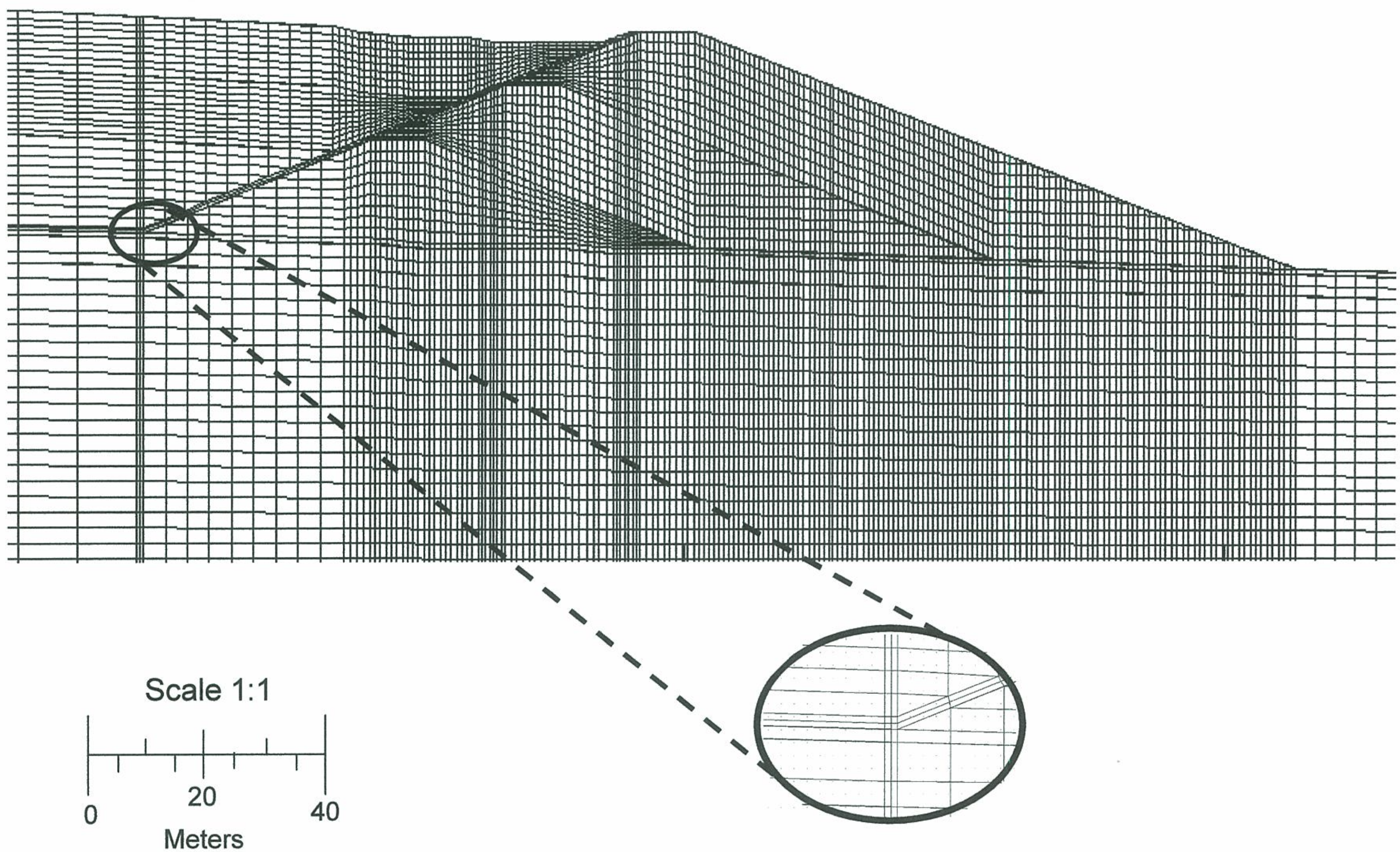
Terra Firma Testing
Northern Geotechnical Engineering, Inc.



THERMOSYPHON PLACEMENT

Rock Creek Dam,
Nome, Alaska

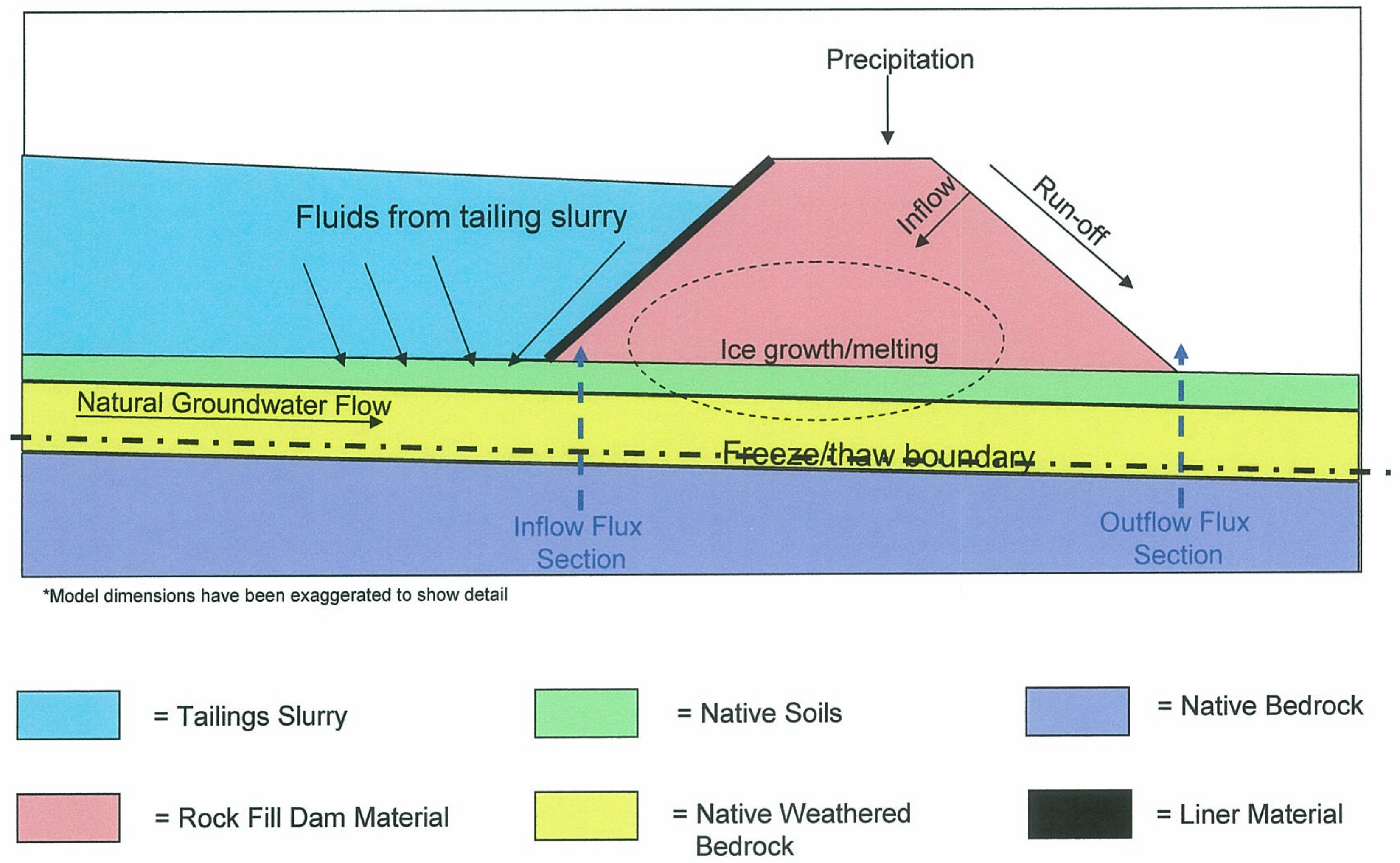
FIG 9



COMPUTER MODEL ELEMENTS AND NODES (EXTENDED LINER MODEL)

Rock Creek Dam, Nome, Alaska

FIG 10



WATER BALANCE DIAGRAM

Rock Creek Dam,
Nome, Alaska

FIG 11

Total Average Annual Discharge from the TSF expressed as: $(Q_A) = F_A * F_T * Q_C$

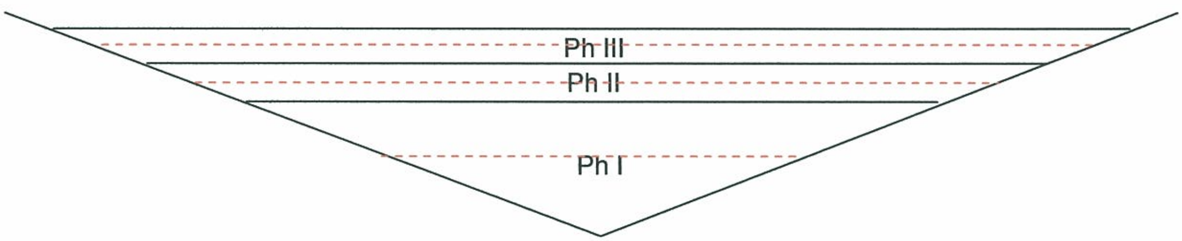
$Q_C = V * L * 8760$ hours

Where: V = Total discharge measured from flux sections for entire length of analysis
L = Effective discharge length of TSFD toe
8760 = # of hours in one year

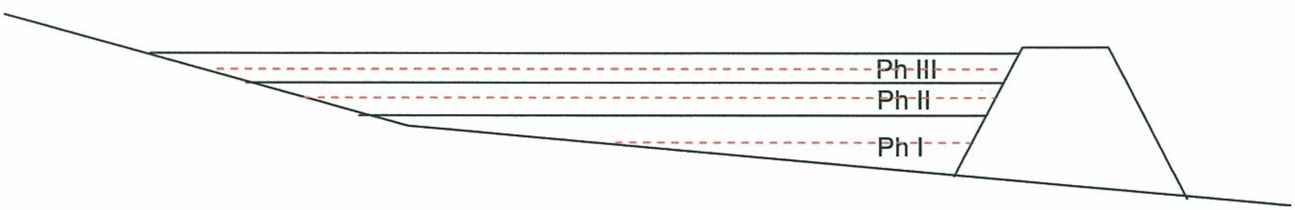
F_A = Correction factor for the average level of tailings within the TSF based on area

F_T = Correction factor for the average level of tailings in TSF based on time

Cross-Section of TSF Along Axis of TSFD



Cross-Section of TSF Perpendicular to Topography



- - - - - - - - - - = Average height of tailings

TSF ANNUAL DISCHARGE DETERMINATION

Rock Creek Dam,
Nome, Alaska

FIG 12

APPENDIX A

THERMAL PROPERTY FUNCTIONS

APPENDIX A
THERMAL PROPERTIES

TEMP/W requires input of thermal properties for each of the different materials used in the model. Each region is defined as a material type and the model references each material type to assigned properties. Where the thermal properties are a function dependent on other variables in the system, a graphical representation of the property is needed. The thermal properties defined for each material in the model include:

1) Latent heat: Thermal energy given off or absorbed by a material during a phase change. In this case the material experiencing the phase change is the ground water/soil water. The amount of thermal energy released/absorbed within a particular material is dependent on the Volumetric Water Content (defined in Appendix B). The latent heat of water is pre-programmed into the model with options to select the correct units. The units of measure used in the model for latent heat are kJ/m^3.

2) Thermal conductivity: The ability of a soil/rock to transmit heat energy by conduction. The thermal conductivity is a function of the mineral type, water content, and temperature. Graphs of the thermal conductivity vs. temperature are presented in Figures A-1 through A-5. The functions represent saturated conditions for the material. The thermal conductivity of the liner was assumed to be the same as the tails so the thermal model of the liner is for a line, not the 2 meter thick unit used in the model. Unit of thermal conductivity used in the model are kJ/hr m ^oC.

3) Unfrozen water content: The percentage of water within a material (i.e. soil/rock) that remains unfrozen at a given temperature. It is expressed as a percentage and is a function of temperature. Unfrozen water occurs at below freezing temperatures in soil due to tensile stresses derived from capillarity. A thin coat of liquid water will also remain on the surface of soil particles, dependent on the mineral type, particle size and temperature. The unfrozen water content functions used for the 5 soil types are presented in Figures A-6 through A-10. The unfrozen water content of the liner was taken to be the same as that

for the tails, again to model the liner as a line and not a 2 meter thick unit. Units used in the model for the unfrozen water content are %.

4) Volumetric heat capacity: The quantity of heat energy required to raise the temperature of a specified volume of a material by a unit degree. The volumetric heat capacity is a function of the mineral properties, water content and temperature. Ice has a different heat capacity than water. The model uses a frozen and thawed volumetric heat capacity. Values used are presented in Table 2 of the main report. Units used in the model for volumetric heat capacity are $kJ/m^3/°C$.

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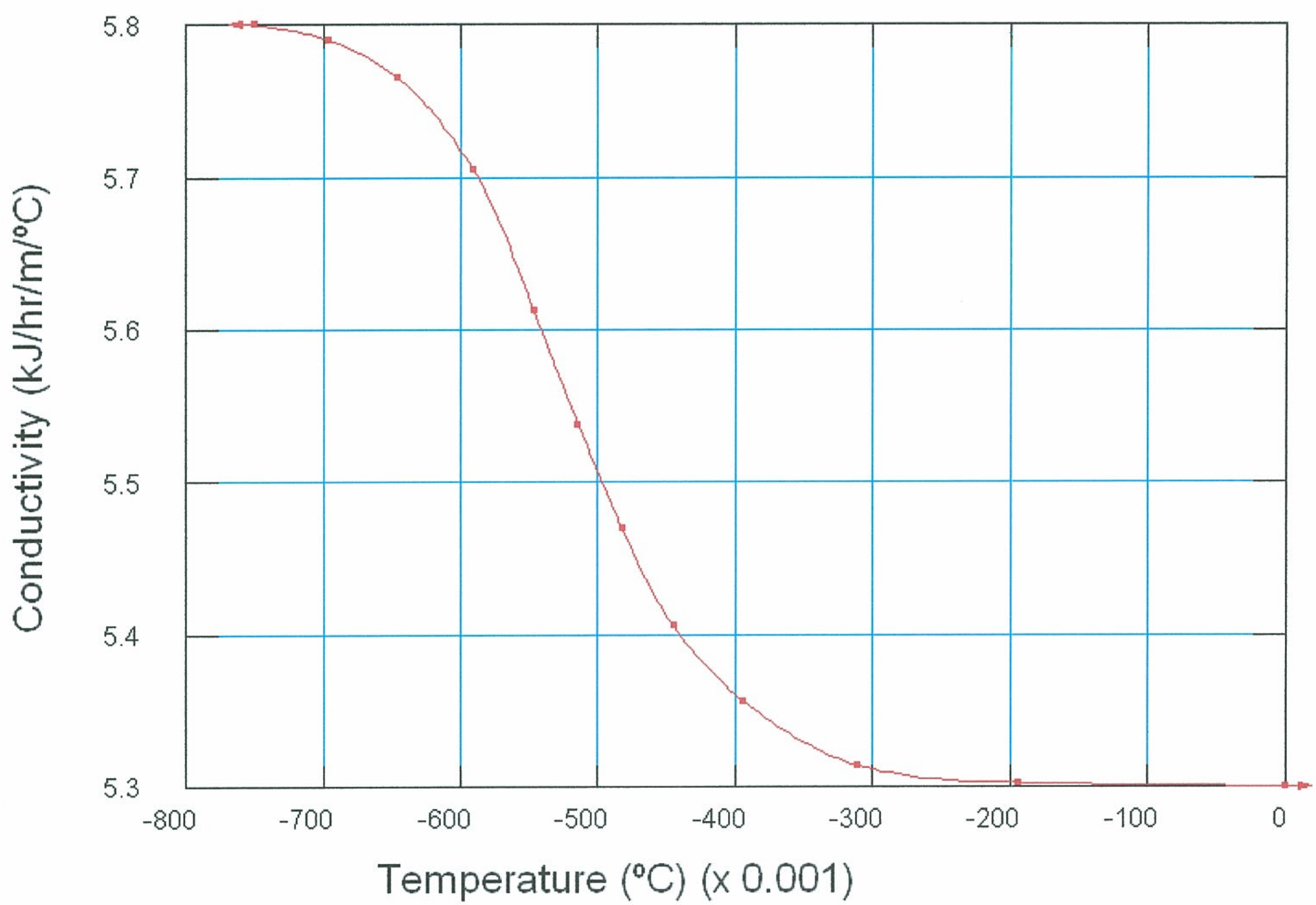
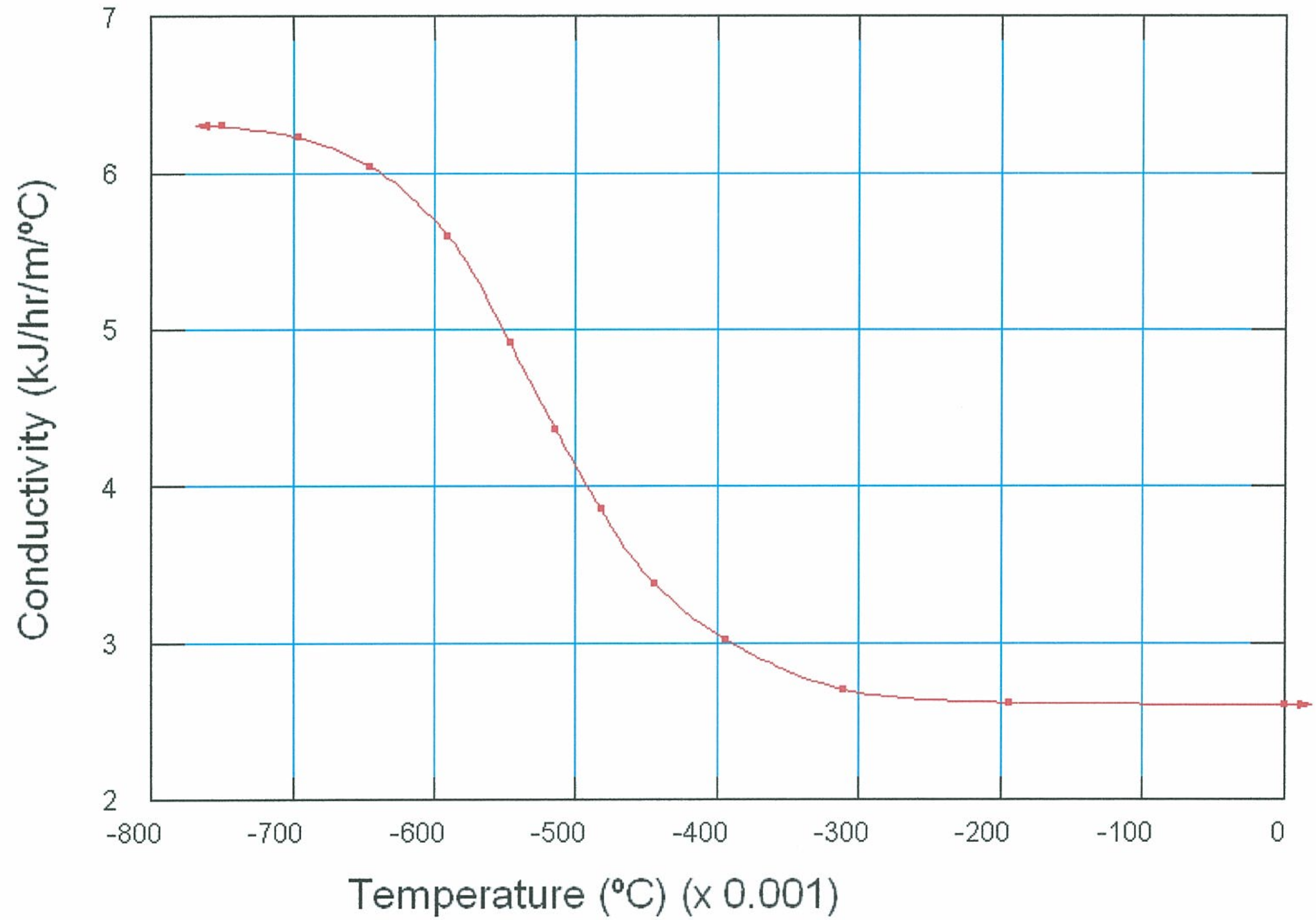


THERMAL CONDUCTIVITY FUNCTION
FOR THE BEDROCK

Rock Creek Dam,
Nome, Alaska

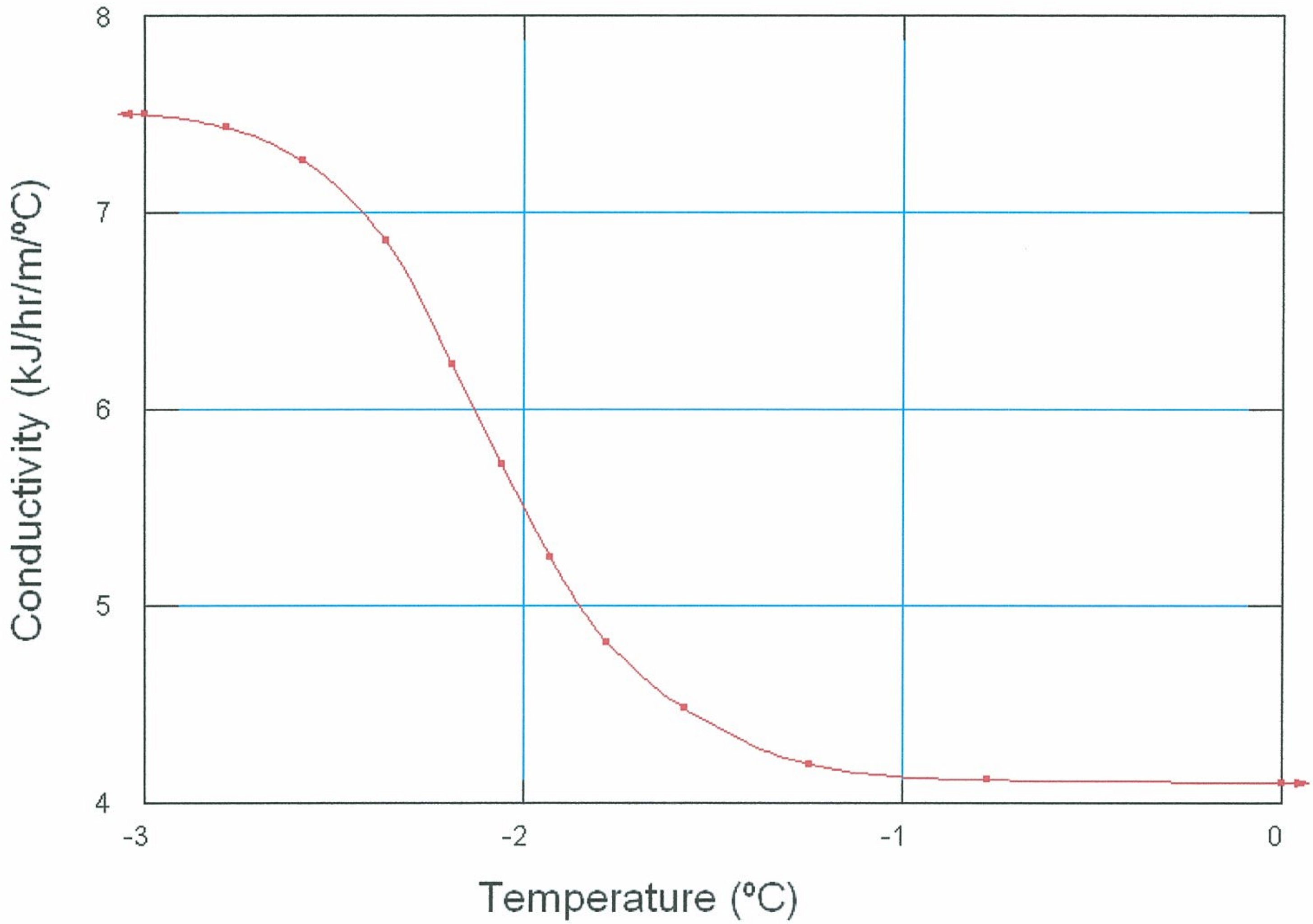
A-1



THERMAL CONDUCTIVITY FUNCTION FOR THE ROCK FILL DAM MATERIAL

Rock Creek Dam,
Nome, Alaska

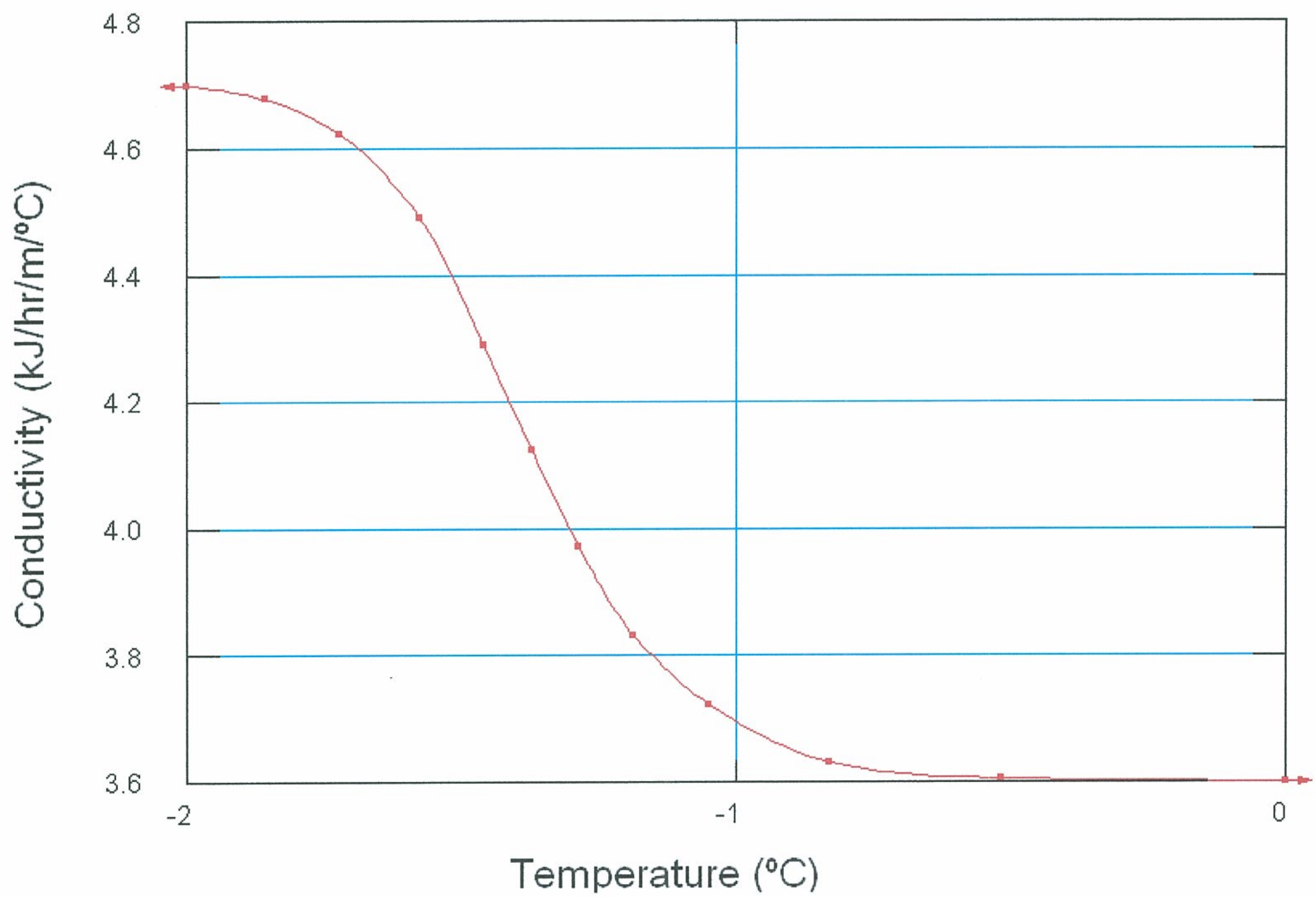
A-2



THERMAL CONDUCTIVITY FUNCTION
FOR THE TAILINGS

Rock Creek Dam,
Nome, Alaska

A-3

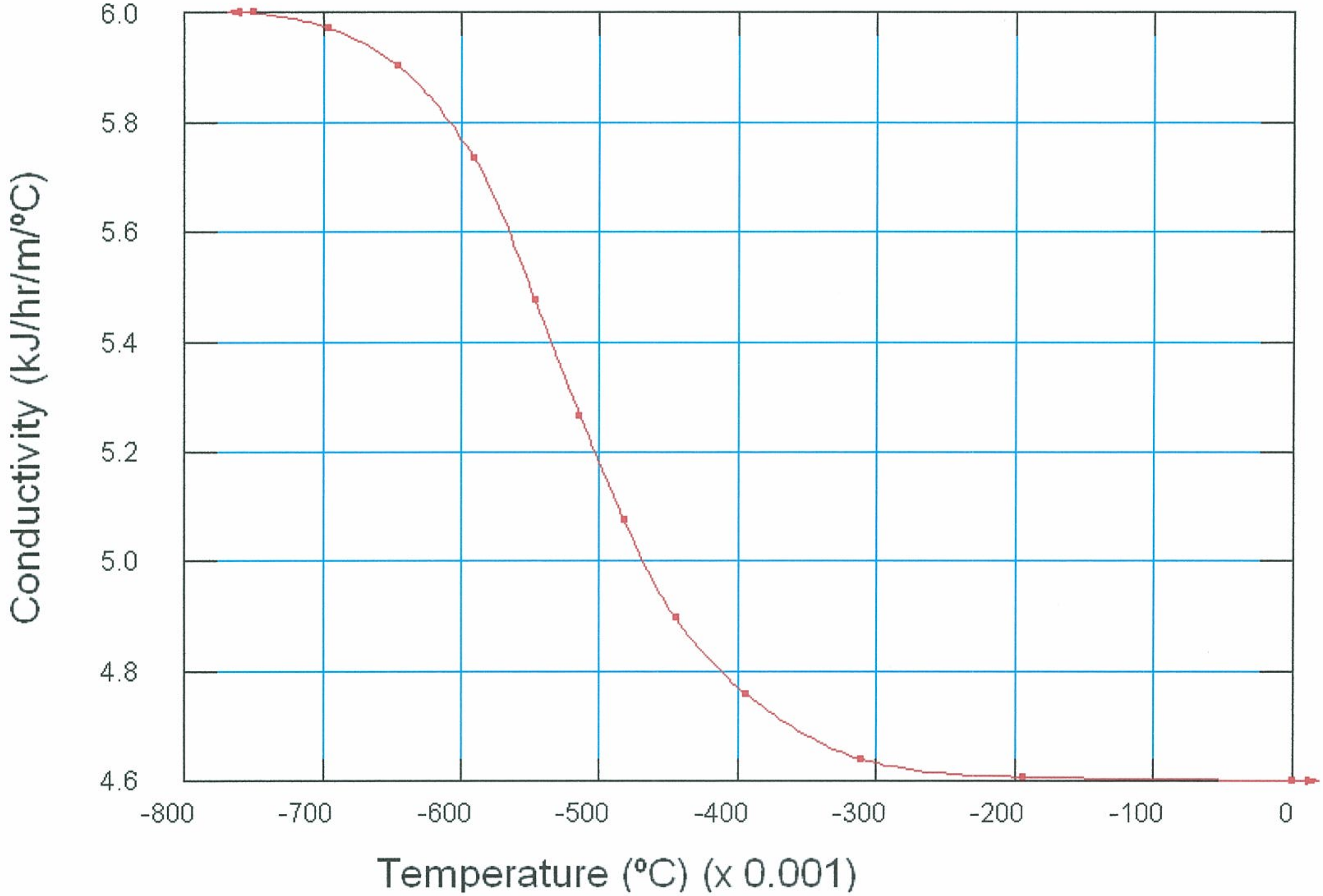


TERRA FIRMA TESTING
NORTHERN GEOTECHNICAL ENGINEERING, INC.

THERMAL CONDUCTIVITY FUNCTION FOR THE NATIVE SURFICAL SOILS

Rock Creek Dam,
Nome, Alaska

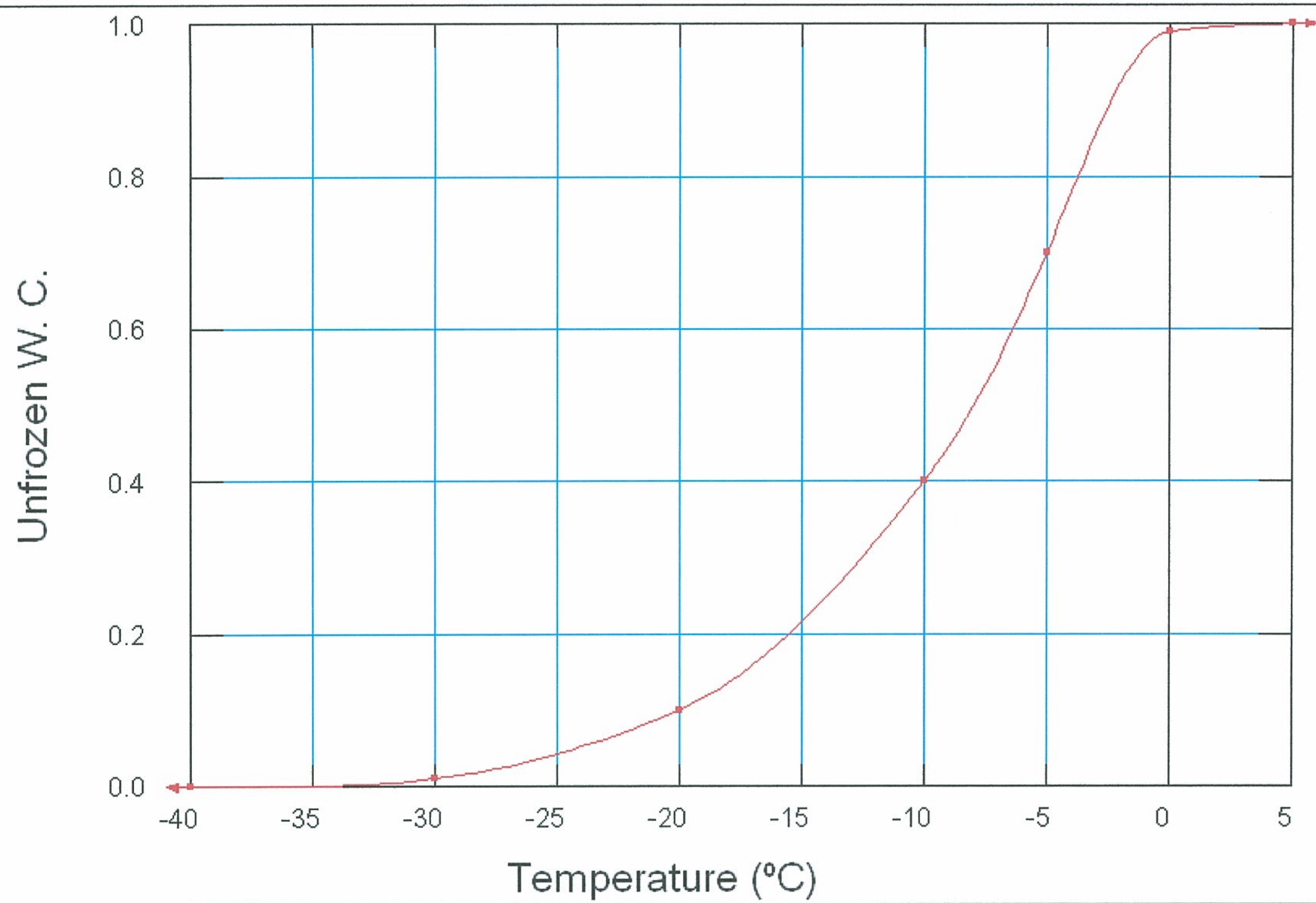
A-4



THERMAL CONDUCTIVITY FUNCTION FOR THE NATIVE WEATHERED BEDROCK

Rock Creek Dam,
Nome, Alaska

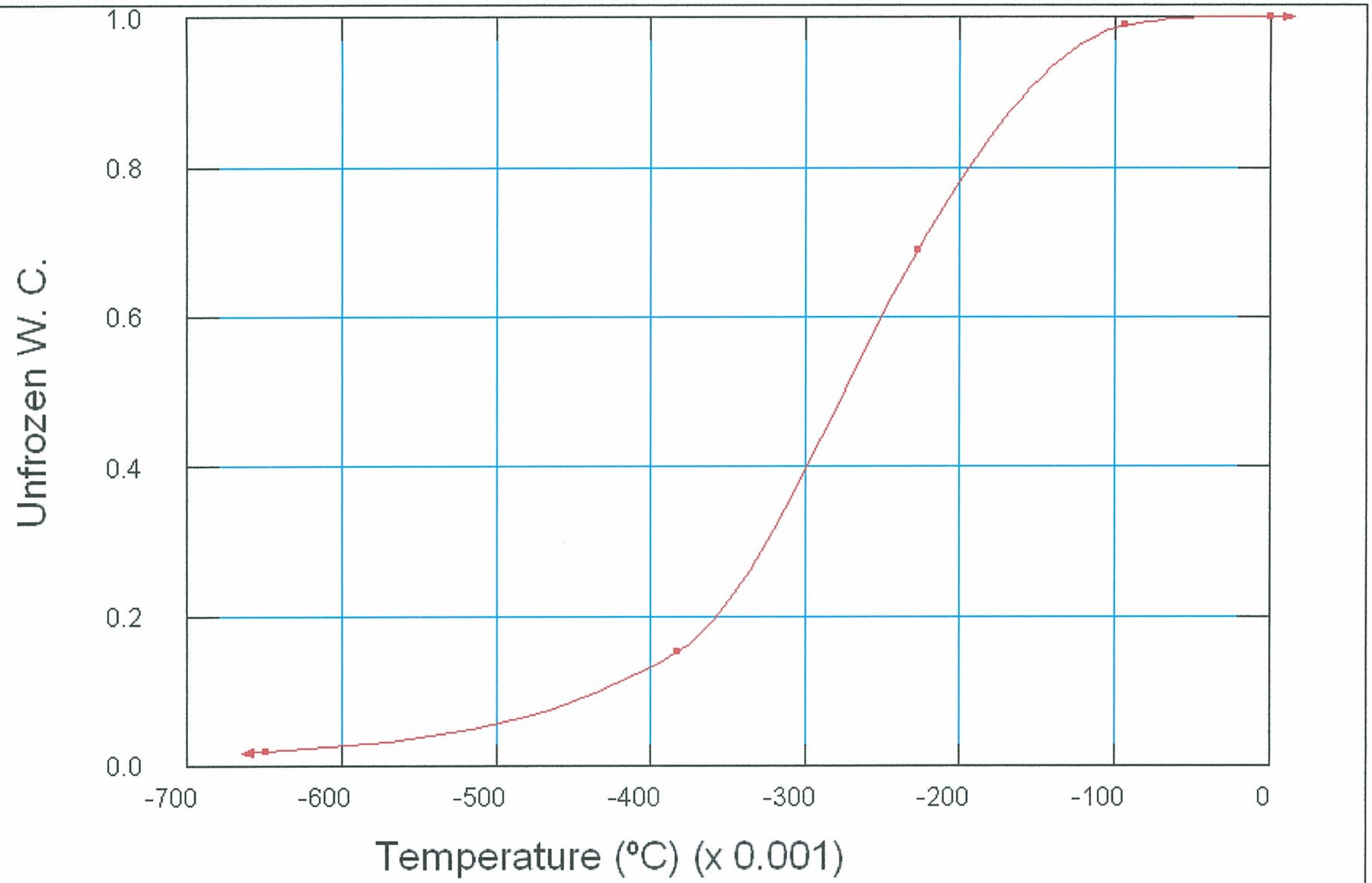
A-5



UNFROZEN WATER CONTENT FUNCTION
FOR THE TAILINGS

Rock Creek Dam,
Nome, Alaska

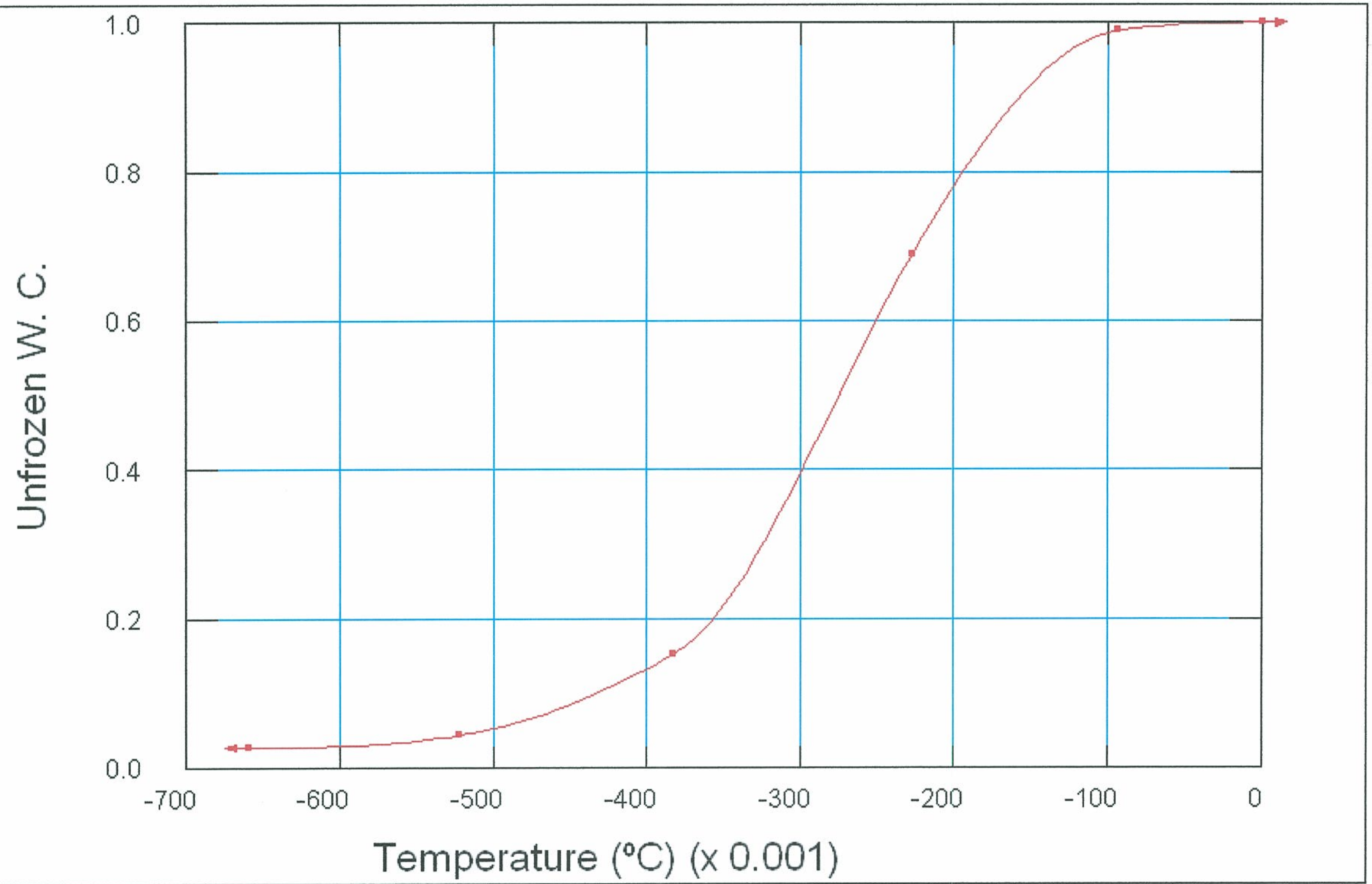
A-6



UNFROZEN WATER CONTENT FUNCTION
FOR THE NATIVE WEATHERED BEDROCK

Rock Creek Dam,
Nome, Alaska

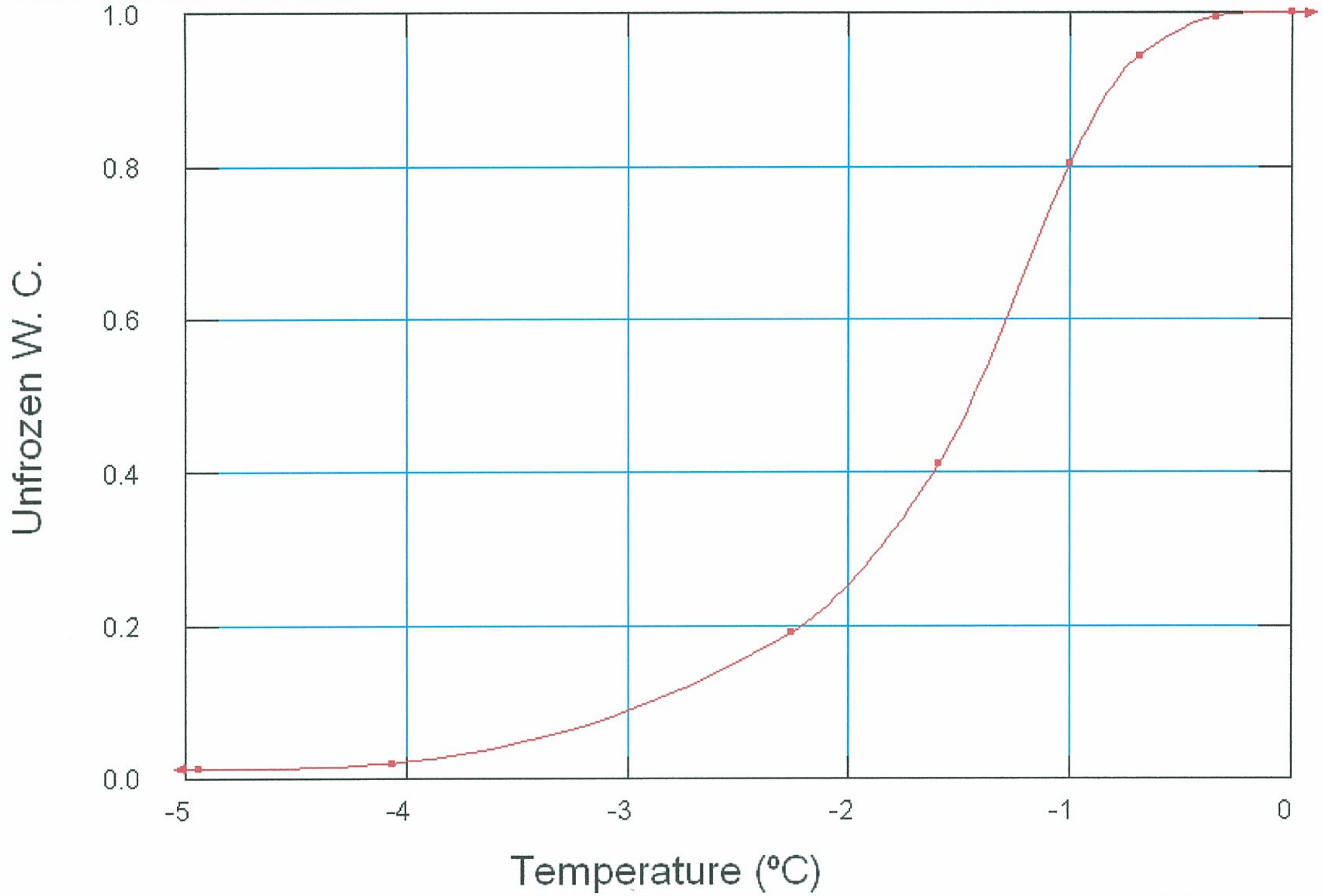
A-7



UNFROZEN WATER CONTENT FUNCTION
FOR THE NATIVE BEDROCK

Rock Creek Dam,
Nome, Alaska

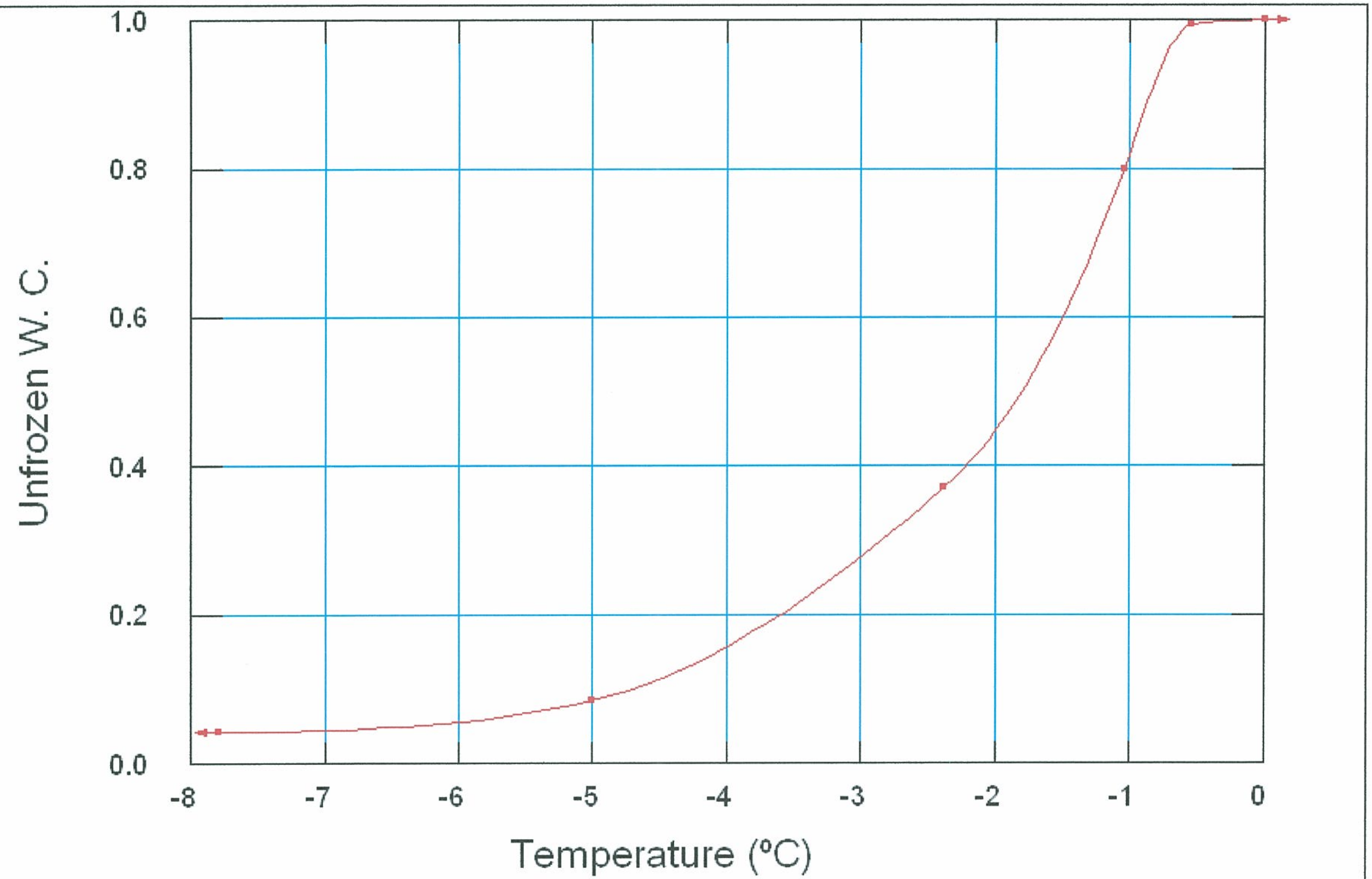
A-8



UNFROZEN WATER CONTENT FUNCTION
FOR THE ROCK FILL DAM MATERIAL

Rock Creek Dam,
Nome, Alaska

A-9



UNFROZEN WATER CONTENT FUNCTION
FOR THE NATIVE SURFICIAL SOILS

Rock Creek Dam,
Nome, Alaska

A-10

APPENDIX B

HYDRAULIC PROPERTY FUNCTIONS

APPENDIX B
HYDRAULIC PROPERTIES

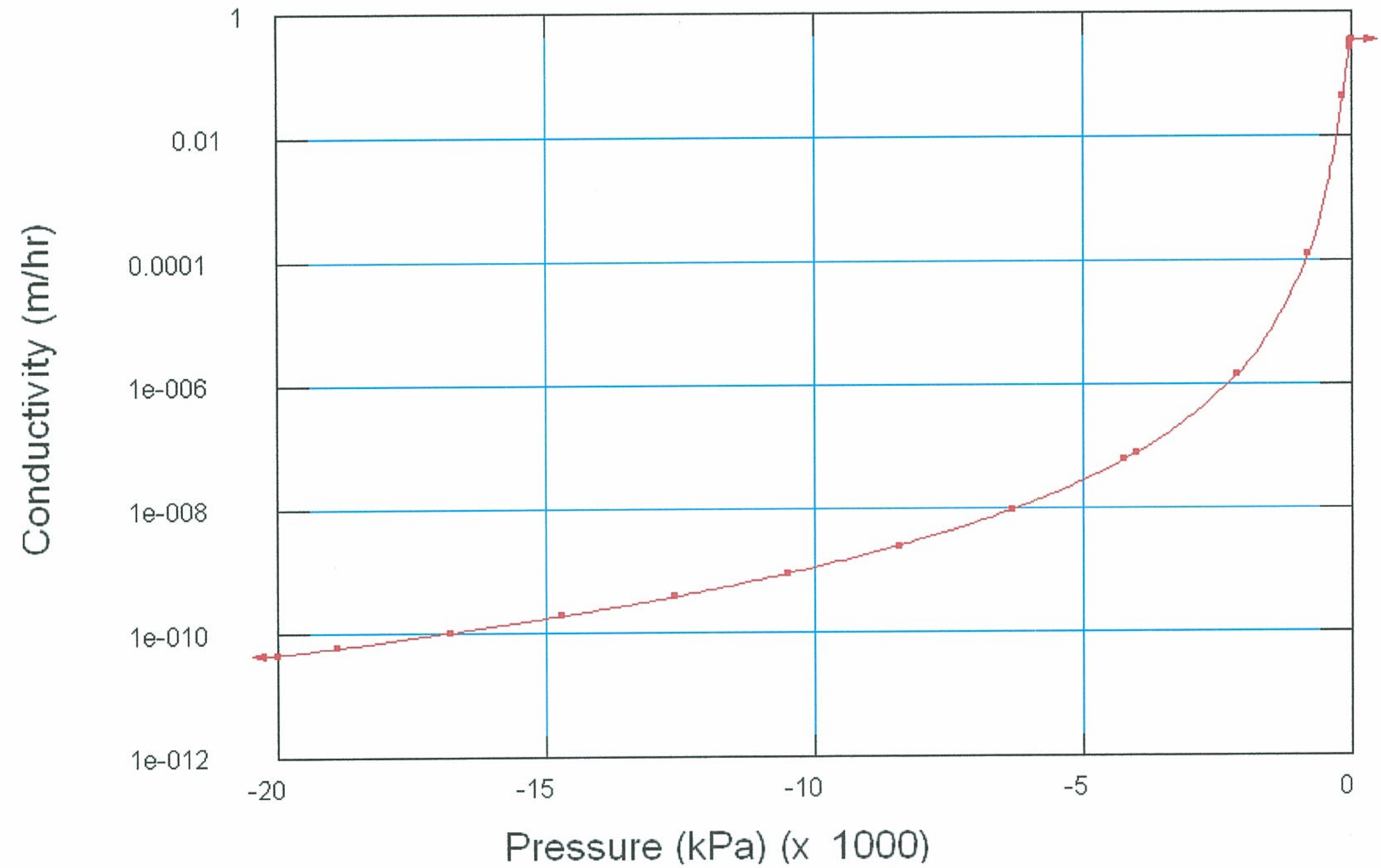
SEEP/W requires input of hydraulic properties for each of the different materials used in the model. Each region is defined as a material type and the model references each material type to assigned properties. Where the hydraulic properties are a function dependent on other variables in the system, a graphical representation of the property is needed. The hydraulic properties defined for each material in the model include:

1) Hydraulic conductivity: The ability of a material to transport or conduct water under both saturated and unsaturated conditions. With unsaturated conditions, the hydraulic conductivity decreases as a function of the head. Because the phreatic surface is below the node in question, a suction pressure is created. The functions are presented in Figures B- through B-6. The units used for the model are m/hr.

The liner hydraulic conductivity was derived from the permeability of the HDPE liner and calculated for an equivalent permeability using a 2 meter thick region. This was required as the liner in essence is a hydraulic discontinuity, but it is not a thermal discontinuity. For the coupled analysis using TEMP/W and SEEP/W, the hydraulic discontinuity needed to be modeled such that heat transfer could be calculated.

2) Volumetric water content: The volume of water which occupies the void spaces within a material. It is expressed as a percentage of water-filled voids to air-filled voids, with 100% indicating saturation. The saturated volumetric water content is defined for each material as shown in Table 2. In unsaturated conditions, the volumetric water content is a function of the suction pressure. These functions are presented in Figures B-7 through B-12. Units used in the model are %.

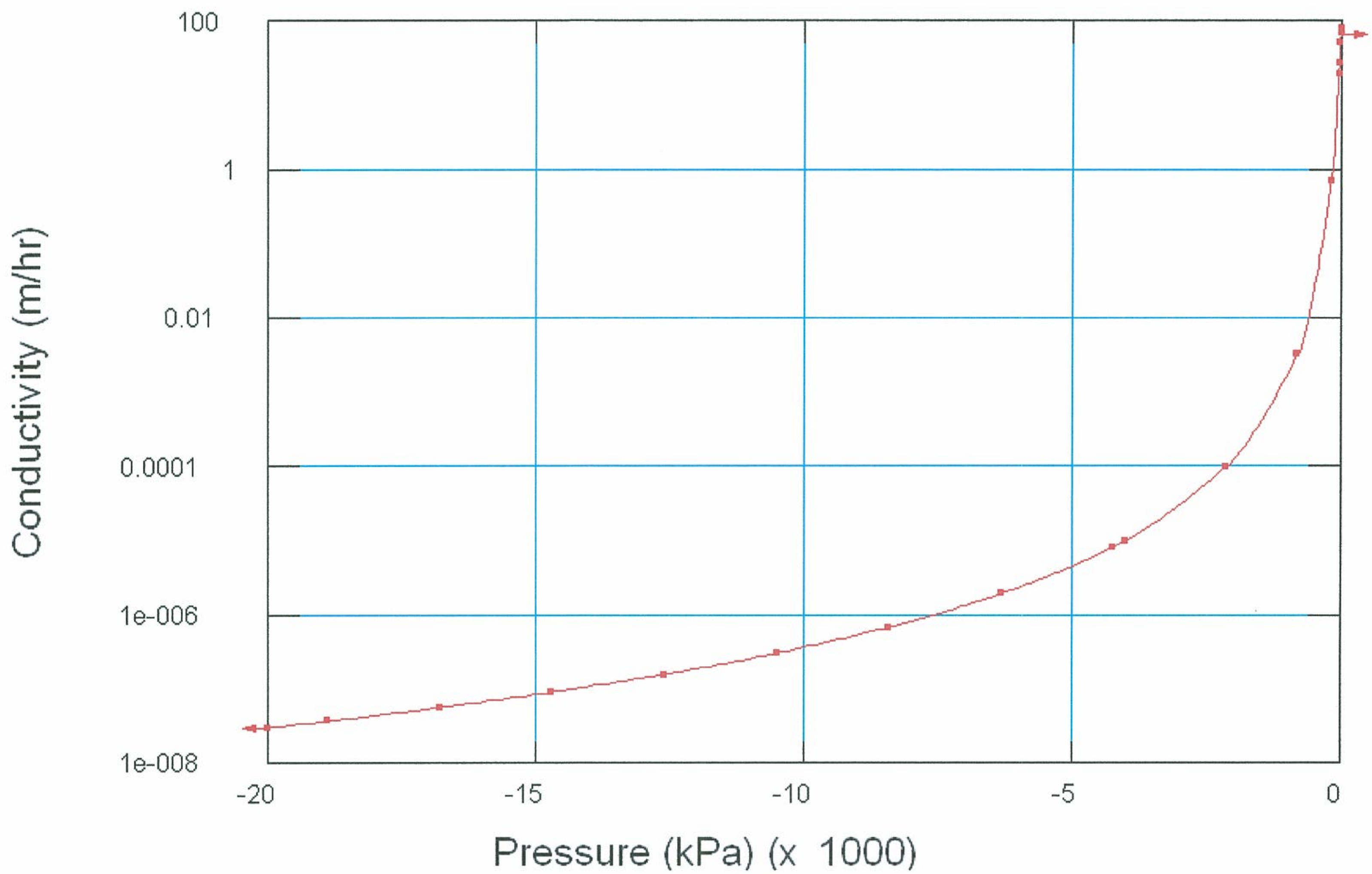
During the seepage analysis, the program calculates the actual volumetric water content in the unsaturated zone based on the calculated suction pressure. This in turn affects the permeability.



HYDRAULIC CONDUCTIVITY FUNCTION FOR THE NATIVE BEDROCK

Rock Creek Dam,
Nome, Alaska

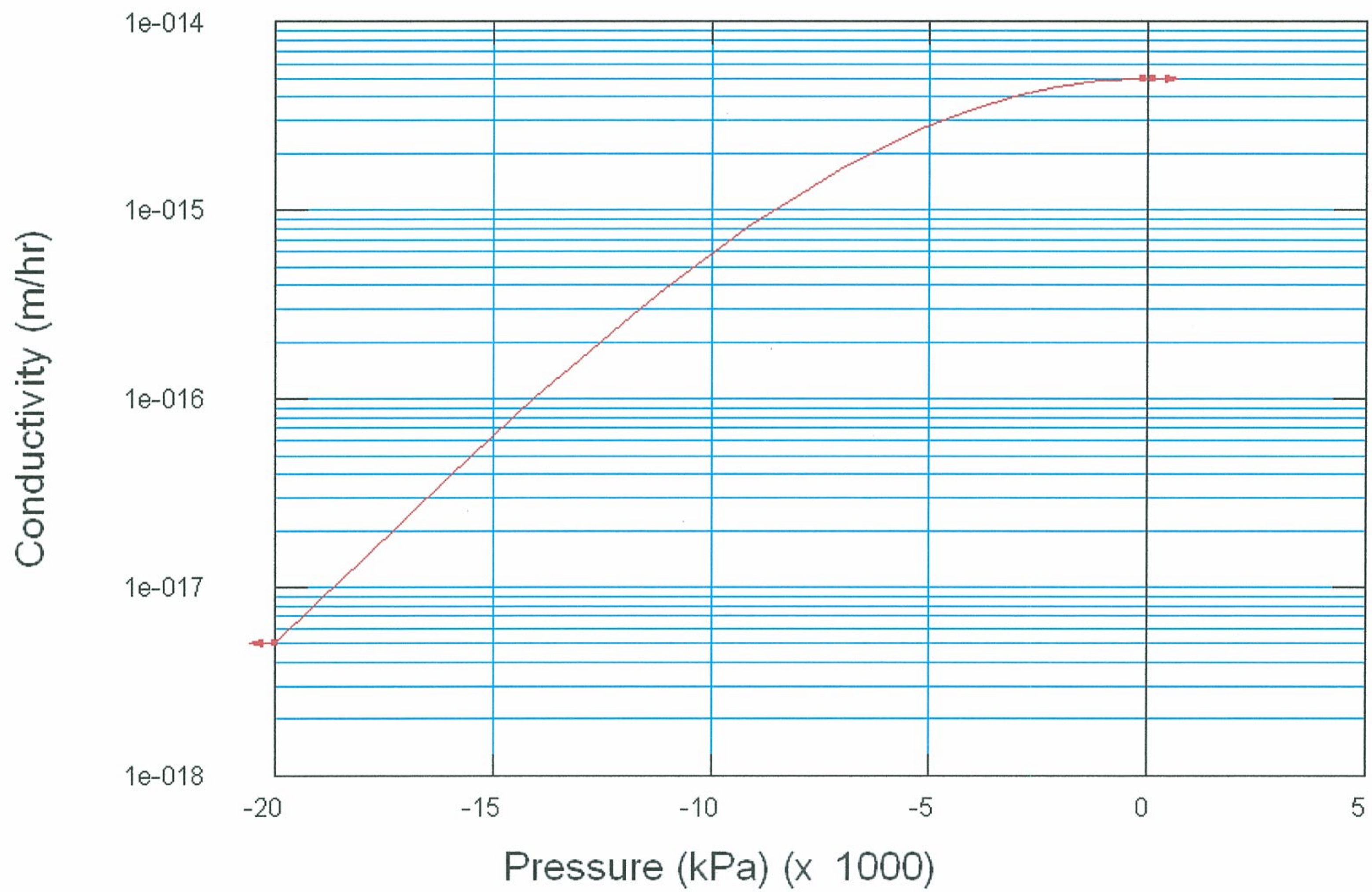
B-1



HYDRAULIC CONDUCTIVITY FUNCTION FOR THE ROCK FILL DAM MATERIAL

Rock Creek Dam, Nome, Alaska

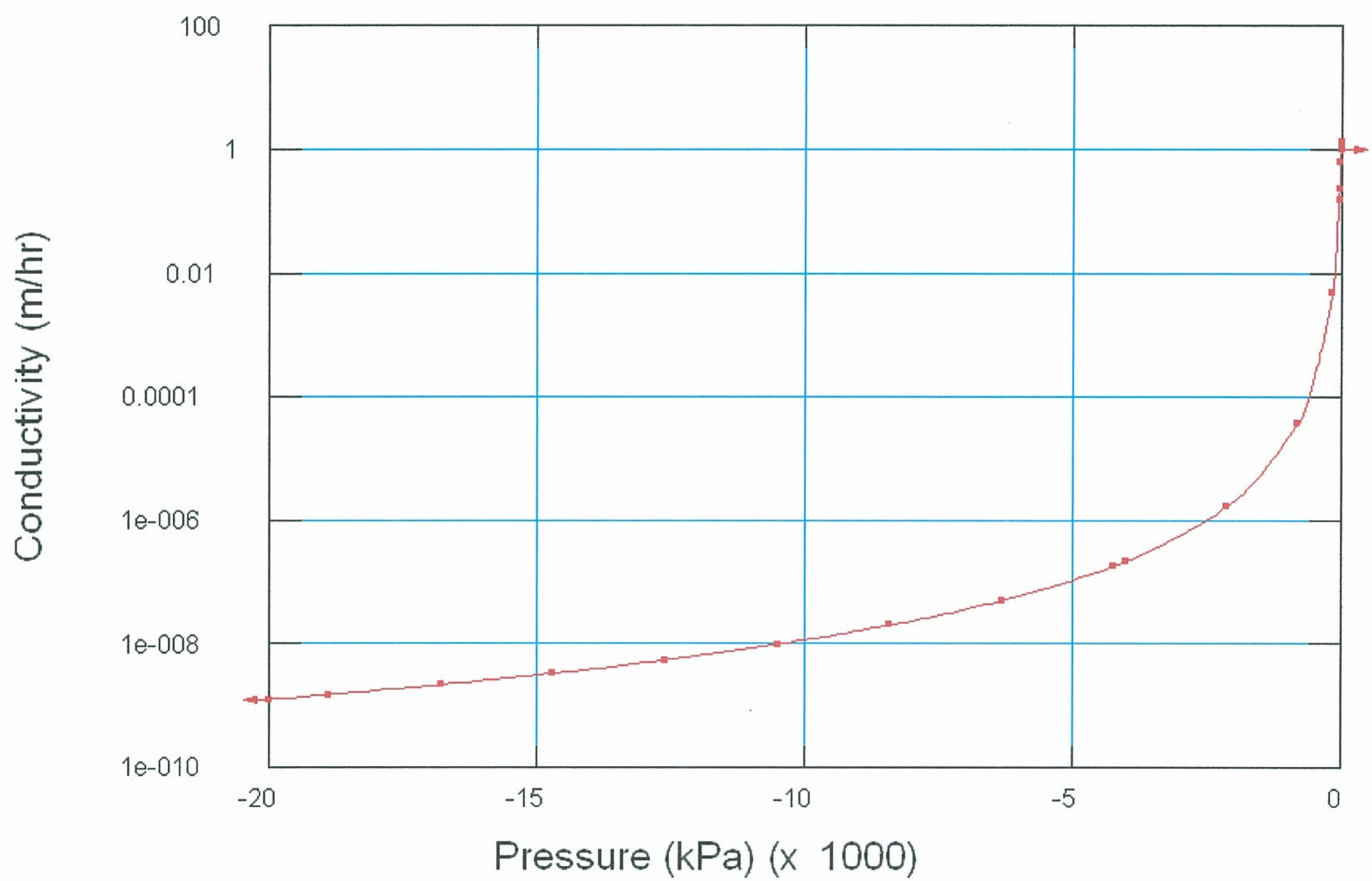
B-2



HYDRAULIC CONDUCTIVITY FUNCTION FOR THE LINER MATERIAL

Rock Creek Dam,
Nome, Alaska

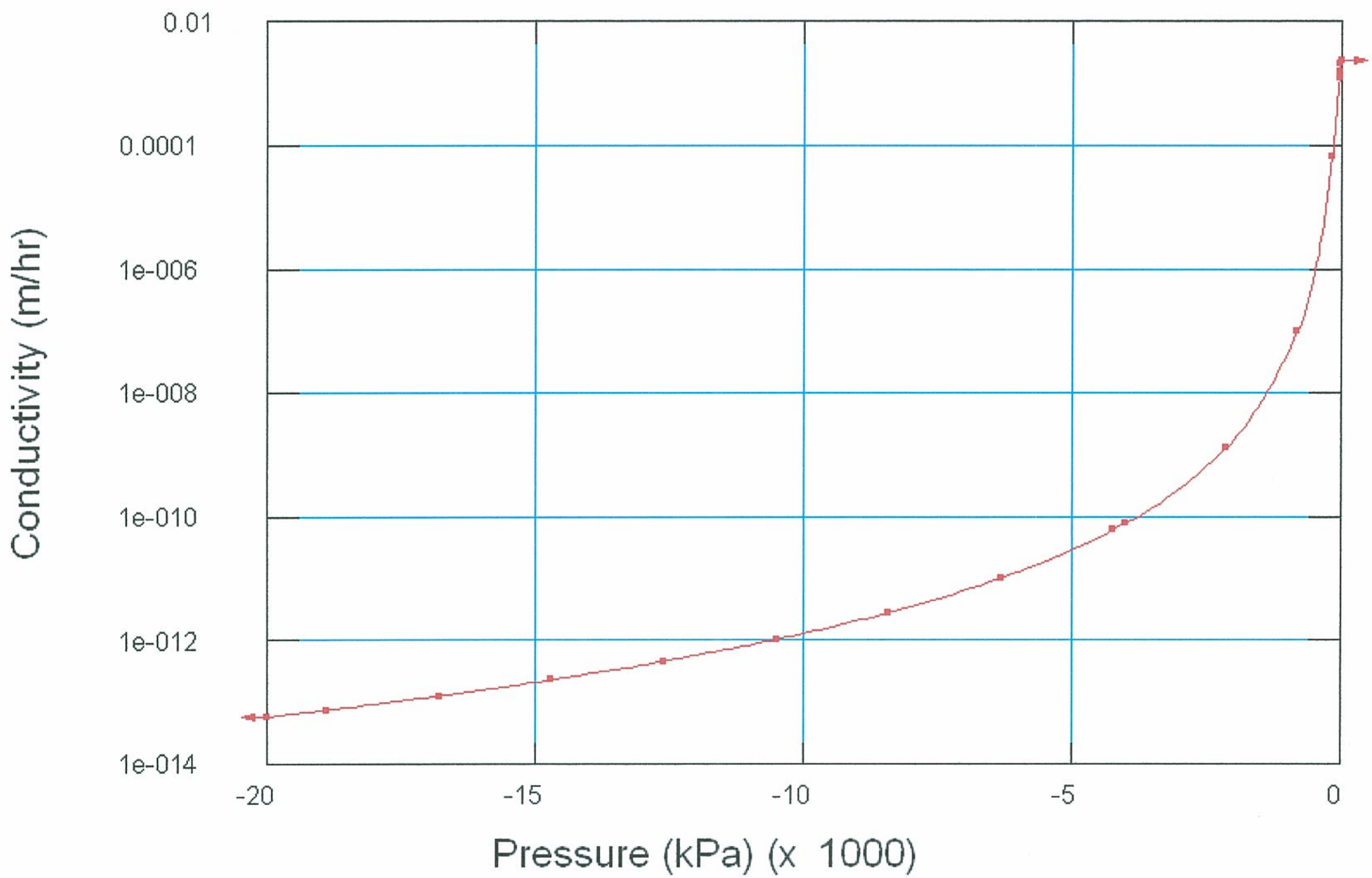
B-3



HYDRAULIC CONDUCTIVITY FUNCTION FOR THE NATIVE SURFICIAL SOILS

Rock Creek Dam, Nome, Alaska

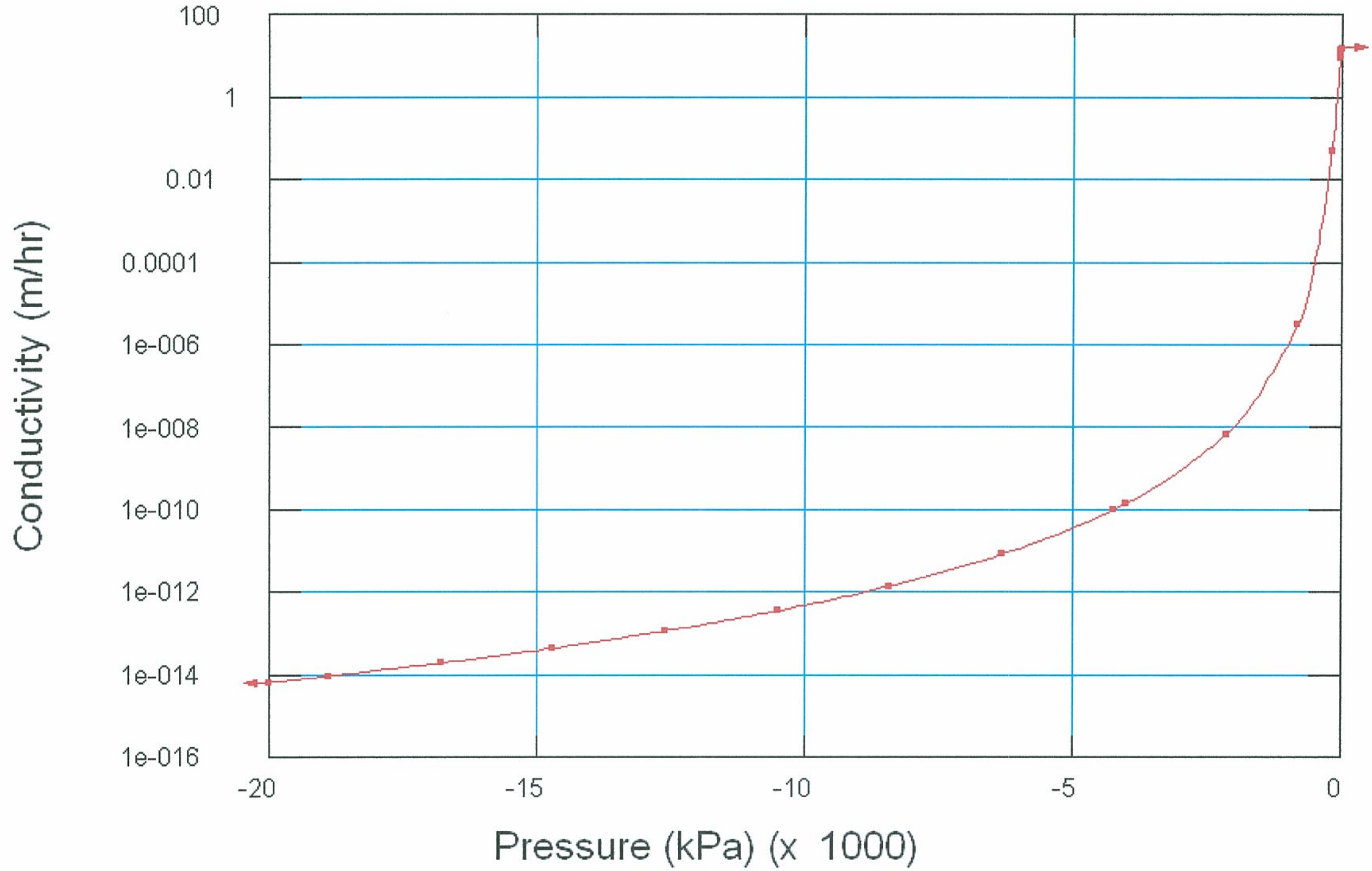
B-4



HYDRAULIC CONDUCTIVITY FUNCTION
FOR THE TAILINGS

Rock Creek Dam,
Nome, Alaska

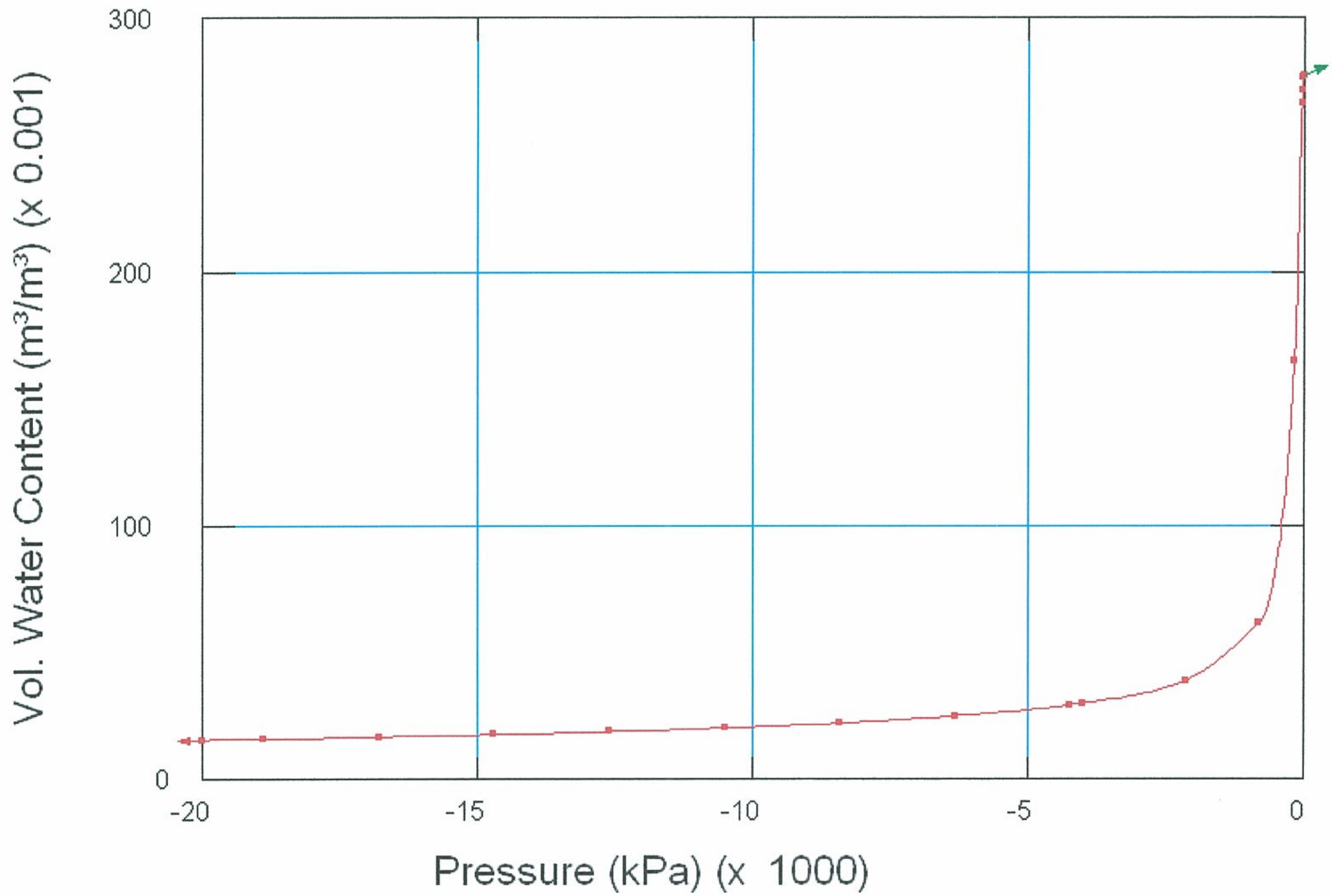
B-5



HYDRAULIC CONDUCTIVITY FUNCTION
FOR THE NATIVE WEATHERED BEDROCK

Rock Creek Dam,
Nome, Alaska

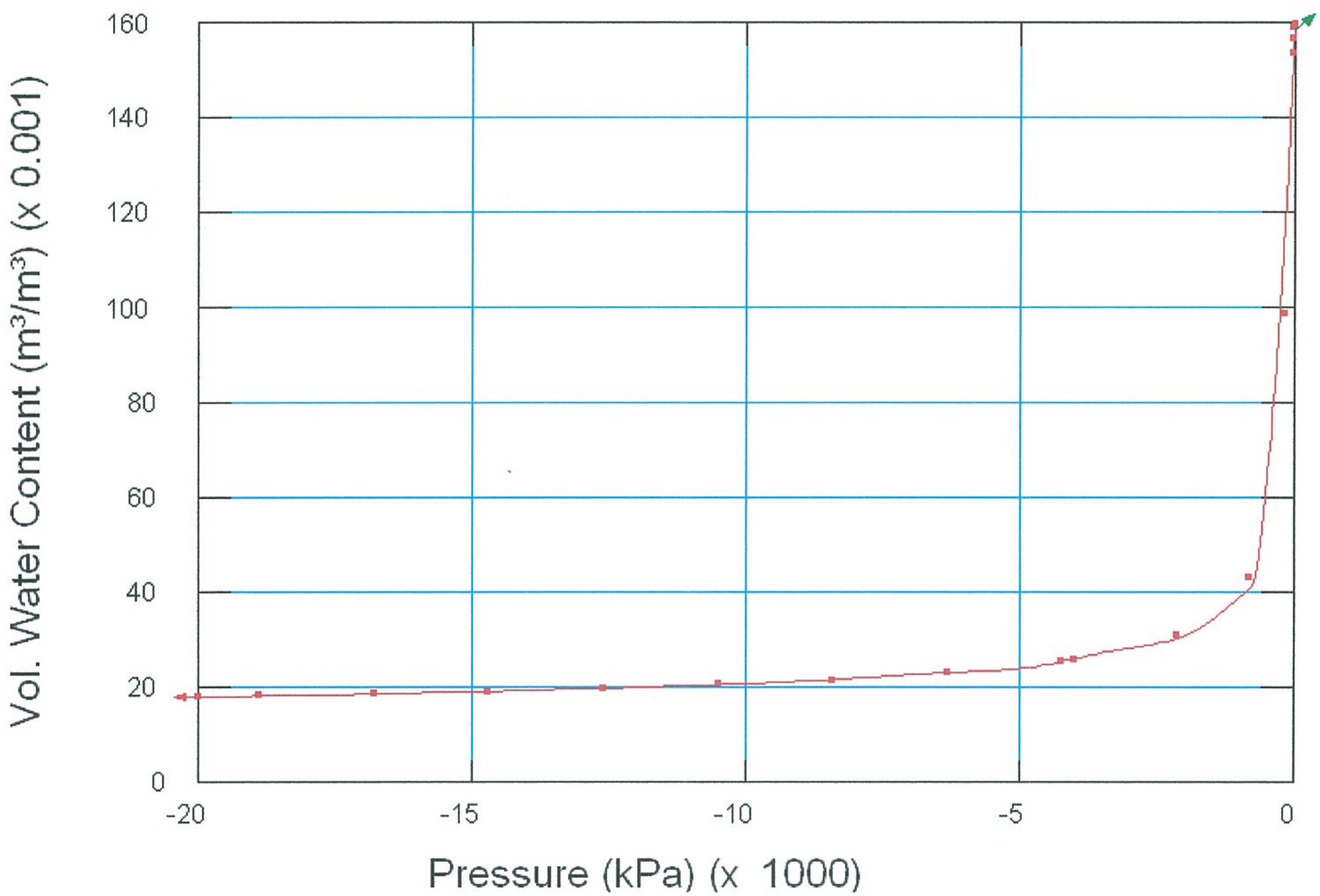
B-6



VOLUMETERIC WATER CONTENT
FUNCTION FOR THE
ROCK FILL DAM MATERIAL

Rock Creek Dam,
Nome, Alaska

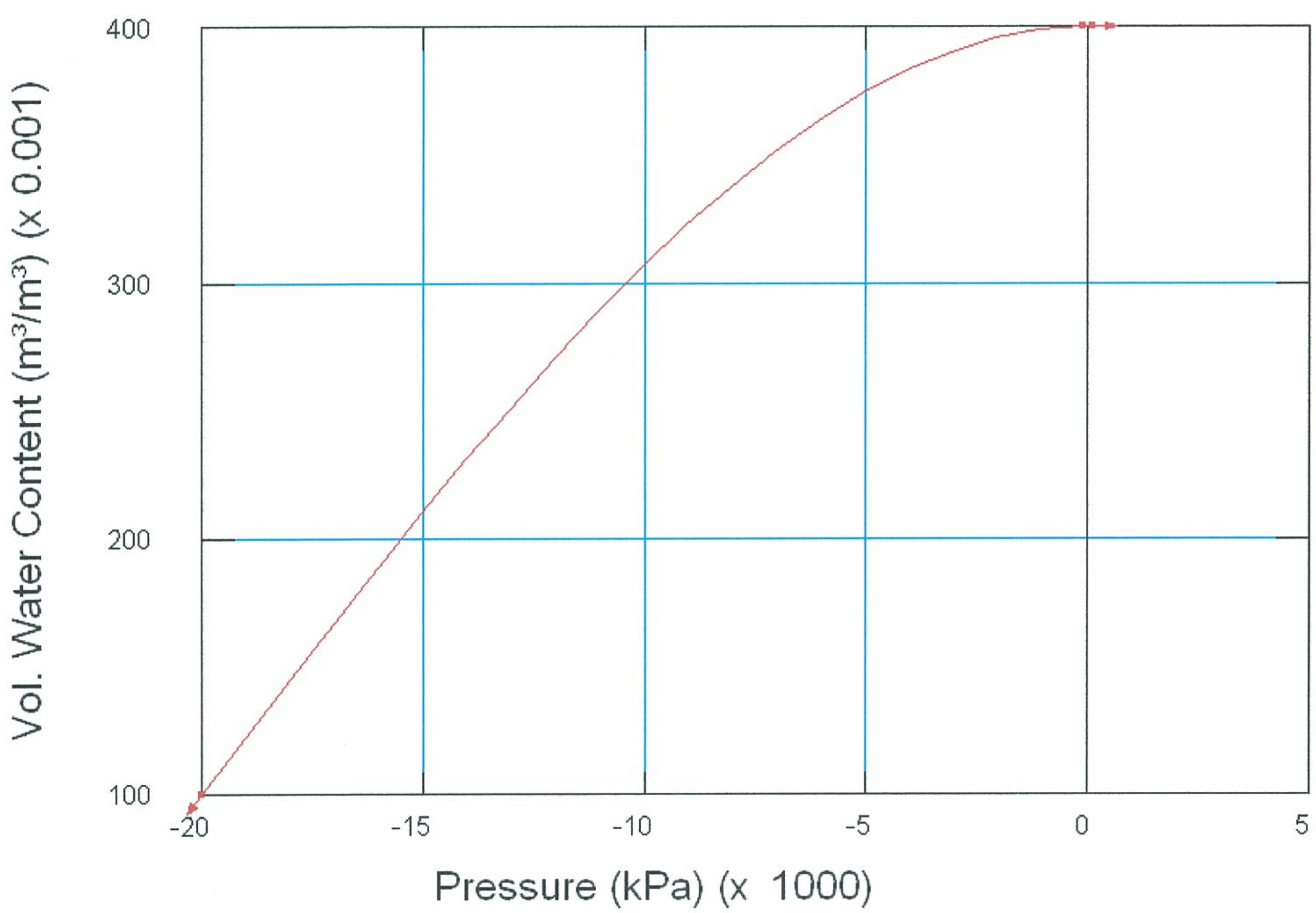
B-7



VOLUMETERIC WATER CONTENT FUNCTION FOR THE NATIVE BEDROCK

Rock Creek Dam,
Nome, Alaska

B-8

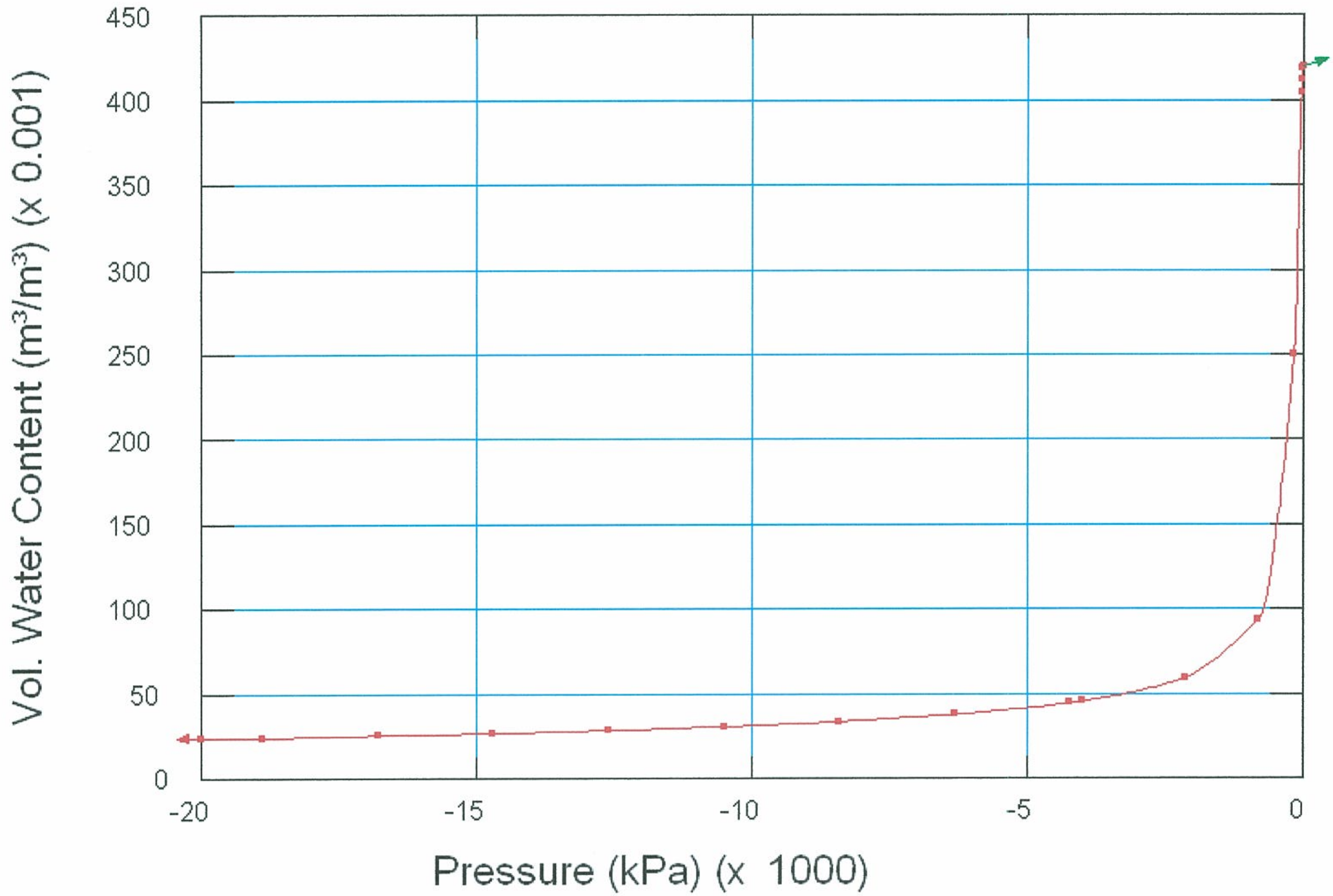


NORTHERN GEOTECHNICAL ENGINEERING, INC. TERRA FIRMA TESTING

VOLUMETERIC WATER CONTENT FUNCTION FOR THE LINER MATERIAL

Rock Creek Dam,
Nome, Alaska

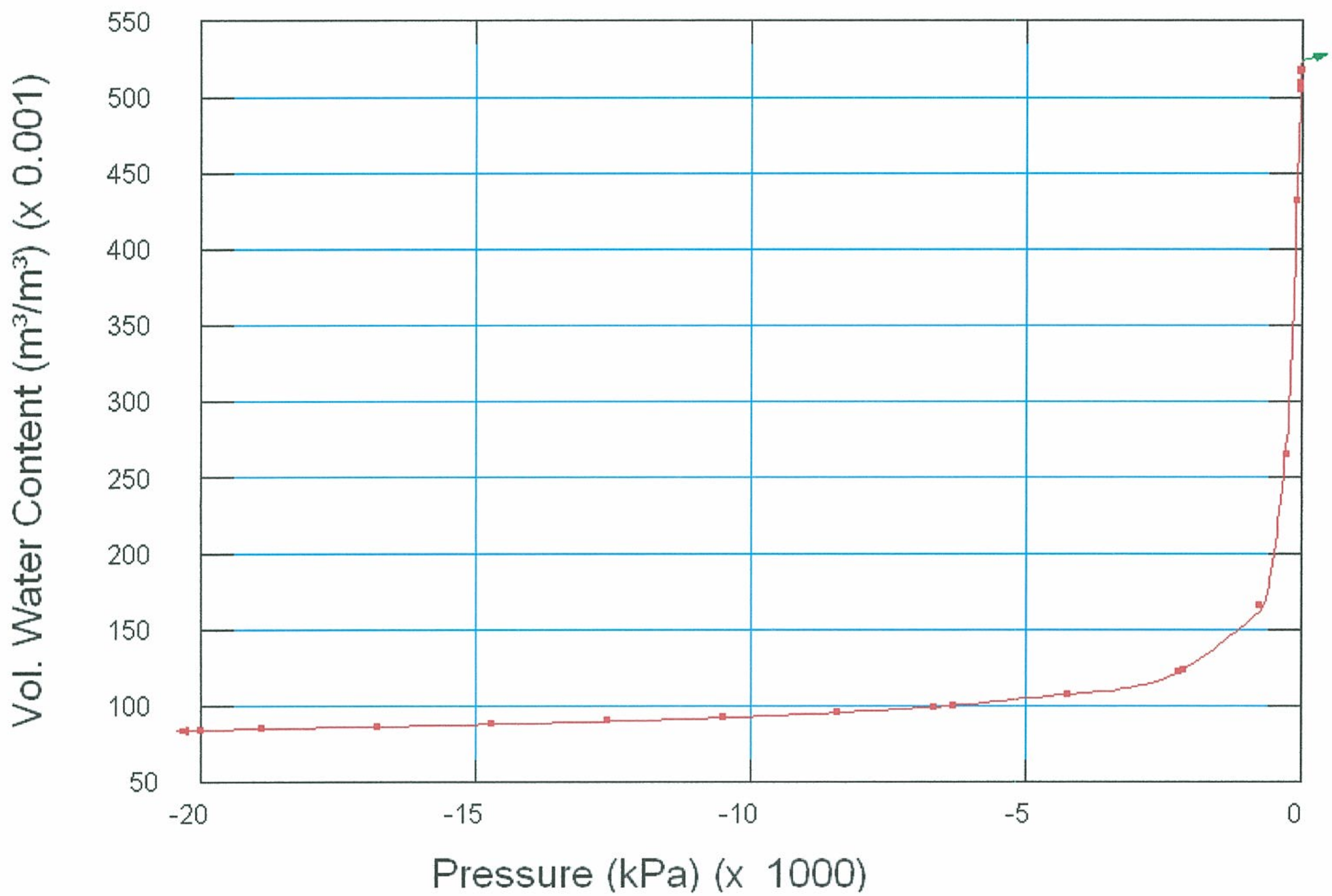
B-9



VOLUMETERIC WATER CONTENT
FUNCTION FOR THE
NATIVE SURFICIAL SOILS

Rock Creek Dam,
Nome, Alaska

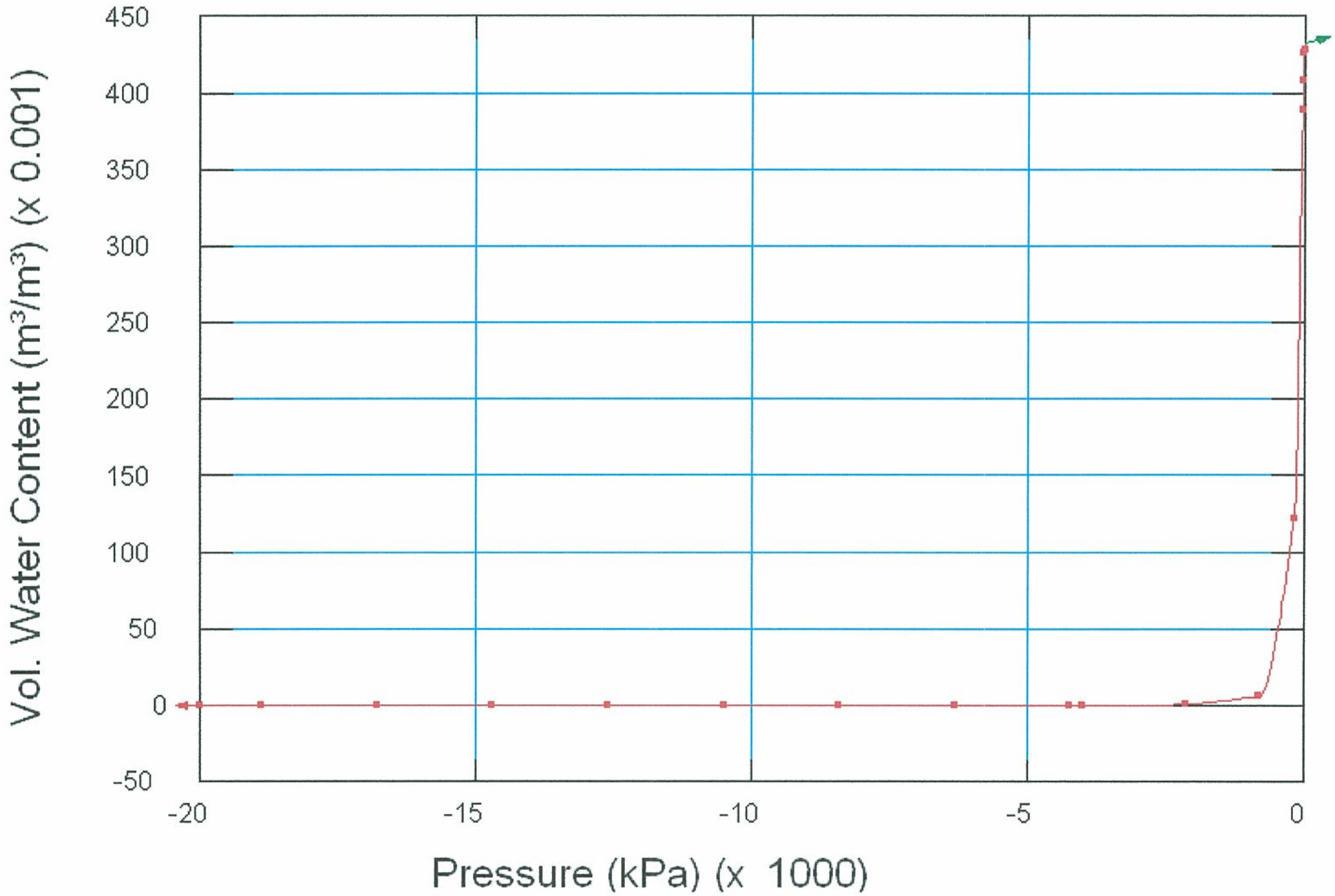
B-10



VOLUMETERIC WATER CONTENT FUNCTION FOR THE TAILINGS

Rock Creek Dam,
Nome, Alaska

B-11



VOLUMETERIC WATER CONTENT
FUNCTION FOR THE
NATIVE WEATHERED BEDROCK

Rock Creek Dam,
Nome, Alaska

B-12

APPENDIX C

BOUNDARY CONDITION FUNCTIONS

APPENDIX C

BOUNDARY CONDITIONS

Thermal Boundaries

Temperature Boundary

The thermal boundary conditions for the model used in this study were defined by either applying: 1) a constant temperature; or 2) a time-related temperature function to individual nodes along a defined boundary (ex. ground surface).

Constant thermal boundary conditions were used to apply site-specific temperature data (recorded in core holes along the TSFD centerline) to linear series of nodes at corresponding depths within the model. These boundary conditions were used in the initial steady state analyses to define the average thermal gradient of the subsurface materials as they currently exist.

A time-related temperature function was developed in the modeling software using ambient air temperature data acquired from the Nome Airport, which defined the annual average hourly change in air temperatures for the area (Figure C-1). This function was subsequently applied (during the transient analyses) to the nodes along the surface of the model to account for the hourly input/removal of thermal energy to/from the model as a result of contact with the ambient air at the site. This temperature function was used for scenarios 1 through 4.

Raised temperatures used in scenarios 5 through 7 to model an extreme global warming condition. The entire function shown in Figure C-1 was increased by 3°C for the entire modeling period. A more realistic model effort would have been to raise the temperature incrementally over the modeling period at the beginning of each phase. This was not completed due to time and budget constraints.

Thermal Modifier Functions

Correction factors, known as modifier functions, were developed for the surficial thermal boundary condition function (i.e. ambient air temperature) to account for differing rates of material heat gain/loss due to factors other than air temperature; such as snow insulation, wind removal, solar incidence, ground cover, etc. The modifier functions are developed in the analysis software and are time-related correction factors which are applied to representative nodes at the time that a thermal boundary condition is applied to a node in the model. Three functions were developed to account for differences in the ground cover at various positions on the model surface.

Native Soil Function

The modifier function for the native soil is shown in Figure C-2. The value of less than 1 for the winter month reflects the insulation value from snow and native plant growth. Mathematically, the surface temperatures during the winter are warmer than the air temperature. During the summer months, the function is greater than 1 representing solar absorption. The factor is lower than for bare material as the plant growth evapo-transpiration and insulating characteristics reduces energy absorption into the ground.

Tailings Function

The modifier function for the tailings is shown in Figure C-3. During the winter the tails are expected to melt some snow and to accumulate in piles. As such some solar gain is expected and little to no insulating value from the snow is expected. The release of latent heat from the snow melt cannot be accommodated in the model as it is above the mesh surface, so a modifier value slightly greater than 1 was used. During the summer months solar gain will be significant with the wet tails on the surface able to absorb the incident heat.

Rock Fill Function

The modifier function for the rock fill to be used in the dam construction is shown on Figure C-4. Most of the downstream dam face points to the south and west. As such, it is expected that snow accumulation will be less, water from the snow melt will percolate deep into the dam, and incident solar radiation will be increased both from the orientation and the sloped face. During the summer months incident solar radiation will be high, however the dam face is expected to be dry, thus reducing the heat absorption.

Geothermal Gradient

A geothermal gradient exists over the entire earth's surface and is the result of heat from the core reaching the ground surface. The gradient is variable, dependent upon numerous

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factors. Lunardini (1981) suggested an order-of-magnitude value for the geothermal gradient. This value was used initially during the calibration phase of the modeling. With a 50 m thick model below the base of the dam, it can be assumed that the temperature of the base would not change during the first year of modeling. To achieve this, the geothermal gradient value was adjusted until thermal equilibrium was reached at depth. The value used for all seven scenarios was 0.21 kJ/hr/M and was applied to the nodes along the bottom the model.

Hydraulic Boundaries

The hydraulic boundary conditions for the model used in this study were defined by either applying: 1) a constant hydraulic head condition (a.k.a. potential head); 2) an elevation dependant hydraulic head condition (a.k.a. pressure head); or 3) a time-related meteoric water input function to individual nodes along the surface.

A hydraulic head boundary condition was used to apply estimated hydraulic head conditions to the nodes which represents the surface of the groundwater table as is reported to exist at the site (top of the weathered bedrock material). Each node was assigned a pressure head value corresponding to the node's elevation. These boundary conditions were used in the initial steady state analyses to define the average hydraulic gradient of the subsurface materials as they currently exist.

Once the initial hydraulic conditions of the native materials was established, Phase I of the TSFD and tailings were added to the model, and a pressure head boundary condition applied to the nodes along the surface of the tailings corresponding to the elevation of the tailing surface. This established the hydraulic gradient within the tailings and underlying native materials.

A time-related meteoric water input function was developed in SEEP/W using rainfall equivalence data acquired from the 2003 Norwest Report, which defined the annual average hourly water input to the site from precipitation (Figure C-5). This function was subsequently applied (during the transient analyses) to the nodes along the surface of the model to account for the hourly input of meteoric water into the model. The function was adjusted to account for the increased runoff which occurs during spring break-up, and the

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limited runoff/infiltration which occurs during winter months. The total annual precipitation accumulation was kept constant with the data used.

Thermosyphon Boundary Conditions

TEMP/W contains an application which allows the user to place a thermosyphon boundary condition at an individual node (or nodes) which represent a single thermosyphon, as if you were viewing the pipe in cross-section. The thermosyphon application within TEMP/W operates on four user-defined criteria: 1) pipe length (750 m); 2) maximum functioning air temperature (-1°C); 3) the minimum air/ground temperature difference that must exist in order for a phase change to occur within the thermosyphon system (3°C); and 4) the area of the thermosyphon's condenser radiator in square meters (variable). The thermosyphon application refers to a user-defined annual climate dataset to determine: 1) when the thermosyphon will be active during the course of the transient analysis; and 2) the heat removal capabilities of the thermosyphon based on air temperatures and wind speeds. For the purposes of this study, thermosyphon boundary conditions were applied to two nodes located downstream of the upstream toe of the TSFD, immediately beneath the liner material (Figure 9 in the main report).

Data used for the thermosyphon function included the 30-year average daily temperatures and 57-year average daily wind speeds were obtained from National Oceanographic and Atmospheric Administration (NOAA) databases. These data were input into the Thermosyphon Boundary Condition application to be used by the application to determine when the heat removal would occur through the thermosysphons.

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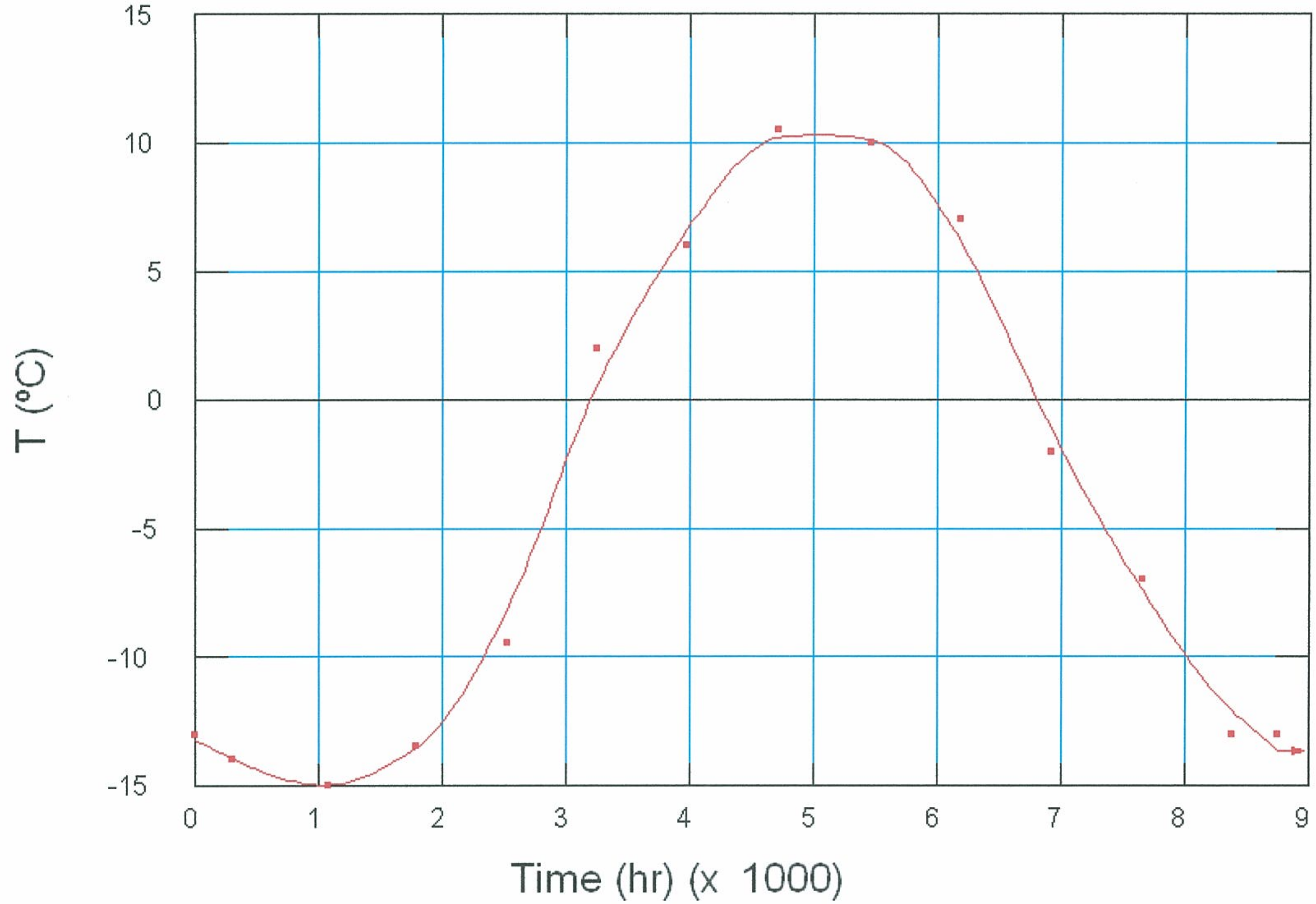
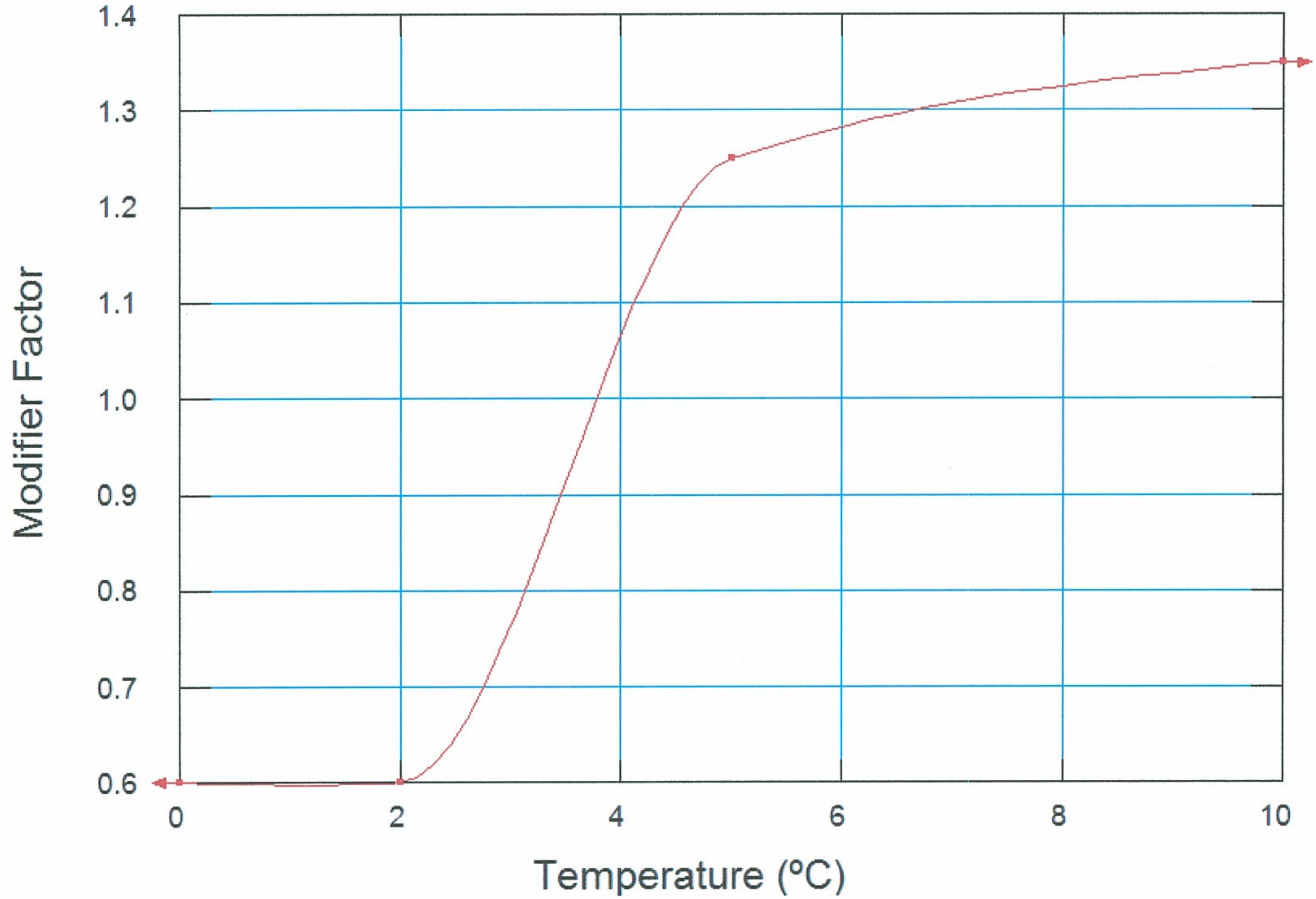


TERRA FIRMA TESTING
NORTHERN GEOTECHNICAL ENGINEERING, INC.

PLOT OF AVERAGE HOURLY AIR TEMPERATURES FOR NOME, AK

Rock Creek Dam,
Nome, Alaska

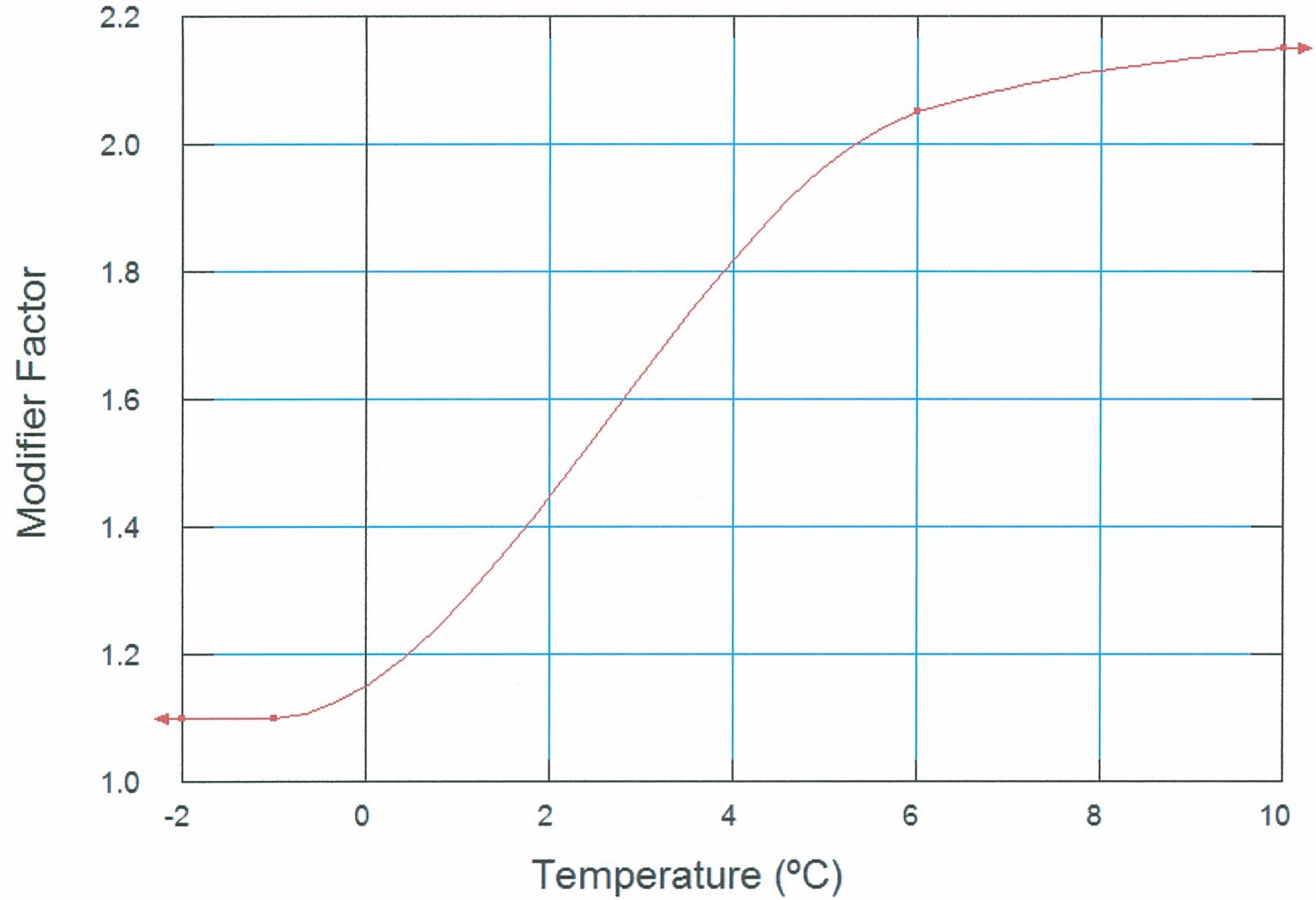
C-1



THERMAL MODIFIER FUNCTION
FOR THE NATIVE SOILS

Rock Creek Dam,
Nome, Alaska

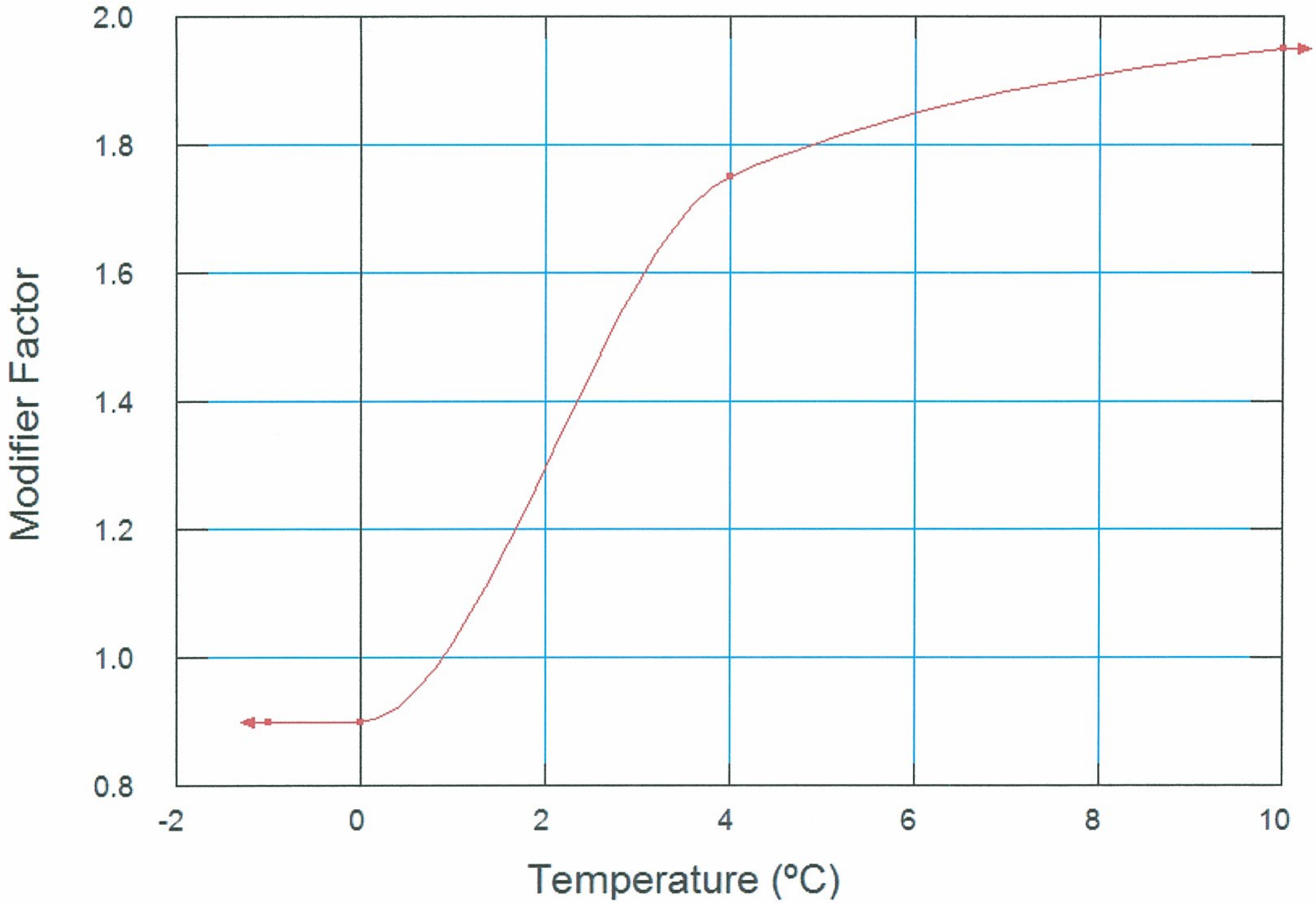
C-2



THERMAL MODIFIER FUNCTION
FOR THE TAILINGS

Rock Creek Dam,
Nome, Alaska

C-3

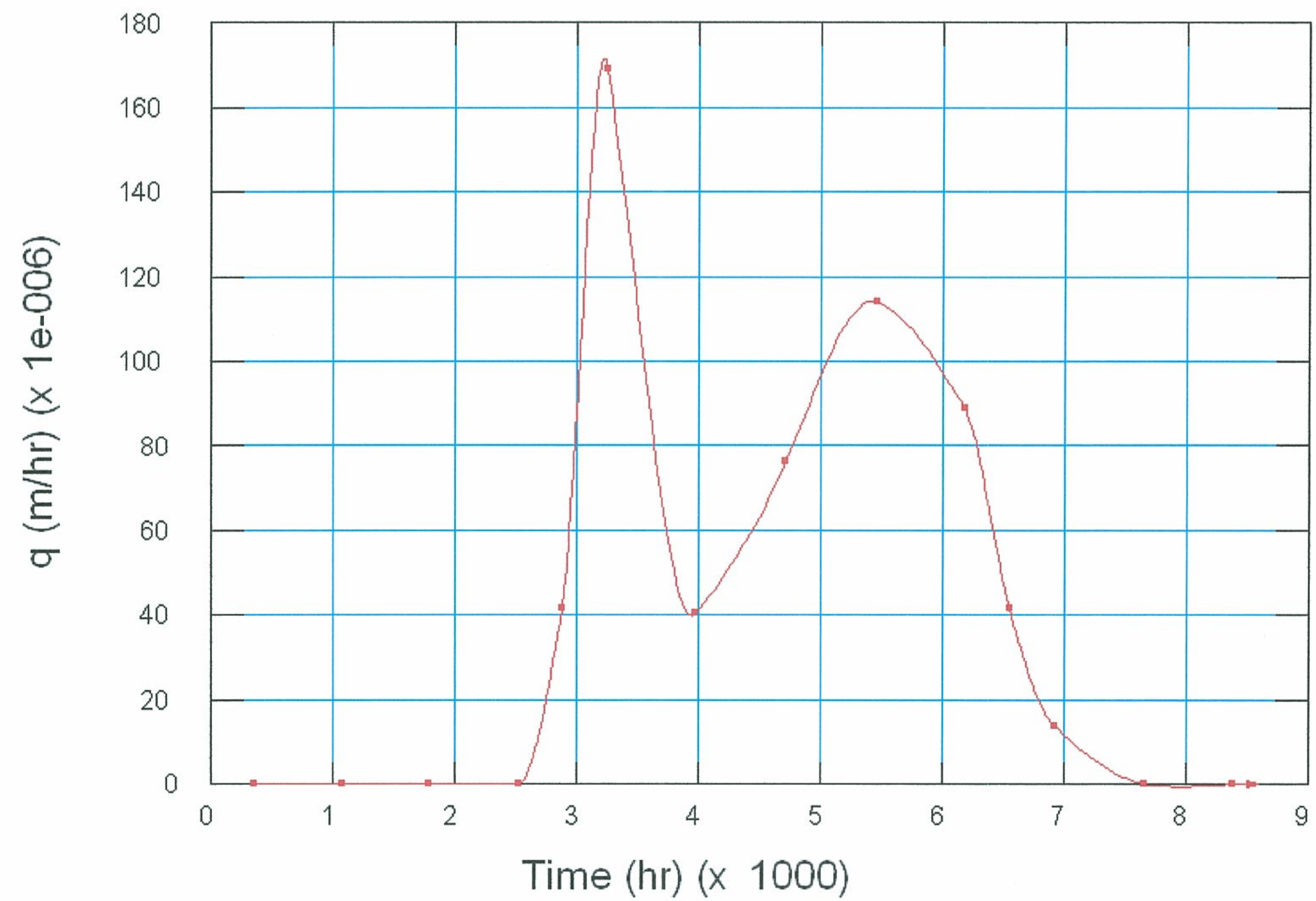


NORTHERN GEOTECHNICAL ENGINEERING, INC. TERRA FIRMA TESTING

THERMAL MODIFIER FUNCTION
FOR THE ROCK FILL MATERIAL

Rock Creek Dam,
Nome, Alaska

C-4



PLOT OF AVERAGE HOURLY PRECIPITATION FOR NOME, AK

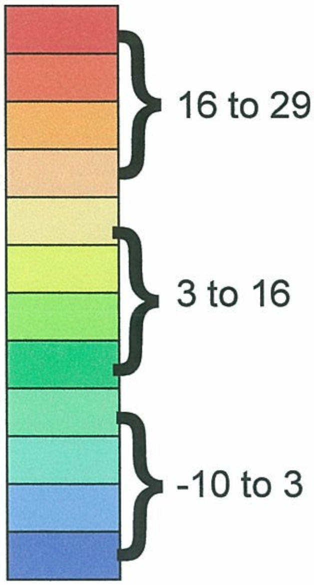
Rock Creek Dam,
Nome, Alaska

C-5

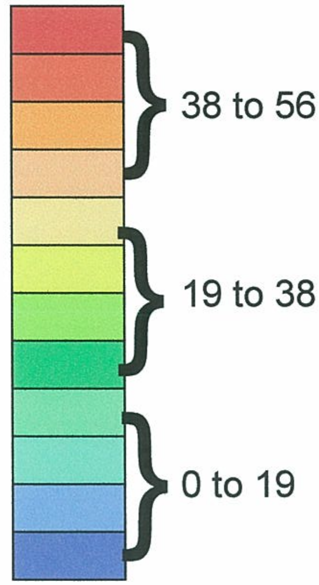
APPENDIX D

PHASE I DAM CONSTRUCTION ANALYSIS RESULTS

Thermal Contour Gradient (Degrees Celsius)



Hydraulic Contour Gradient (Meters above MSL)



= Freeze/thaw Interface

= Contour Interval Line

Scenario 1 = Current site conditions w/ no thermosyphons

Scenario 2 = Current site conditions w/ liner material extended into weathered bedrock unit and w/ no thermosyphons

Scenario 3 = Current site conditions w/ two thermosyphons and equipped w/ 50m^2 radiators

Scenario 4 = Current site conditions w/ two thermosyphons and equipped w/ 200m2 radiators

Scenario 5 = Elevated air temperatures (+3°C) and elevated hydraulic conductivity values (5x) for the weathered bedrock unit. No thermosyphons.

Scenario 6 = Elevated air temperatures (+3°C) and elevated hydraulic conductivity values (5x) for the weathered bedrock unit. Contains two thermosyphons w/ 50m^2 radiators

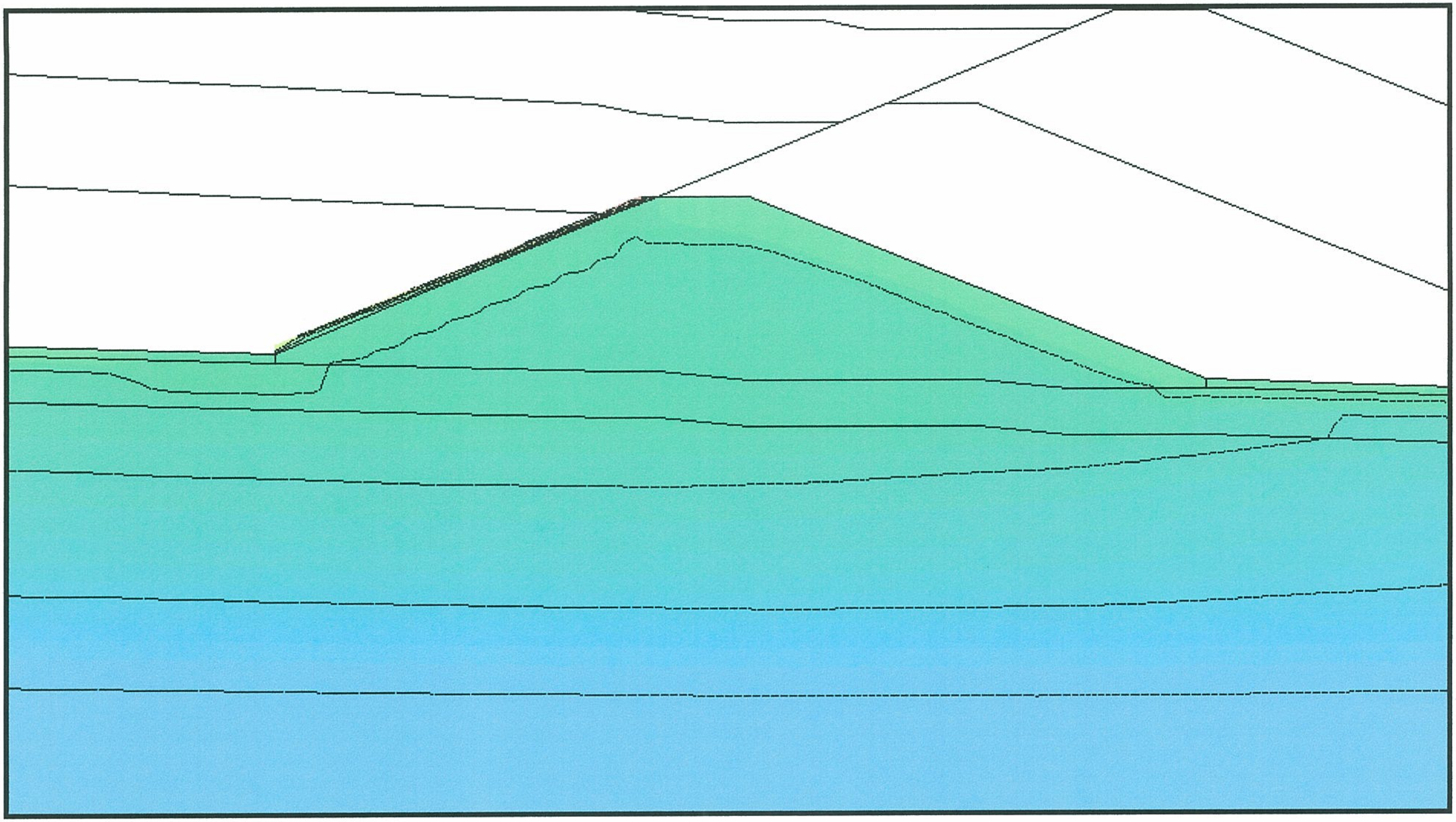
Scenario 7 = Elevated air temperatures (+3°C) and elevated hydraulic conductivity values (5x) for the weathered bedrock unit. Contains two thermosyphons w/ 200m^2 radiators

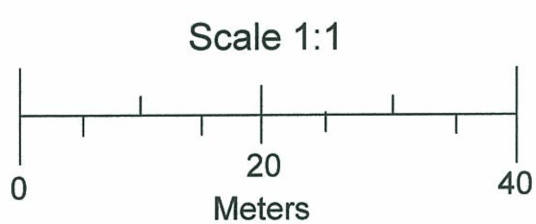
NORTHERN GEOTECHNICAL ENGINEERING, INC. TERRA FIRMA TESTING

APPENDIX D KEY

Rock Creek Dam, Nome, Alaska

D-0

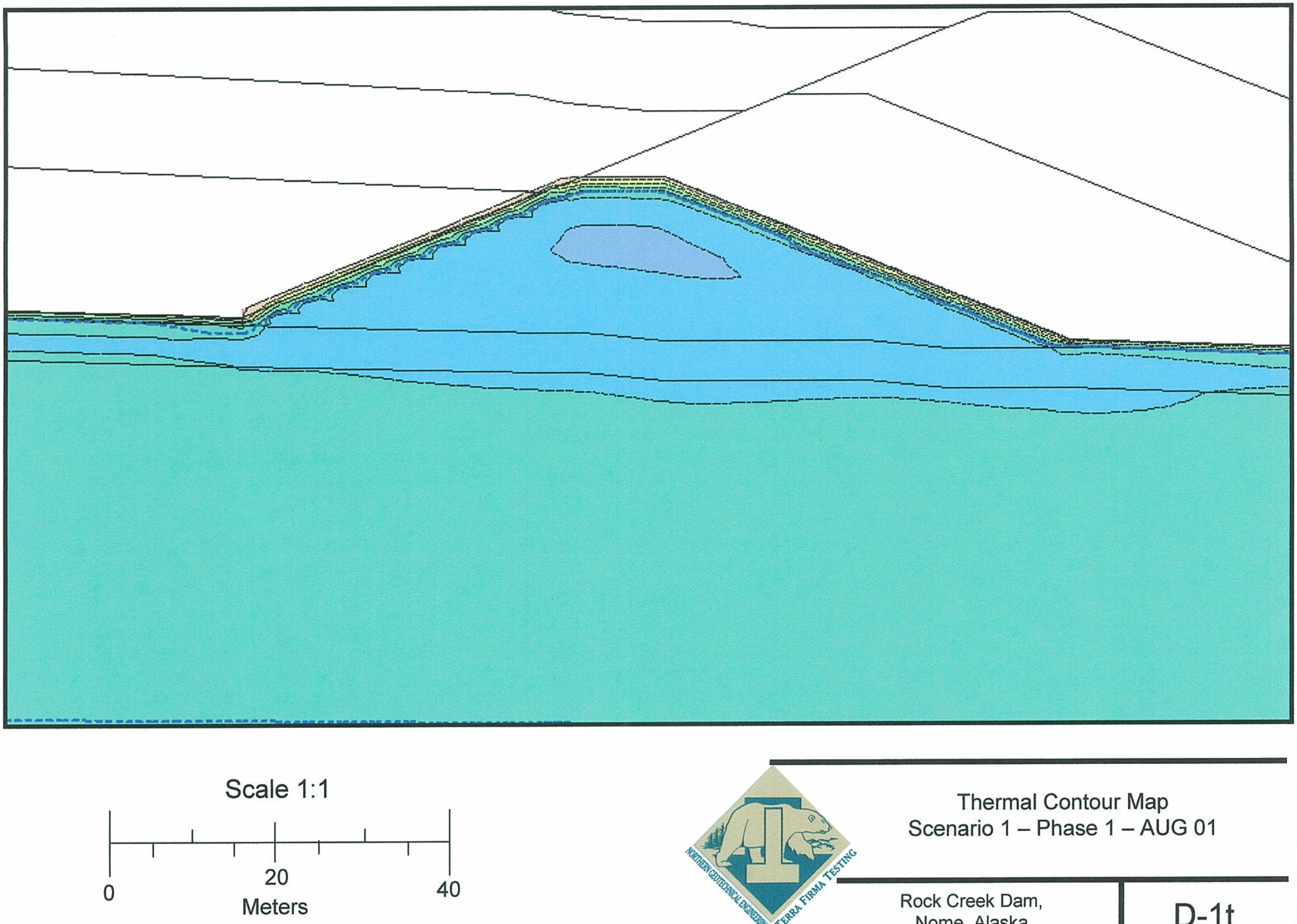




Hydraulic head Contour Map
Scenario 1 – Phase 1 – AUG 01

Rock Creek Dam,
Nome, Alaska

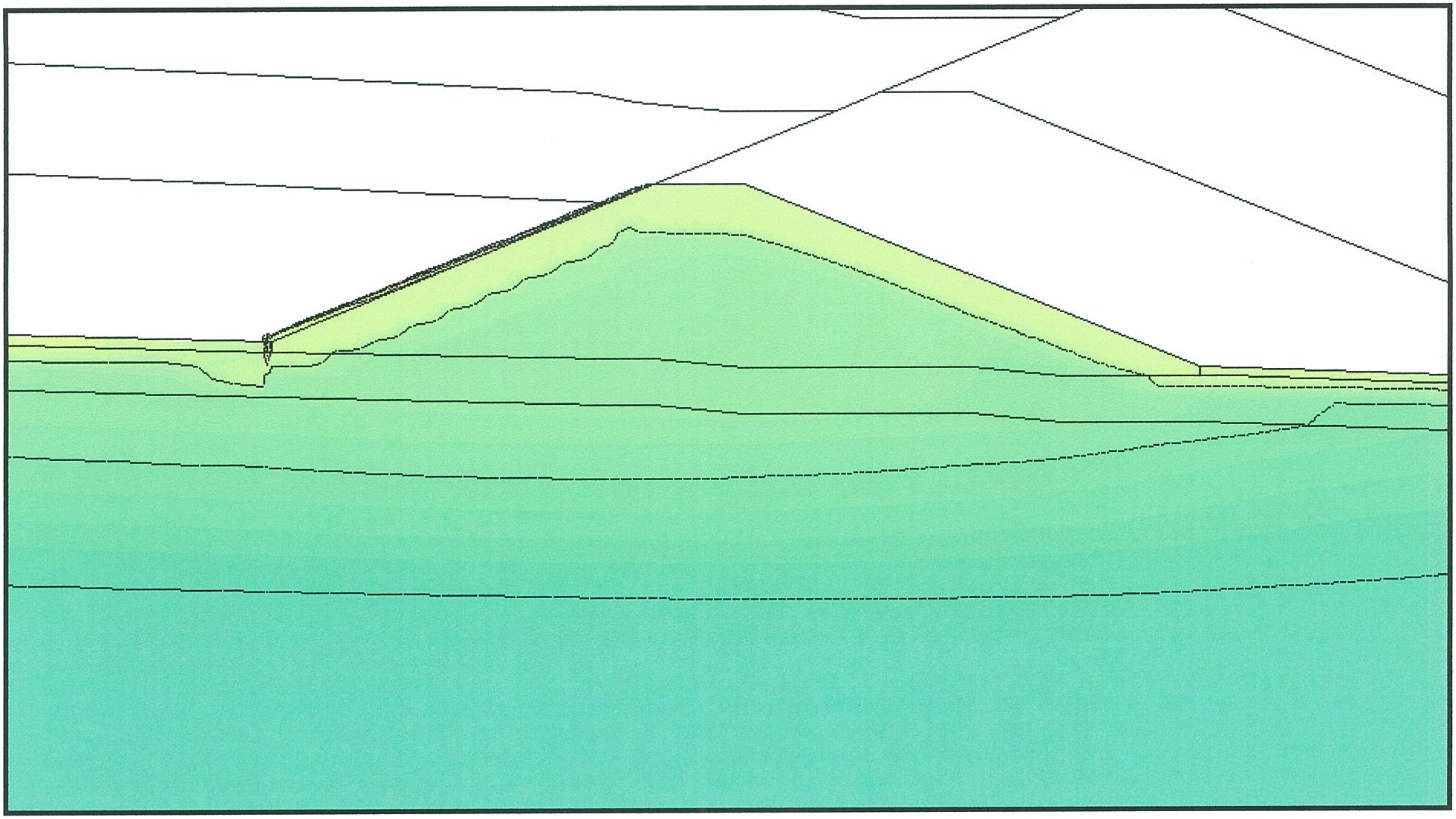
D-1h

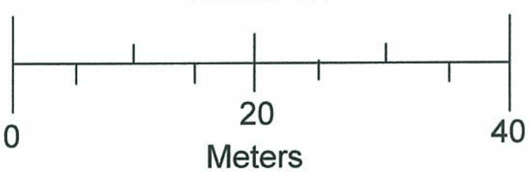


Thermal Contour Map
Scenario 1 – Phase 1 – AUG 01

Rock Creek Dam,
Nome, Alaska

D-1t

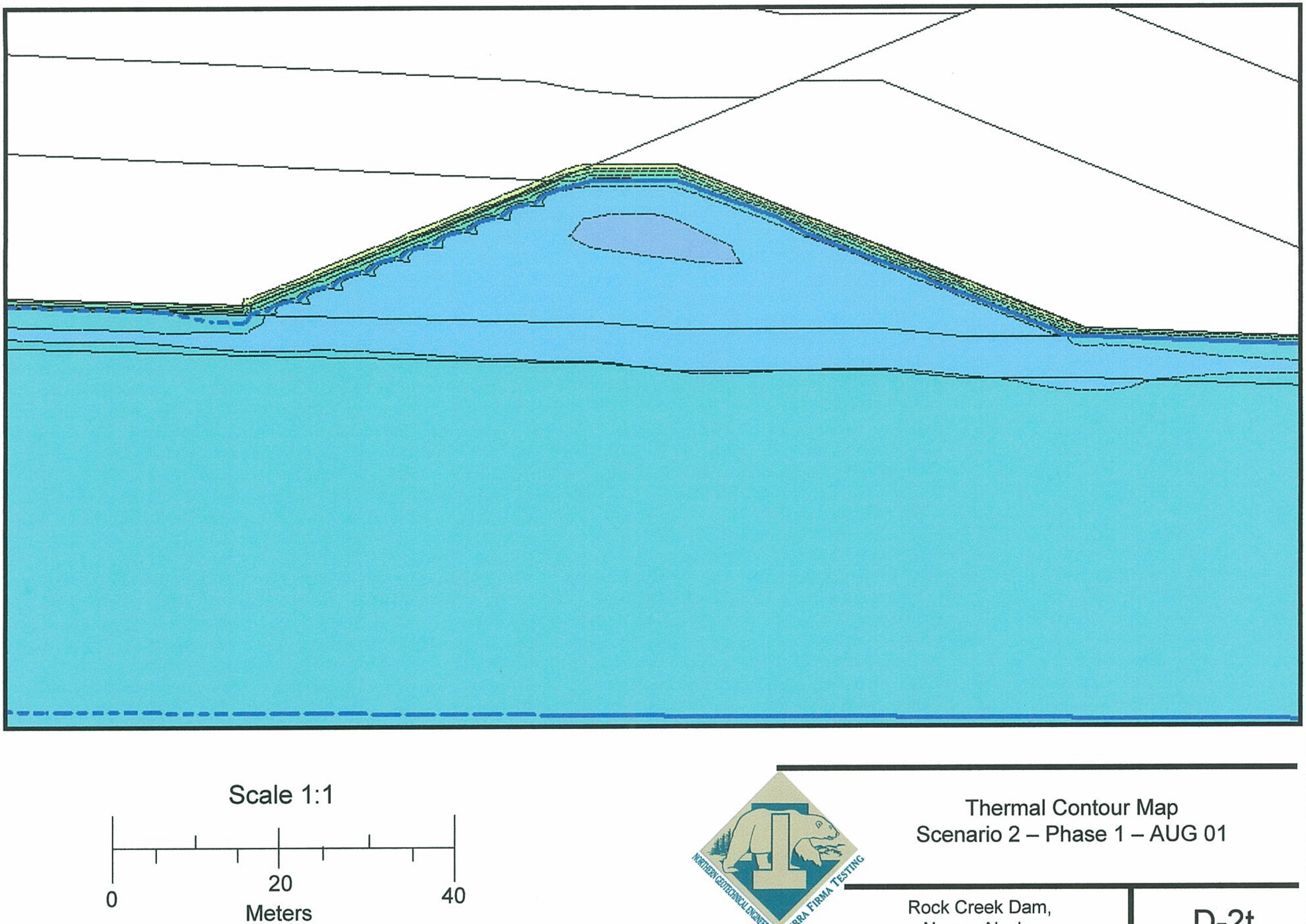




Hydraulic head Contour Map
Scenario 2 – Phase 1 – AUG 01

Rock Creek Dam,
Nome, Alaska

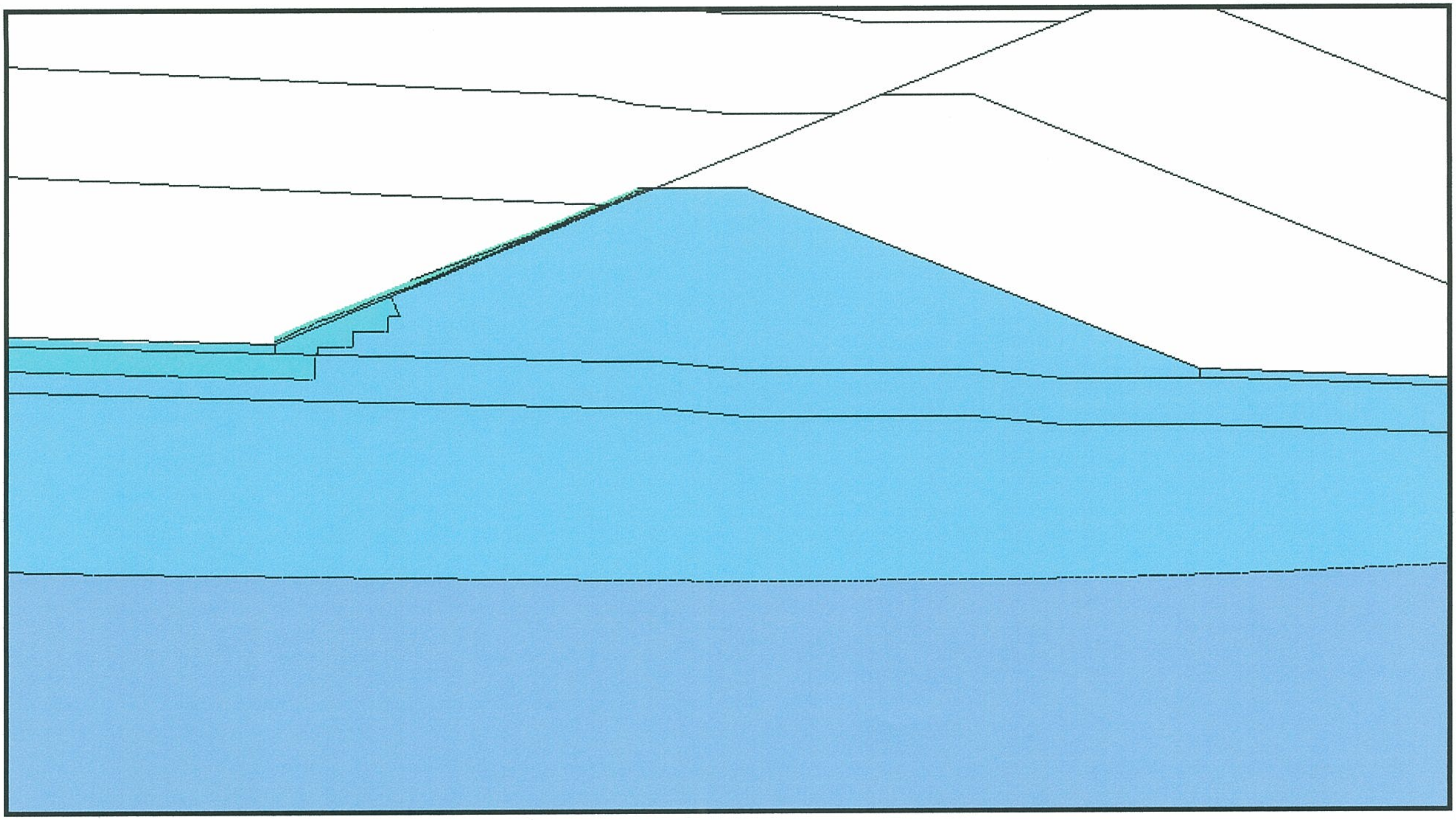
D-2h

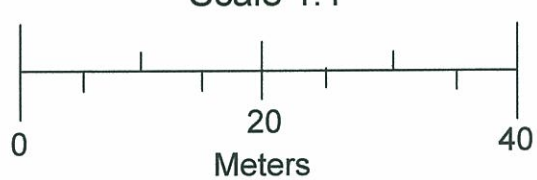


Thermal Contour Map
Scenario 2 – Phase 1 – AUG 01

Rock Creek Dam,
Nome, Alaska

D-2t

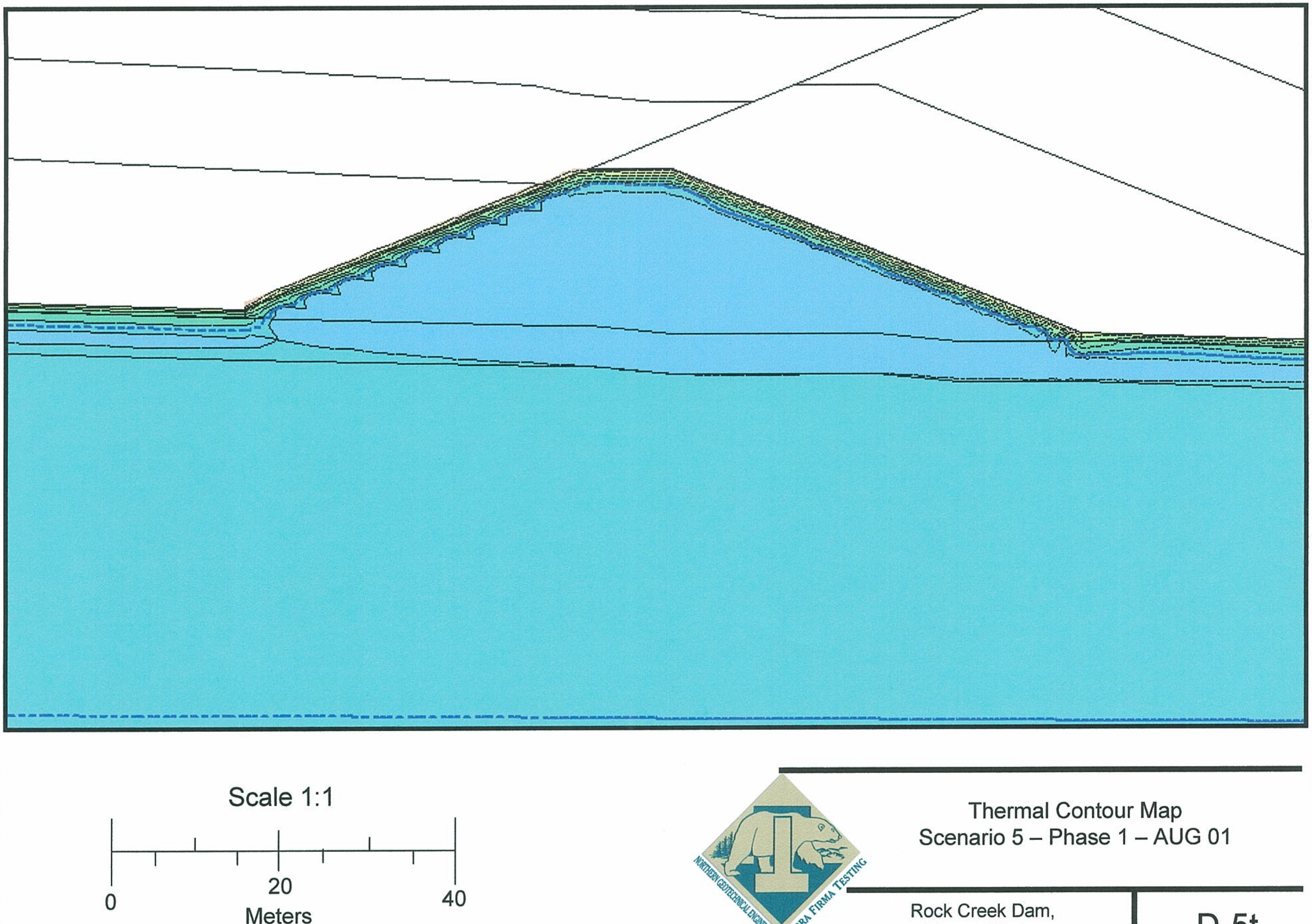




Hydraulic head Contour Map
Scenario 5 – Phase 1 – AUG 01

Rock Creek Dam,
Nome, Alaska

D-5h



Thermal Contour Map
Scenario 5 – Phase 1 – AUG 01

Rock Creek Dam,
Nome, Alaska

D-5t

APPENDIX E

PHASE I TAILS ANALYSIS RESULTS

Thermal Contour Gradient (Degrees Celsius)

- 16 to 29
- 3 to 16
- -10 to 3

Hydraulic Contour Gradient (Meters above MSL)

- 38 to 56
- 19 to 38
- 0 to 19

= Freeze/thaw Interface

= Contour Interval Line

Scenario 1 = Current site conditions w/ no thermosyphons

Scenario 2 = Current site conditions w/ liner material extended into weathered bedrock unit and w/ no thermosyphons

Scenario 3 = Current site conditions w/ two thermosyphons and equipped w/ 50m^2 radiators

Scenario 4 = Current site conditions w/ two thermosyphons and equipped w/ 200m2 radiators

Scenario 5 = Elevated air temperatures (+3°C) and elevated hydraulic conductivity values (5x) for the weathered bedrock unit. No thermosyphons.

Scenario 6 = Elevated air temperatures (+3°C) and elevated hydraulic conductivity values (5x) for the weathered bedrock unit. Contains two thermosyphons w/ 50m^2 radiators

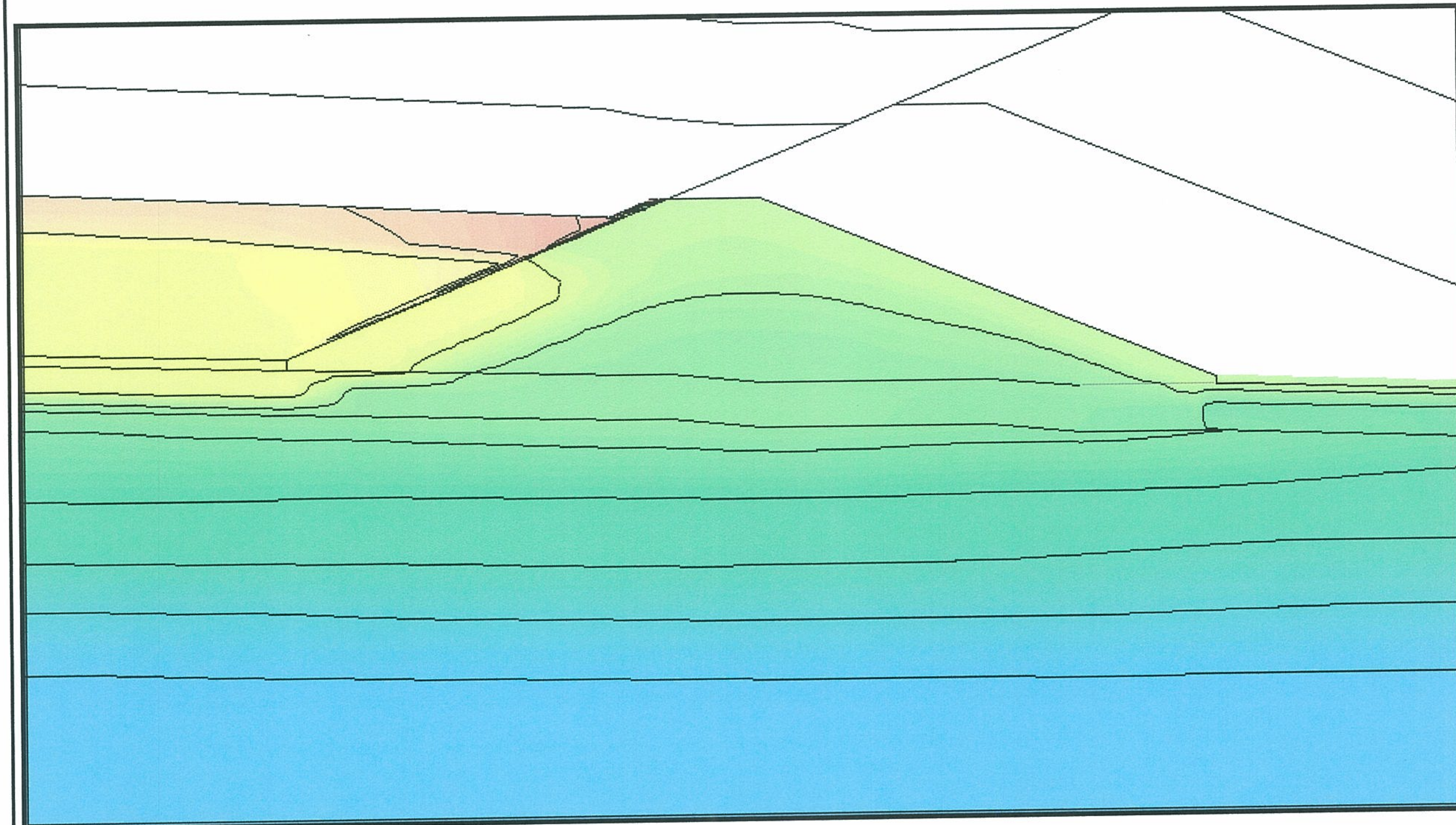
Scenario 7 = Elevated air temperatures (+3°C) and elevated hydraulic conductivity values (5x) for the weathered bedrock unit. Contains two thermosyphons w/ 200m^2 radiators

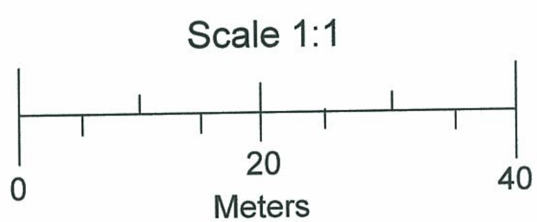
NORTHERN GEOTECHNICAL ENGINEERING, INC. TERRA FIRMA TESTING

APPENDIX E KEY

Rock Creek Dam, Nome, Alaska

E-0

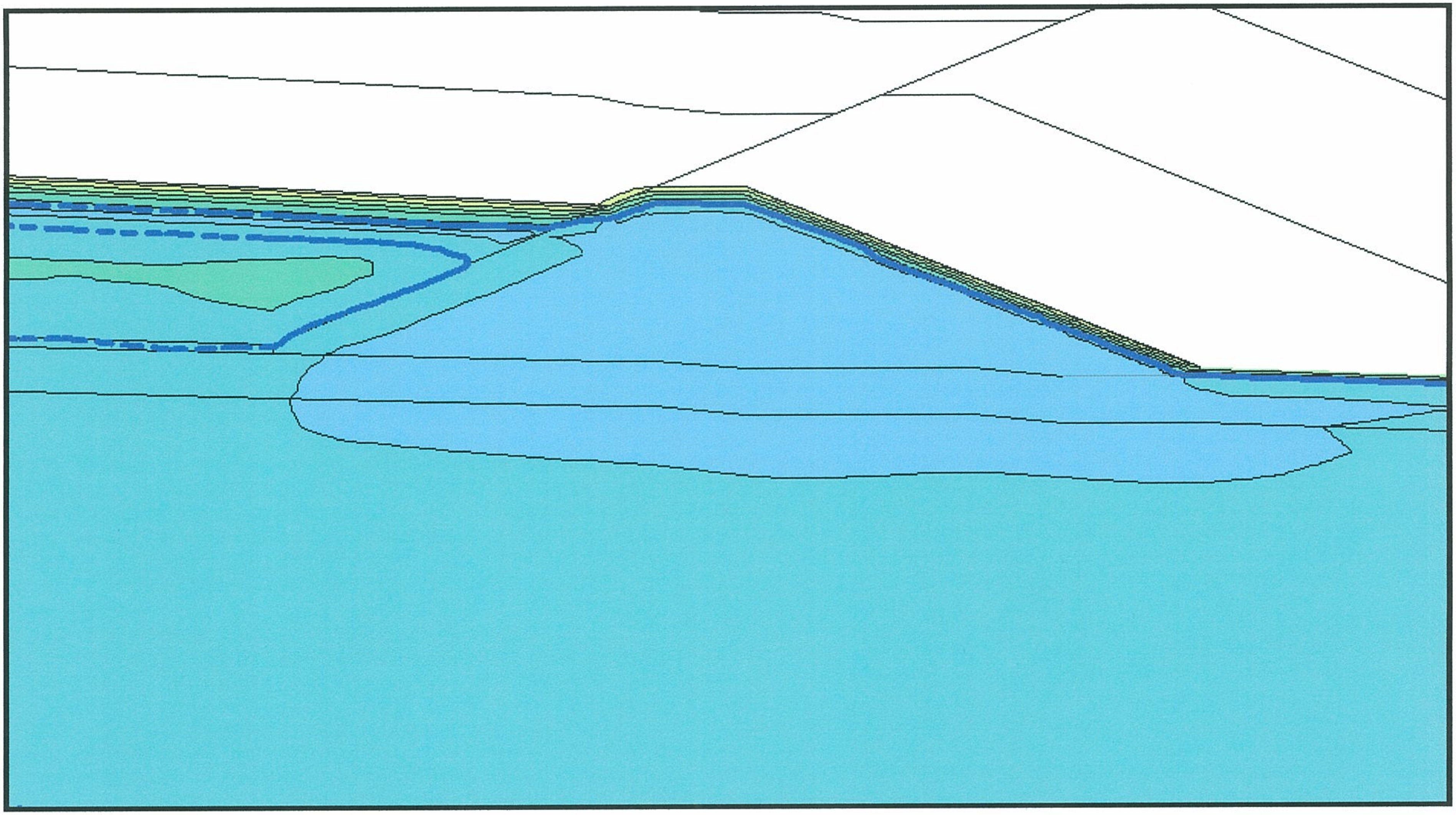




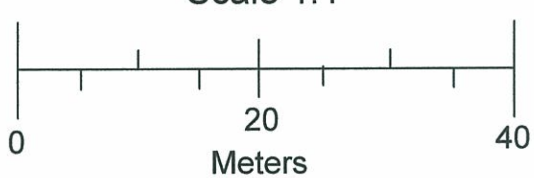
Hydraulic Head Contour Map
Scenario 1 – Phase 1 – AUG 02

Rock Creek Dam,
Nome, Alaska

E-1h



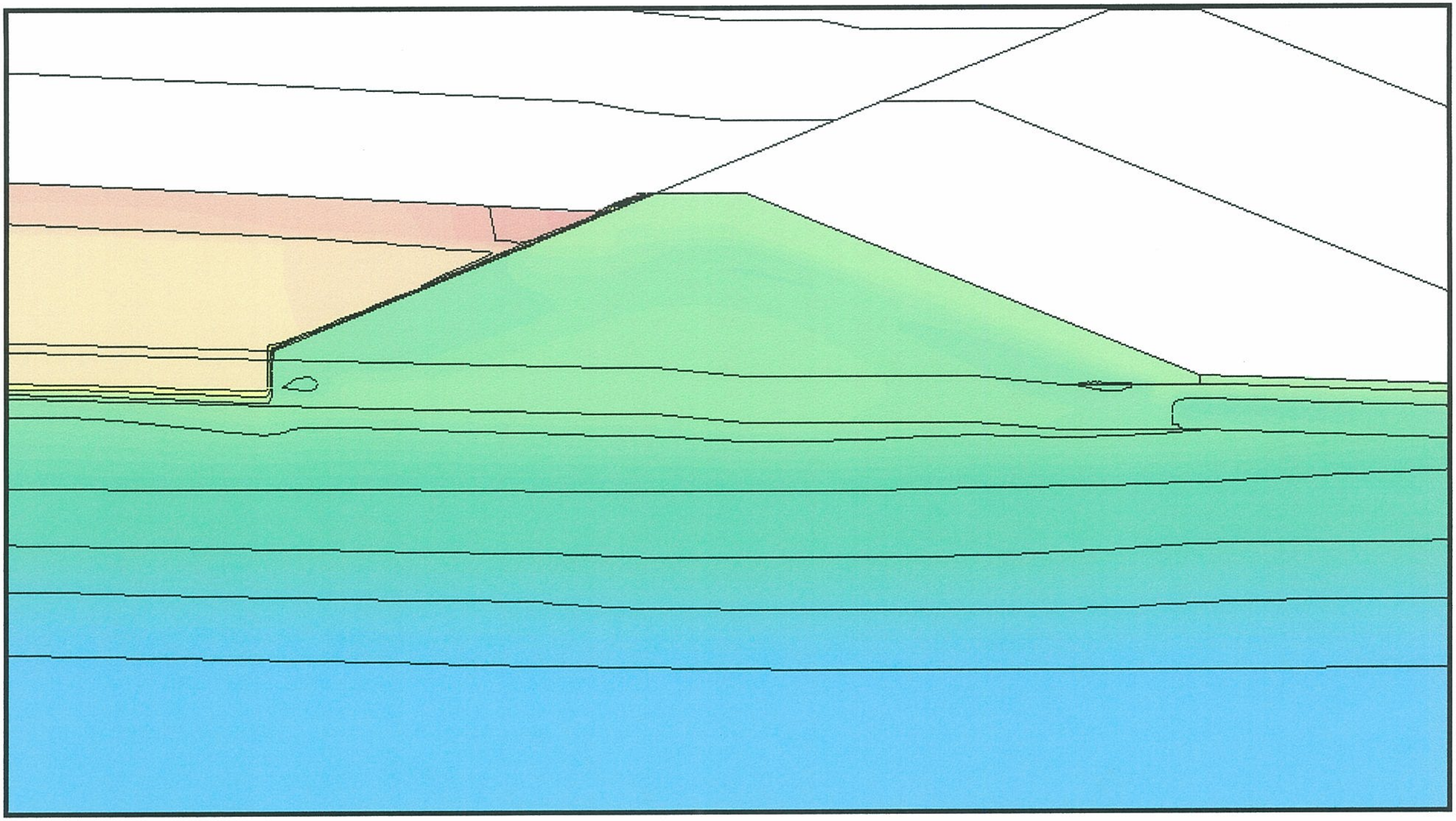
Scale 1:1



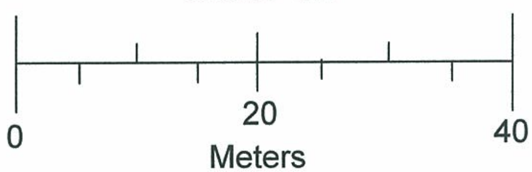
Thermal Contour Map
Scenario 1 – Phase 1 – AUG 02

Rock Creek Dam,
Nome, Alaska

E-1t



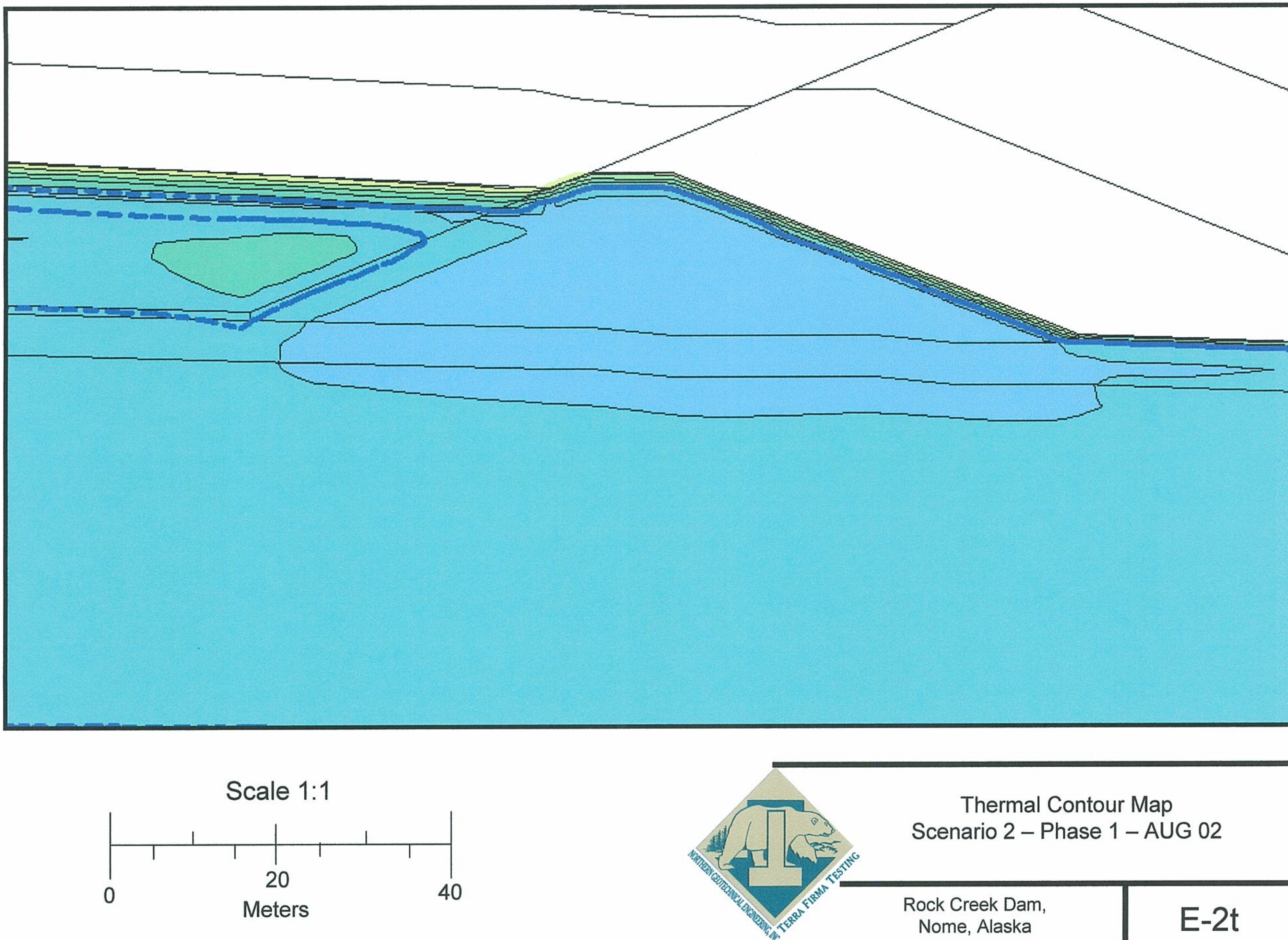
Scale 1:1



Hydraulic Head Contour Map
Scenario 2 – Phase 1 – AUG 02

Rock Creek Dam,
Nome, Alaska

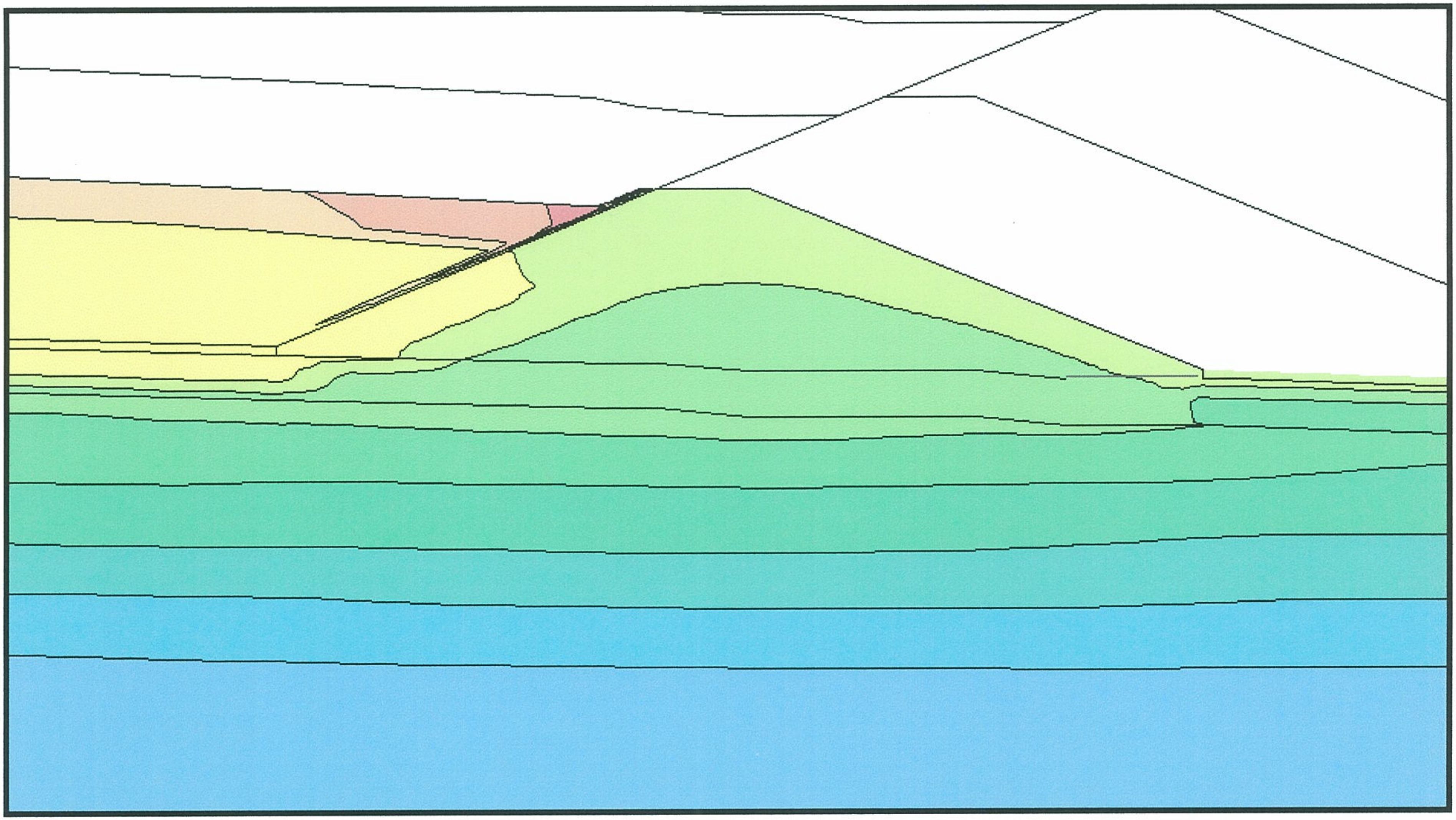
E-2h



Thermal Contour Map
Scenario 2 – Phase 1 – AUG 02

Rock Creek Dam,
Nome, Alaska

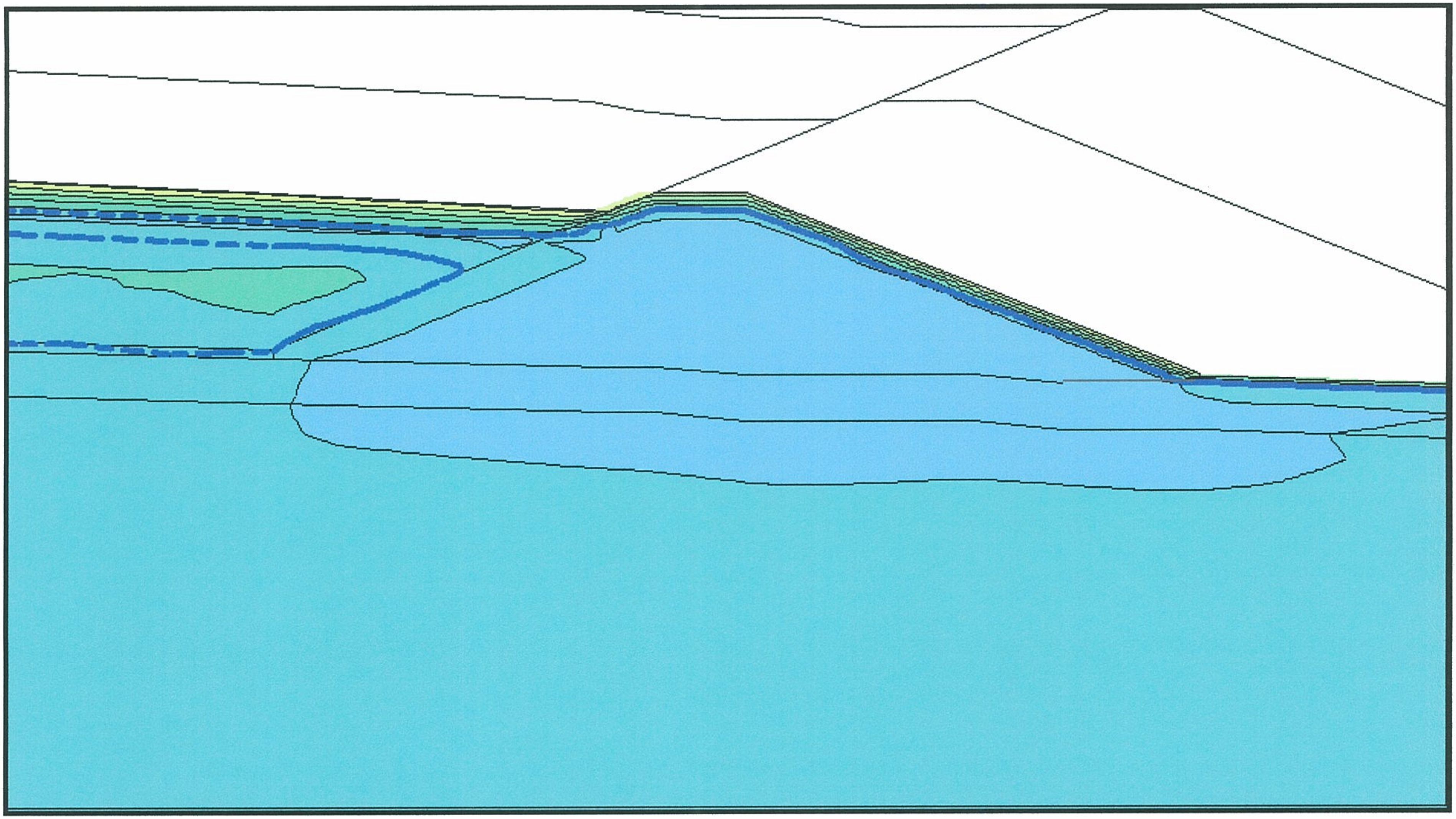
E-2t



Hydraulic Head Contour Map
Scenario 3 – Phase 1 – AUG 02

Rock Creek Dam,
Nome, Alaska

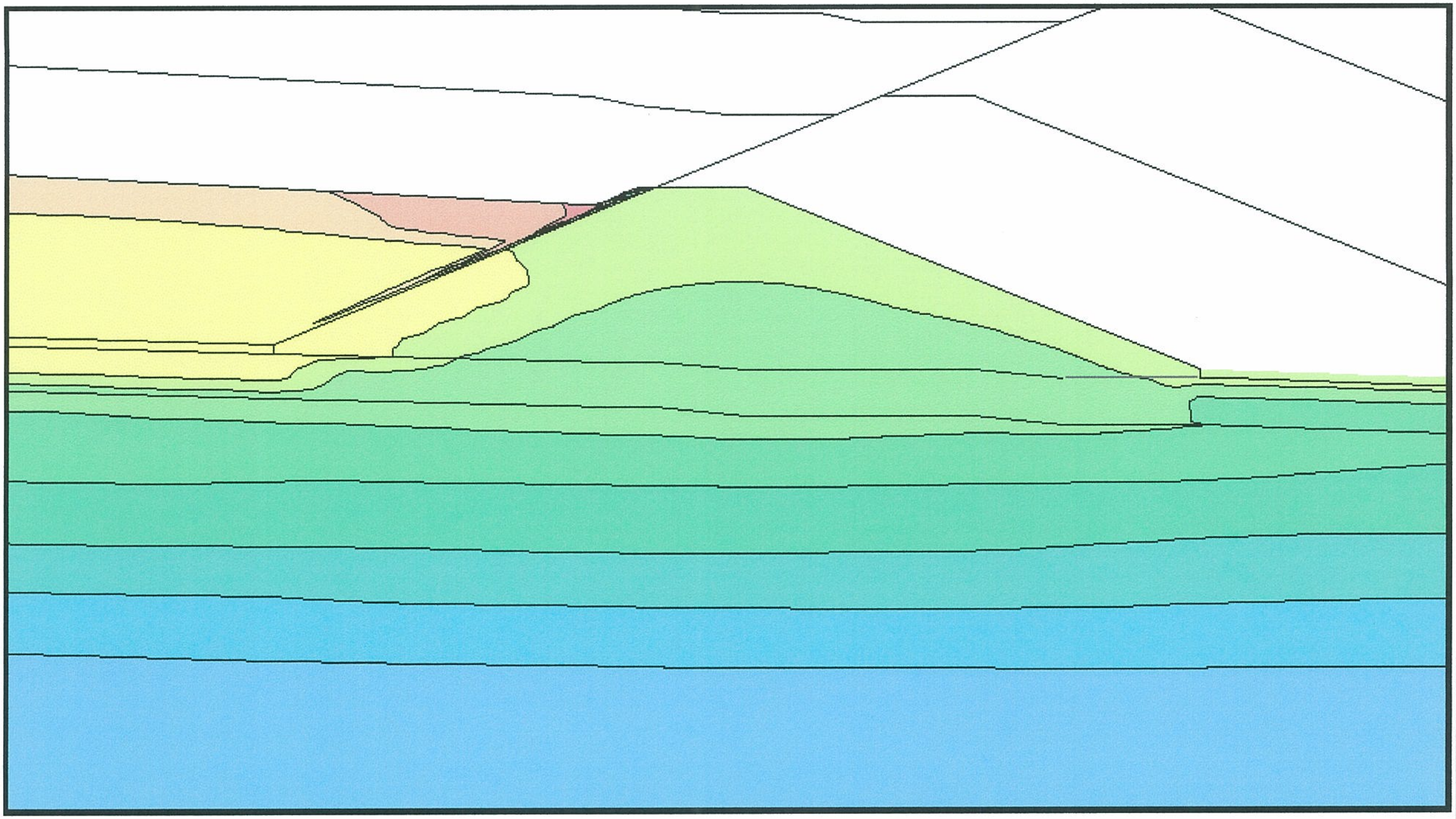
E-3h



Thermal Contour Map
Scenario 3 – Phase 1 – AUG 02

Rock Creek Dam,
Nome, Alaska

E-3t

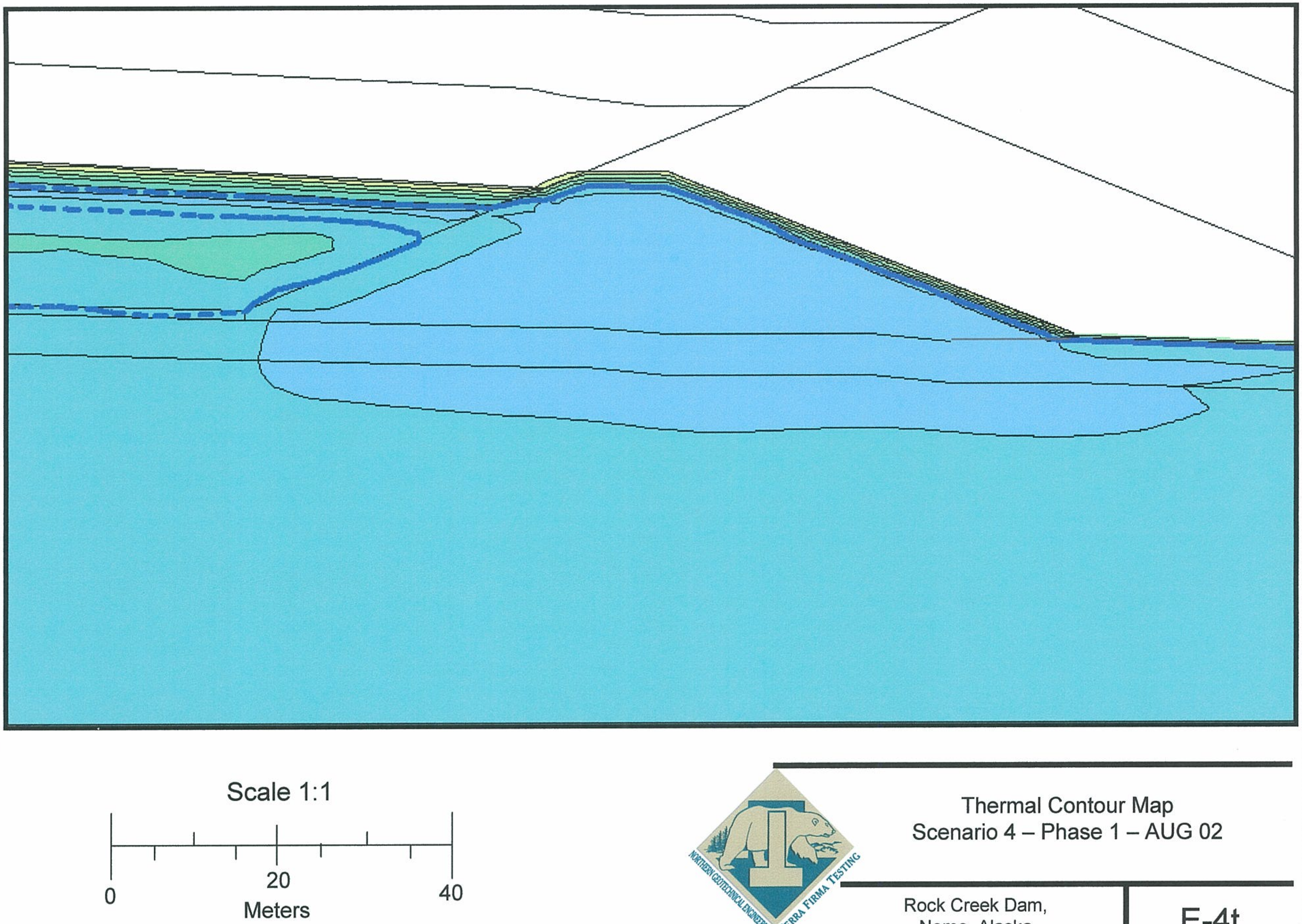


Scale 1:1

Hydraulic Head Contour Map
Scenario 4 – Phase 1 – AUG 02

Rock Creek Dam,
Nome, Alaska

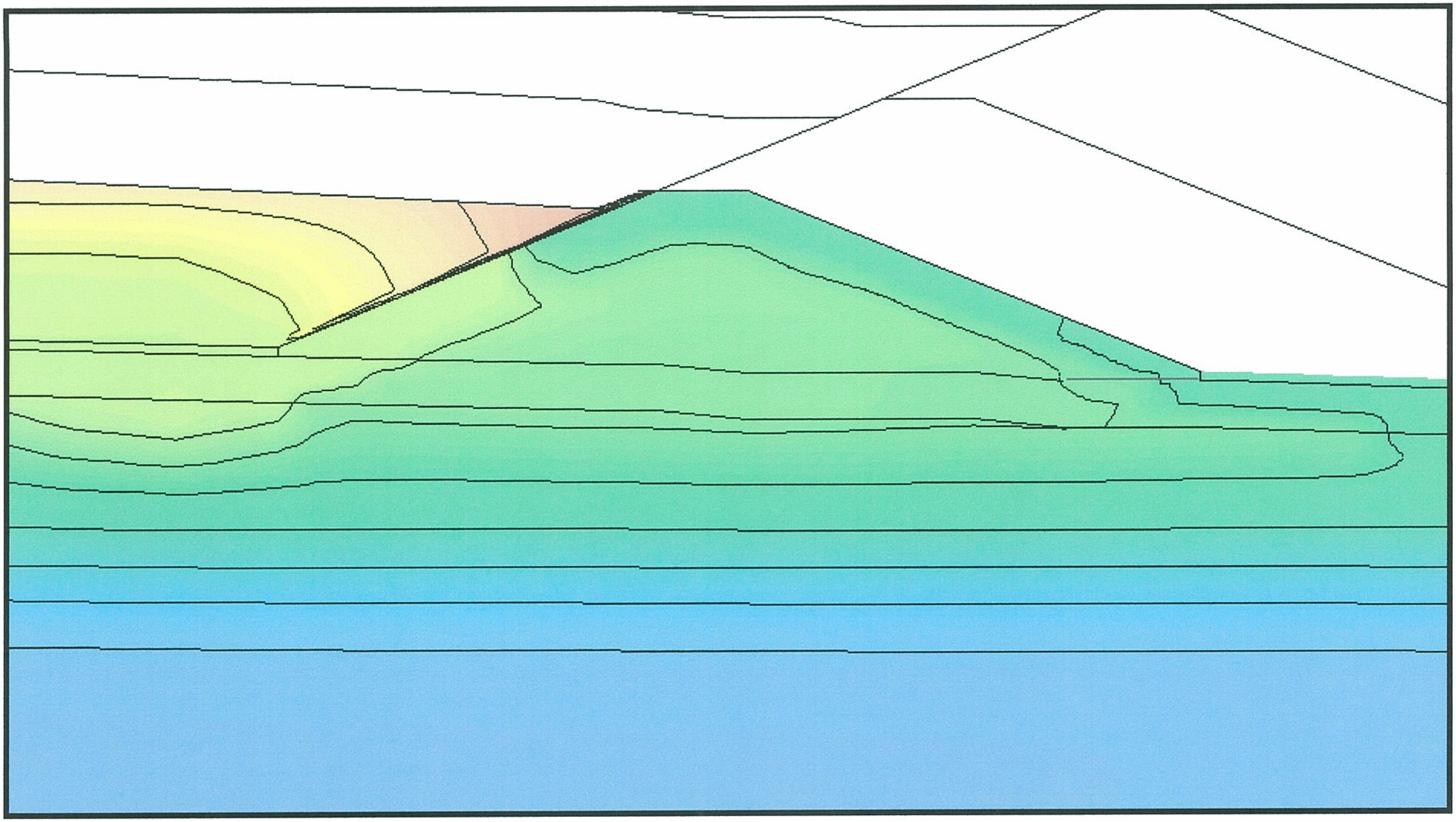
E-4h



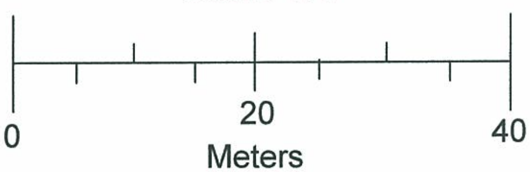
Thermal Contour Map
Scenario 4 – Phase 1 – AUG 02

Rock Creek Dam,
Nome, Alaska

E-4t



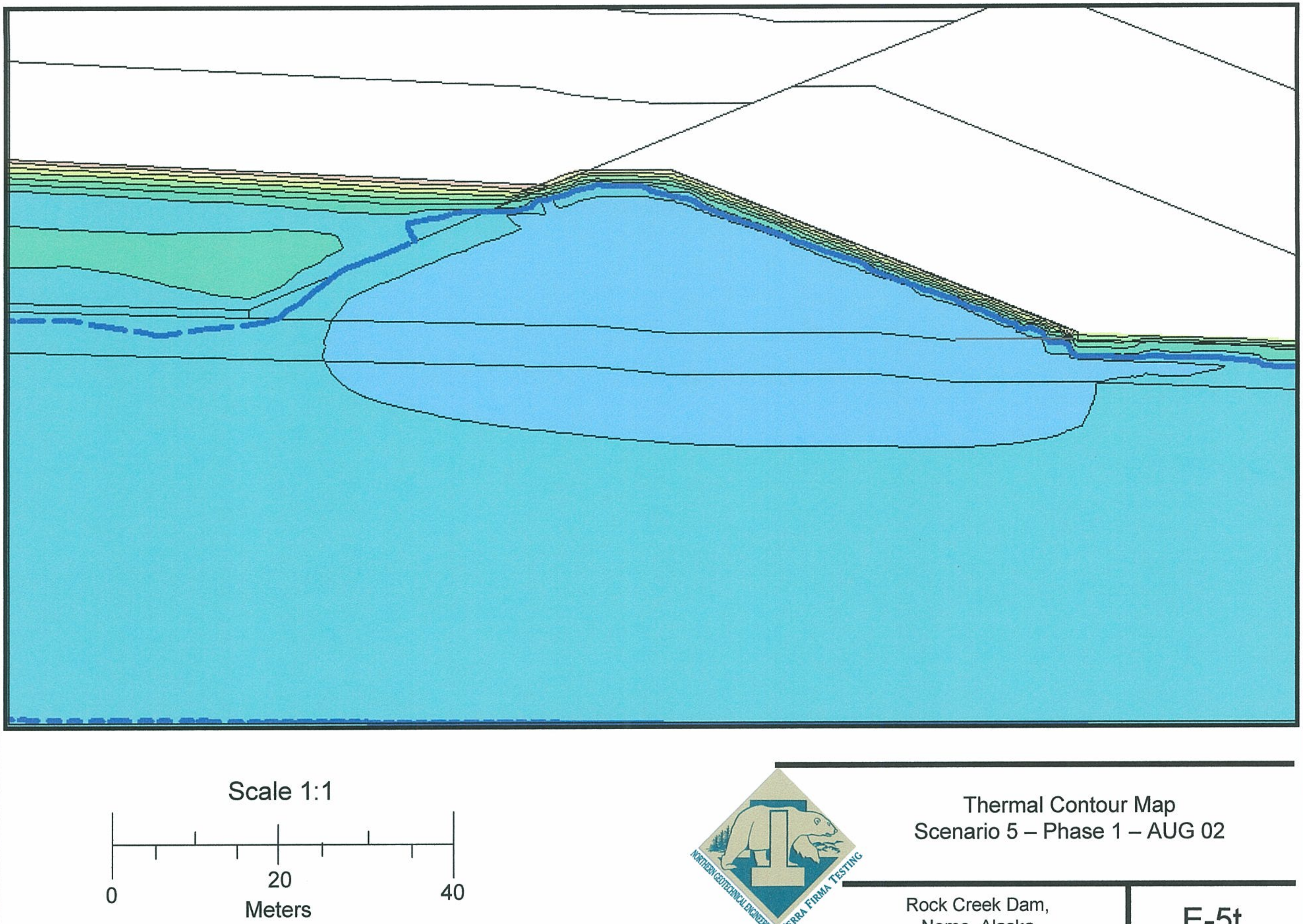
Scale 1:1



Hydraulic Head Contour Map
Scenario 5 – Phase 1 – AUG 02

Rock Creek Dam,
Nome, Alaska

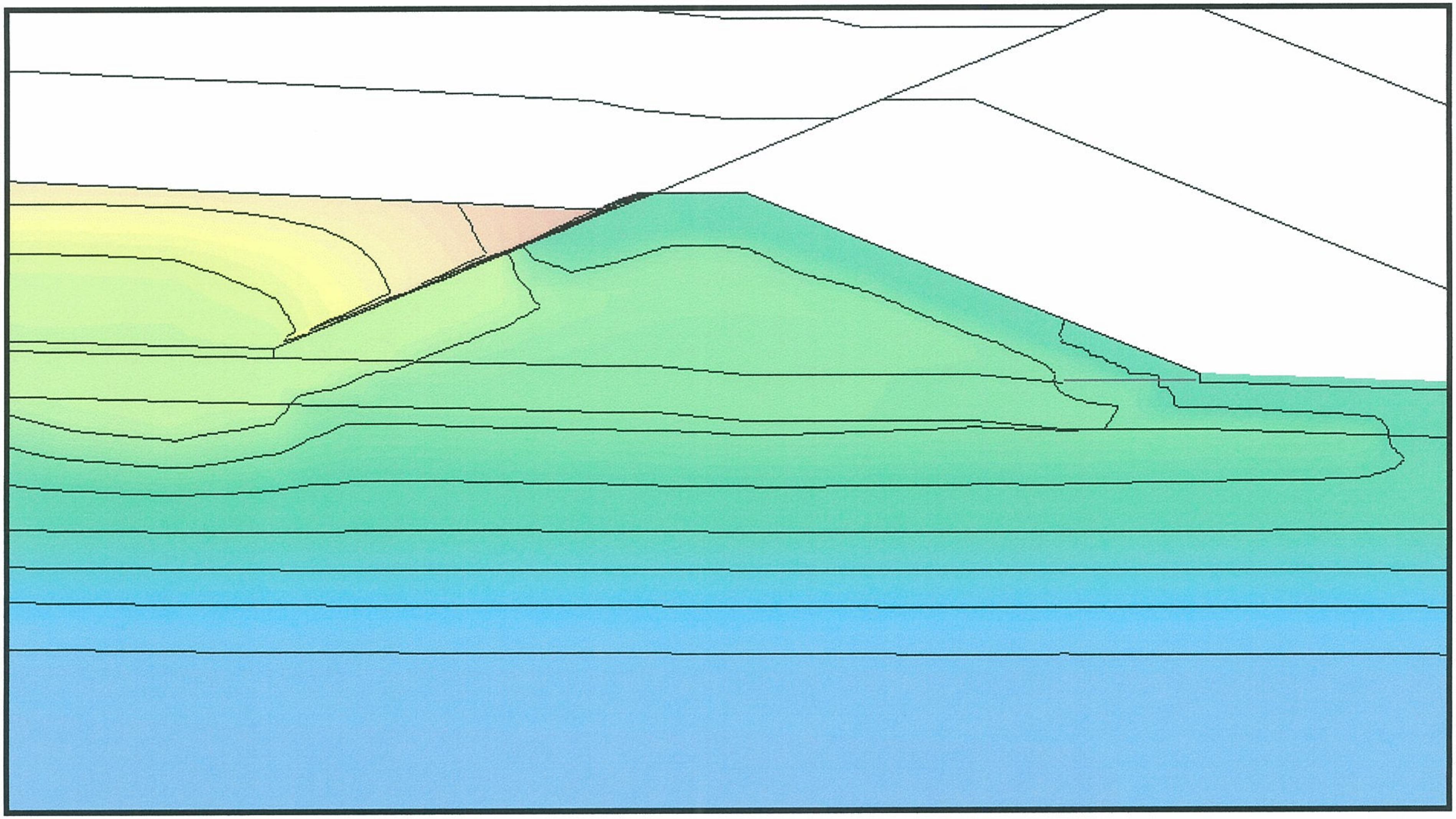
E-5h

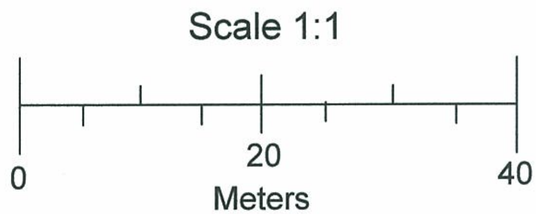


Thermal Contour Map
Scenario 5 – Phase 1 – AUG 02

Rock Creek Dam,
Nome, Alaska

E-5t

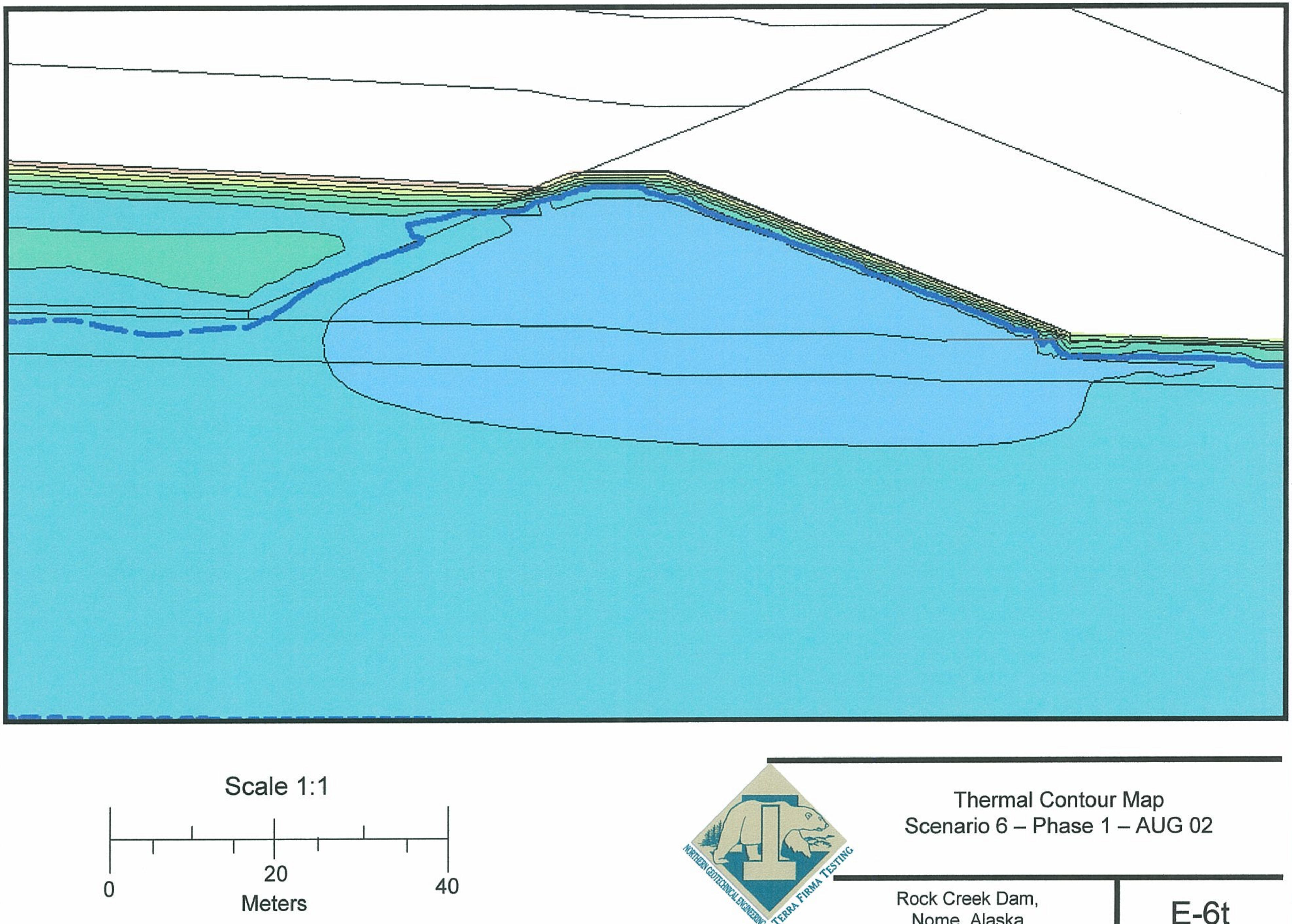




Hydraulic Head Contour Map
Scenario 6 – Phase 1 – AUG 02

Rock Creek Dam,
Nome, Alaska

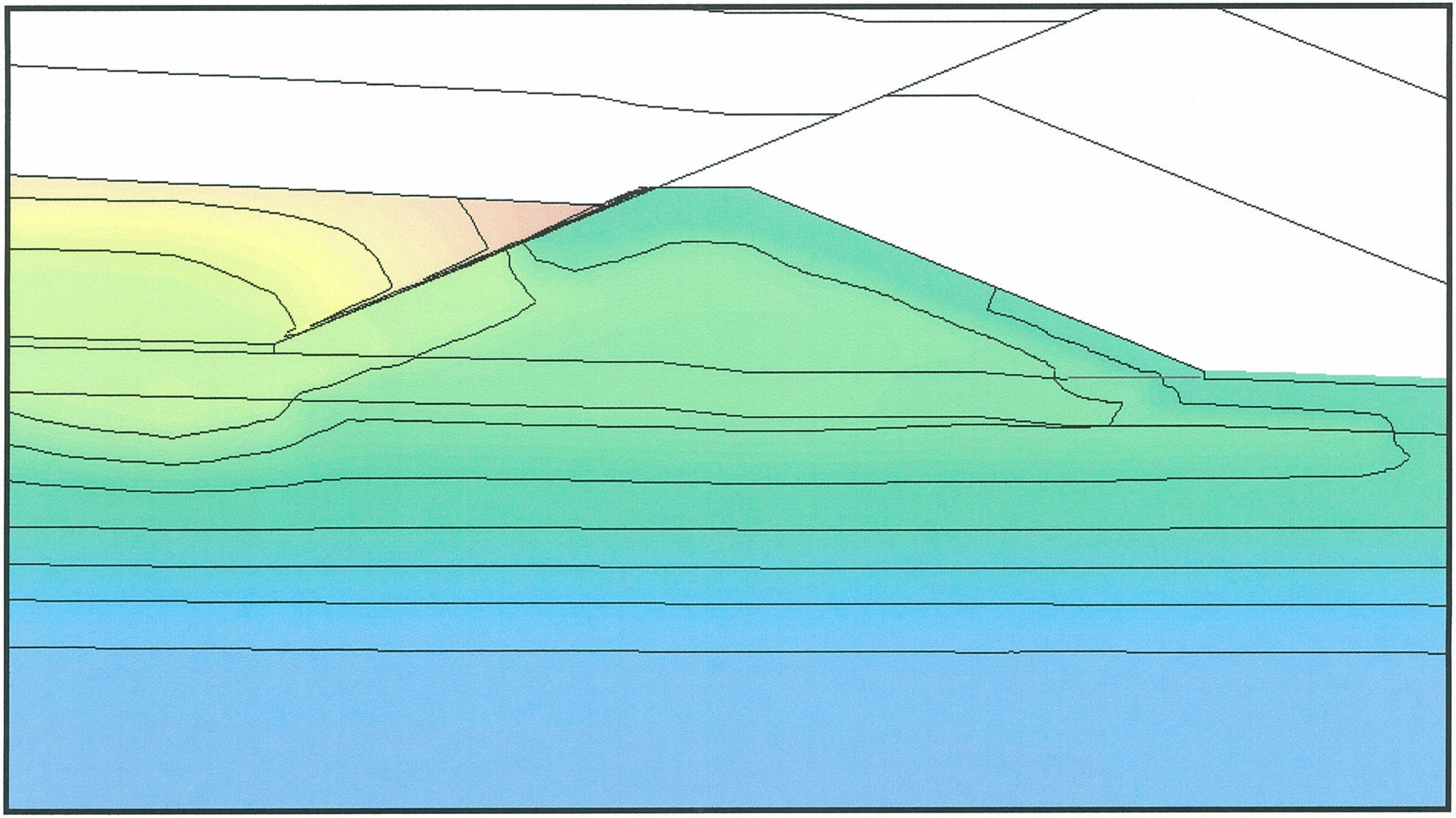
E-6h



Thermal Contour Map
Scenario 6 – Phase 1 – AUG 02

Rock Creek Dam,
Nome, Alaska

E-6t



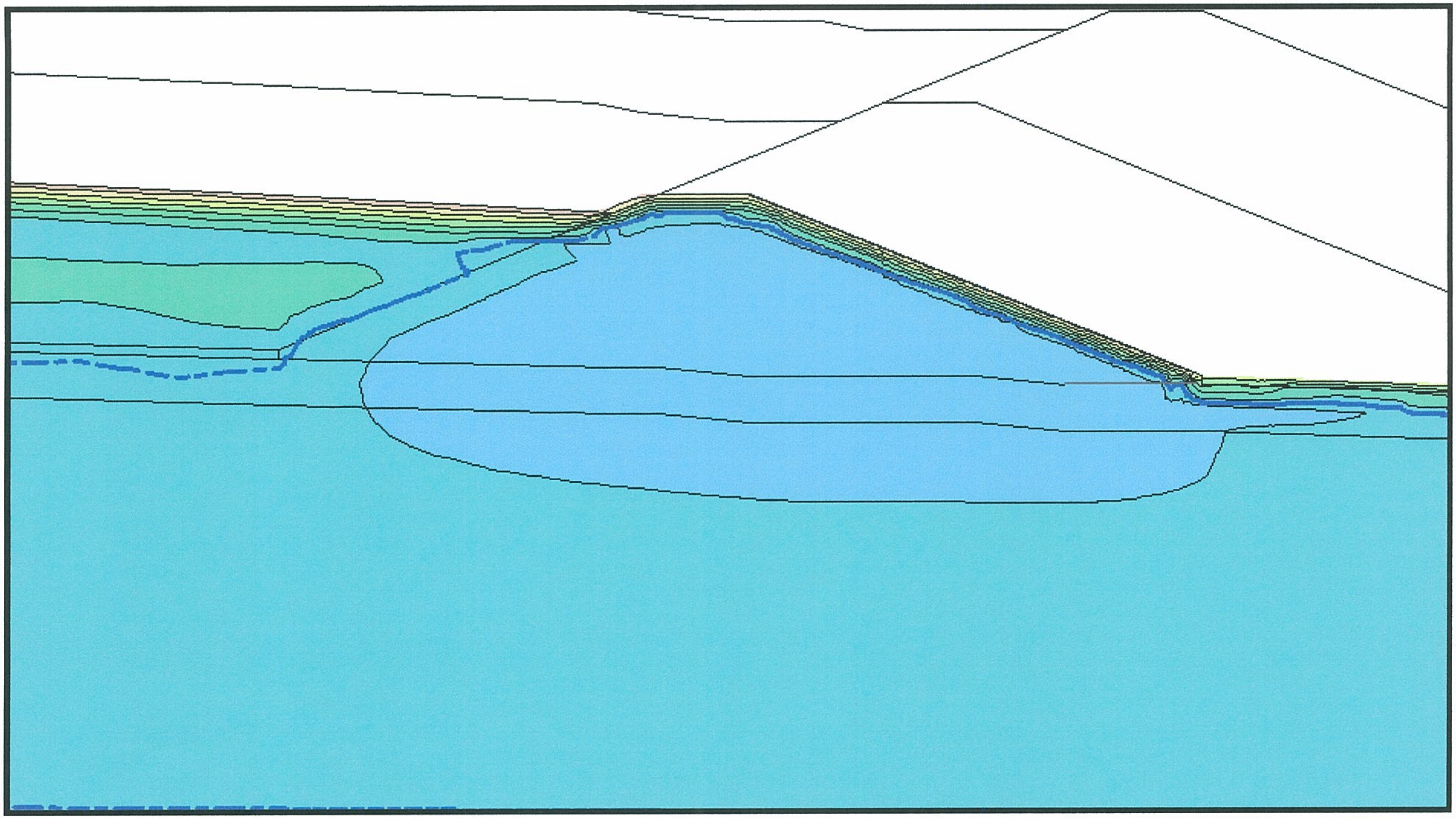
Scale 1:1

0 20 40
Meters

Hydraulic Head Contour Map
Scenario 7 – Phase 1 – AUG 02

Rock Creek Dam,
Nome, Alaska

E-7h



Scale 1:1

0 20 40
Meters

Thermal Contour Map
Scenario 7 – Phase 1 – AUG 02

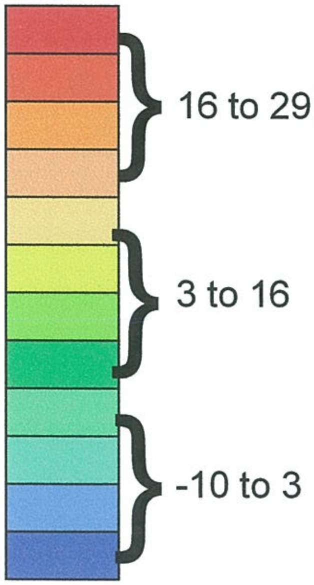
Rock Creek Dam,
Nome, Alaska

E-7t

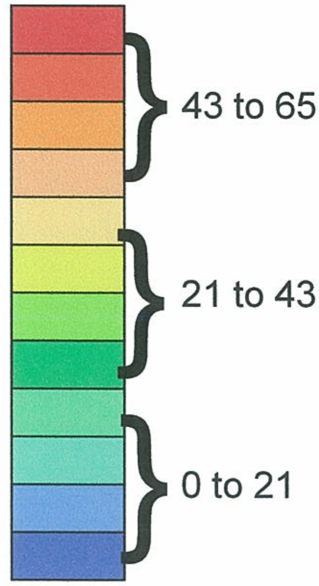
APPENDIX F

PHASE II ANALYSIS RESULTS

Thermal Contour Gradient (Degrees Celsius)



Hydraulic Contour Gradient (Meters above MSL)



— — — — = Freeze/thaw Interface

——— = Contour Interval Line

Scenario 1 = Current site conditions w/ no thermosyphons

Scenario 2 = Current site conditions w/ liner material extended into weathered bedrock unit and w/ no thermosyphons

Scenario 3 = Current site conditions w/ two thermosyphons and equipped w/ 50m^2 radiators

Scenario 4 = Current site conditions w/ two thermosyphons and equipped w/ 200m2 radiators

Scenario 5 = Elevated air temperatures (+3°C) and elevated hydraulic conductivity values (5x) for the weathered bedrock unit. No thermosyphons.

Scenario 6 = Elevated air temperatures (+3°C) and elevated hydraulic conductivity values (5x) for the weathered bedrock unit. Contains two thermosyphons w/ 50m^2 radiators

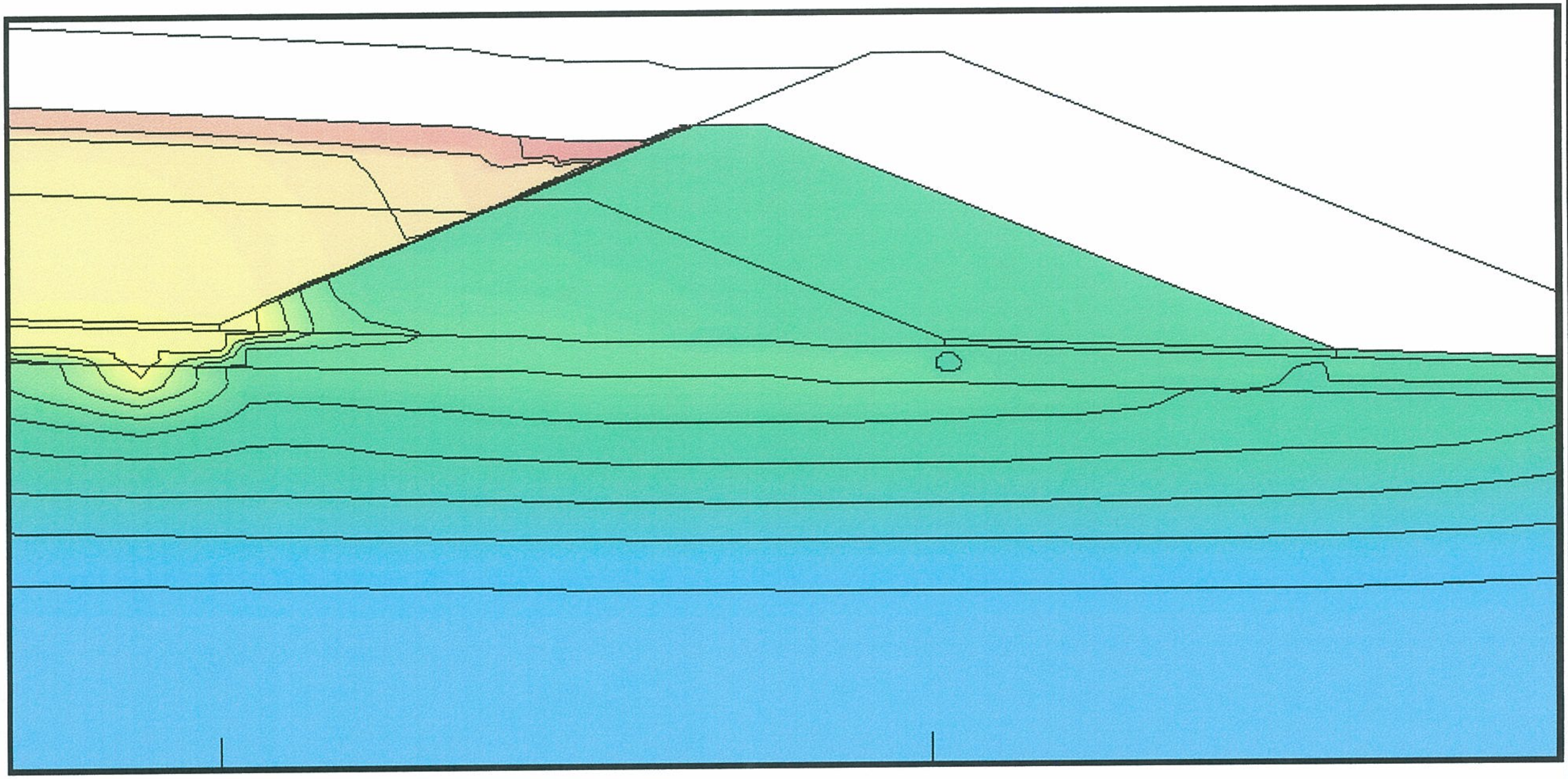
Scenario 7 = Elevated air temperatures (+3°C) and elevated hydraulic conductivity values (5x) for the weathered bedrock unit. Contains two thermosyphons w/ 200m^2 radiators

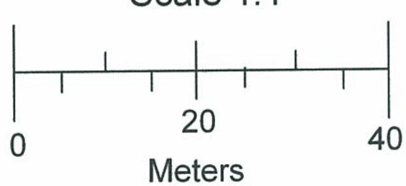
NORTHERN GEOTECHNICAL ENGINEERING, INC. TERRA FIRMA TESTING

APPENDIX F KEY

Rock Creek Dam,
Nome, Alaska

F-0

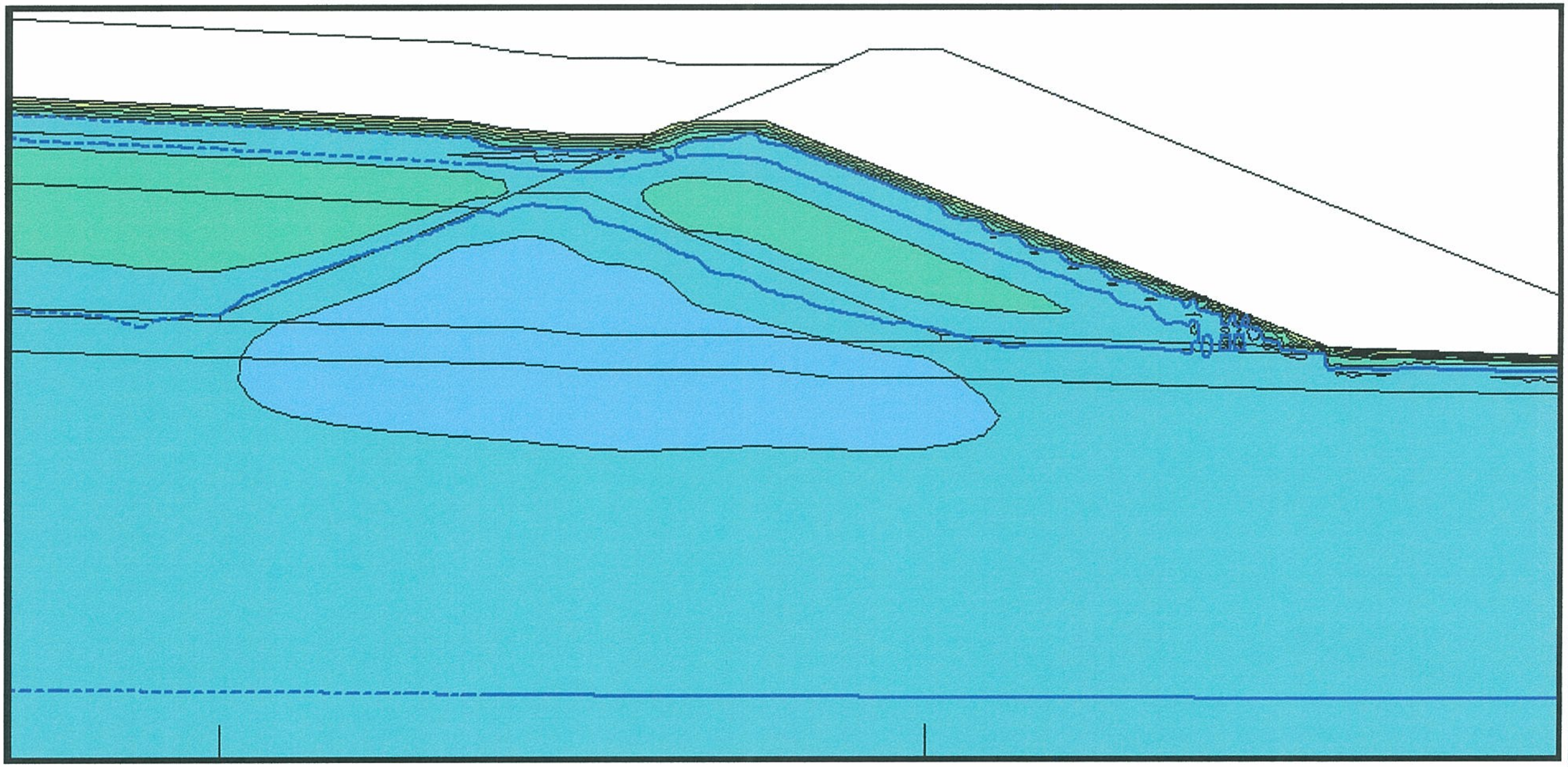


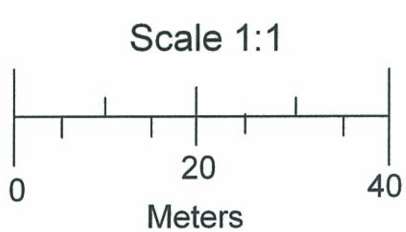


Hydraulic Head Contour Map
Scenario 1 – Phase 2 – AUG 03

Rock Creek Dam,
Nome, Alaska

F-1h

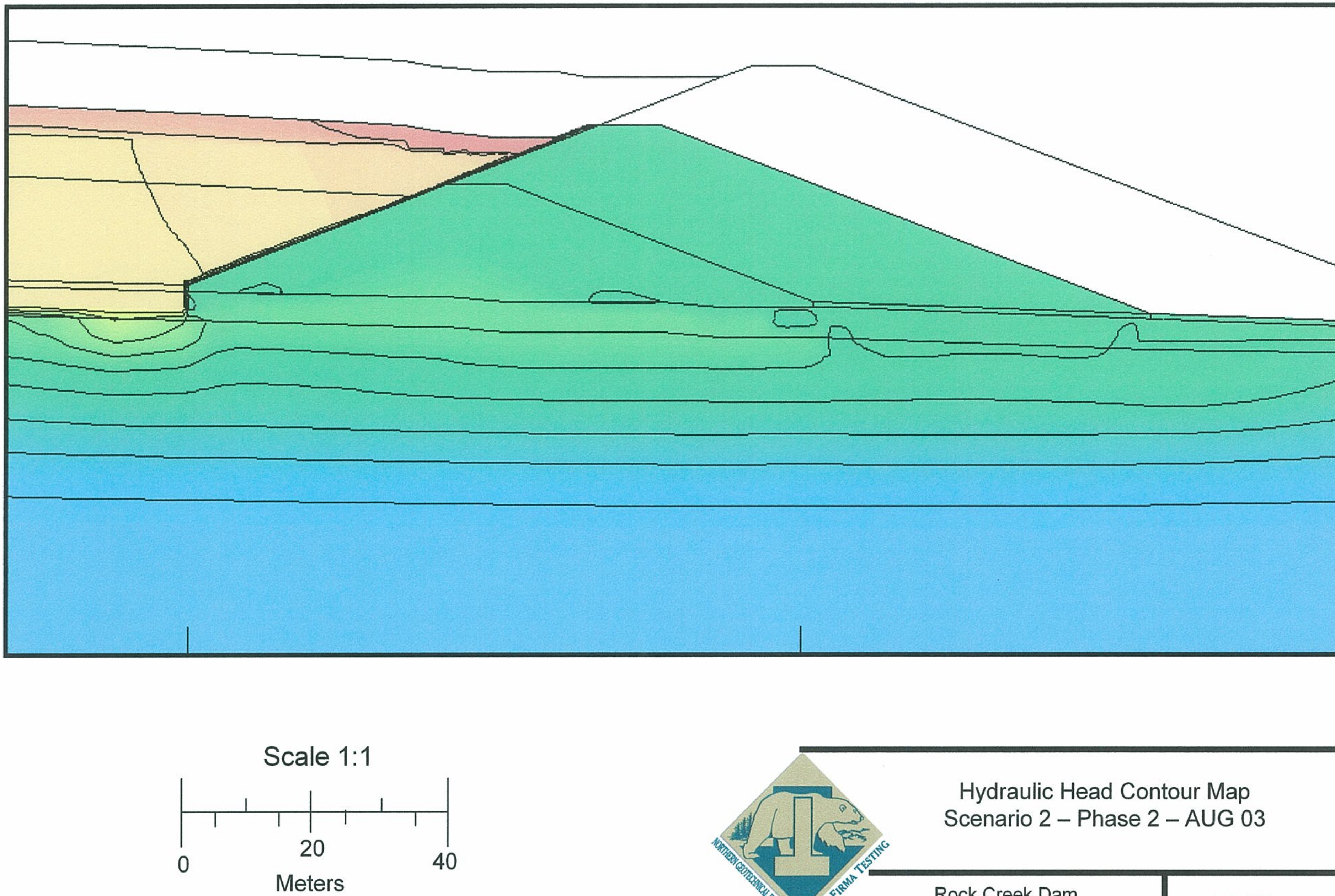




Thermal Contour Map
Scenario 1 – Phase 2 – AUG 03

Rock Creek Dam,
Nome, Alaska

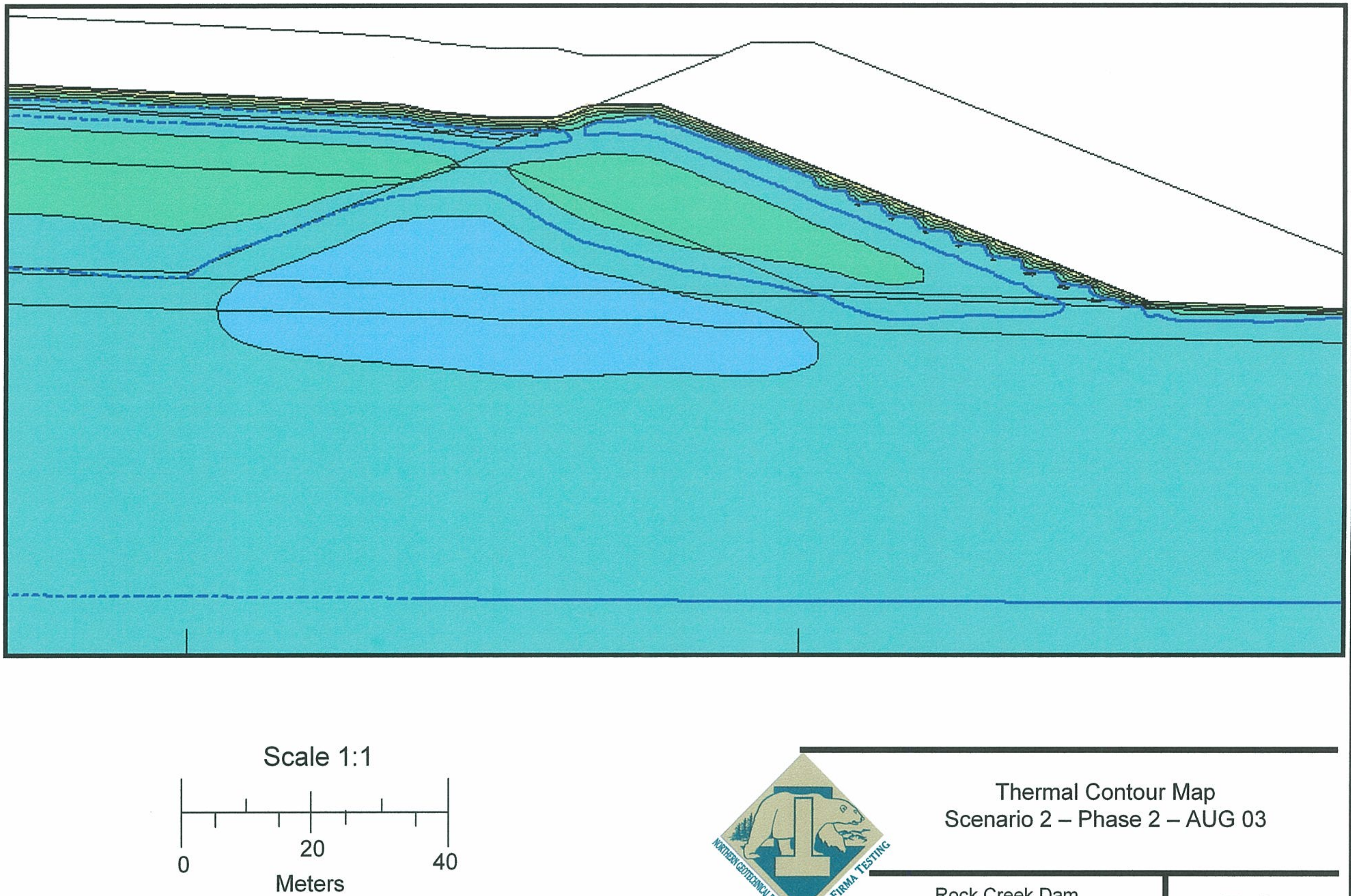
F-1t



Hydraulic Head Contour Map
Scenario 2 – Phase 2 – AUG 03

Rock Creek Dam,
Nome, Alaska

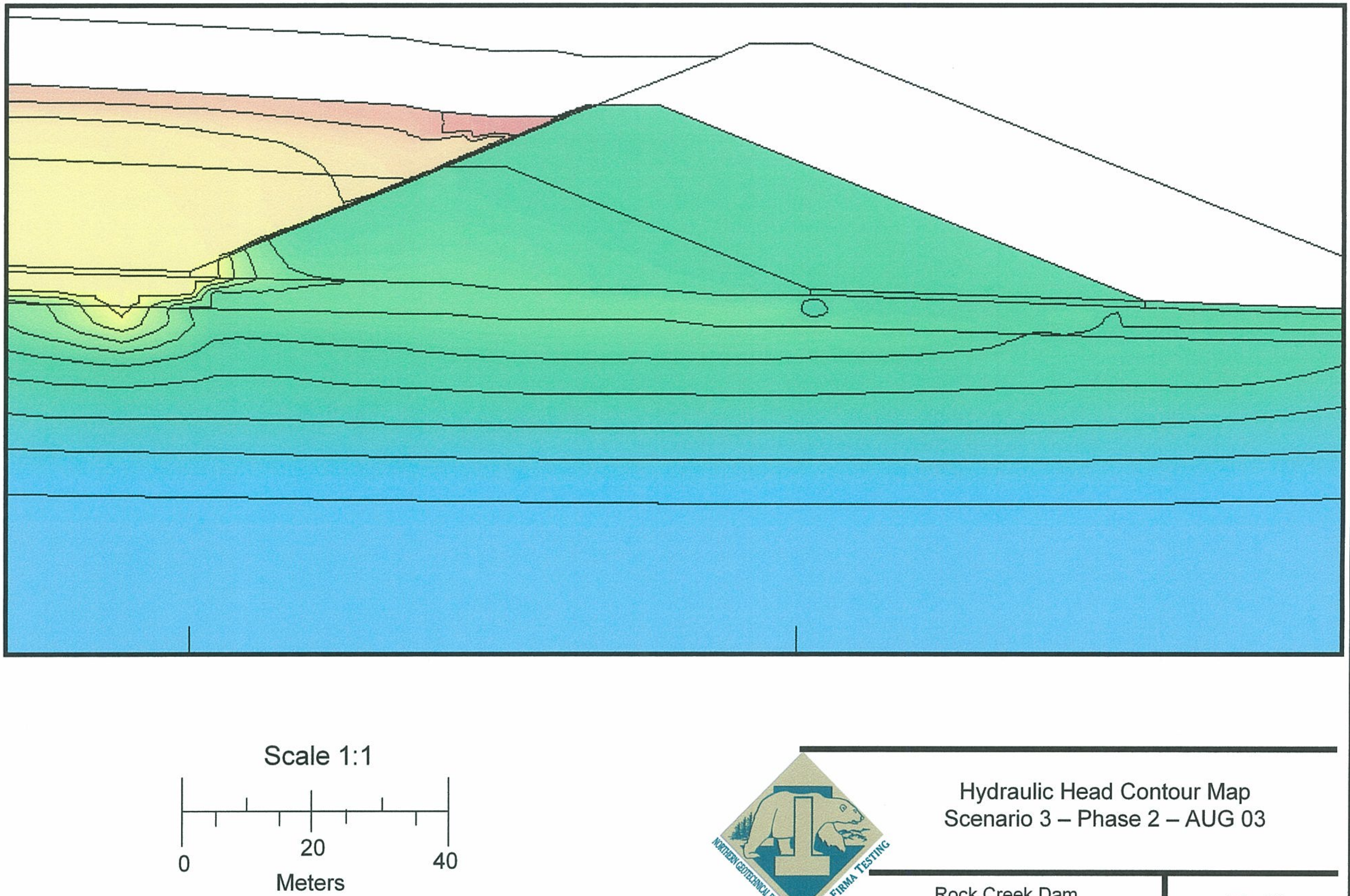
F-2h



Thermal Contour Map
Scenario 2 – Phase 2 – AUG 03

Rock Creek Dam,
Nome, Alaska

F-2t

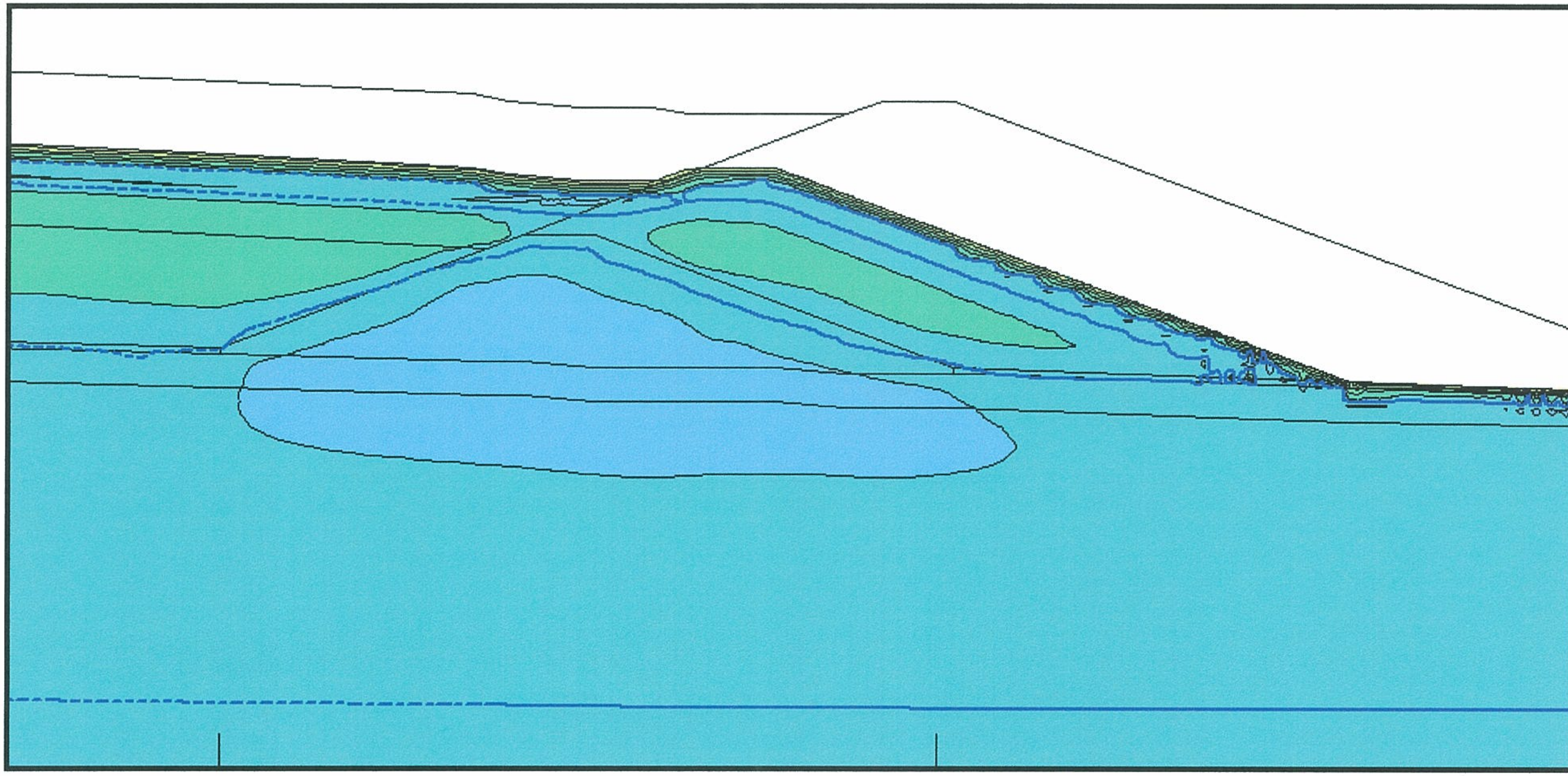


Hydraulic Head Contour Map
Scenario 3 – Phase 2 – AUG 03

Rock Creek Dam,
Nome, Alaska

NORTHERN GEOTECHNICAL ENGINEERING, INC. TERRA FIRMA TESTING

F-3h



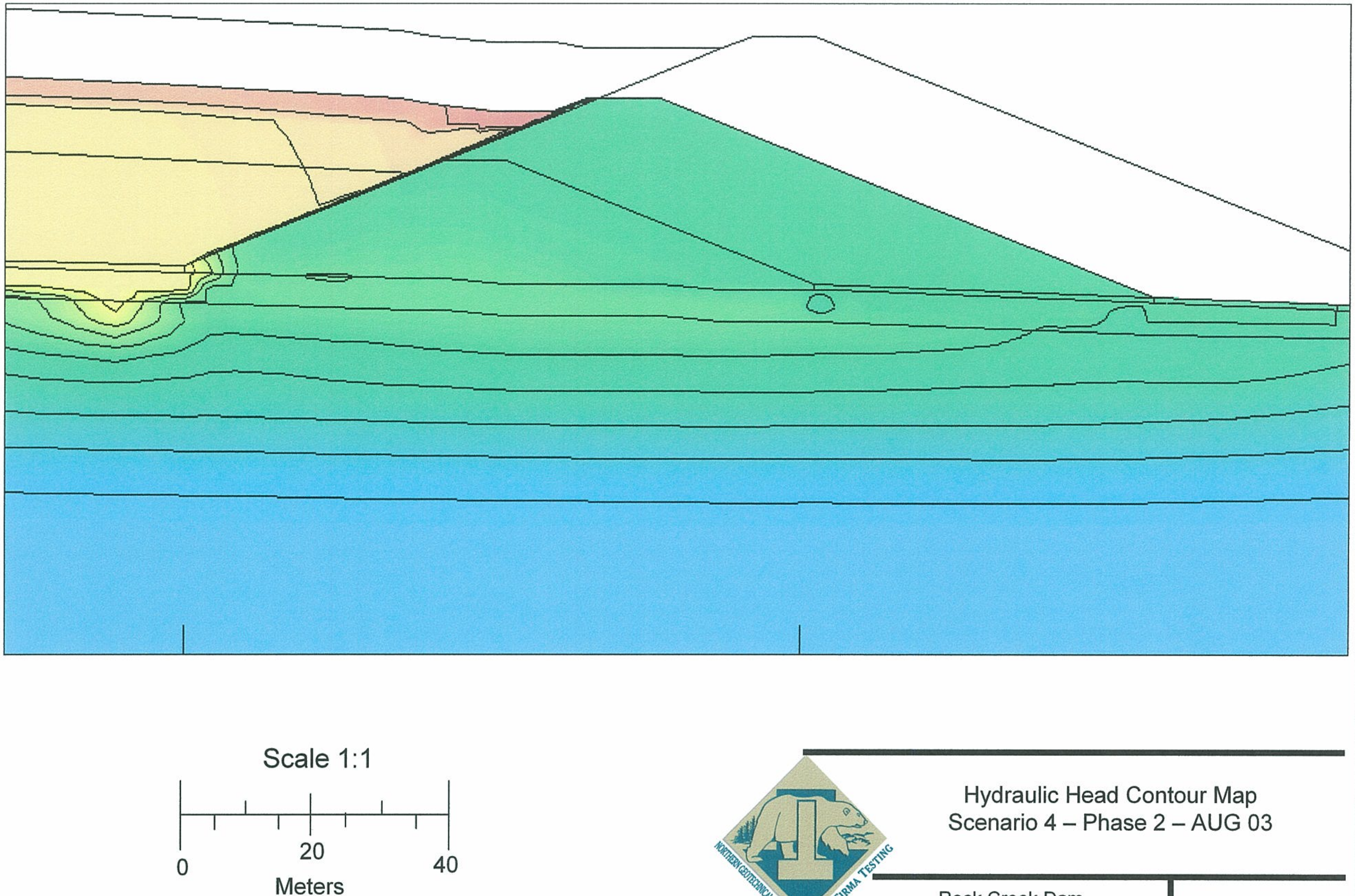
Scale 1:1

0 20 40
Meters

Thermal Contour Map
Scenario 3 – Phase 2 – AUG 03

Rock Creek Dam,
Nome, Alaska

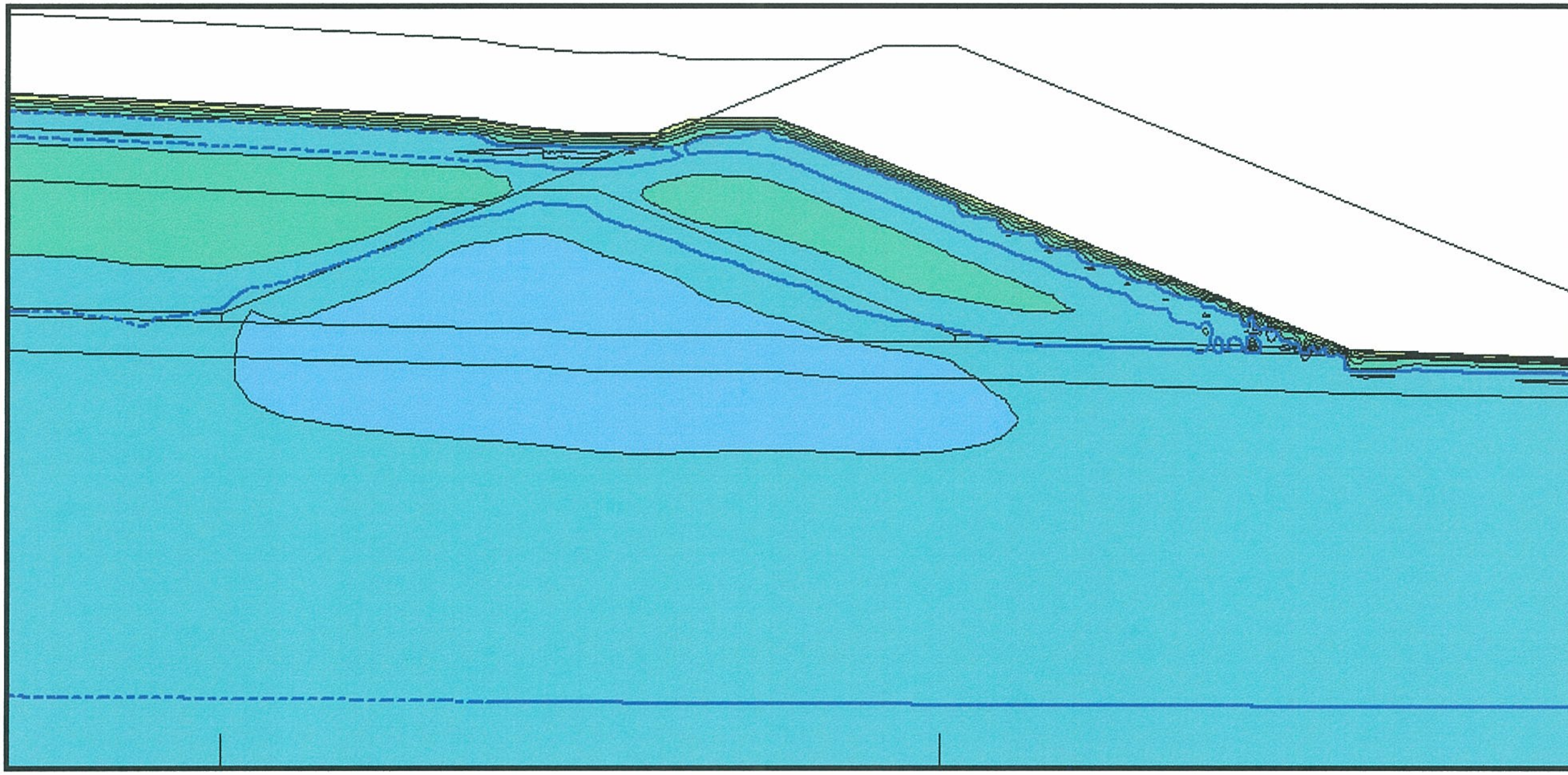
F-3t



Hydraulic Head Contour Map
Scenario 4 – Phase 2 – AUG 03

Rock Creek Dam,
Nome, Alaska

F-4h



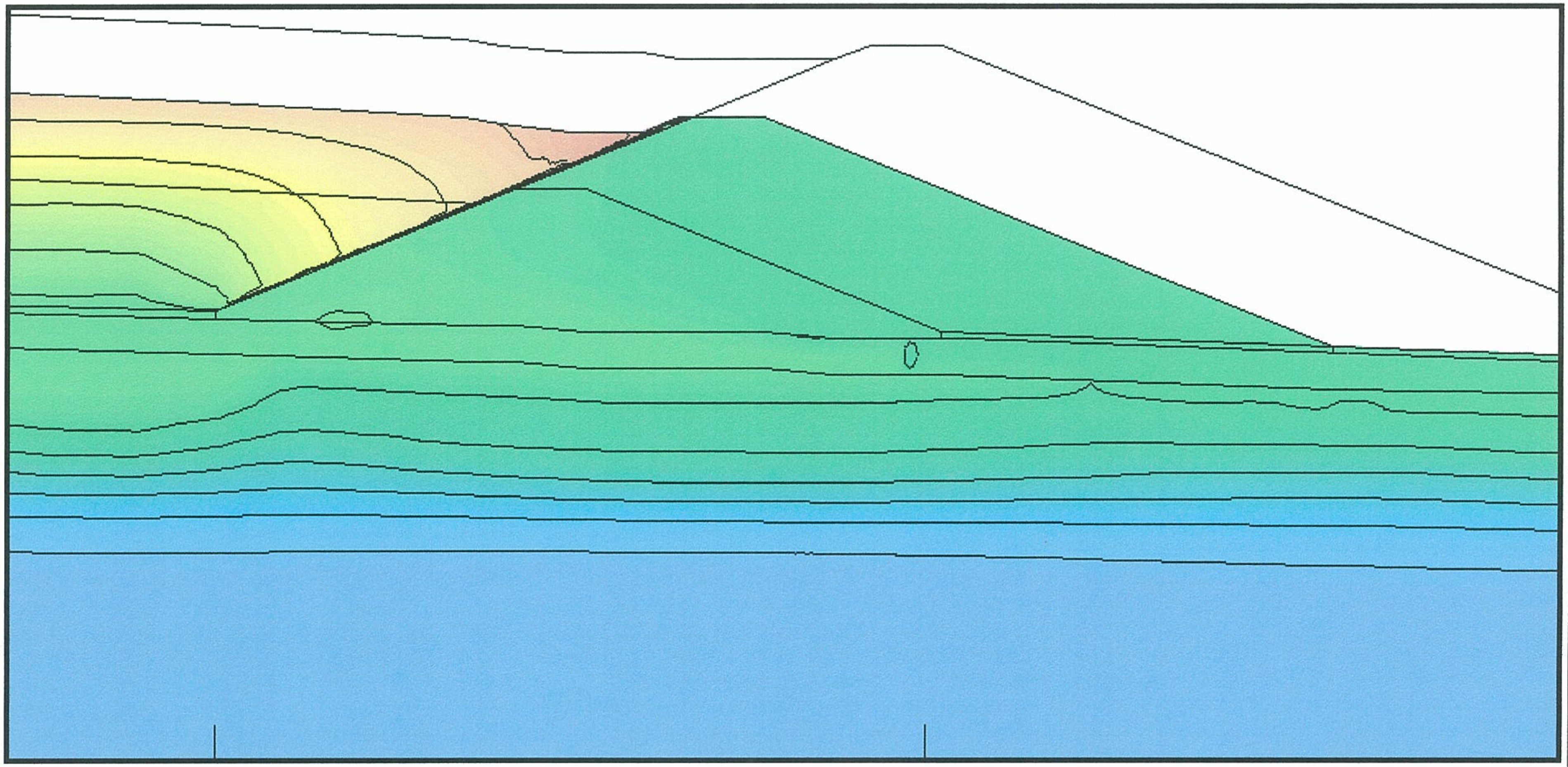
Scale 1:1

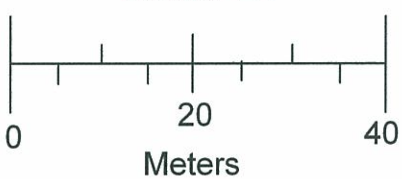
0 20 40
Meters

Thermal Contour Map
Scenario 4 – Phase 2 – AUG 03

Rock Creek Dam,
Nome, Alaska

F-4t

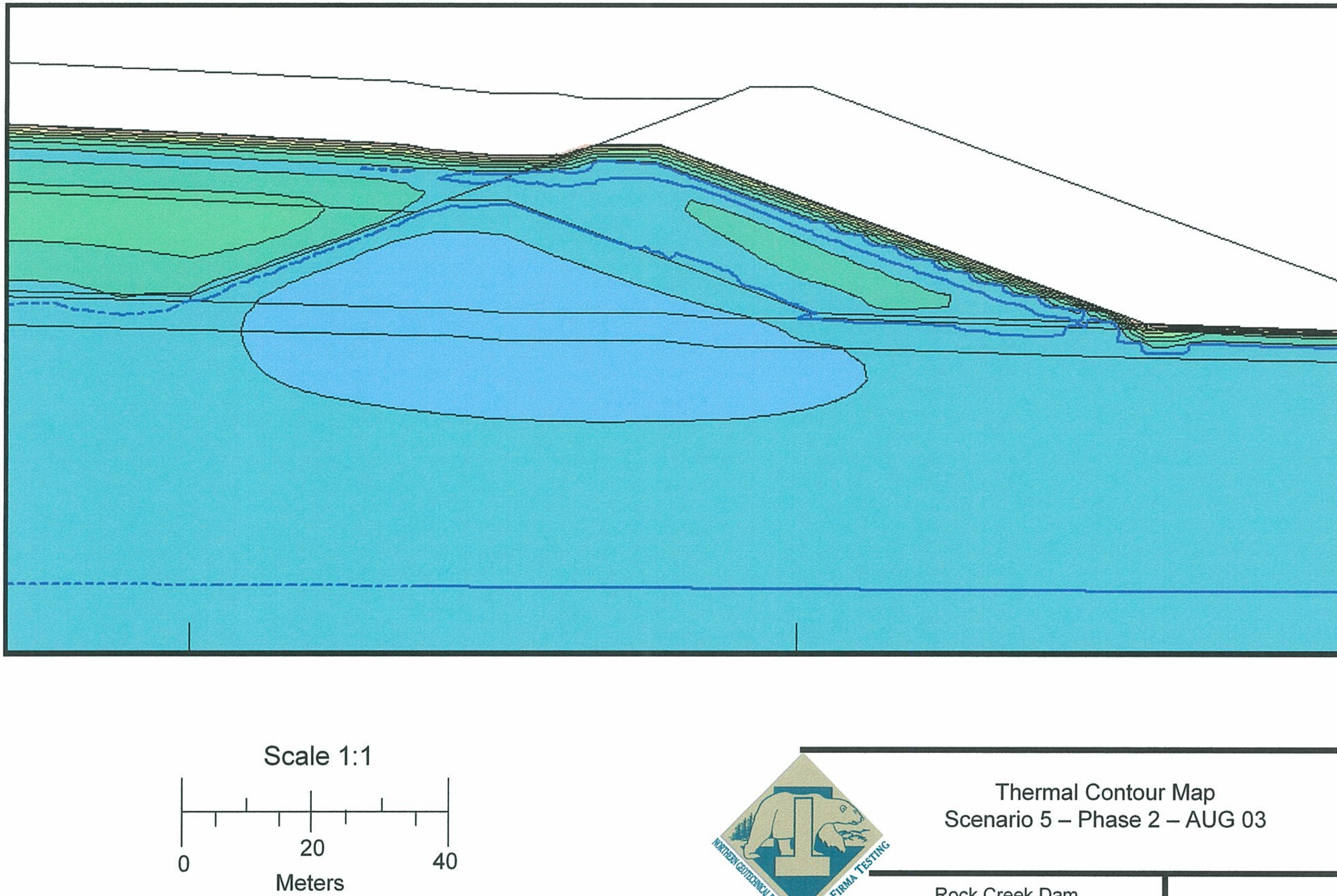




Hydraulic Head Contour Map
Scenario 5 – Phase 2 – AUG 03

Rock Creek Dam,
Nome, Alaska

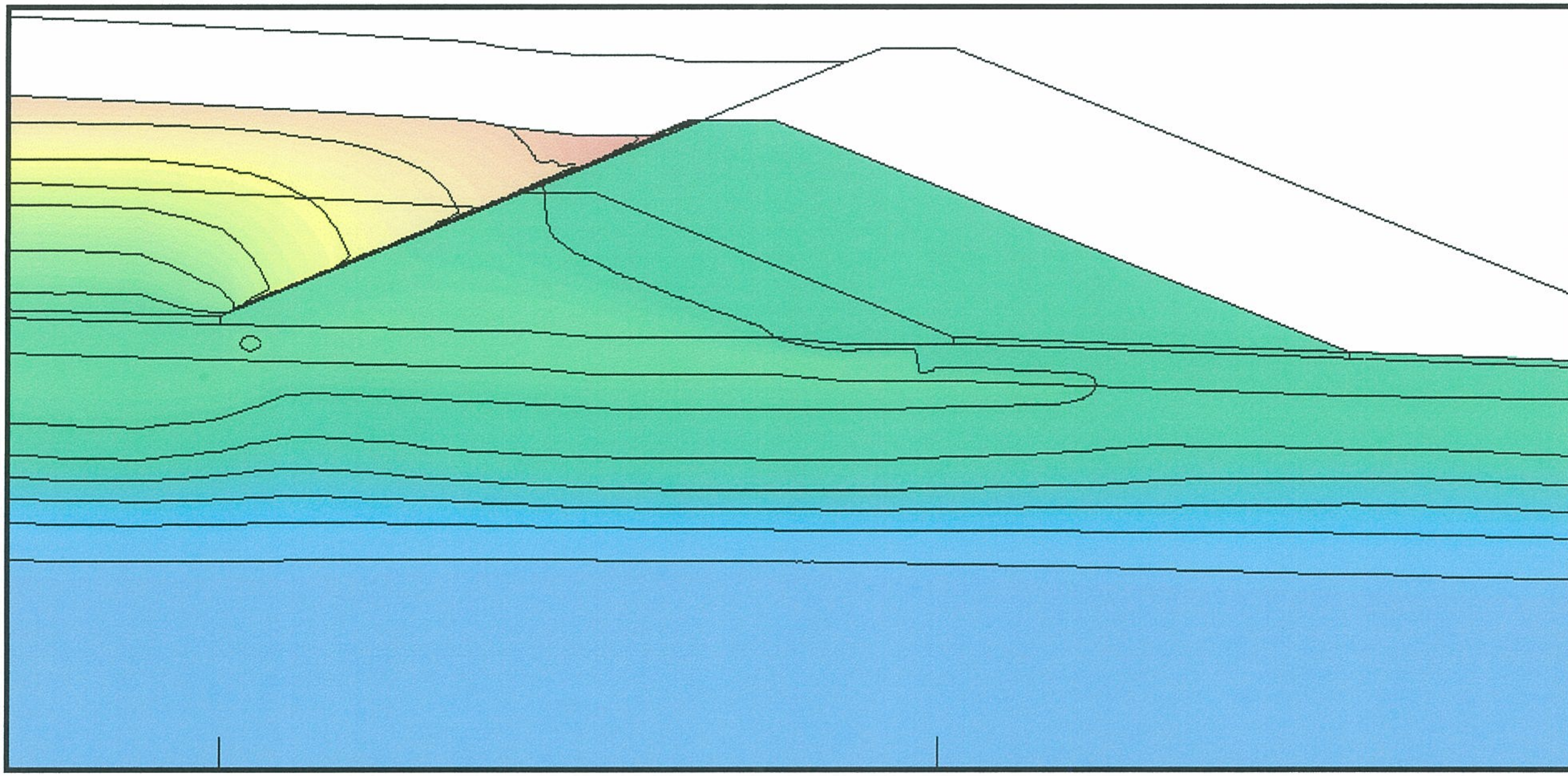
F-5h

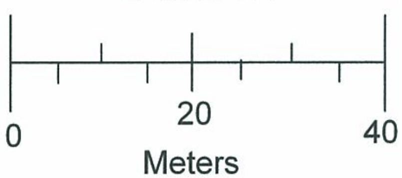


Thermal Contour Map
Scenario 5 – Phase 2 – AUG 03

Rock Creek Dam,
Nome, Alaska

F-5t



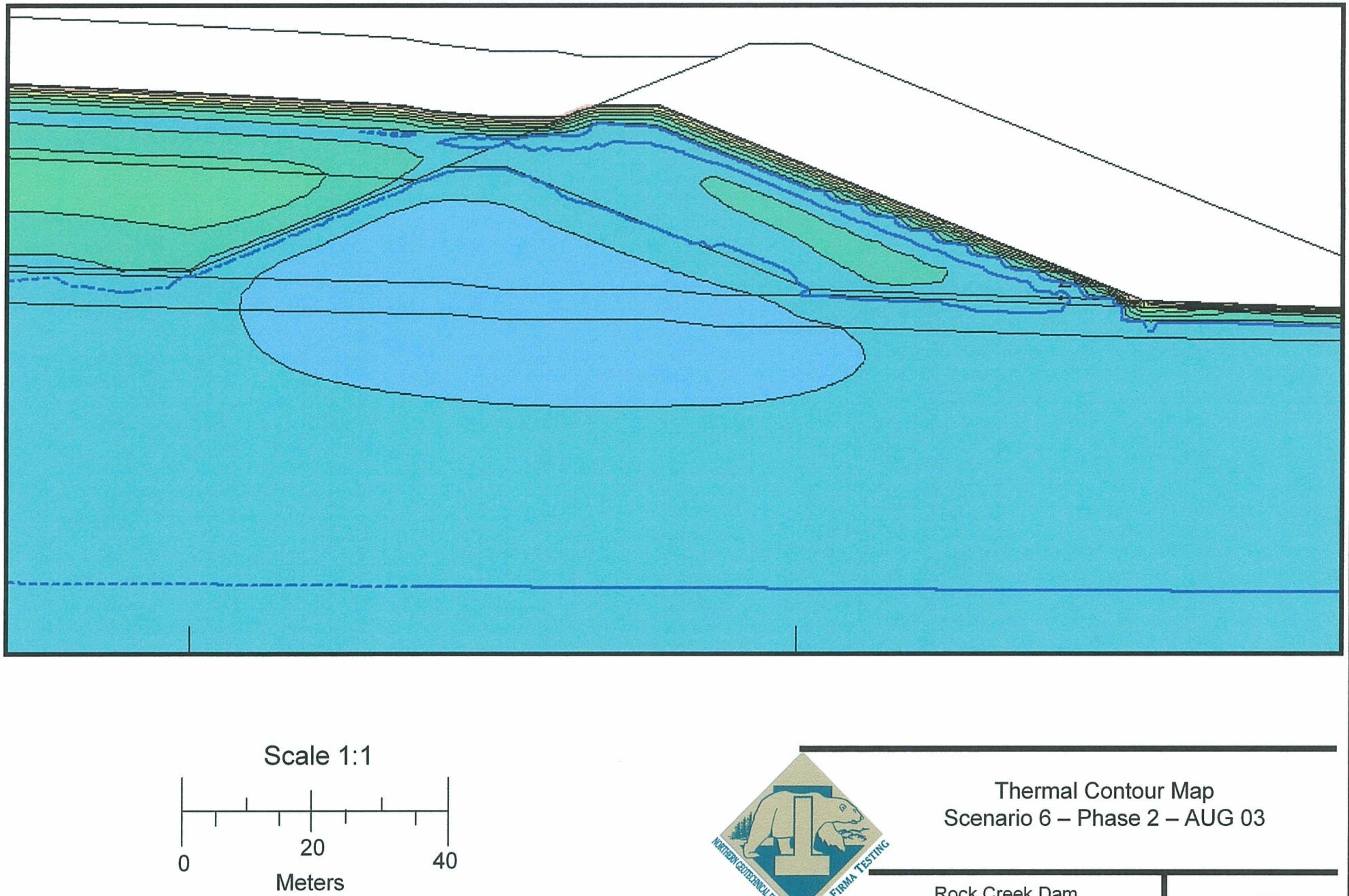


Terra Firma Testing
Northern Geotechnical Engineering, Inc.

Hydraulic Head Contour Map
Scenario 6 – Phase 2 – AUG 03

Rock Creek Dam,
Nome, Alaska

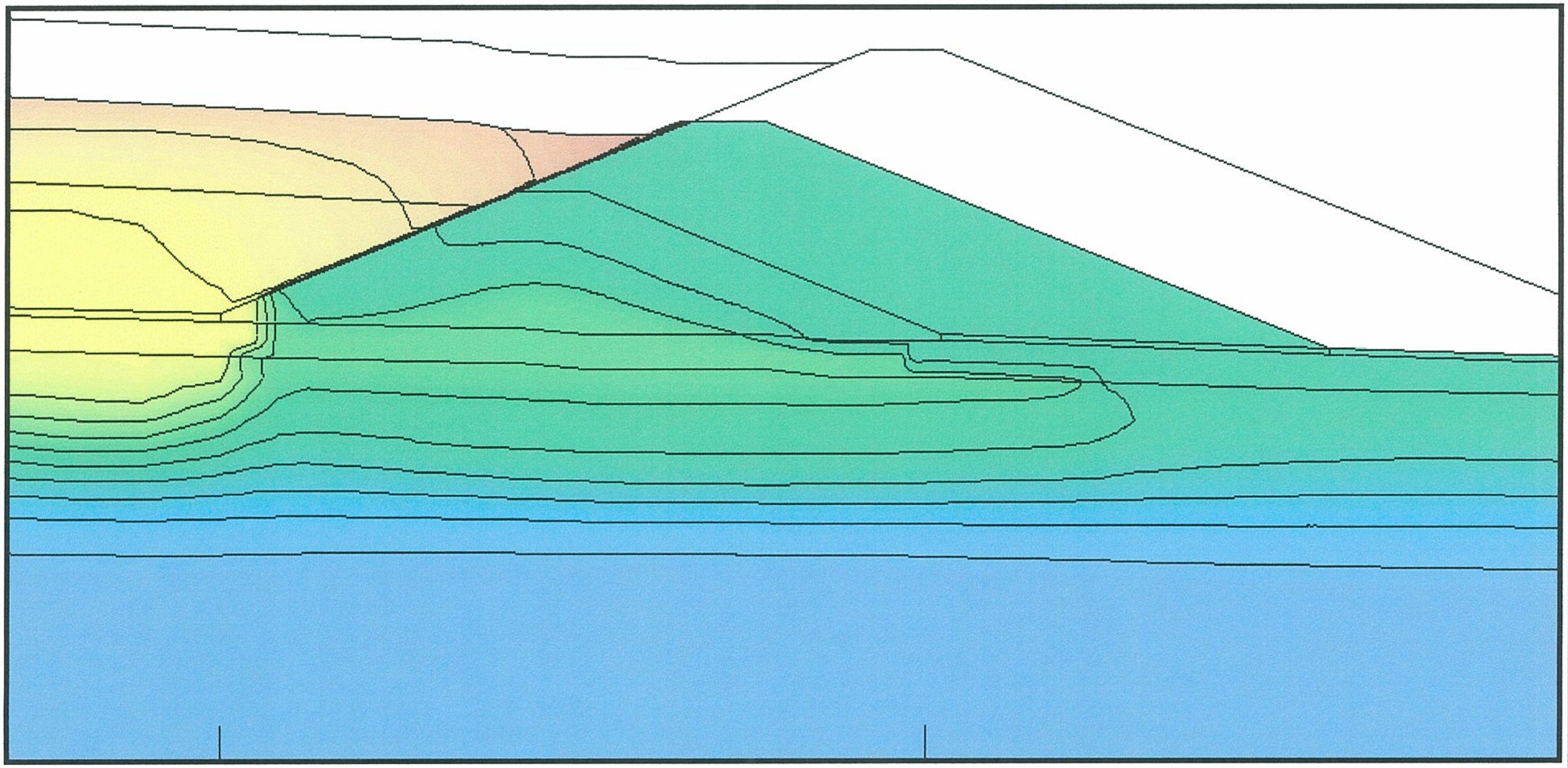
F-6h

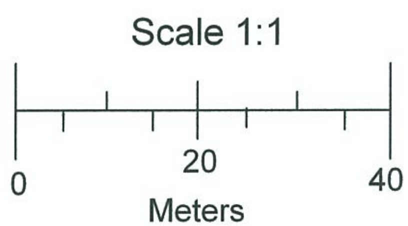


Thermal Contour Map
Scenario 6 – Phase 2 – AUG 03

Rock Creek Dam,
Nome, Alaska

F-6t

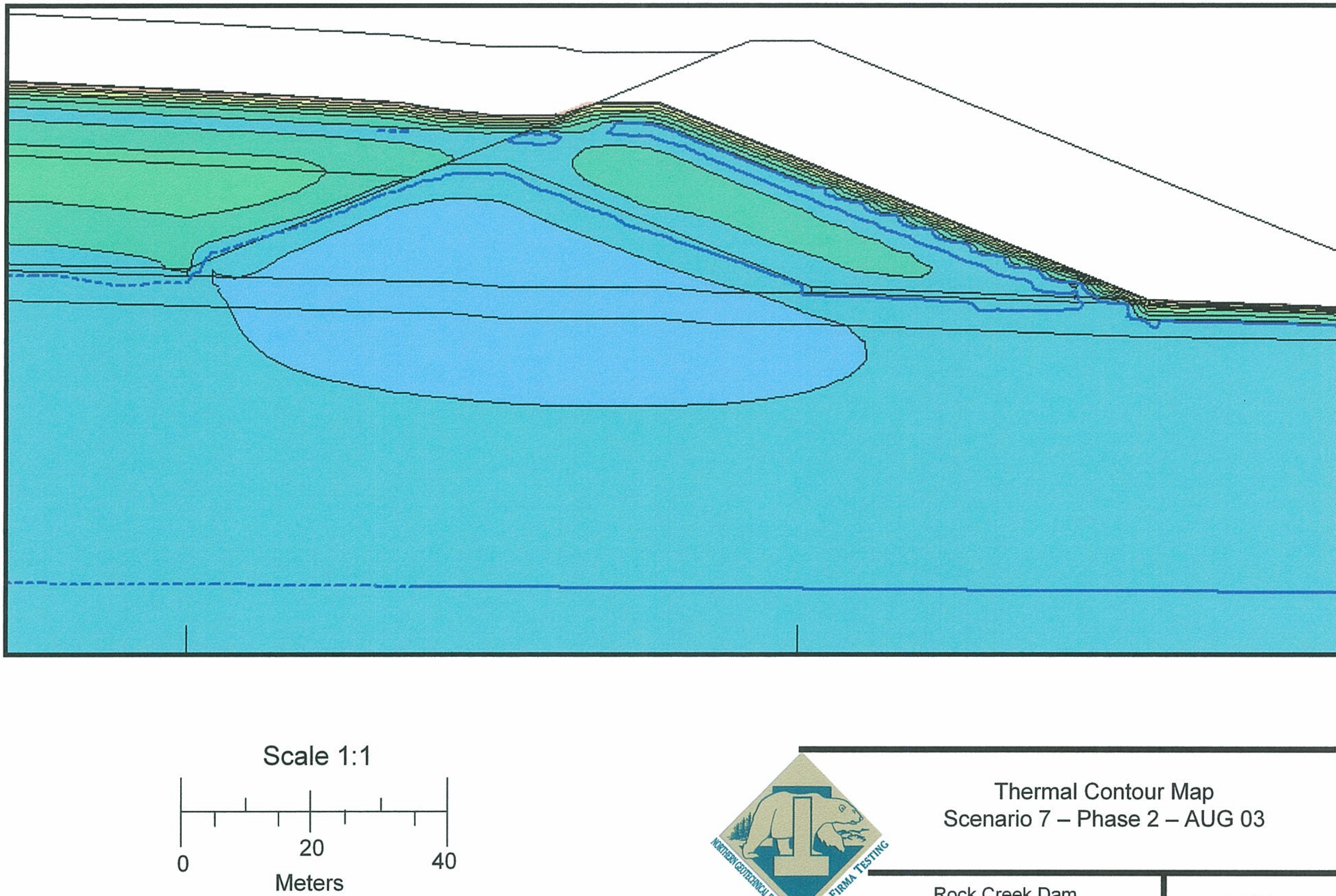




Hydraulic Head Contour Map
Scenario 7 – Phase 2 – AUG 03

Rock Creek Dam,
Nome, Alaska

F-7h



Thermal Contour Map
Scenario 7 – Phase 2 – AUG 03

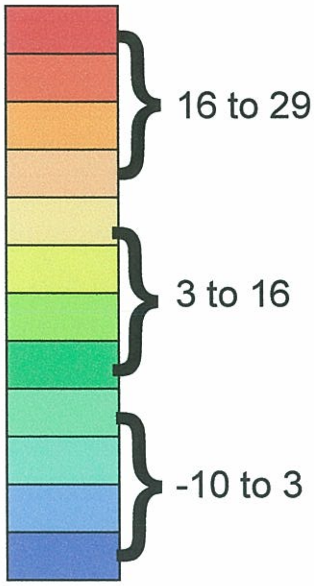
Rock Creek Dam,
Nome, Alaska

F-7t

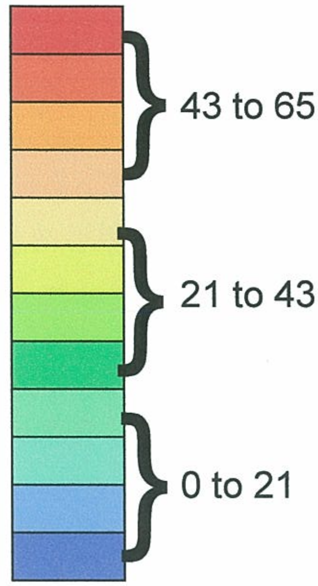
APPENDIX G

PHASE III ANALYSIS RESULTS

Thermal Contour Gradient (Degrees Celsius)



Hydraulic Contour Gradient (Meters above MSL)



= Freeze/thaw Interface

= Contour Interval Line

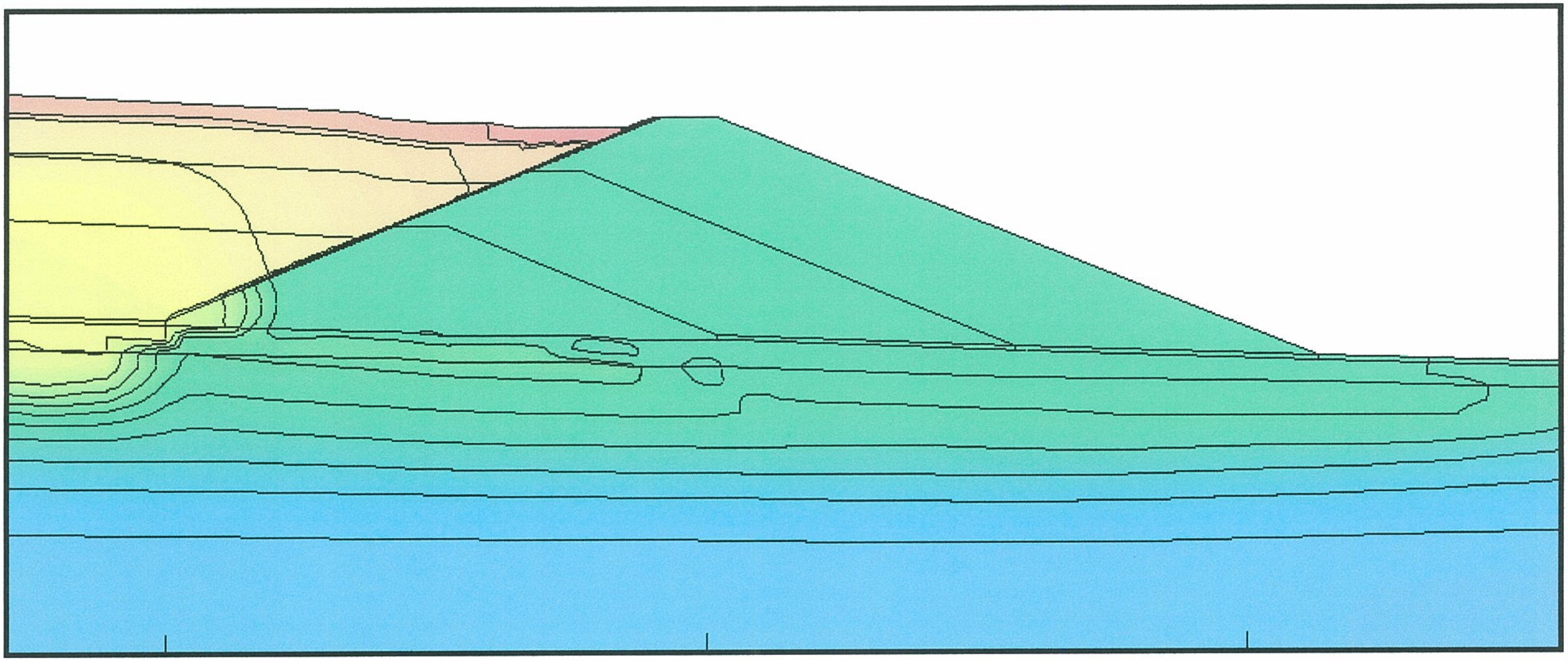
Scenario 1 = Current site conditions w/ no thermosyphons
Scenario 2 = Current site conditions w/ liner material extended into weathered bedrock unit and w/ no thermosyphons
Scenario 3 = Current site conditions w/ two thermosyphons and equipped w/ 50m^2 radiators
Scenario 4 = Current site conditions w/ two thermosyphons and equipped w/ 200m2 radiators
Scenario 5 = Elevated air temperatures (+3°C) and elevated hydraulic conductivity values (5x) for the weathered bedrock unit. No thermosyphons.
Scenario 6 = Elevated air temperatures (+3°C) and elevated hydraulic conductivity values (5x) for the weathered bedrock unit. Contains two thermosyphons w/ 50m^2 radiators
Scenario 7 = Elevated air temperatures (+3°C) and elevated hydraulic conductivity values (5x) for the weathered bedrock unit. Contains two thermosyphons w/ 200m^2 radiators

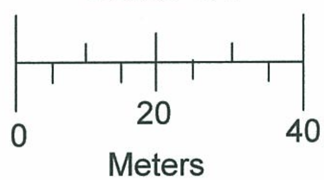
NORTHERN GEOTECHNICAL ENGINEERING, INC. TERRA FIRMA TESTING

APPENDIX G KEY

Rock Creek Dam, Nome, Alaska

G-0

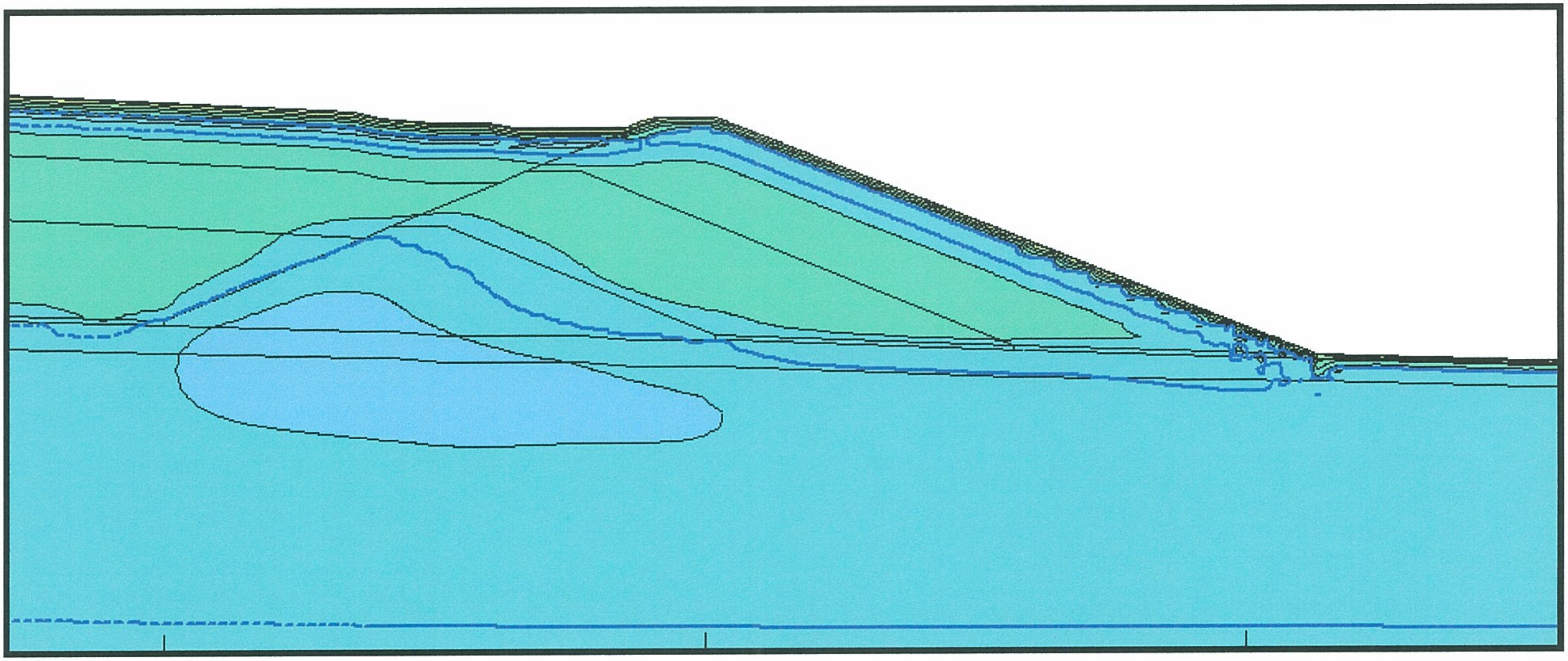




Hydraulic Head Contour Map
Scenario 1 – Phase 3 – AUG 04

Rock Creek Dam,
Nome, Alaska

G-1h

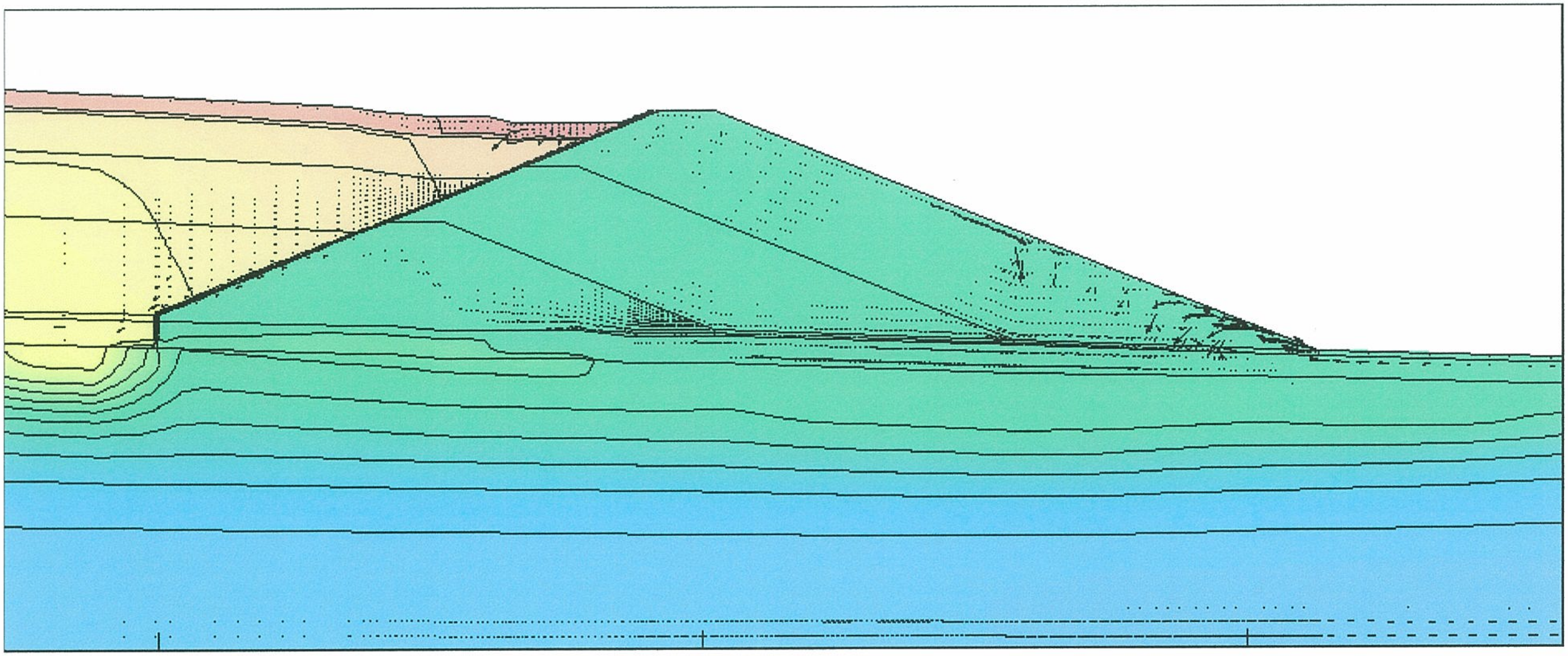


Scale 1:1

Thermal Contour Map
Scenario 1 – Phase 3 – AUG 04

Rock Creek Dam,
Nome, Alaska

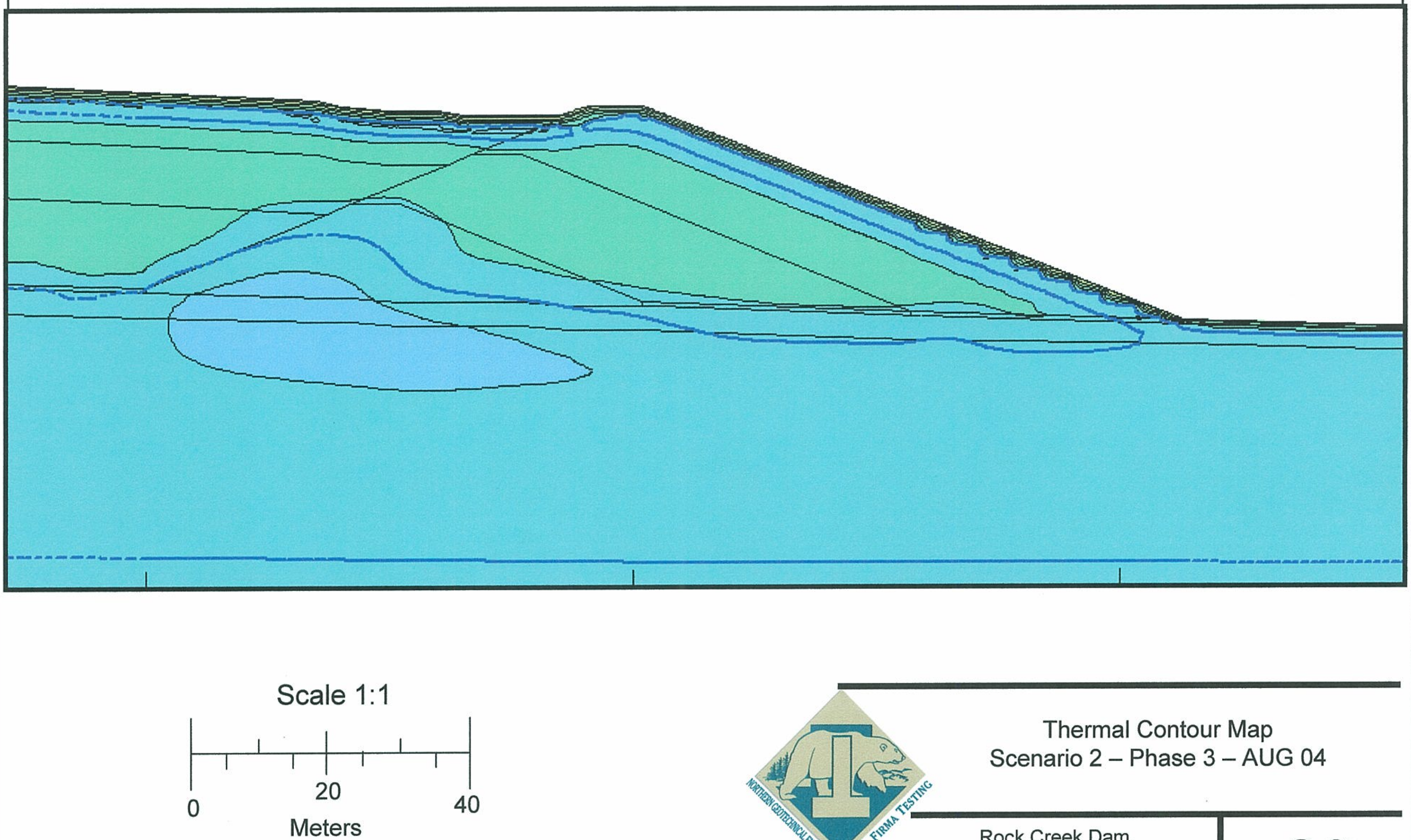
G-1t



Hydraulic Head Contour Map
Scenario 2 – Phase 3 – AUG 04

Rock Creek Dam,
Nome, Alaska

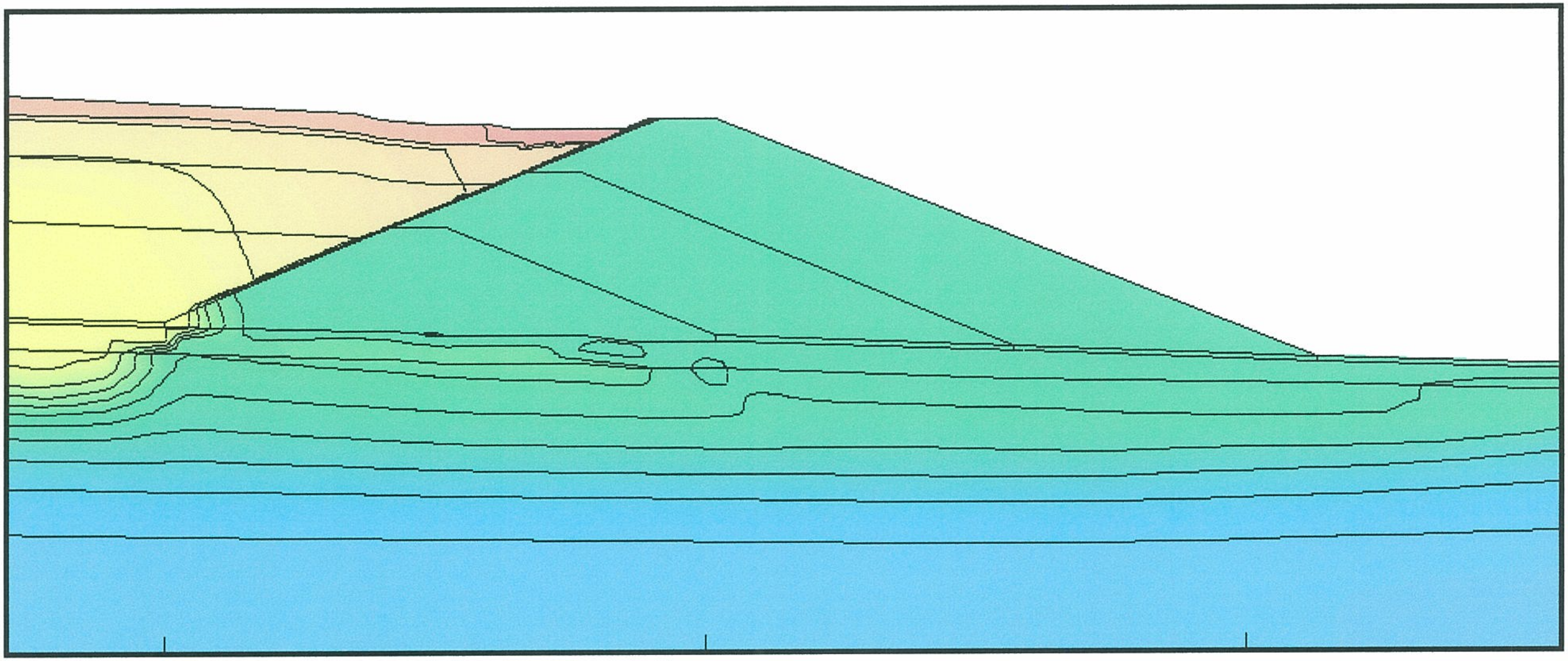
G-2h



Thermal Contour Map
Scenario 2 – Phase 3 – AUG 04

Rock Creek Dam,
Nome, Alaska

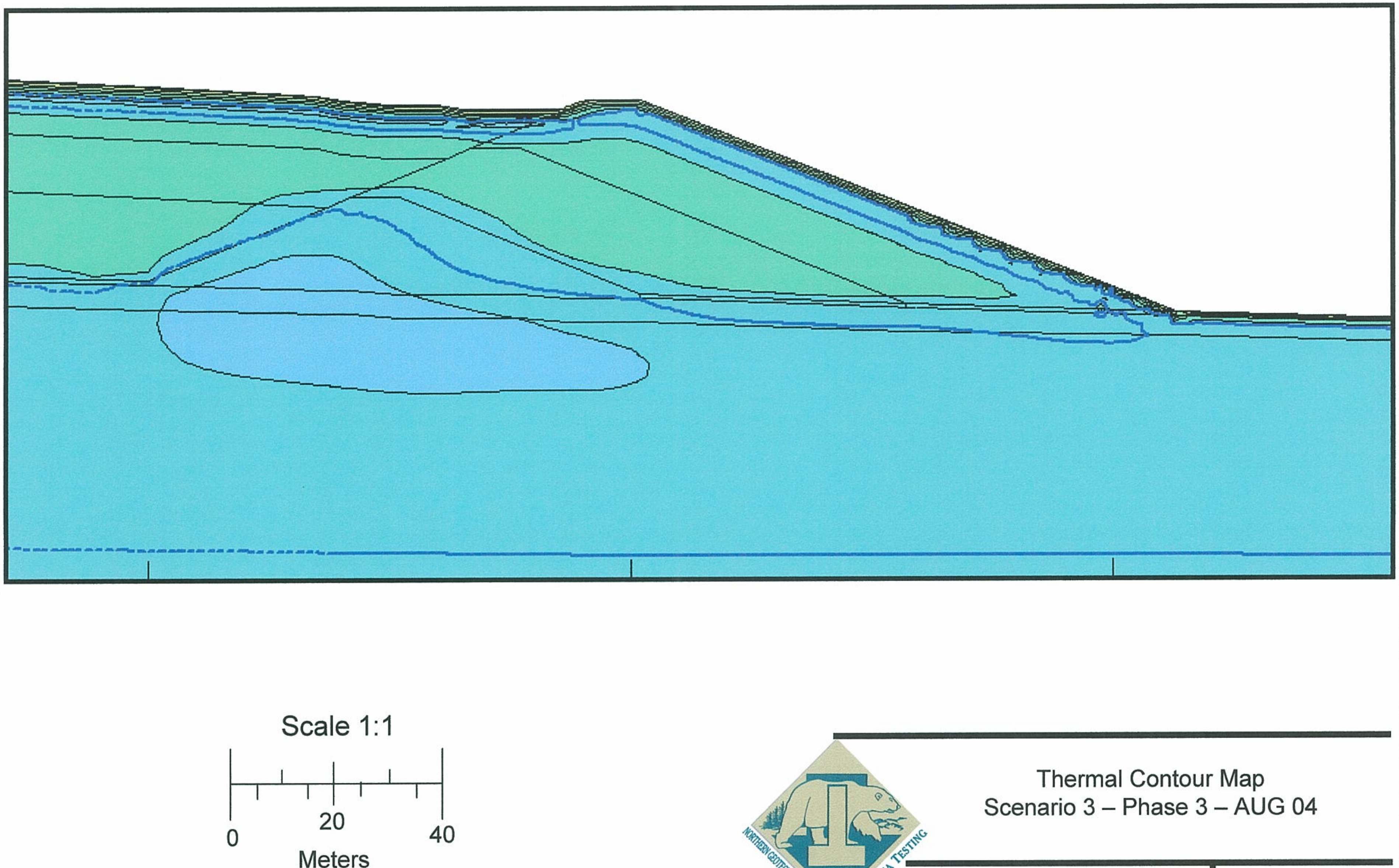
G-2t



Hydraulic Head Contour Map
Scenario 3 – Phase 3 – AUG 04

Rock Creek Dam,
Nome, Alaska

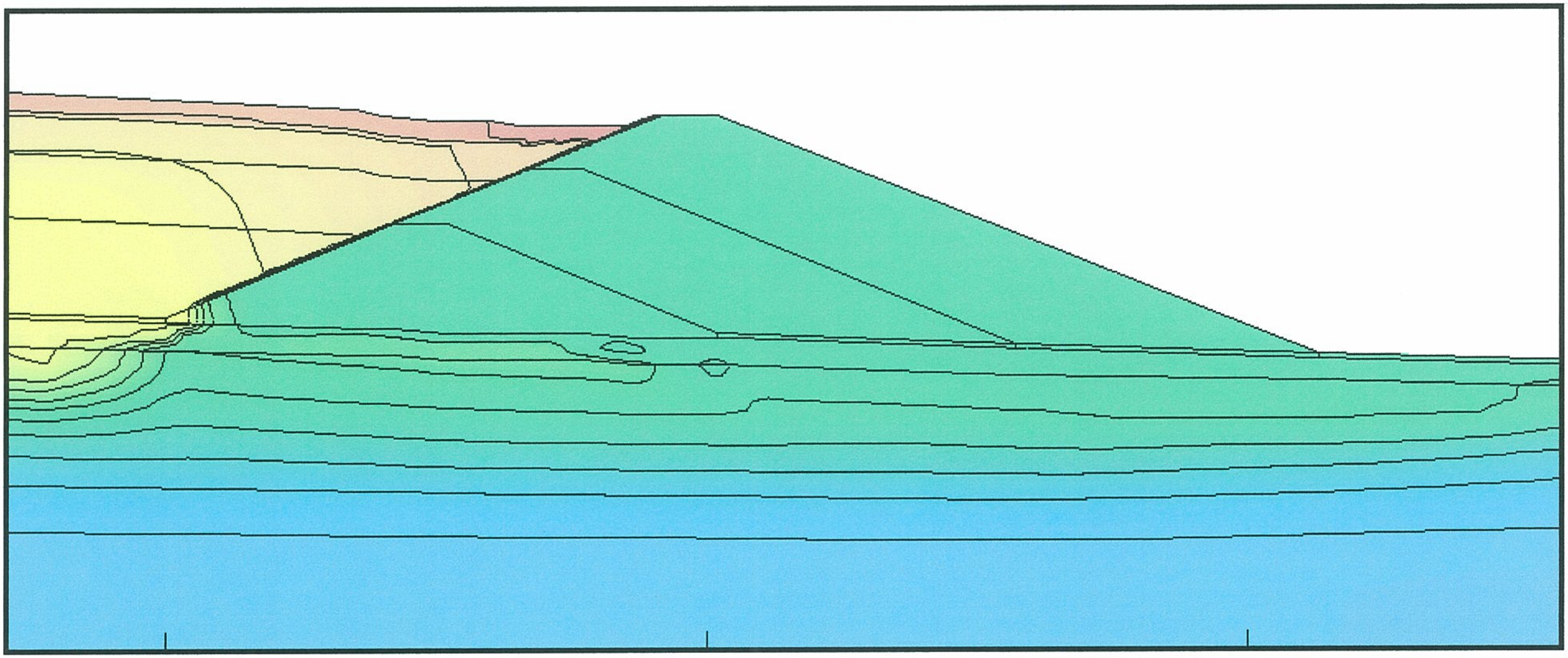
G-3h

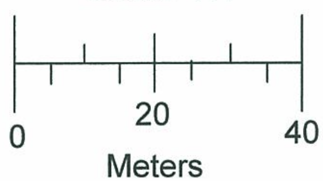


Thermal Contour Map
Scenario 3 – Phase 3 – AUG 04

Rock Creek Dam,
Nome, Alaska

G-3t

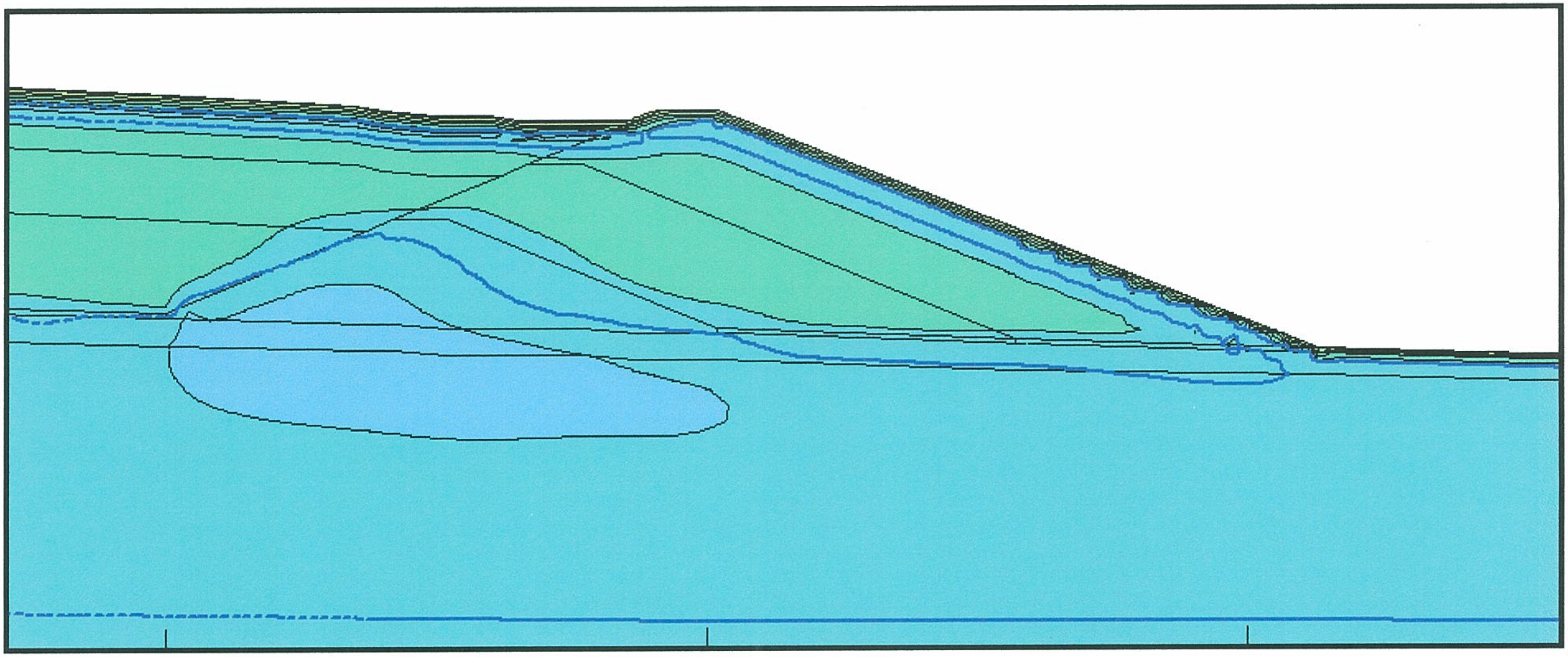


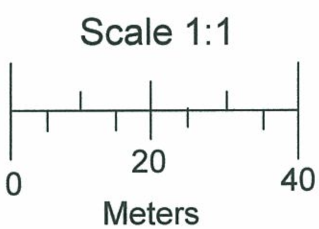


Hydraulic Head Contour Map
Scenario 4 – Phase 3 – AUG 04

Rock Creek Dam,
Nome, Alaska

G-4h

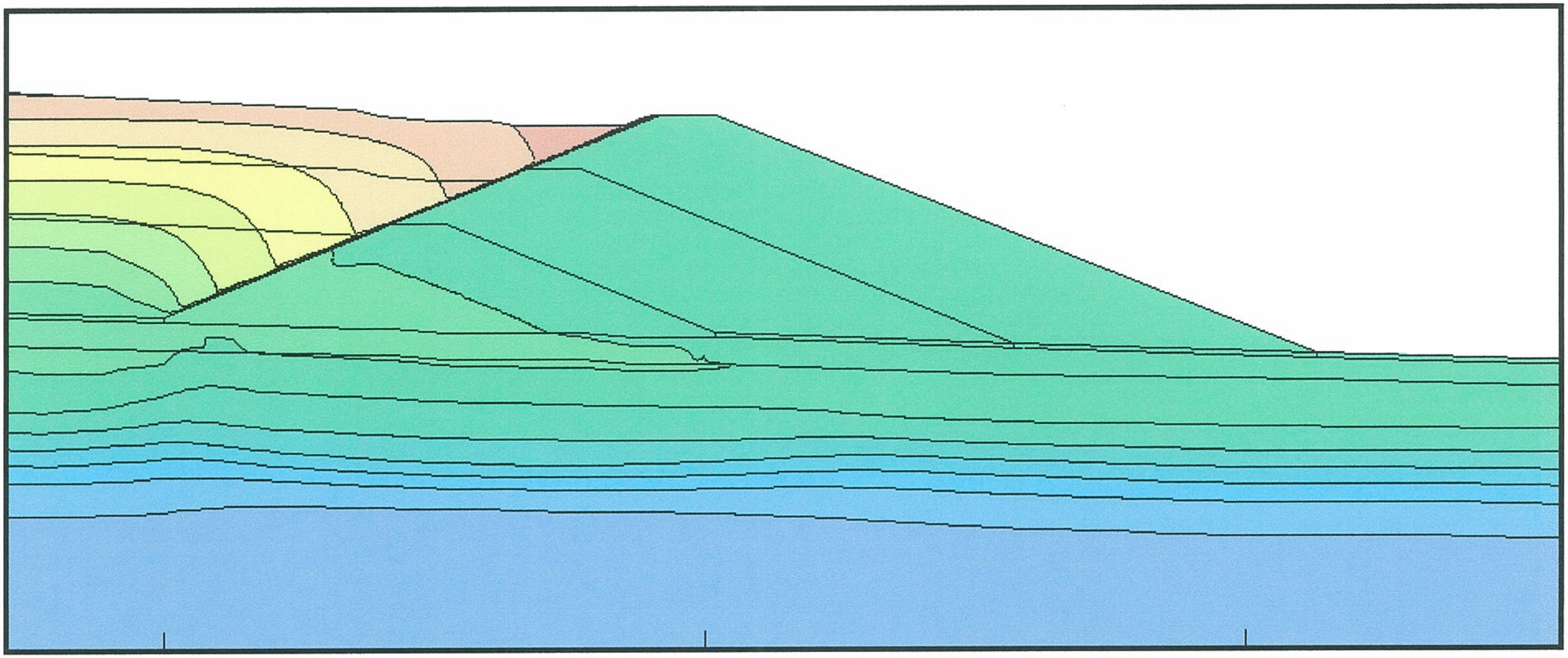




Thermal Contour Map
Scenario 4 – Phase 3 – AUG 04

Rock Creek Dam,
Nome, Alaska

G-4t



Scale 1:1

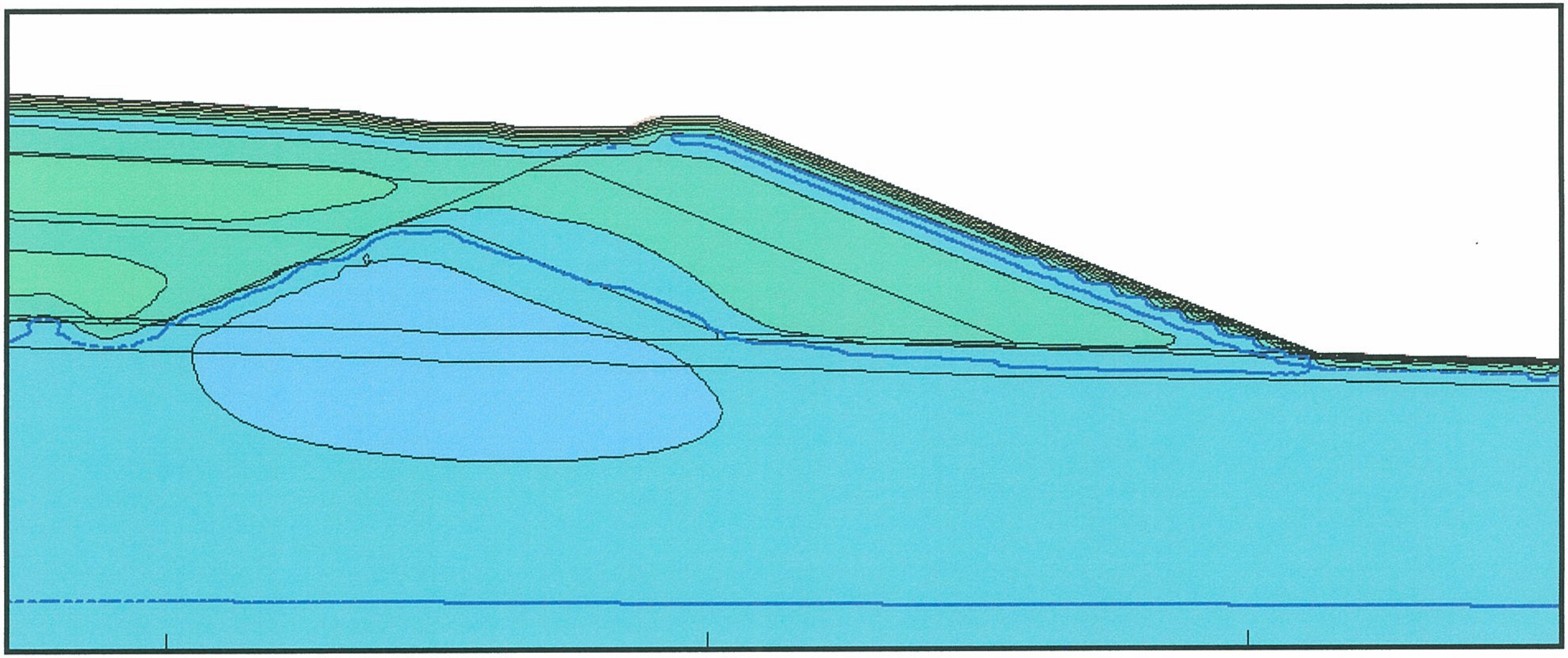
0 20 40

Meters

Hydraulic Head Contour Map
Scenario 5 – Phase 3 – AUG 04

Rock Creek Dam,
Nome, Alaska

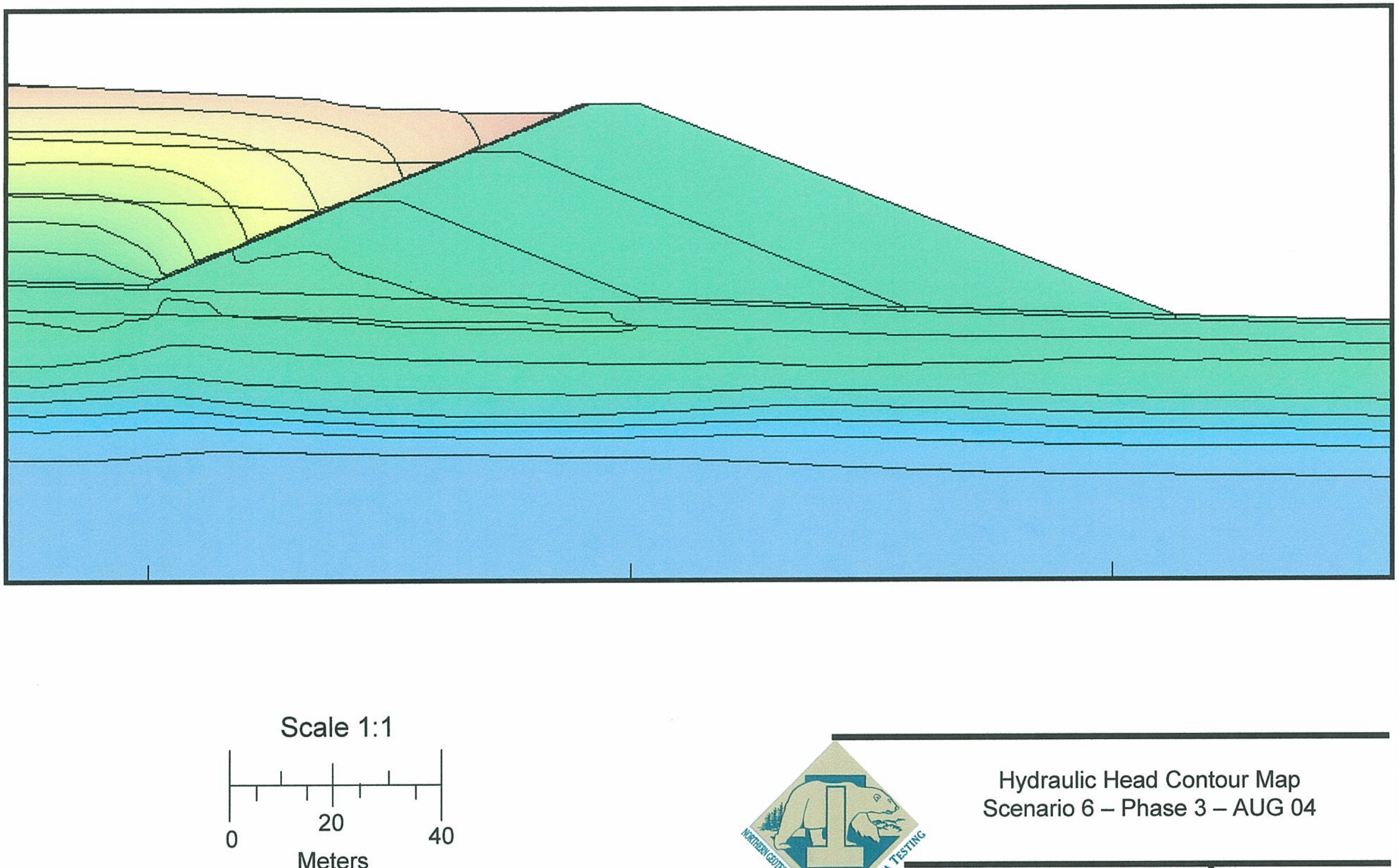
G-5h



Thermal Contour Map
Scenario 5 – Phase 3 – AUG 04

Rock Creek Dam,
Nome, Alaska

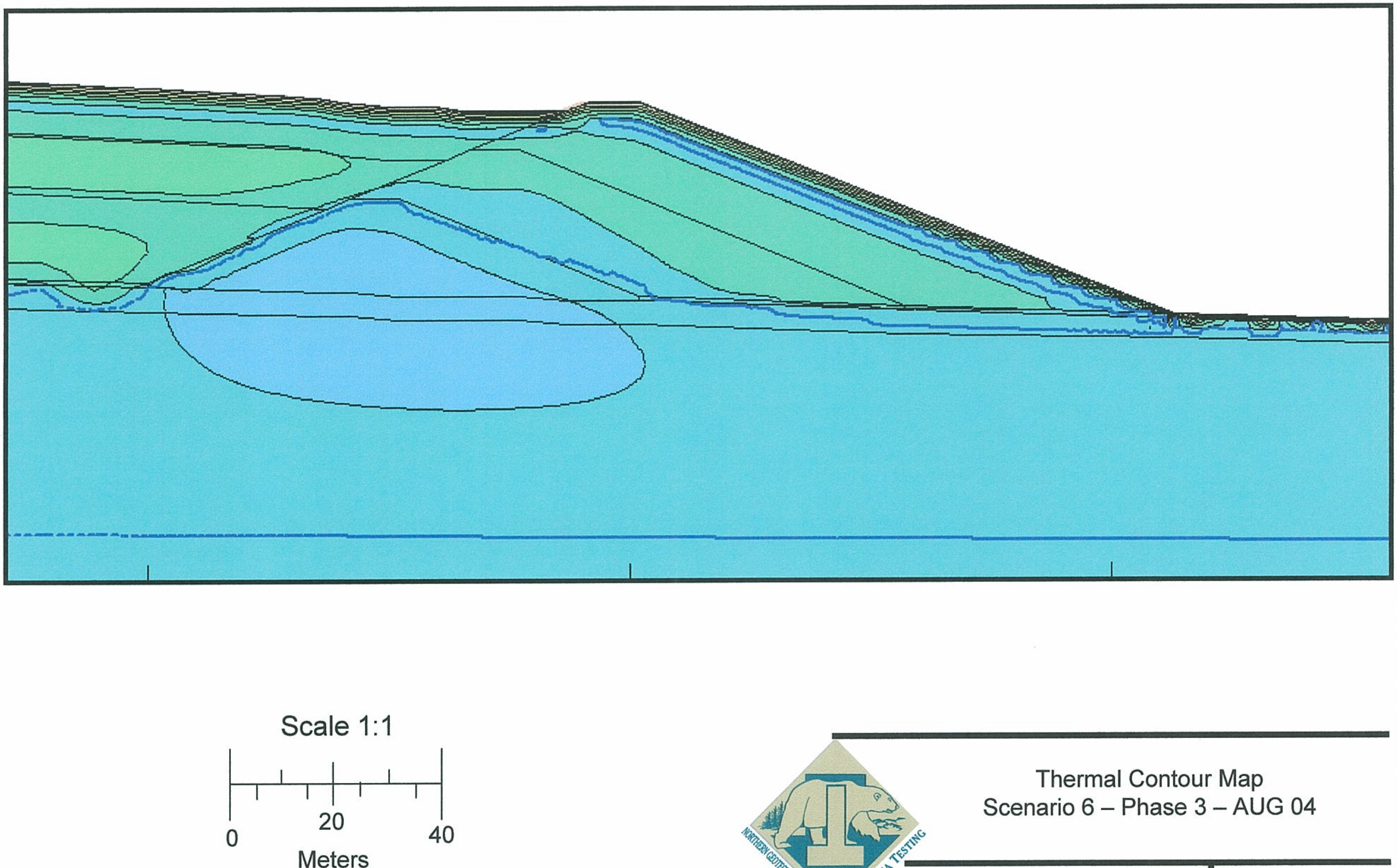
G-5t



Hydraulic Head Contour Map
Scenario 6 – Phase 3 – AUG 04

Rock Creek Dam,
Nome, Alaska

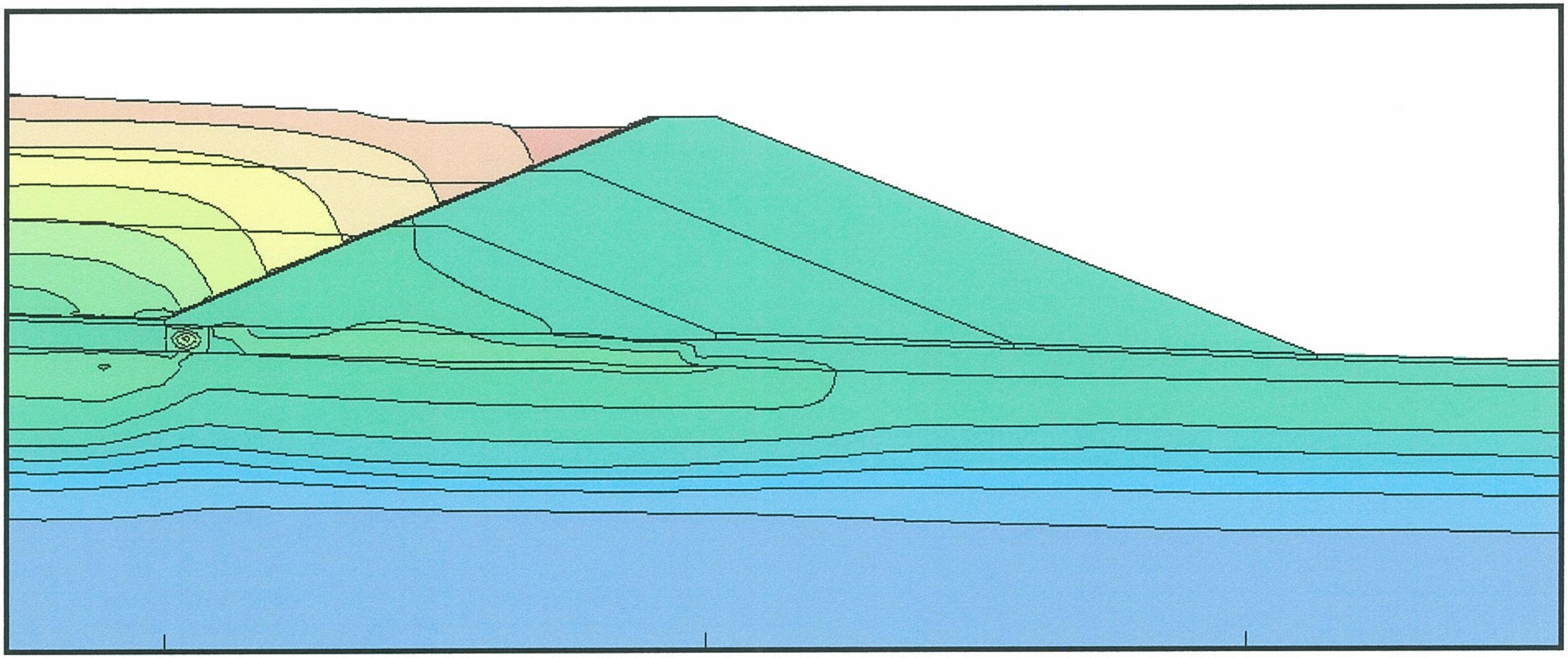
G-6h

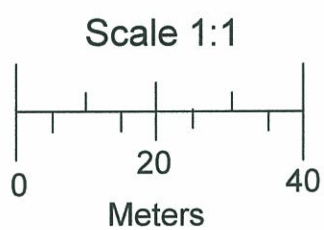


Thermal Contour Map
Scenario 6 – Phase 3 – AUG 04

Rock Creek Dam,
Nome, Alaska

G-6t

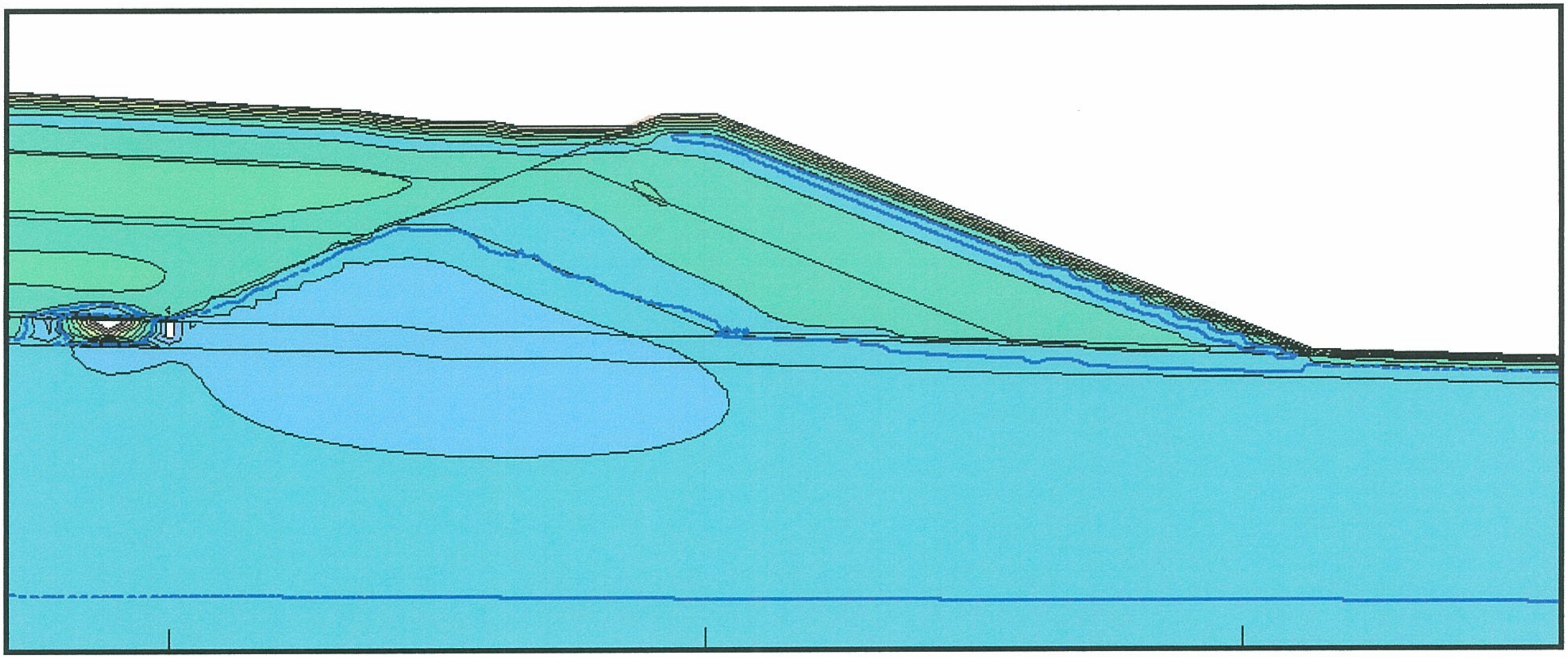




Hydraulic Head Contour Map
Scenario 7 – Phase 3 – AUG 04

Rock Creek Dam,
Nome, Alaska

G-7h



Thermal Contour Map
Scenario 7 – Phase 3 – AUG 04

Rock Creek Dam,
Nome, Alaska

G-7t

APPENDIX H

POST OPERATIONS ANALYSIS RESULTS

Thermal Contour Gradient (Degrees Celsius)

- 16 to 29
- 3 to 16
- -10 to 3

Hydraulic Contour Gradient (Meters above MSL)

- 43 to 65
- 21 to 43
- 0 to 21

= Freeze/thaw Interface

= Contour Interval Line

Scenario 1 = Current site conditions w/ no thermosyphons

Scenario 2 = Current site conditions w/ liner material extended into weathered bedrock unit and w/ no thermosyphons

Scenario 3 = Current site conditions w/ two thermosyphons and equipped w/ 50m^2 radiators

Scenario 4 = Current site conditions w/ two thermosyphons and equipped w/ 200m2 radiators

Scenario 5 = Elevated air temperatures (+3°C) and elevated hydraulic conductivity values (5x) for the weathered bedrock unit. No thermosyphons.

Scenario 6 = Elevated air temperatures (+3°C) and elevated hydraulic conductivity values (5x) for the weathered bedrock unit. Contains two thermosyphons w/ 50m^2 radiators

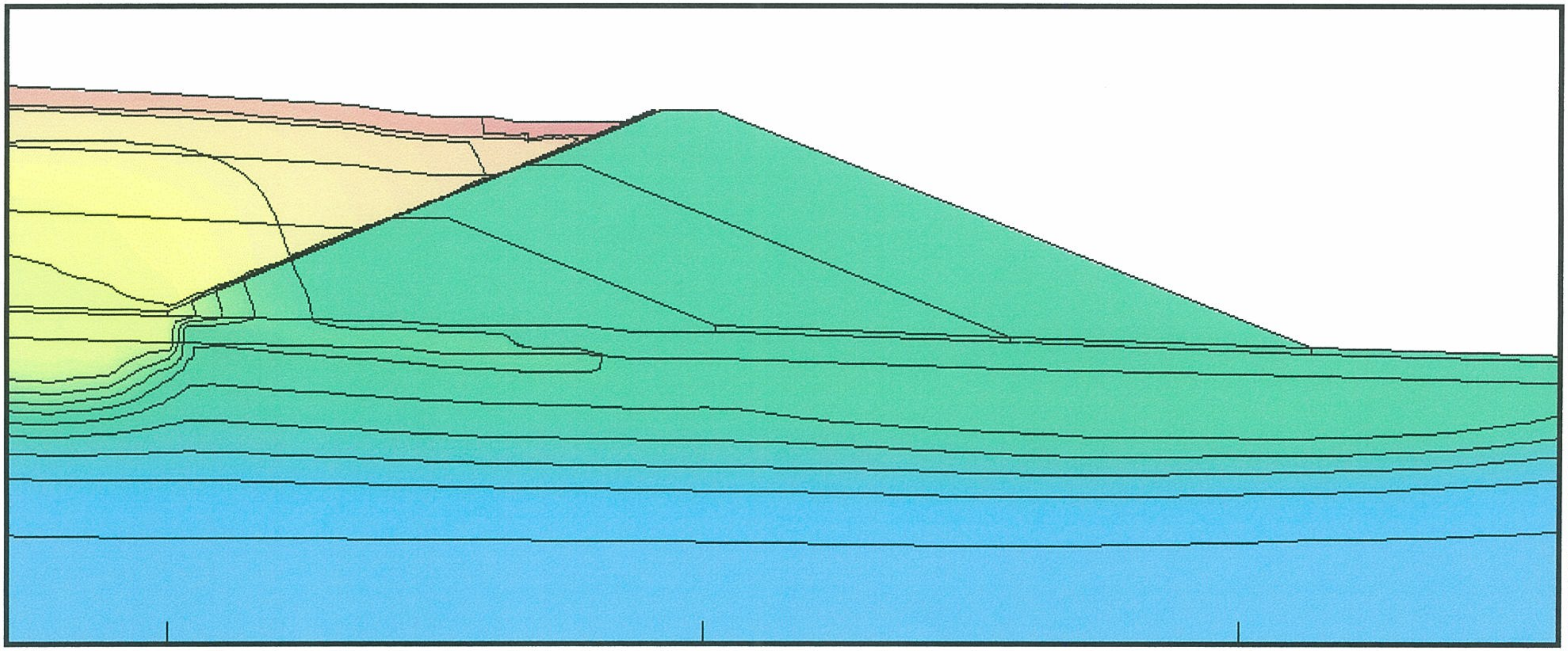
Scenario 7 = Elevated air temperatures (+3°C) and elevated hydraulic conductivity values (5x) for the weathered bedrock unit. Contains two thermosyphons w/ 200m^2 radiators

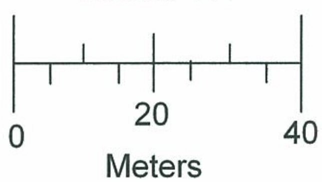
NORTHERN GEOTECHNICAL ENGINEERING, INC. TERRA FIRMA TESTING

APPENDIX H KEY

Rock Creek Dam,
Nome, Alaska

H-0

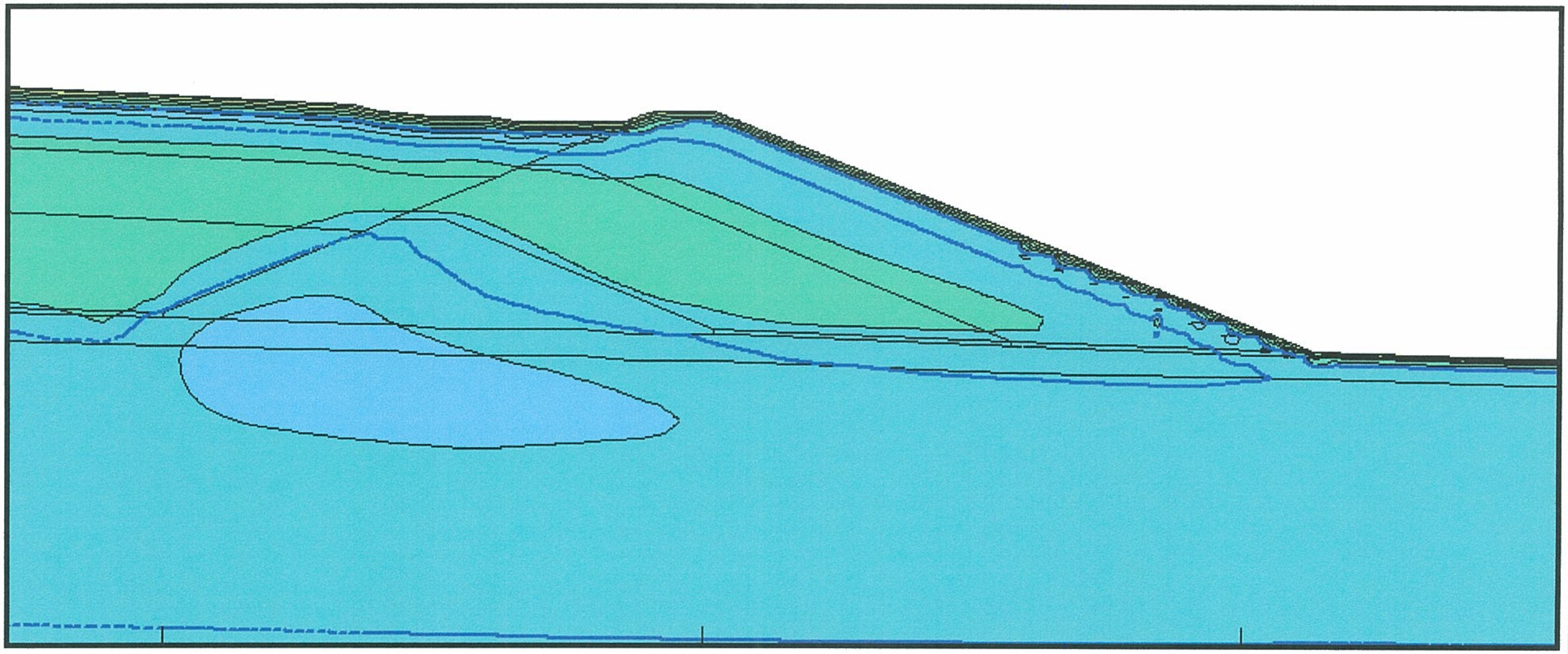


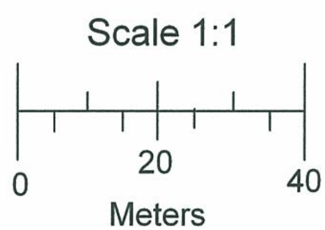


Hydraulic Head Contour Map
Scenario 1 – Phase 3 – AUG 05

Rock Creek Dam,
Nome, Alaska

H-1h

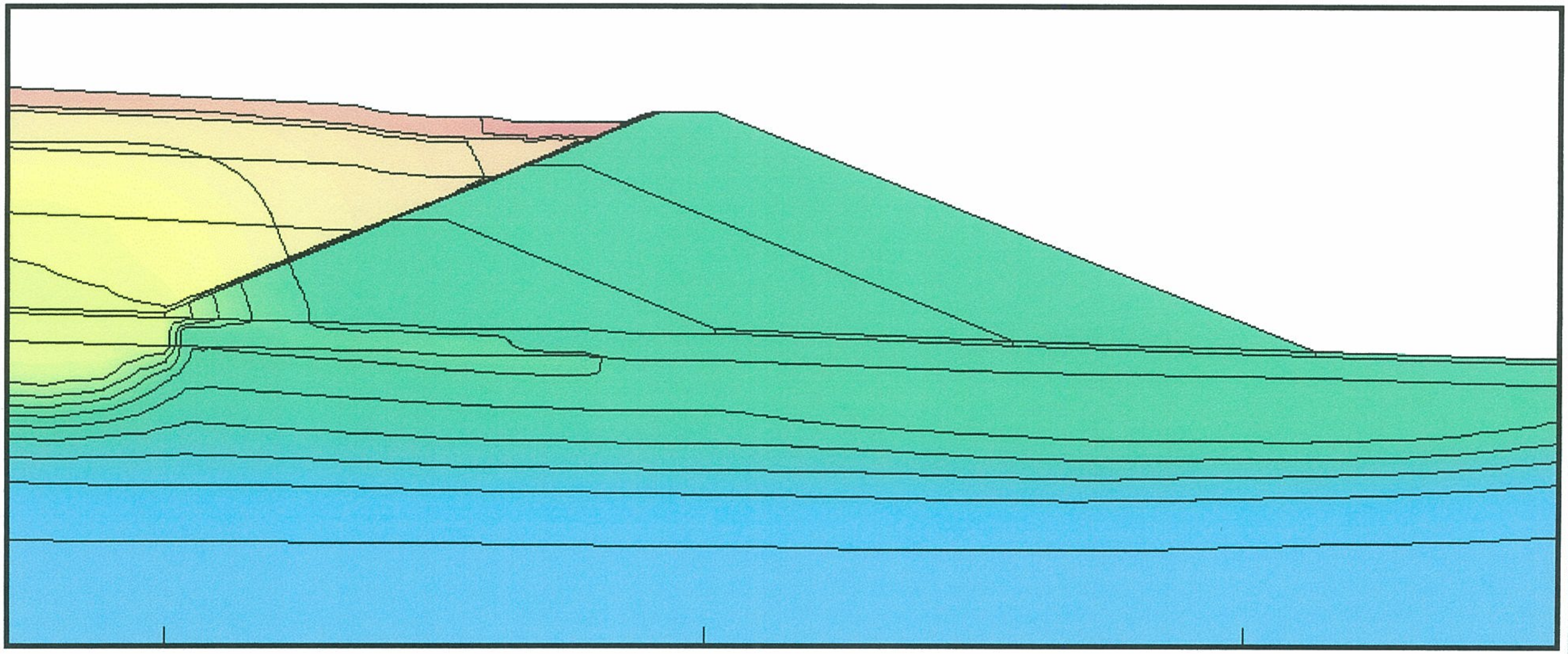


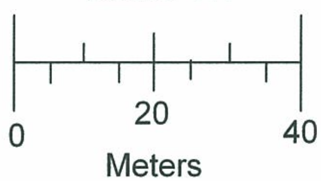


Thermal Contour Map
Scenario 1 – Phase 3 – AUG 05

Rock Creek Dam,
Nome, Alaska

H-1t

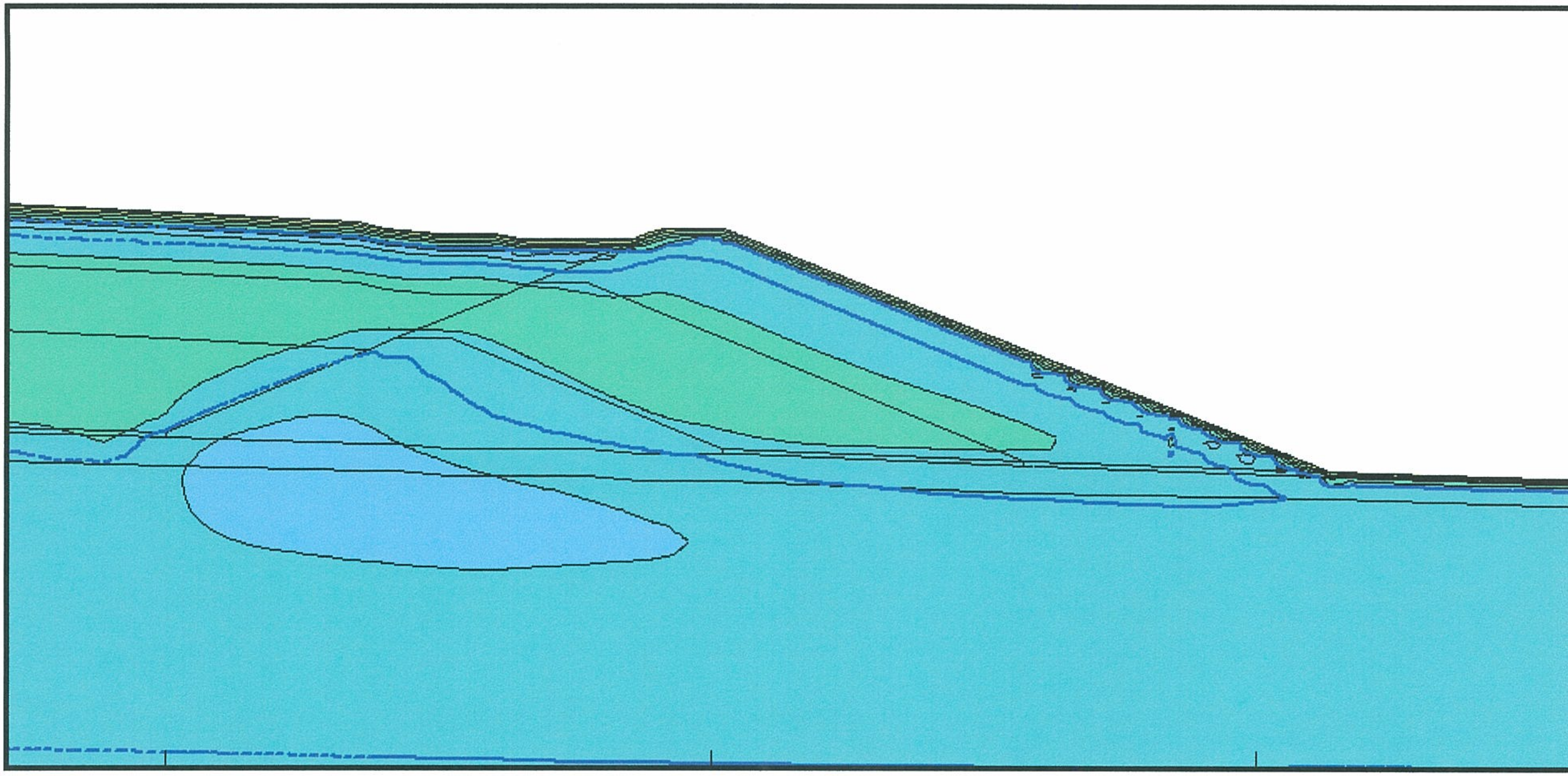




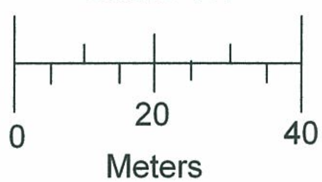
Hydraulic Head Contour Map
Scenario 2 – Phase 3 – AUG 05

Rock Creek Dam,
Nome, Alaska

H-2h



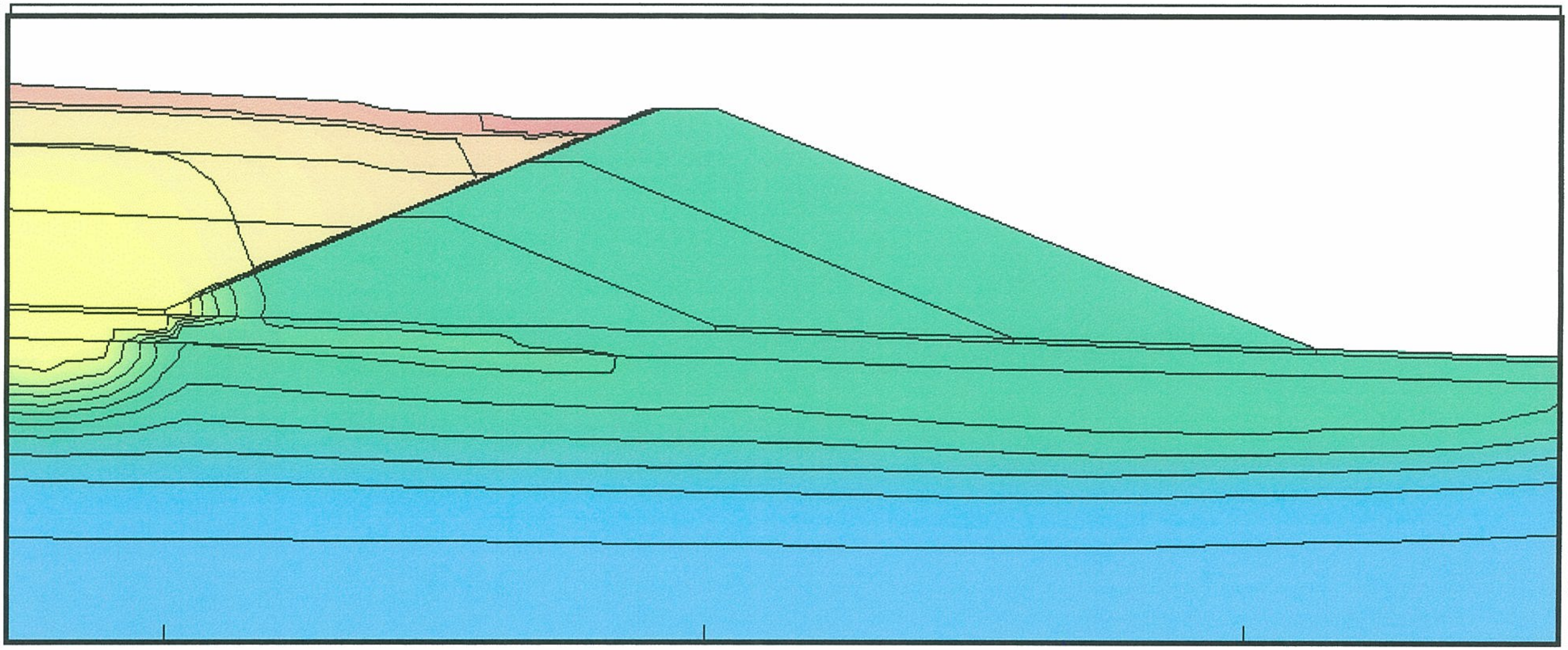
Scale 1:1

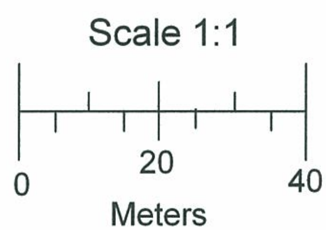


Thermal Contour Map
Scenario 2 – Phase 3 – AUG 05

Rock Creek Dam,
Nome, Alaska

H-2t

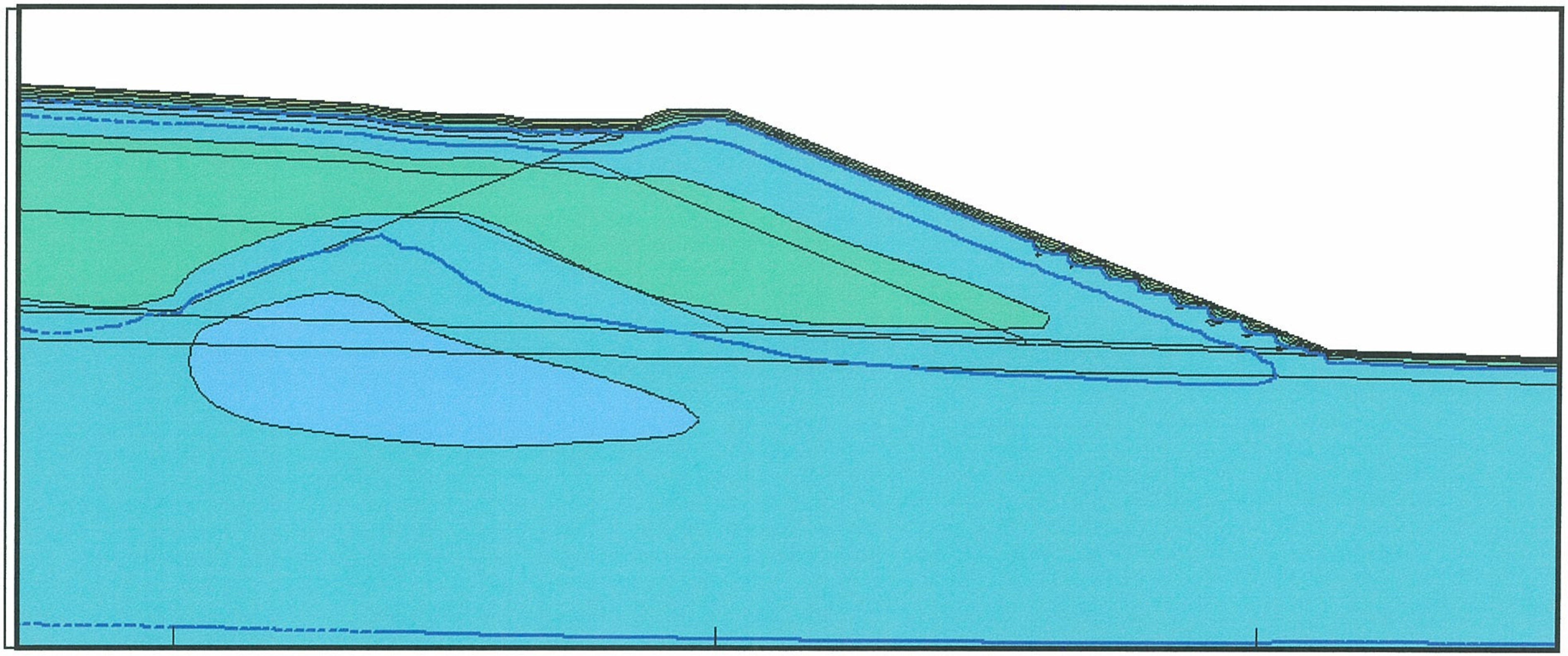


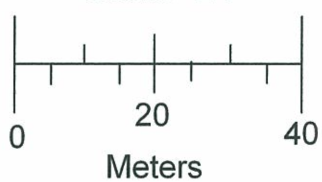


Hydraulic Head Contour Map
Scenario 3 – Phase 3 – AUG 05

Rock Creek Dam,
Nome, Alaska

H-3h

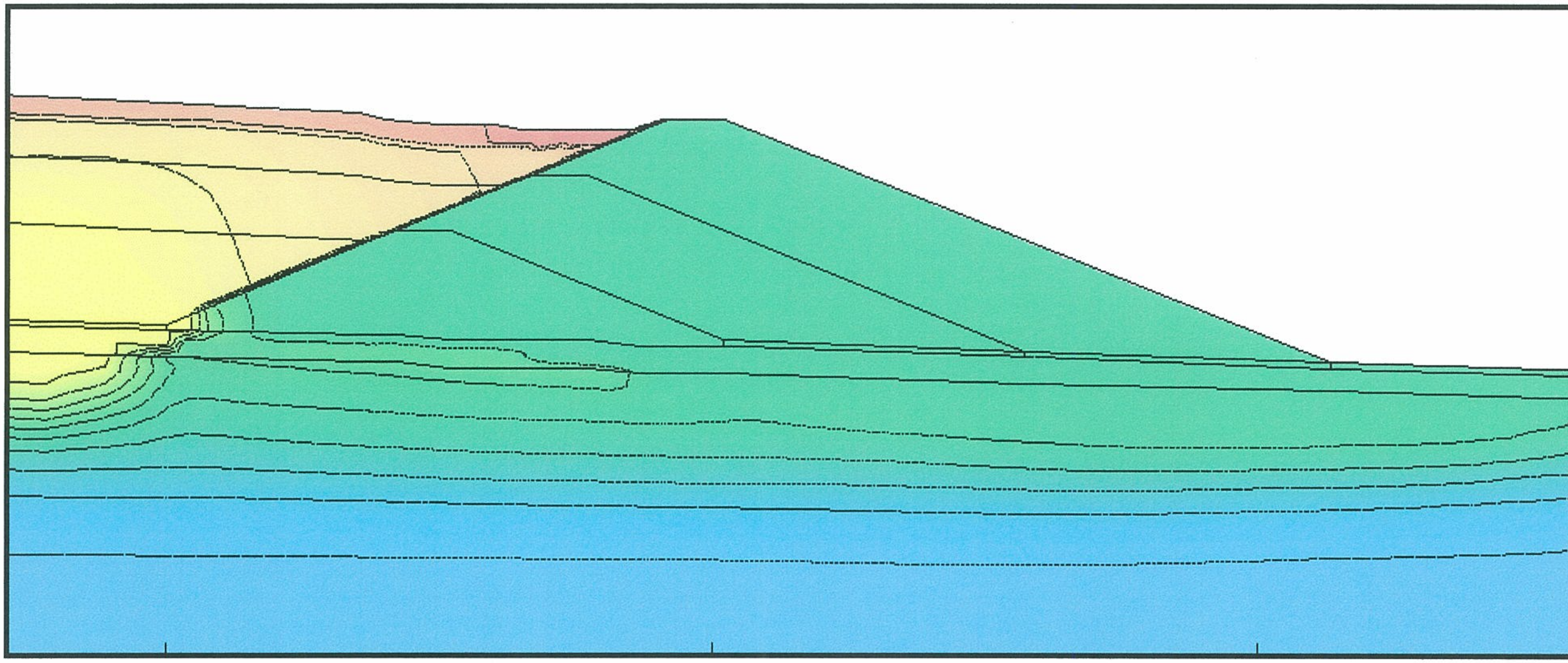




Thermal Contour Map
Scenario 3 – Phase 3 – AUG 05

Rock Creek Dam,
Nome, Alaska

H-3t



Scale 1:1

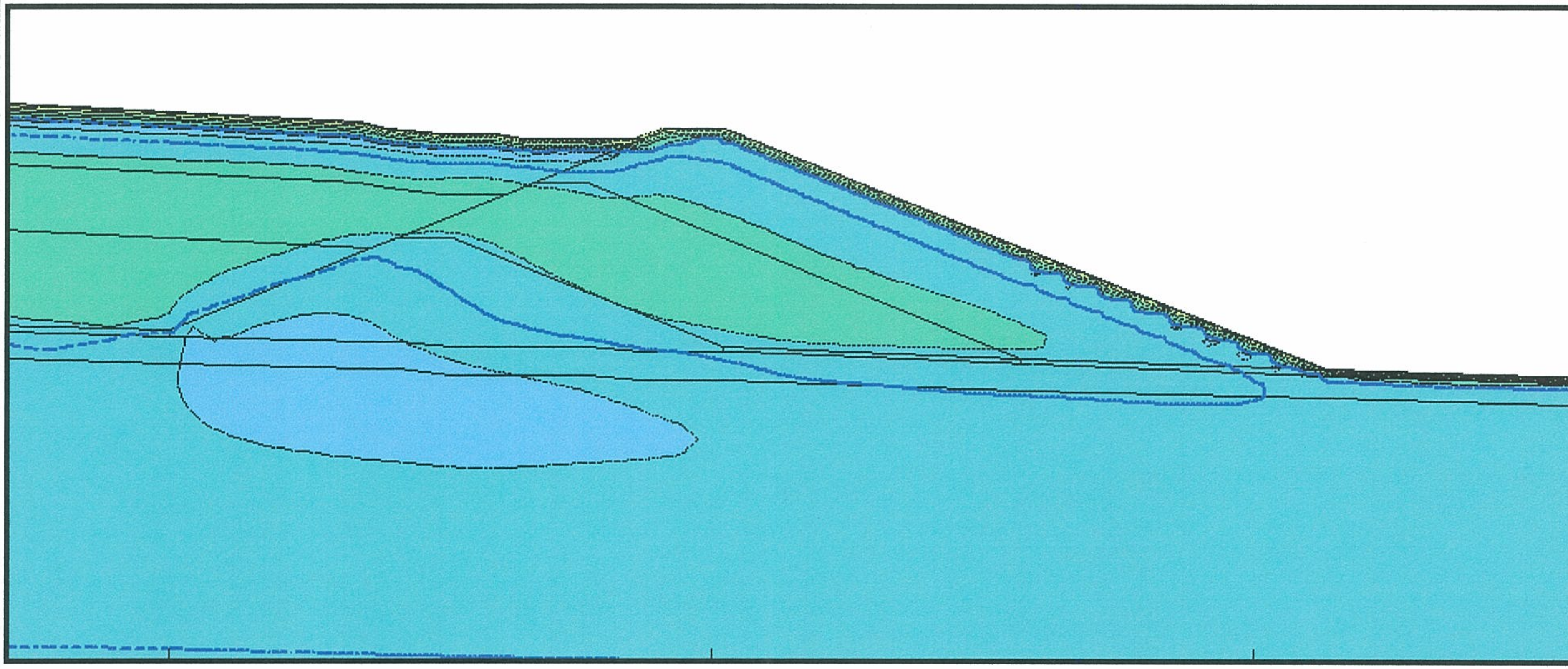
0 20 40

Meters

Hydraulic Head Contour Map
Scenario 4 – Phase 3 – AUG 05

Rock Creek Dam,
Nome, Alaska

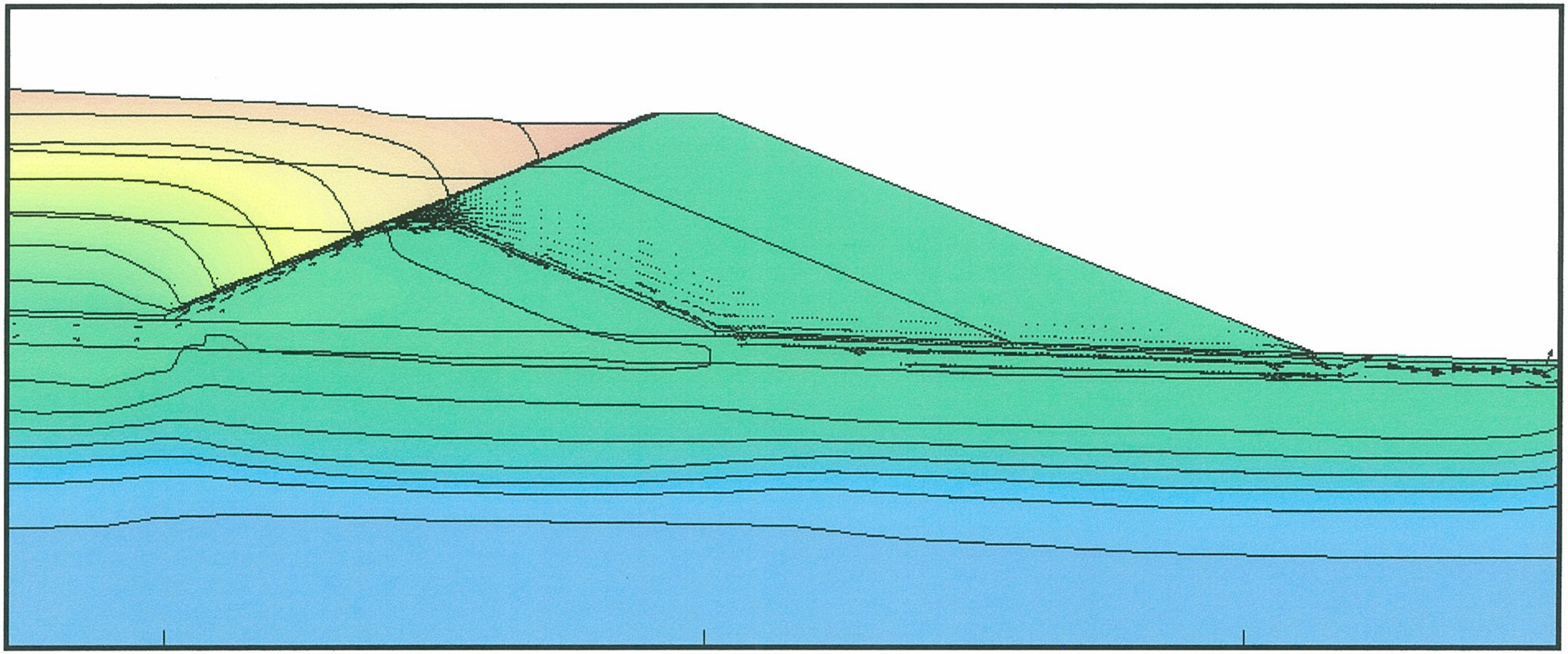
H-4h



Thermal Contour Map
Scenario 4 – Phase 3 – AUG 05

Rock Creek Dam,
Nome, Alaska

H-4t



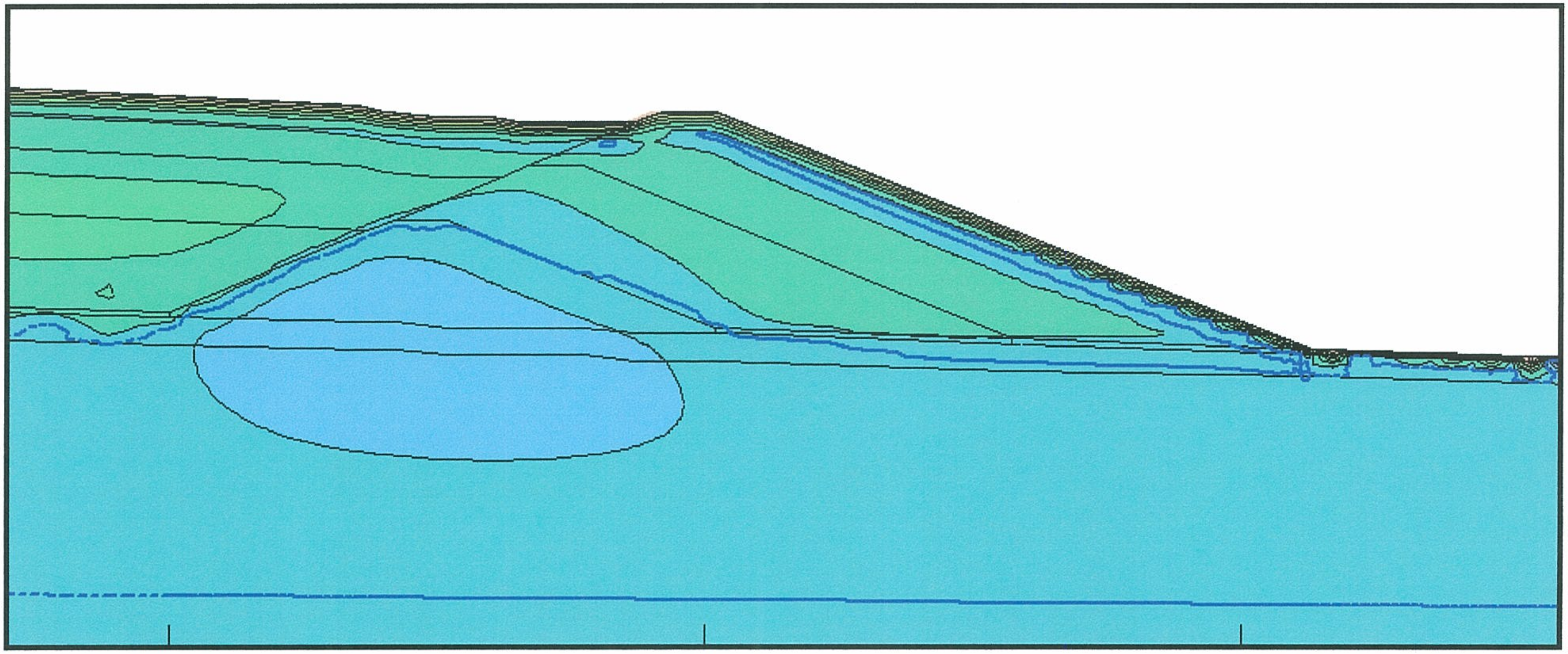
Scale 1:1

0 20 40
Meters

Hydraulic head Contour Map
Scenario 5 – Phase 3 – AUG 05

Rock Creek Dam,
Nome, Alaska

H-5h



Scale 1:1

0 20 40

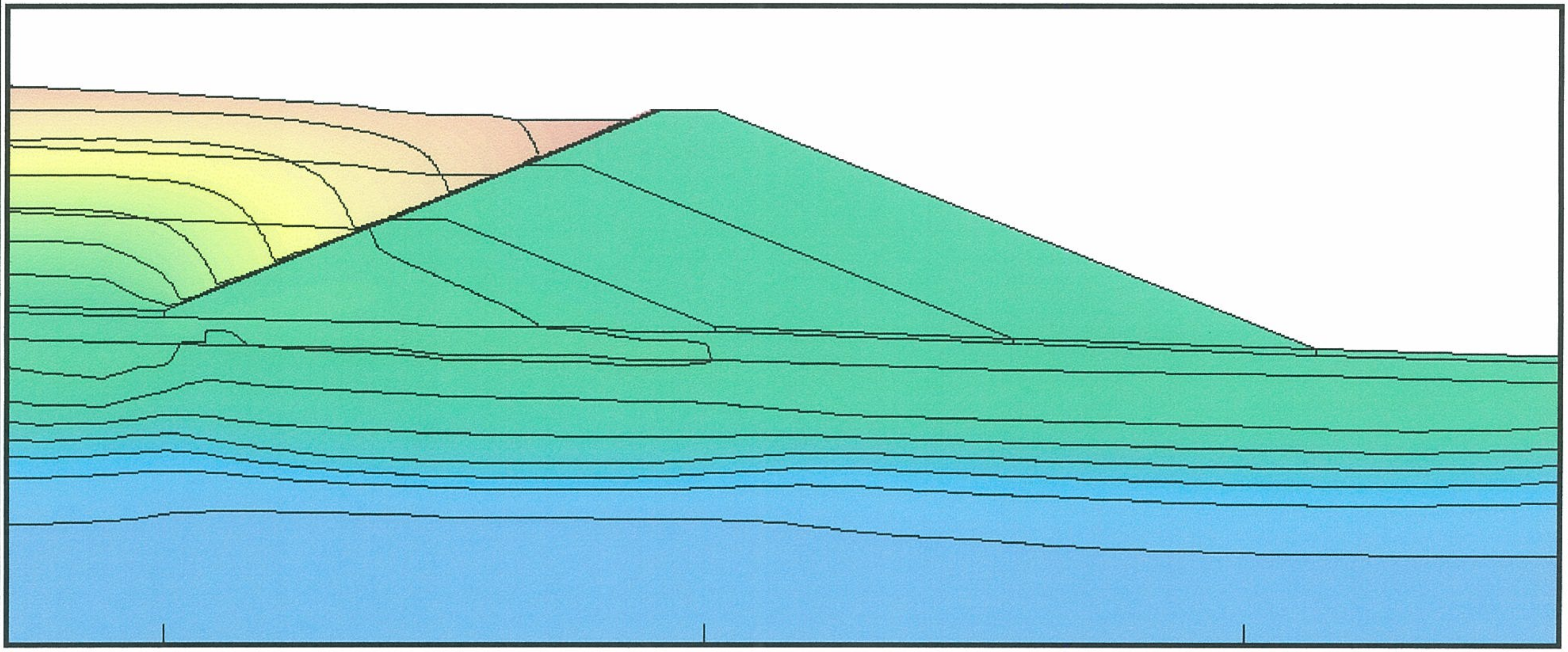
Meters

Thermal Contour Map

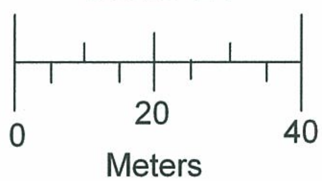
Scenario 5 – Phase 3 – AUG 05

Rock Creek Dam,
Nome, Alaska

H-5t



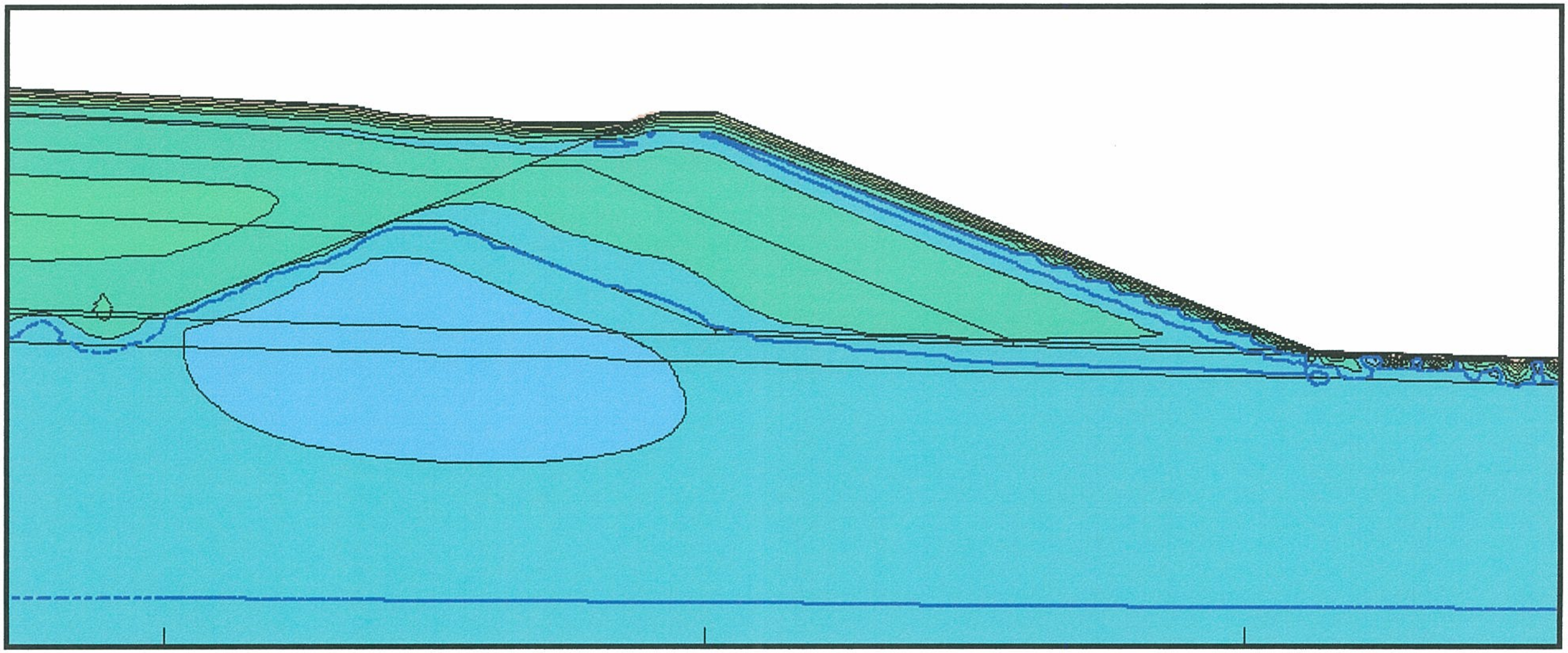
Scale 1:1



Hydraulic Head Contour Map
Scenario 6 – Phase 3 – AUG 05

Rock Creek Dam,
Nome, Alaska

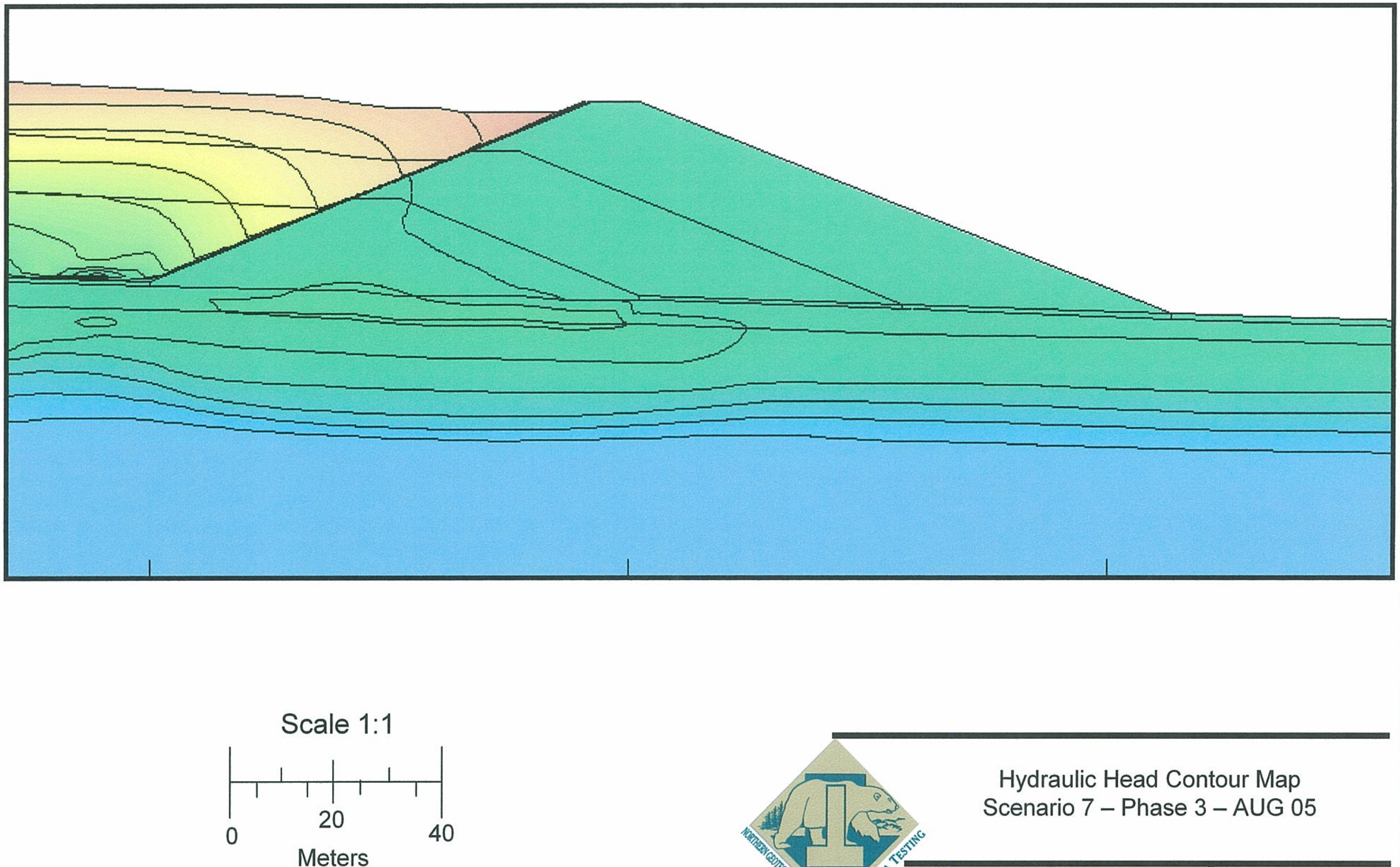
H-6h



Thermal Contour Map
Scenario 6 – Phase 3 – AUG 05

Rock Creek Dam,
Nome, Alaska

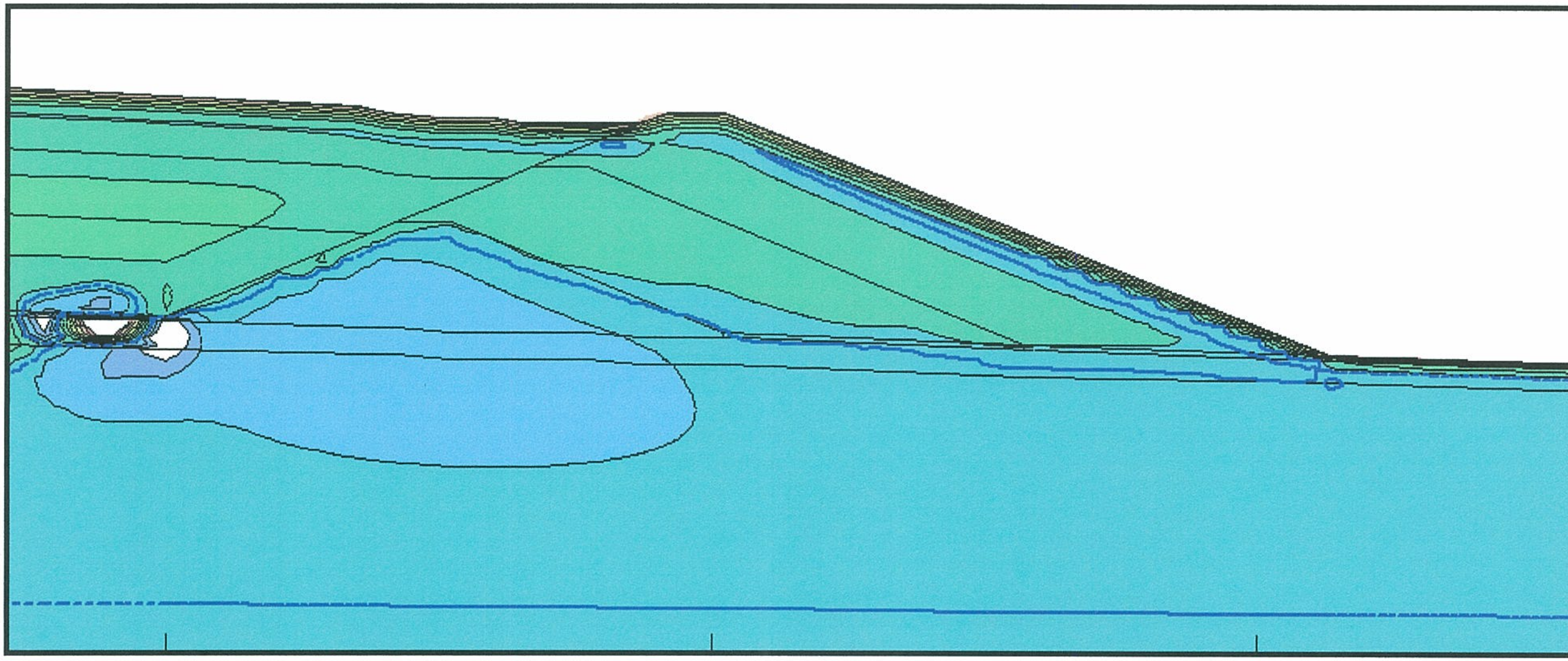
H-6t



Hydraulic Head Contour Map
Scenario 7 – Phase 3 – AUG 05

Rock Creek Dam,
Nome, Alaska

H-7h



Thermal Contour Map
Scenario 7 – Phase 3 – AUG 05

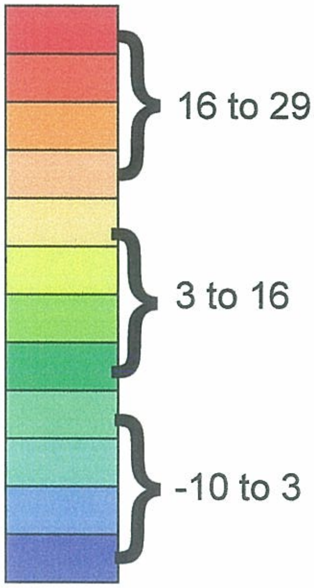
Rock Creek Dam,
Nome, Alaska

H-7t

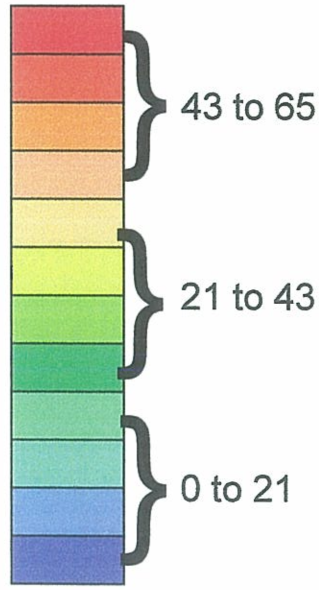
APPENDIX I

SCENARIO 2
PHASE III TIME STEP
RESULTS

Thermal Contour Gradient (Degrees Celsius)



Hydraulic Contour Gradient (Meters above MSL)



= Freeze/thaw Interface

= Contour Interval Line

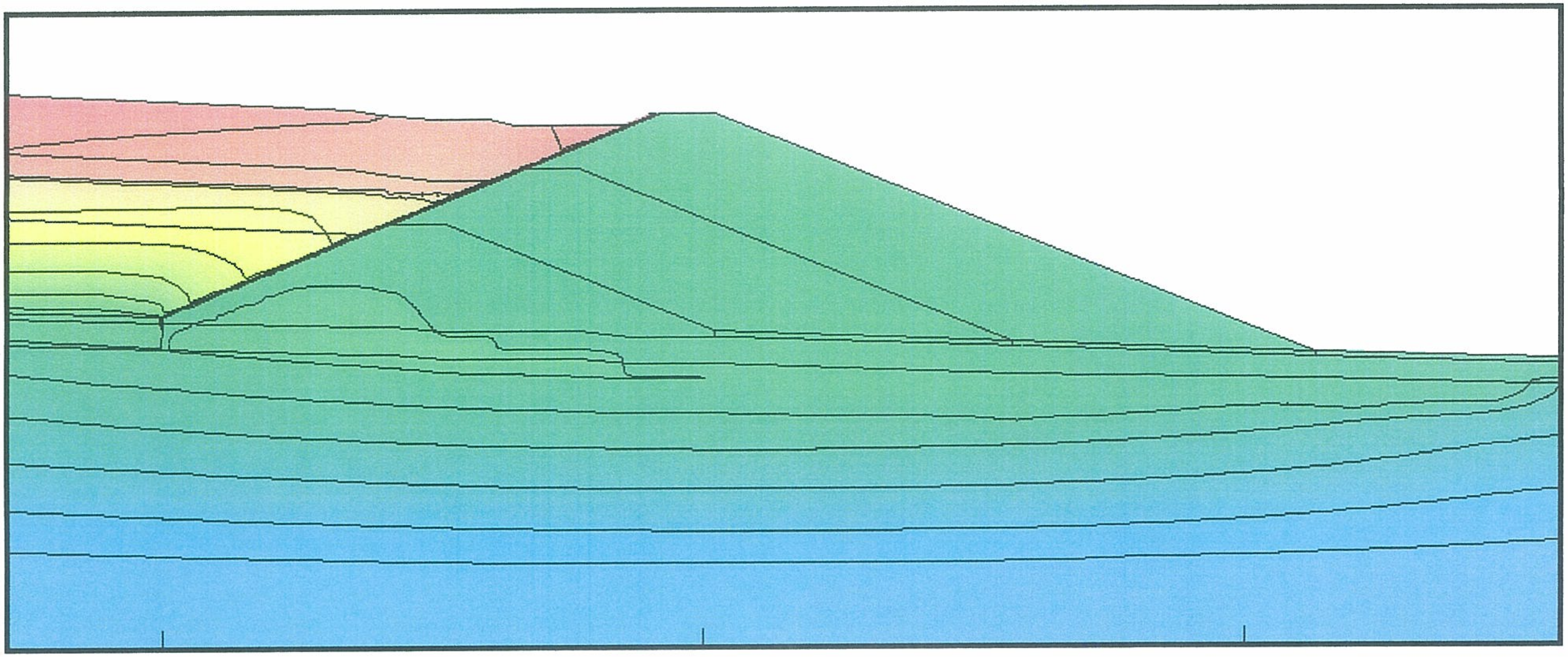
Scenario 2 = Current site conditions w/ liner material extended into weathered bedrock unit and w/ no thermosyphons

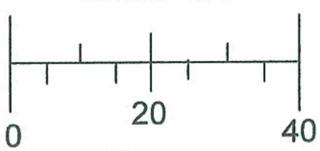
NORTHERN GEOTECHNICAL ENGINEERING, INC. TERRA FIRMA TESTING

APPENDIX I KEY

Rock Creek Dam,
Nome, Alaska

I - 0

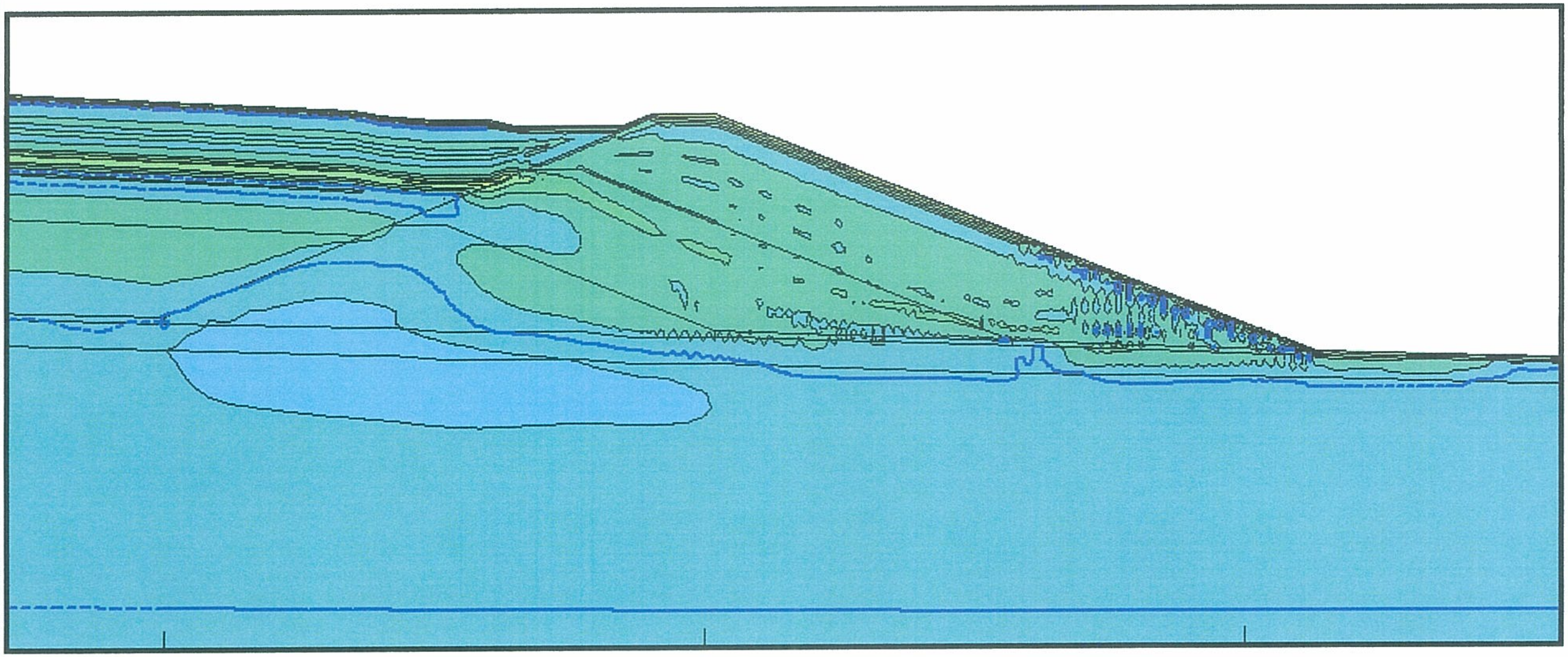




Hydraulic Head Contour Map
Scenario 2 – Phase 3 – Time step 20
Aug 5 / 04

Rock Creek Dam,
Nome, Alaska

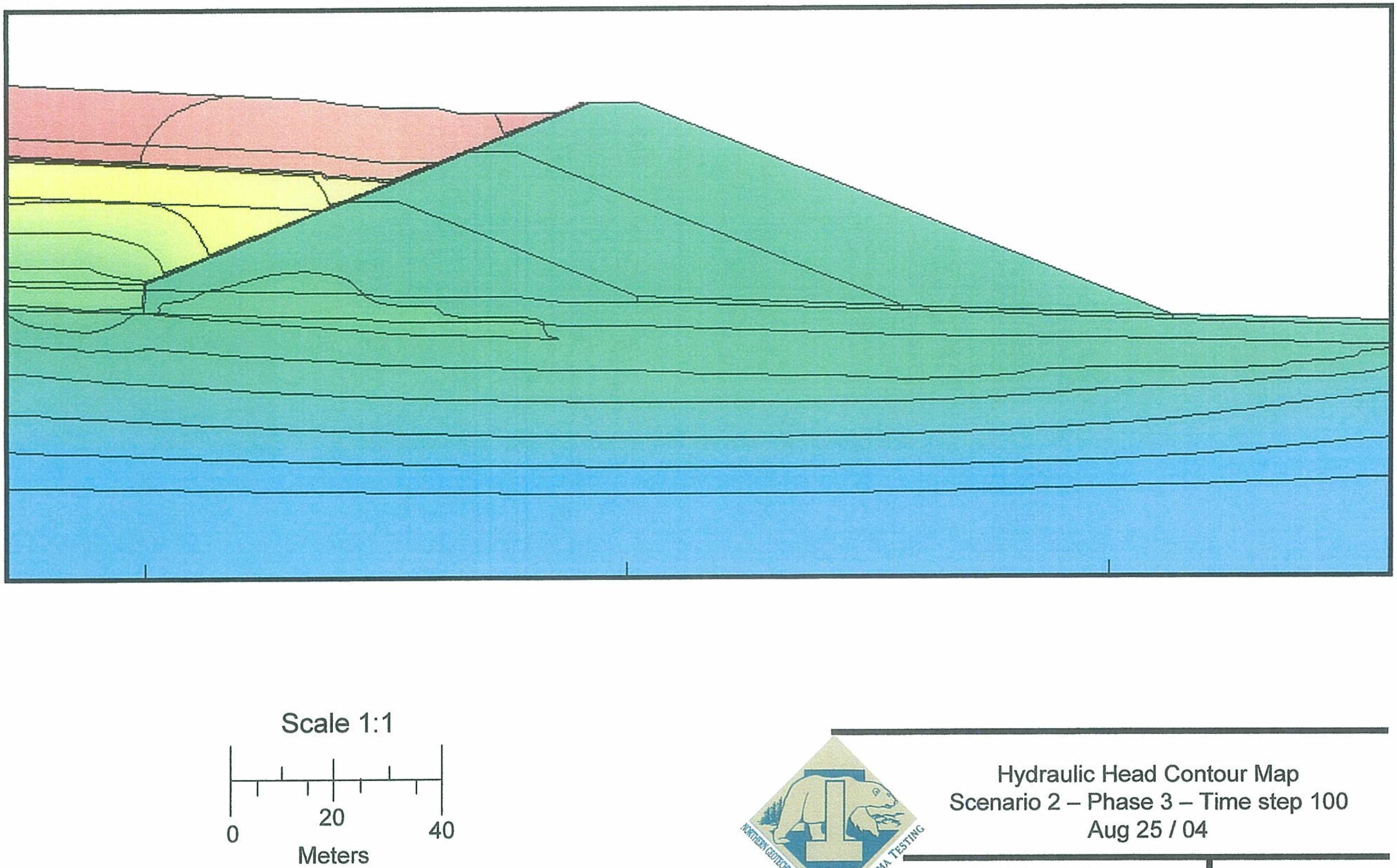
I-1h



Thermal Contour Map
Scenario 2 – Phase 3 – Time step 20
Aug 5 / 04

Rock Creek Dam,
Nome, Alaska

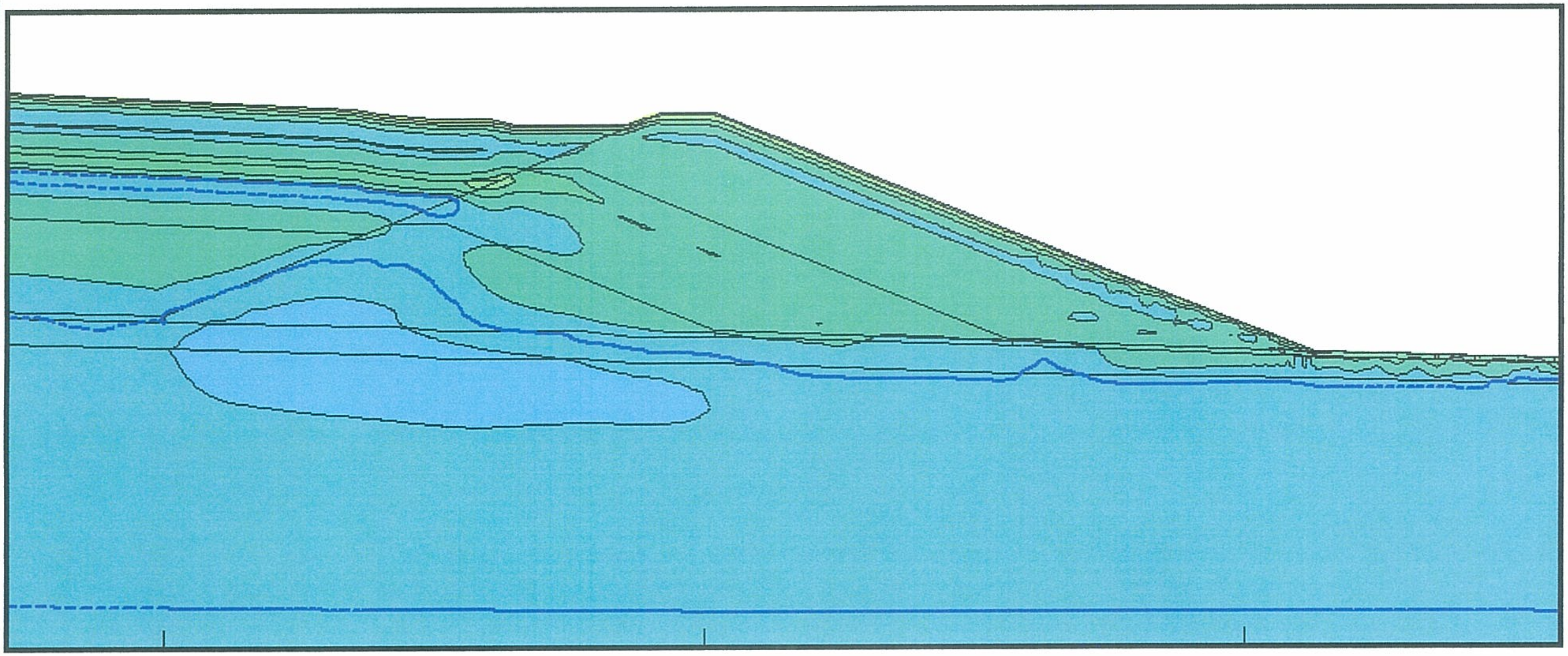
I-1t

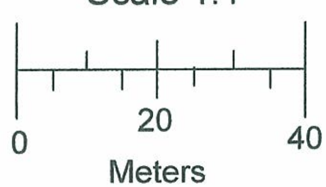


Hydraulic Head Contour Map
Scenario 2 – Phase 3 – Time step 100
Aug 25 / 04

Rock Creek Dam,
Nome, Alaska

I-2h

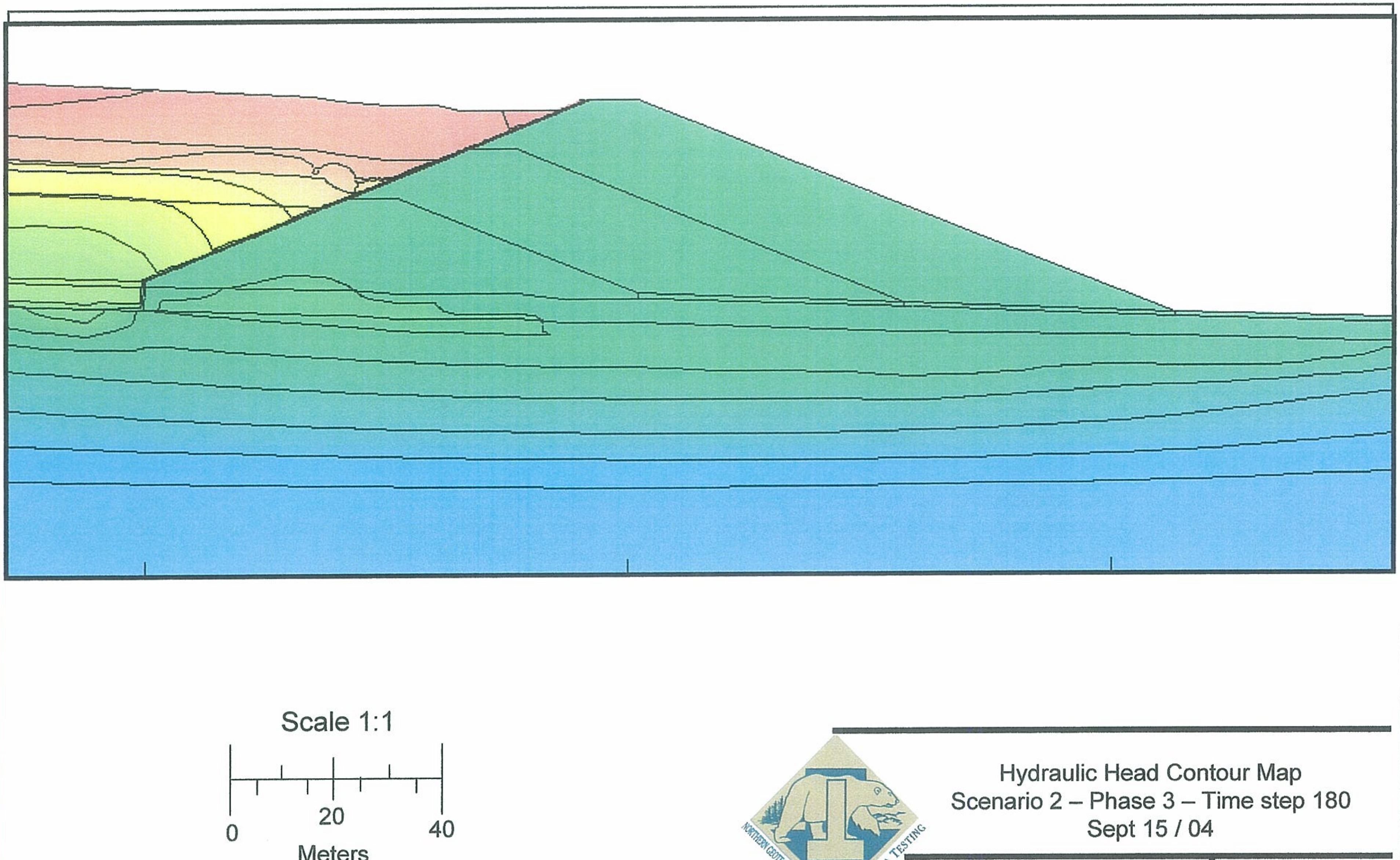




Thermal Contour Map
Scenario 2 – Phase 3 – Time step 100
Aug 25 / 04

Rock Creek Dam,
Nome, Alaska

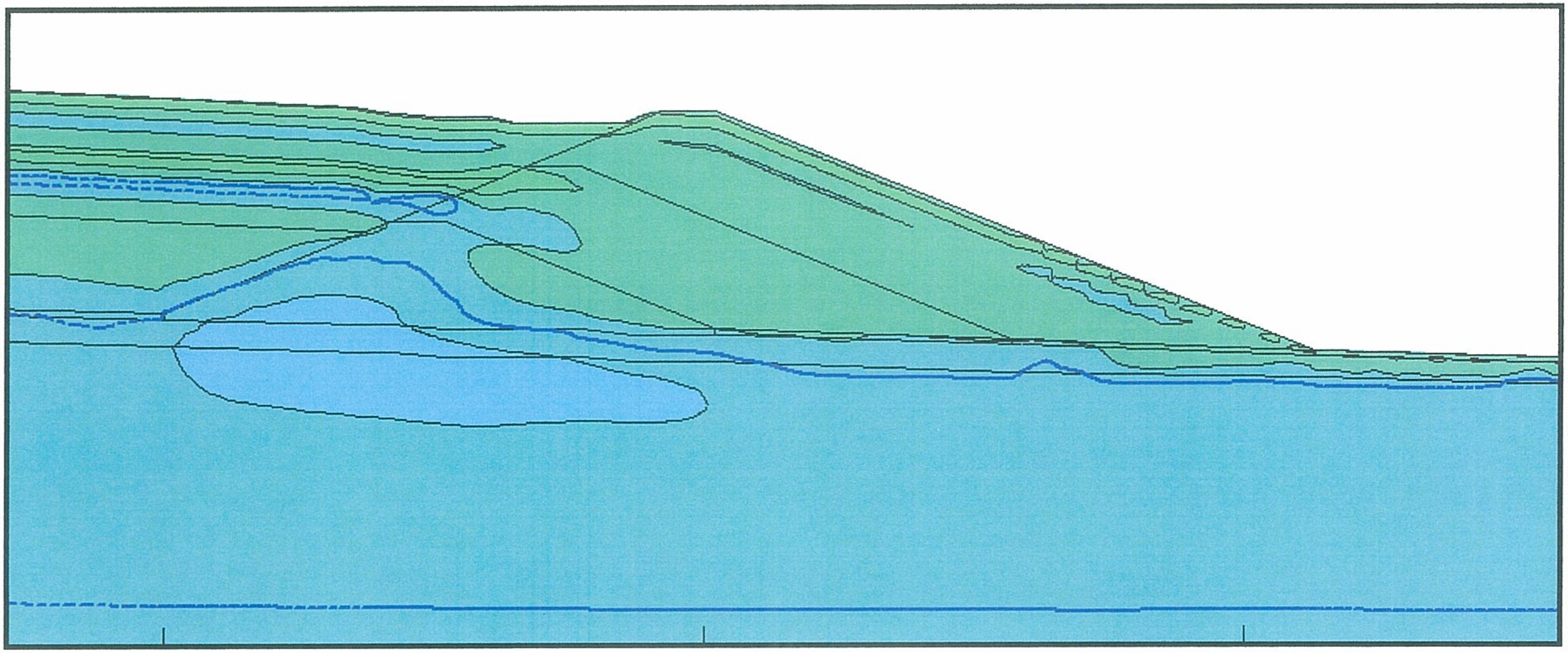
I-2t



Hydraulic Head Contour Map
Scenario 2 – Phase 3 – Time step 180
Sept 15 / 04

Rock Creek Dam,
Nome, Alaska

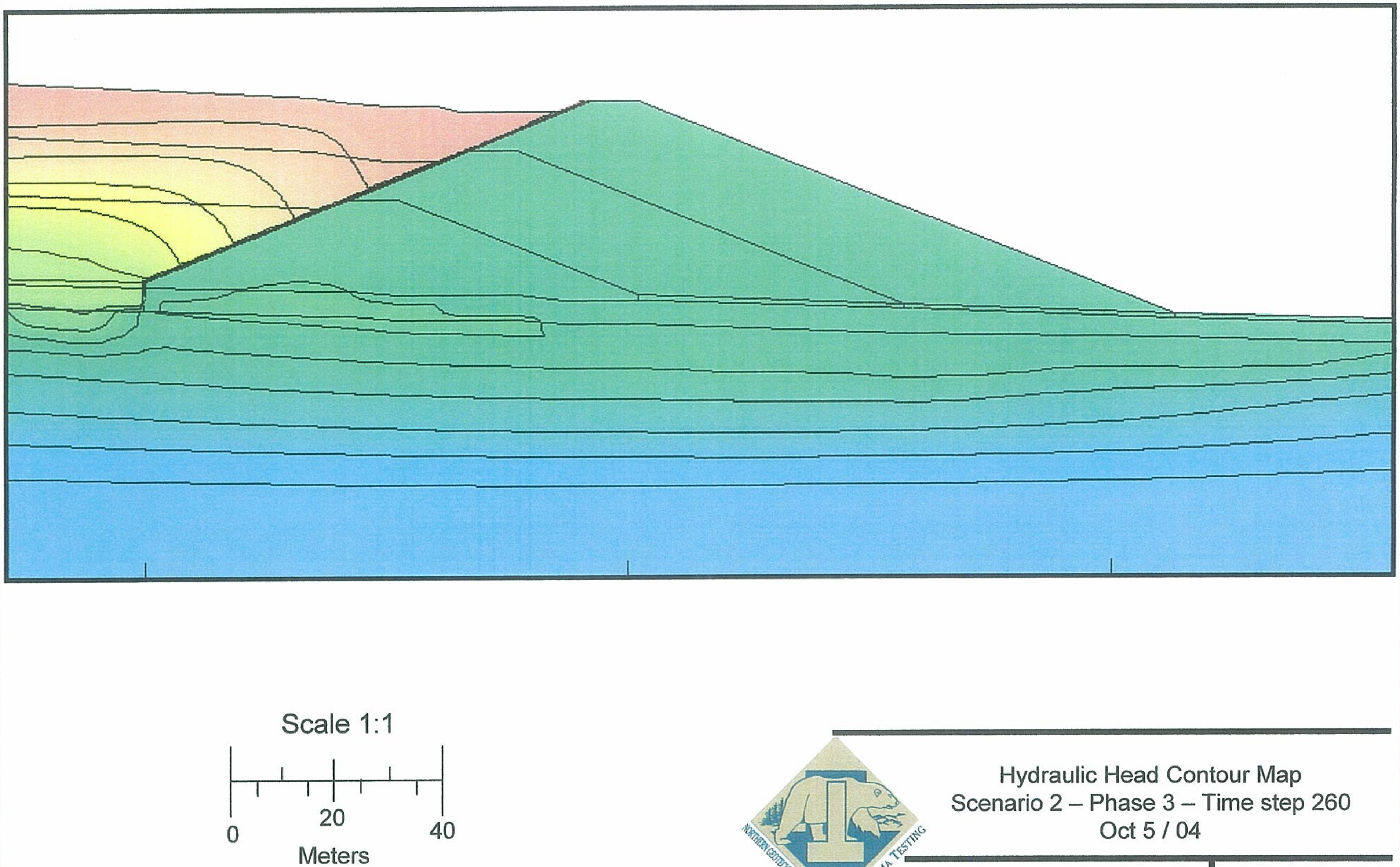
I-3h



Thermal Contour Map
Scenario 2 – Phase 3 – Time step 180
Sept 15 / 04

Rock Creek Dam,
Nome, Alaska

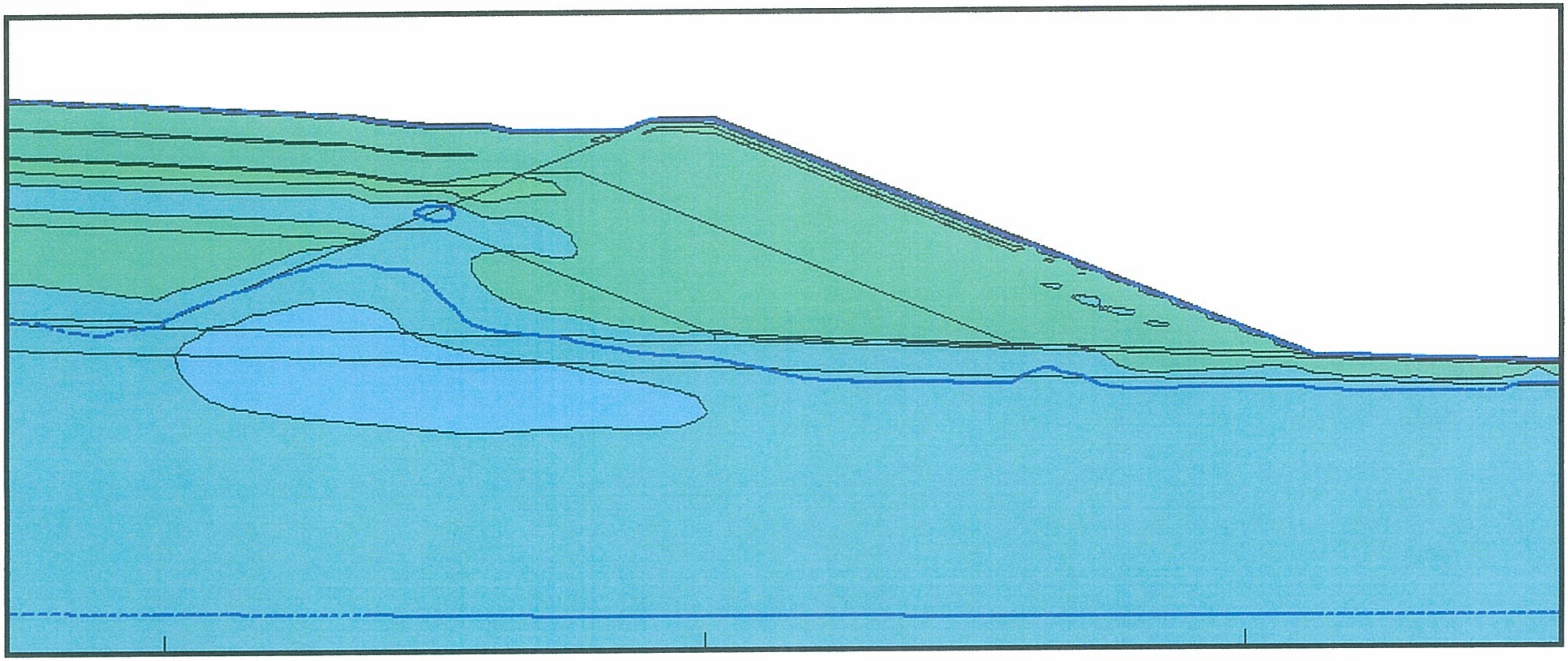
I-3t

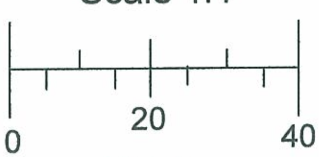


Hydraulic Head Contour Map
Scenario 2 – Phase 3 – Time step 260
Oct 5 / 04

Rock Creek Dam,
Nome, Alaska

I-4h

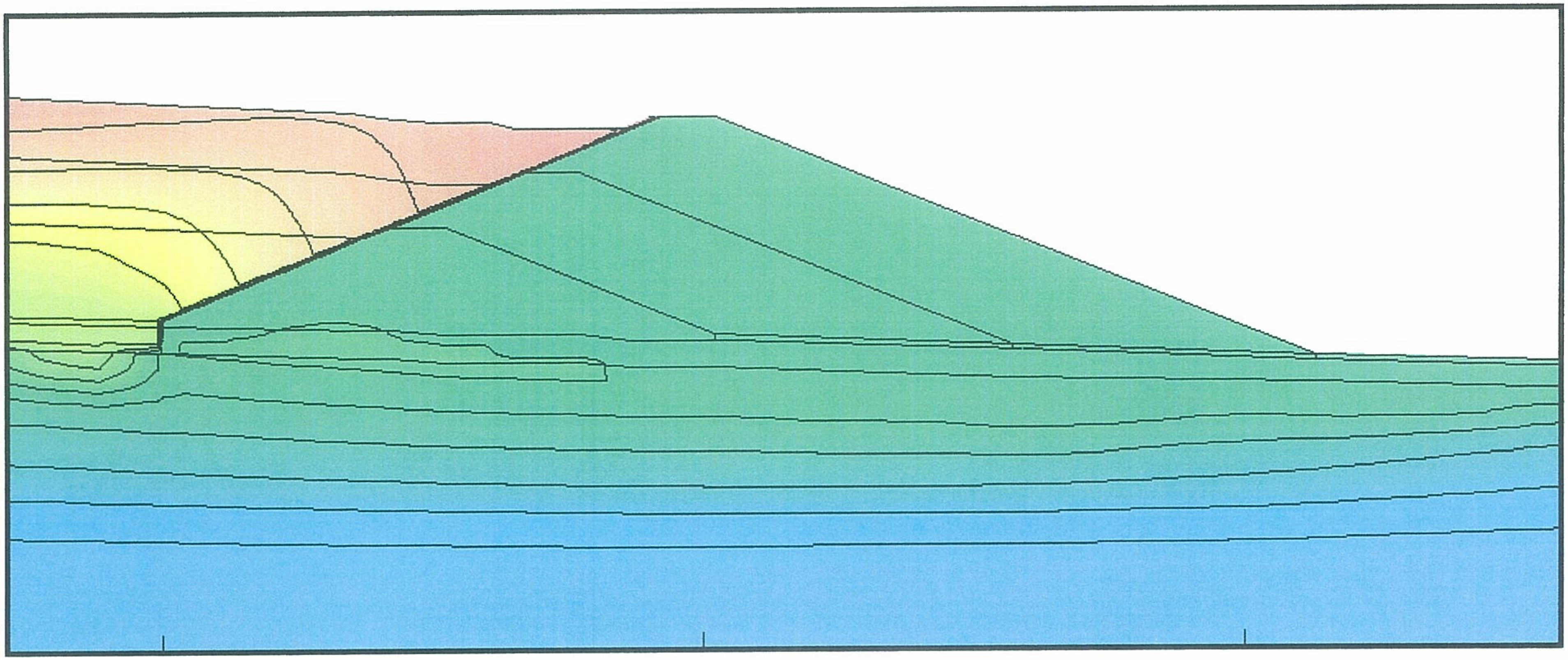


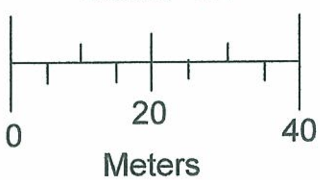


Thermal Contour Map
Scenario 2 – Phase 3 – Time step 260
Oct 5 / 04

Rock Creek Dam,
Nome, Alaska

I-4t

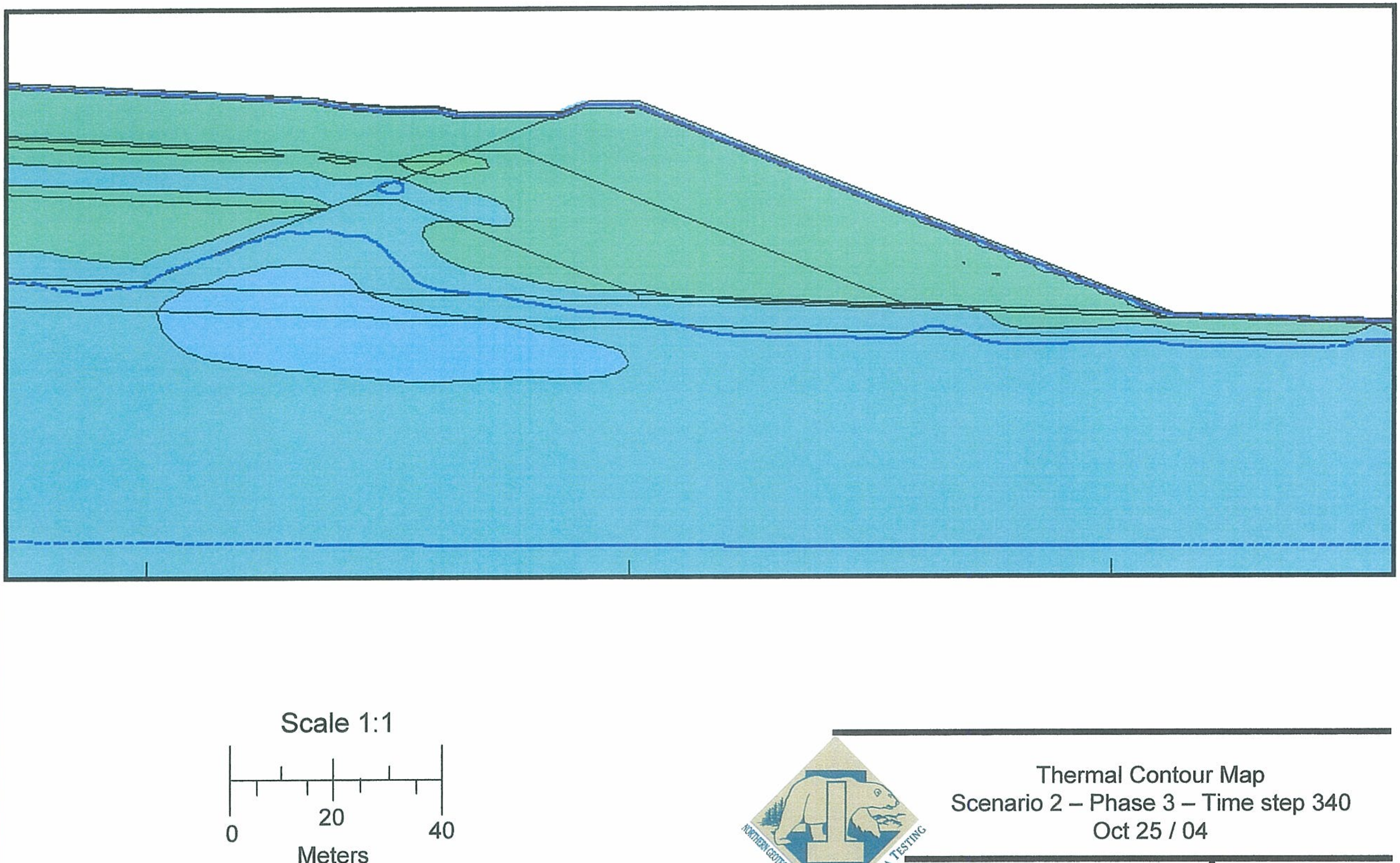




Hydraulic Head Contour Map
Scenario 2 – Phase 3 – Time step 340
Oct 25 / 04

Rock Creek Dam,
Nome, Alaska

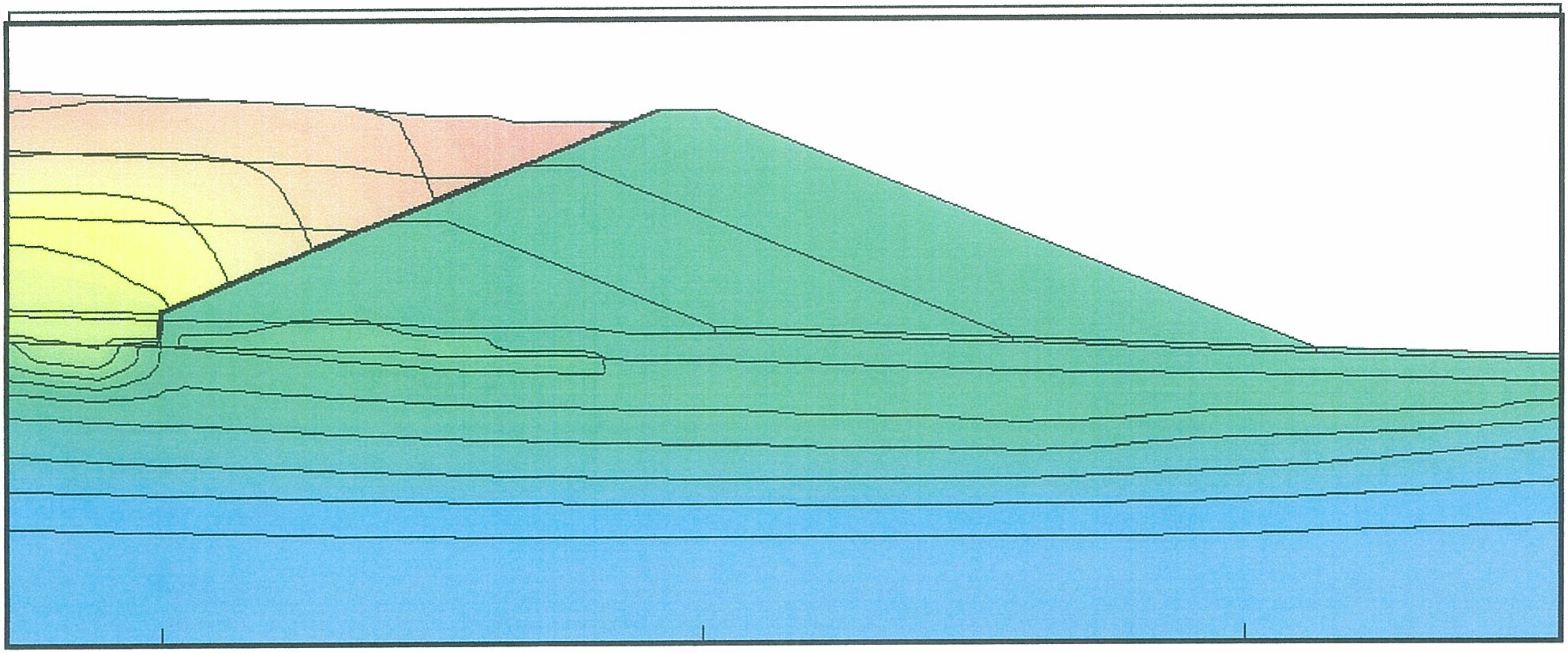
I-5h

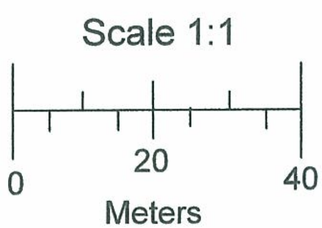


Thermal Contour Map
Scenario 2 – Phase 3 – Time step 340
Oct 25 / 04

Rock Creek Dam,
Nome, Alaska

I-5t

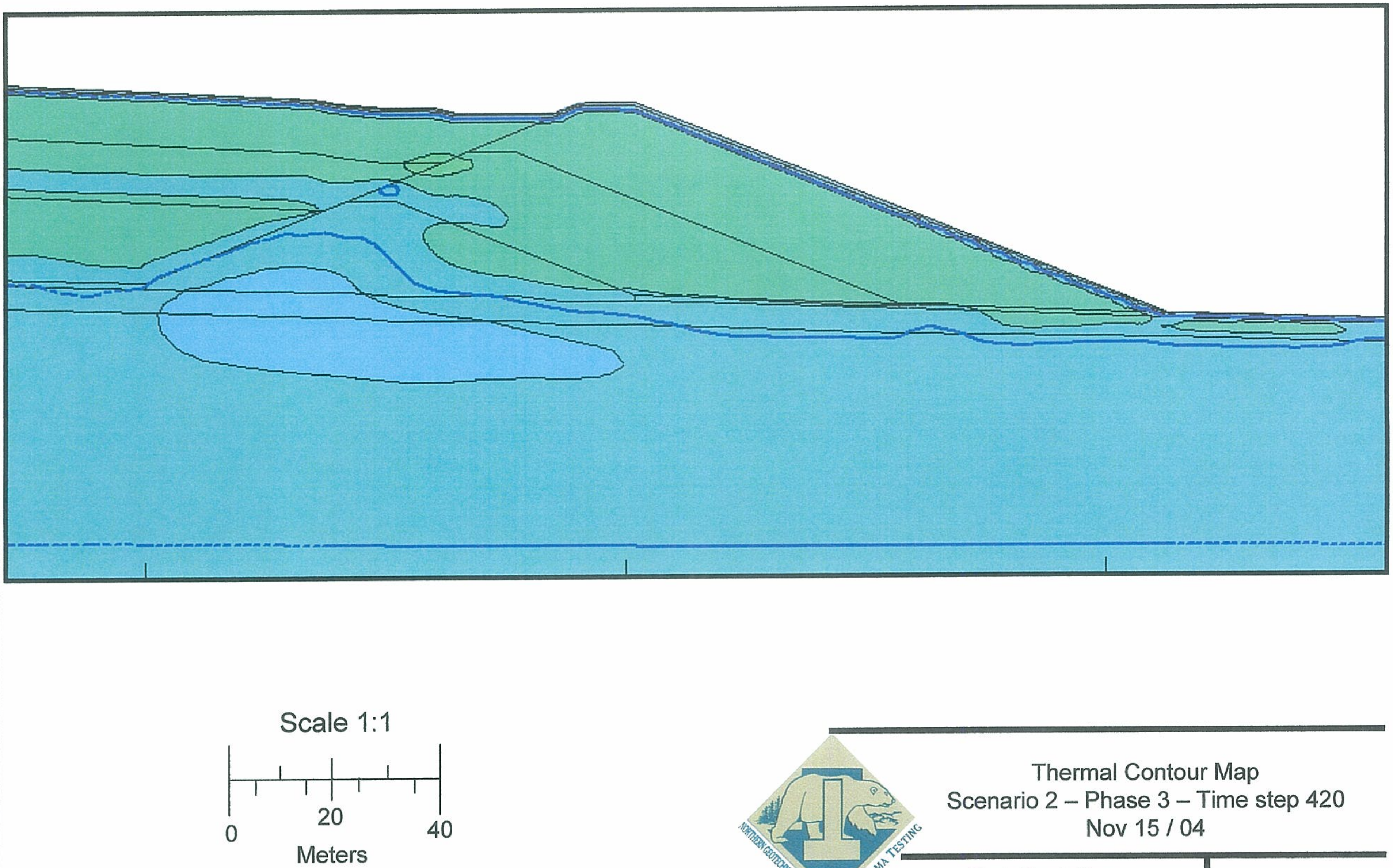




Hydraulic Head Contour Map
Scenario 2 – Phase 3 – Time step 420
Nov 15 / 04

Rock Creek Dam,
Nome, Alaska

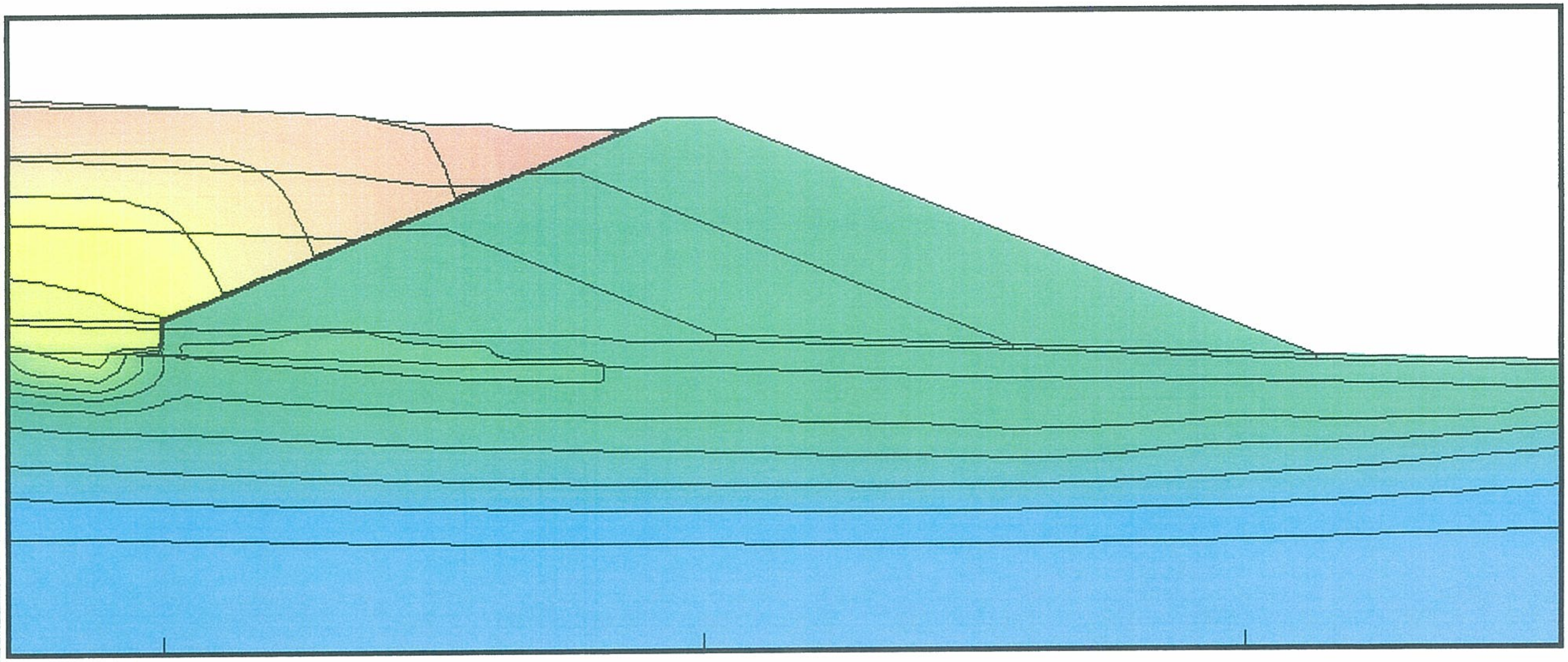
I-6h

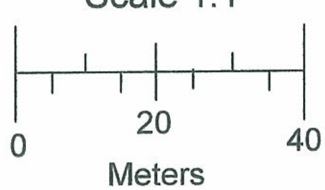


Thermal Contour Map
Scenario 2 – Phase 3 – Time step 420
Nov 15 / 04

Rock Creek Dam,
Nome, Alaska

I-6t

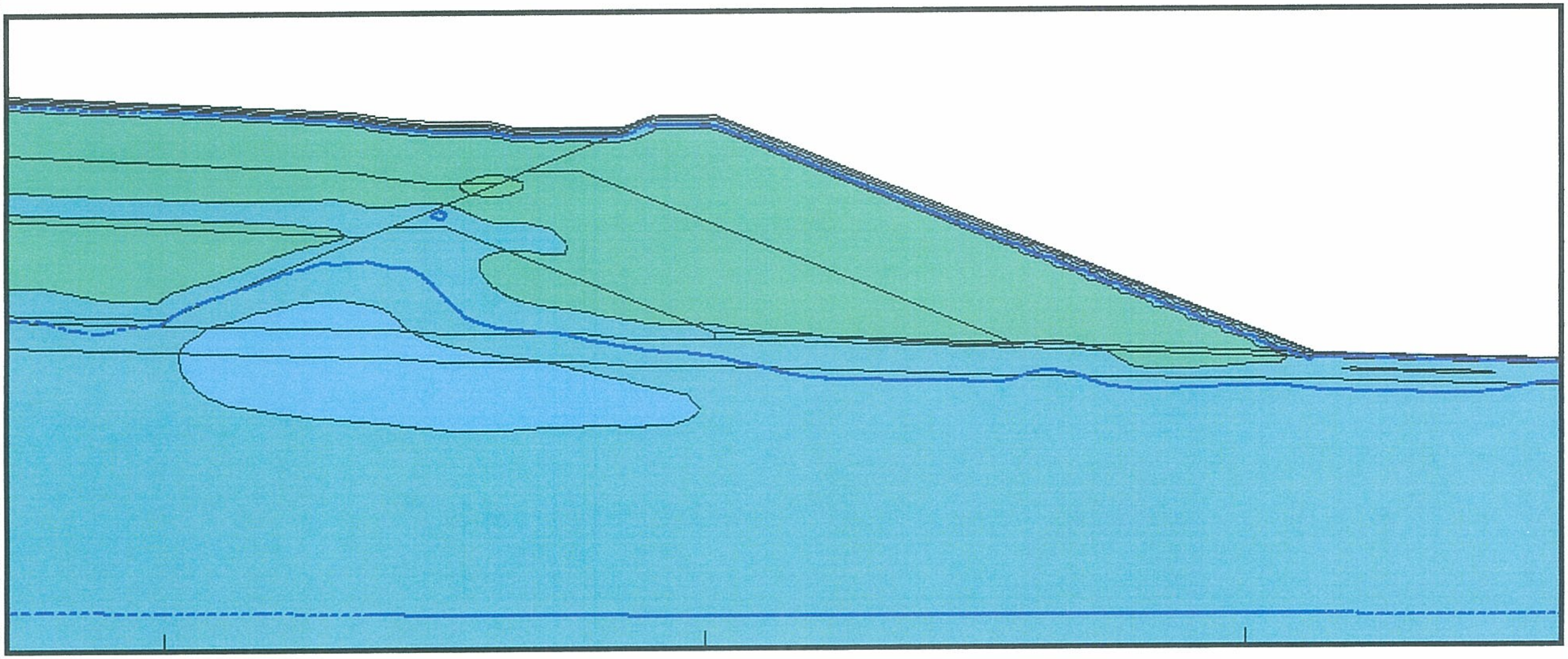


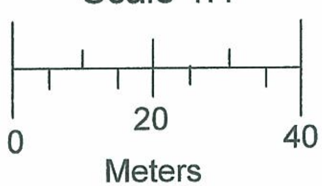


Hydraulic Head Contour Map
Scenario 2 – Phase 3 – Time step 500
Dec 5 / 04

Rock Creek Dam,
Nome, Alaska

I-7h

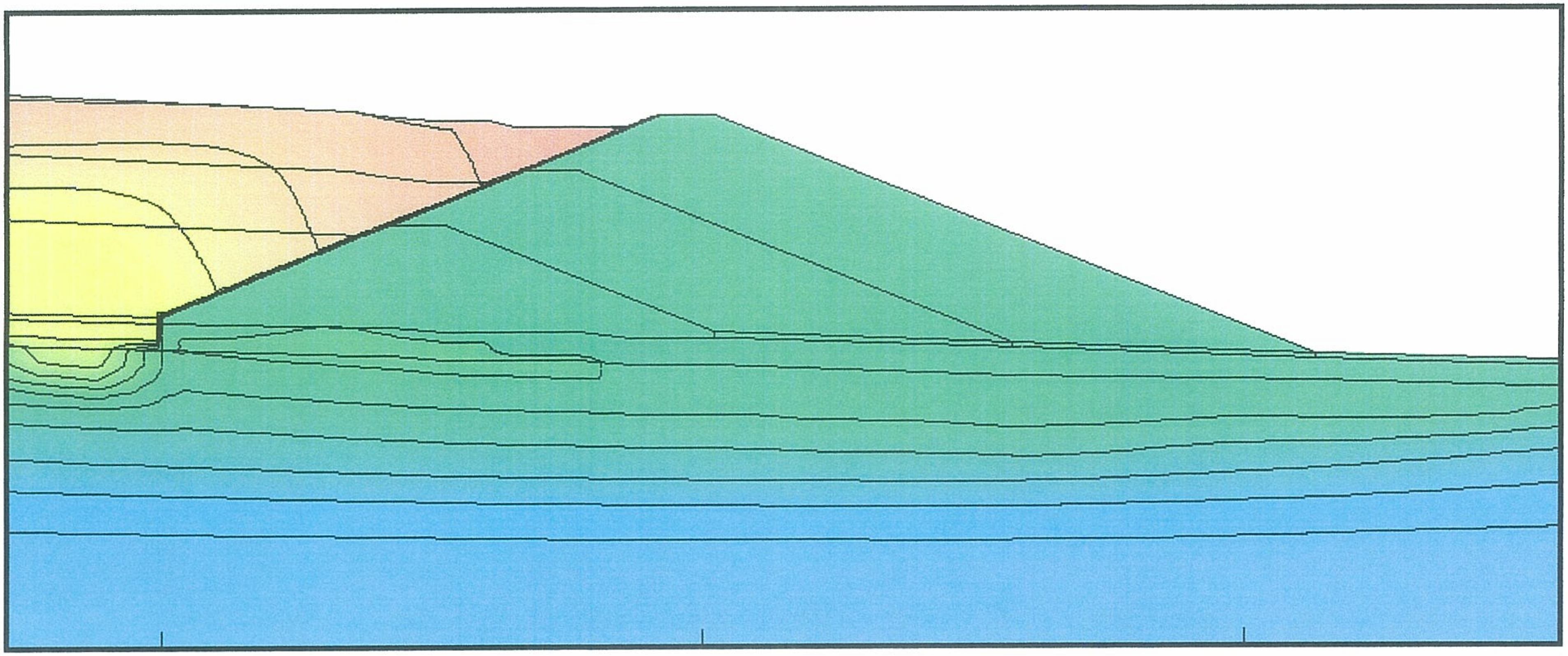


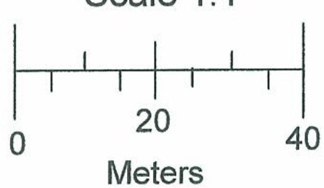


Thermal Contour Map
Scenario 2 – Phase 3 – Time step 500
Dec 5 / 04

Rock Creek Dam,
Nome, Alaska

I-7t

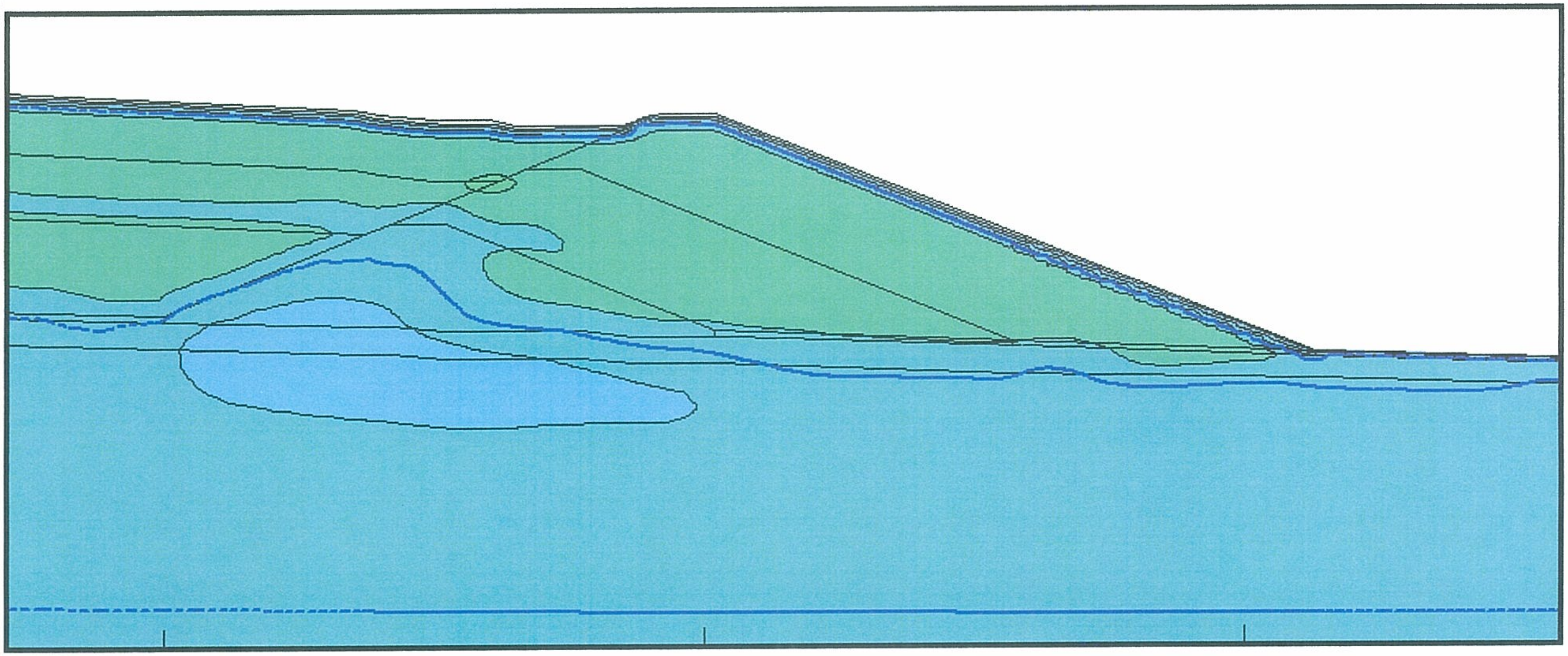


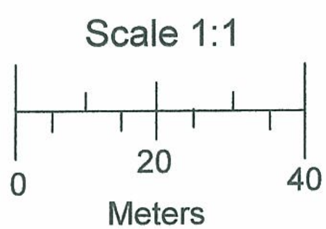


Hydraulic Head Contour Map
Scenario 2 – Phase 3 – Time step 580
Dec 25 / 04

Rock Creek Dam,
Nome, Alaska

I-8h

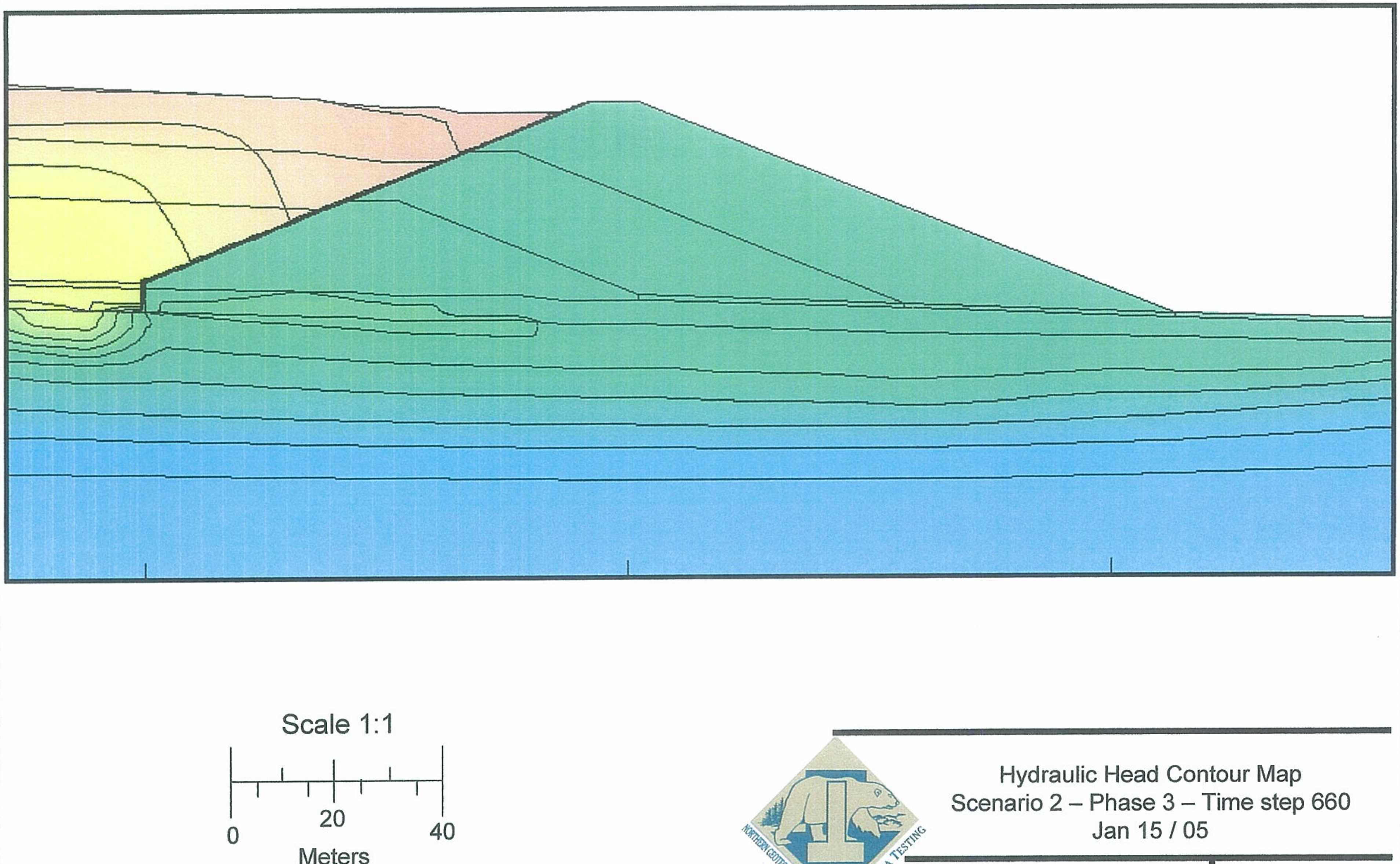




Thermal Contour Map
Scenario 2 – Phase 3 – Time step 580
Dec 25 / 04

Rock Creek Dam,
Nome, Alaska

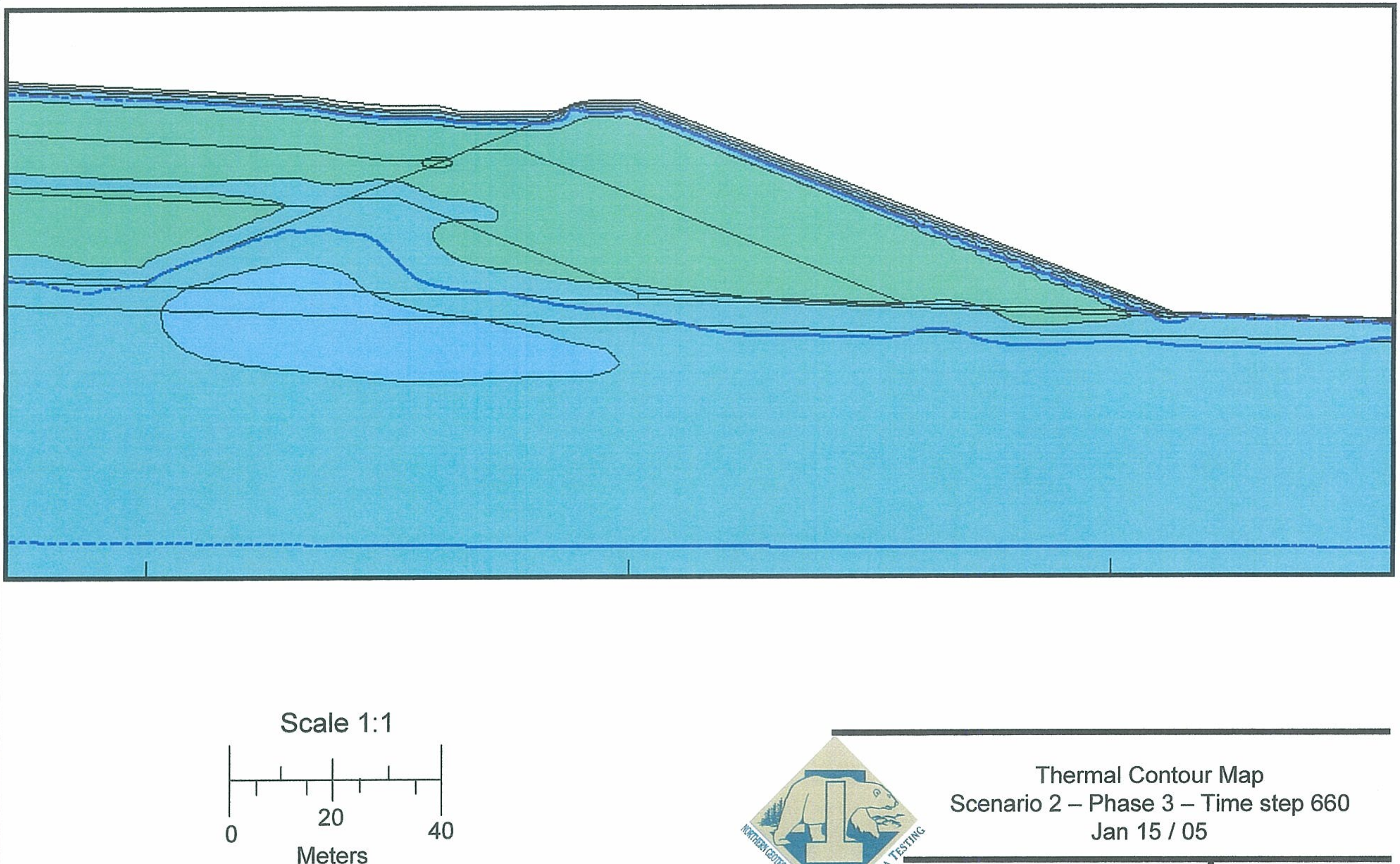
I-8t



Hydraulic Head Contour Map
Scenario 2 – Phase 3 – Time step 660
Jan 15 / 05

Rock Creek Dam,
Nome, Alaska

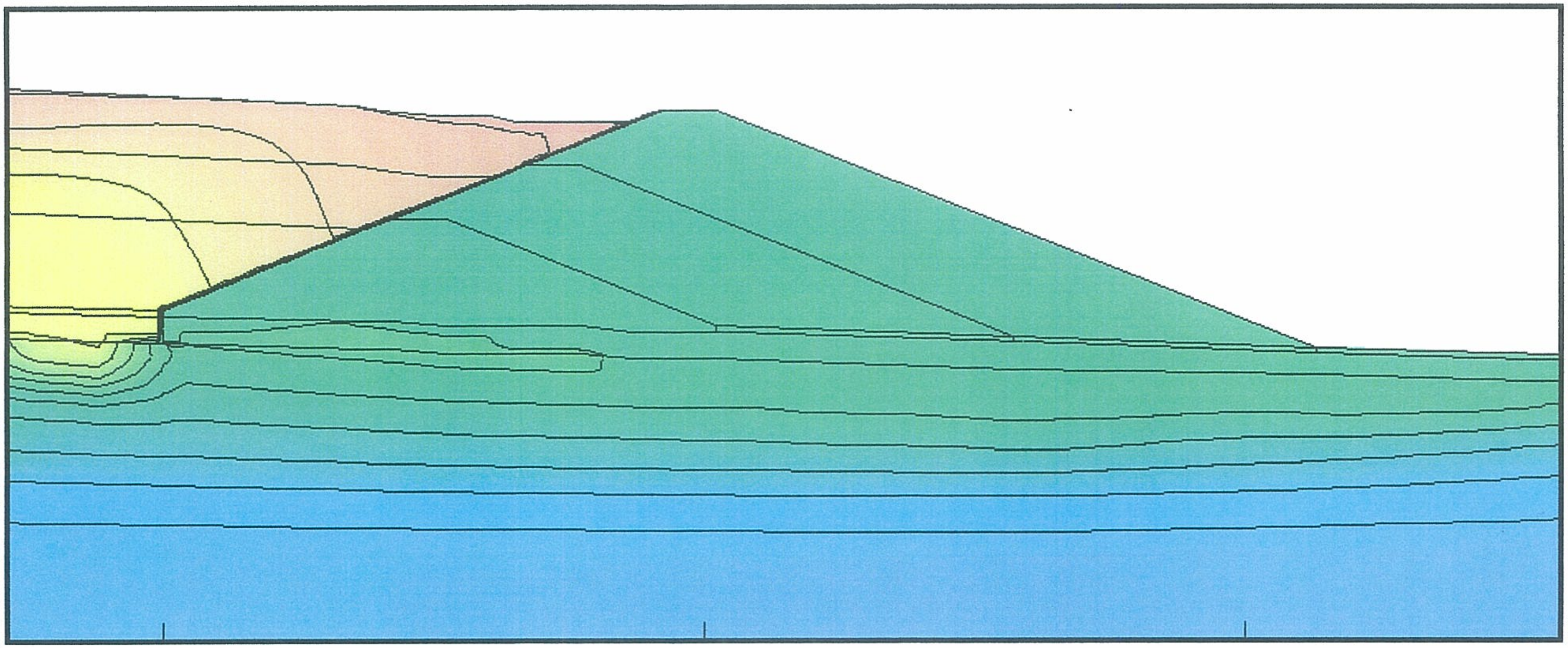
I-9h



Thermal Contour Map
Scenario 2 – Phase 3 – Time step 660
Jan 15 / 05

Rock Creek Dam,
Nome, Alaska

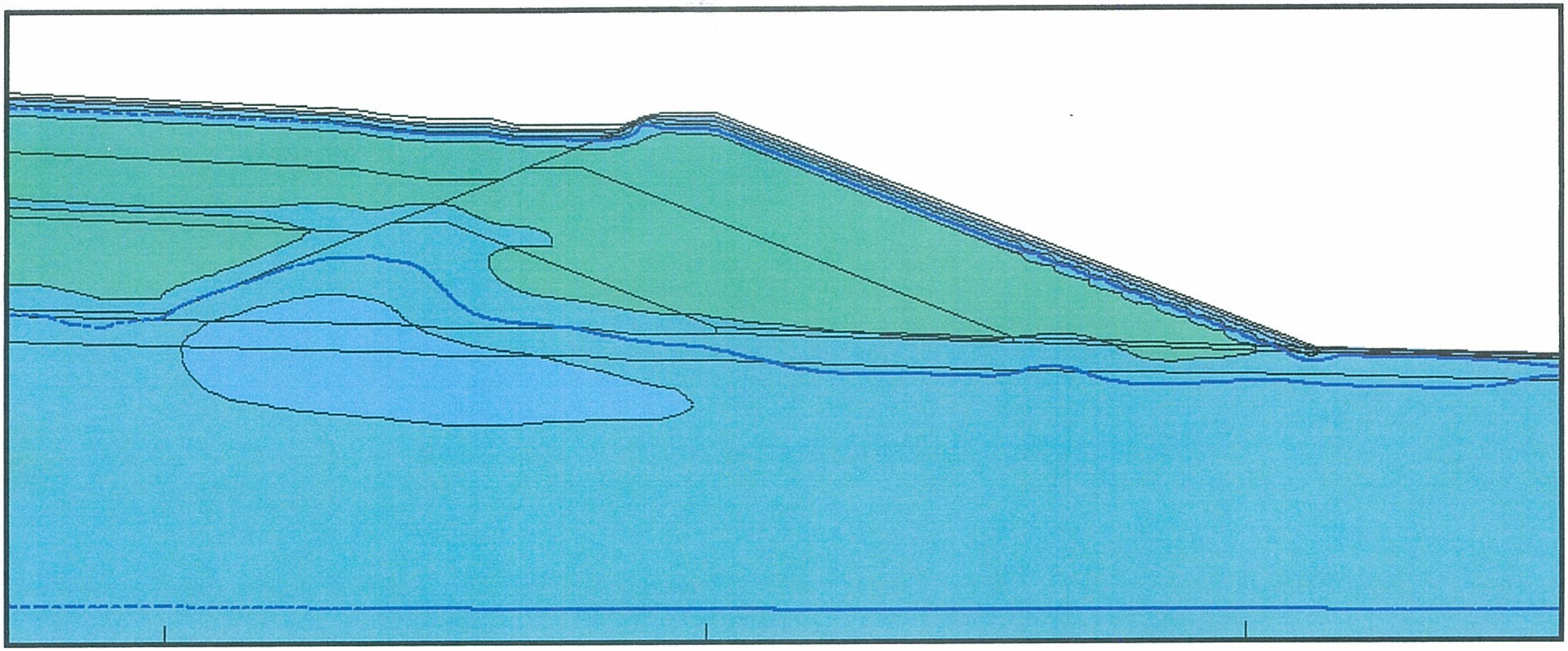
I-9t



Hydraulic Head Contour Map
Scenario 2 – Phase 3 – Time step 740
Feb 5 / 05

Rock Creek Dam,
Nome, Alaska

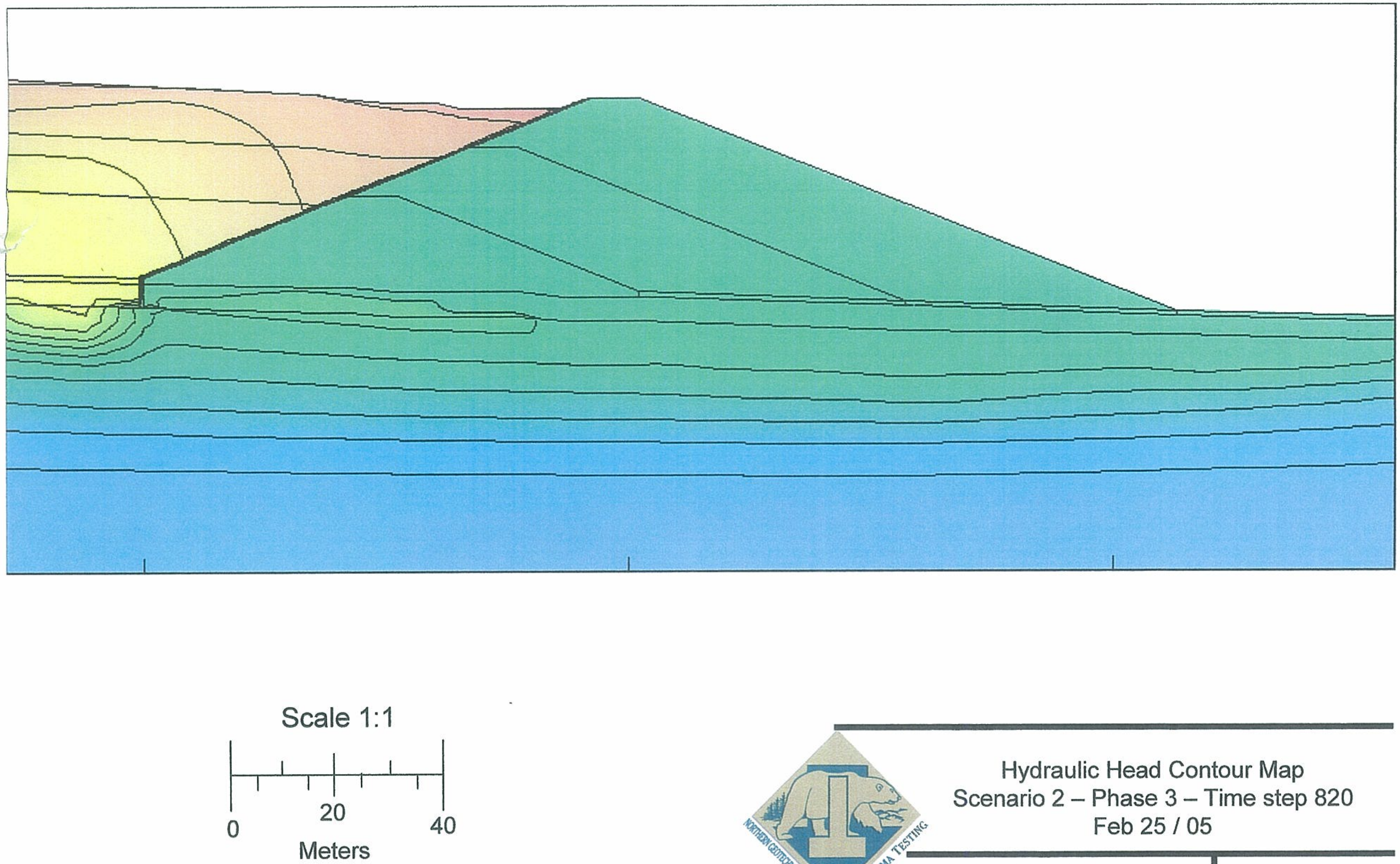
I-10h



Thermal Contour Map
Scenario 2 – Phase 3 – Time step 740
Feb 5 / 05

Rock Creek Dam,
Nome, Alaska

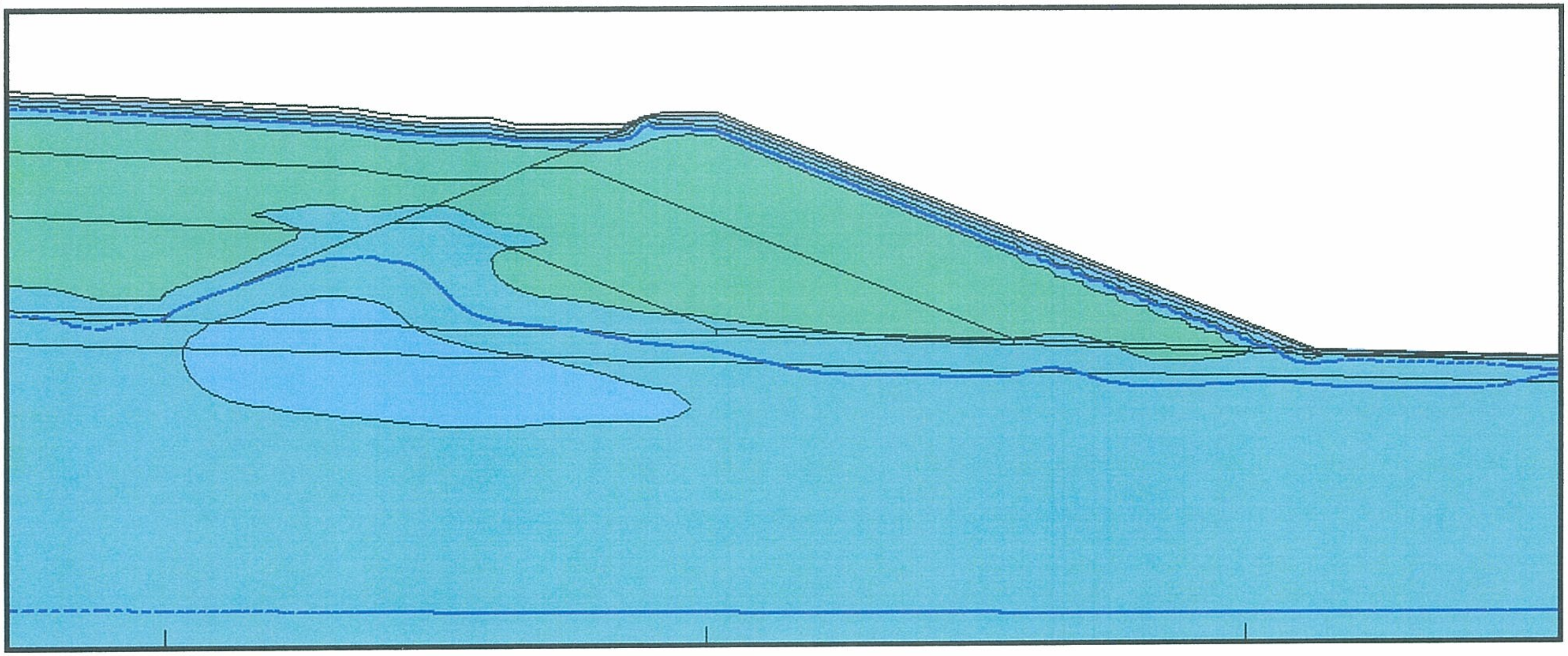
I-10t

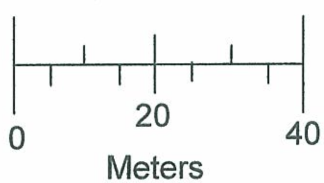


Hydraulic Head Contour Map
Scenario 2 – Phase 3 – Time step 820
Feb 25 / 05

Rock Creek Dam,
Nome, Alaska

I-11h

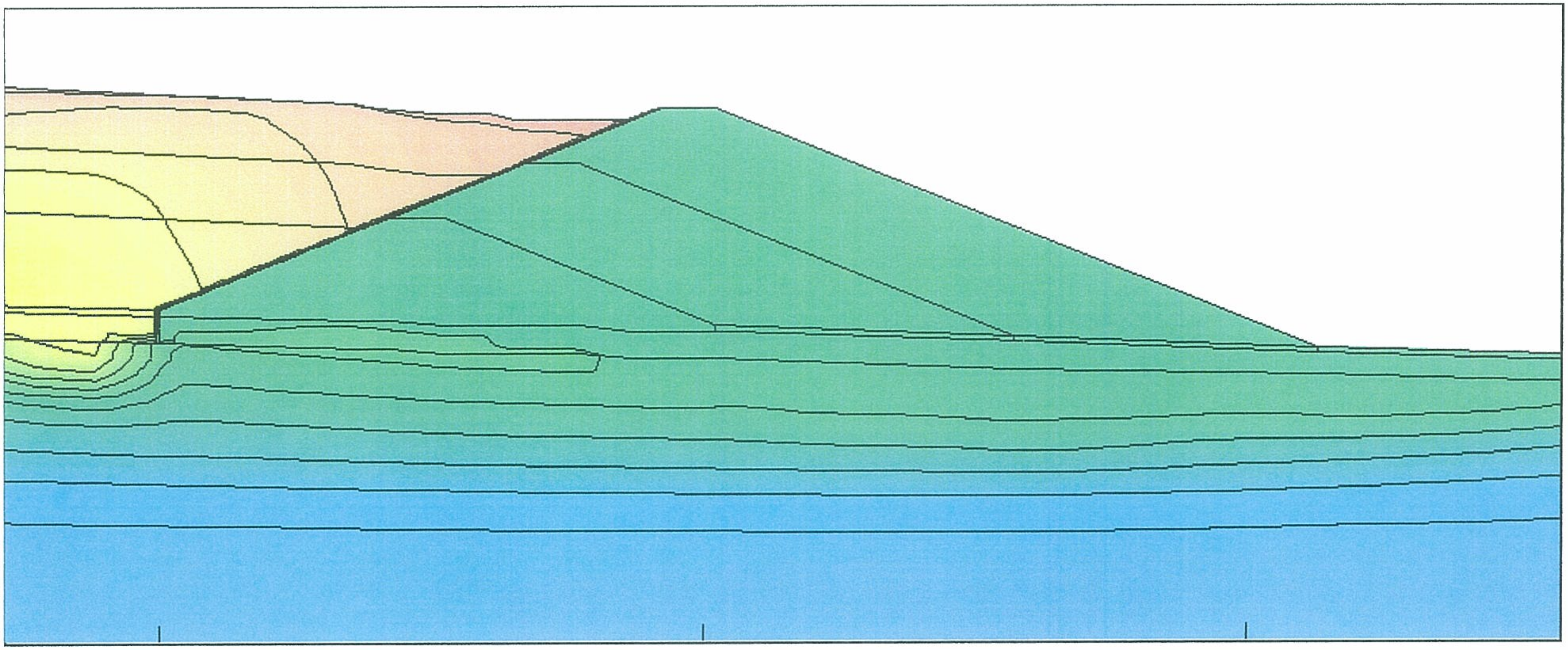


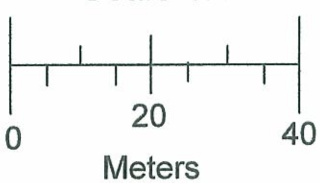


Thermal Contour Map
Scenario 2 – Phase 3 – Time step 820
Feb 25 / 05

Rock Creek Dam,
Nome, Alaska

I-11t

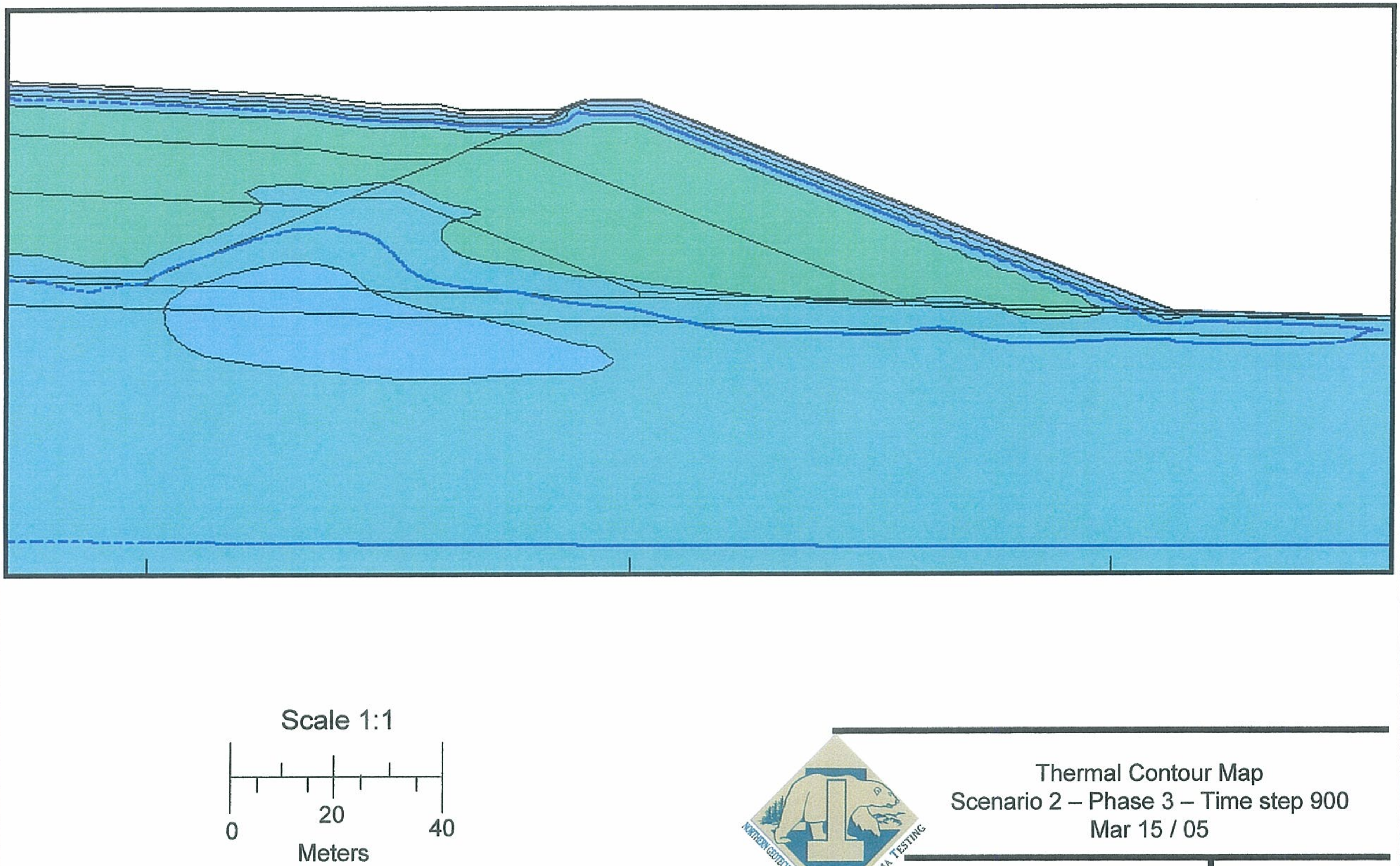




Hydraulic Head Contour Map
Scenario 2 – Phase 3 – Time step 900
Mar 15 / 05

Rock Creek Dam,
Nome, Alaska

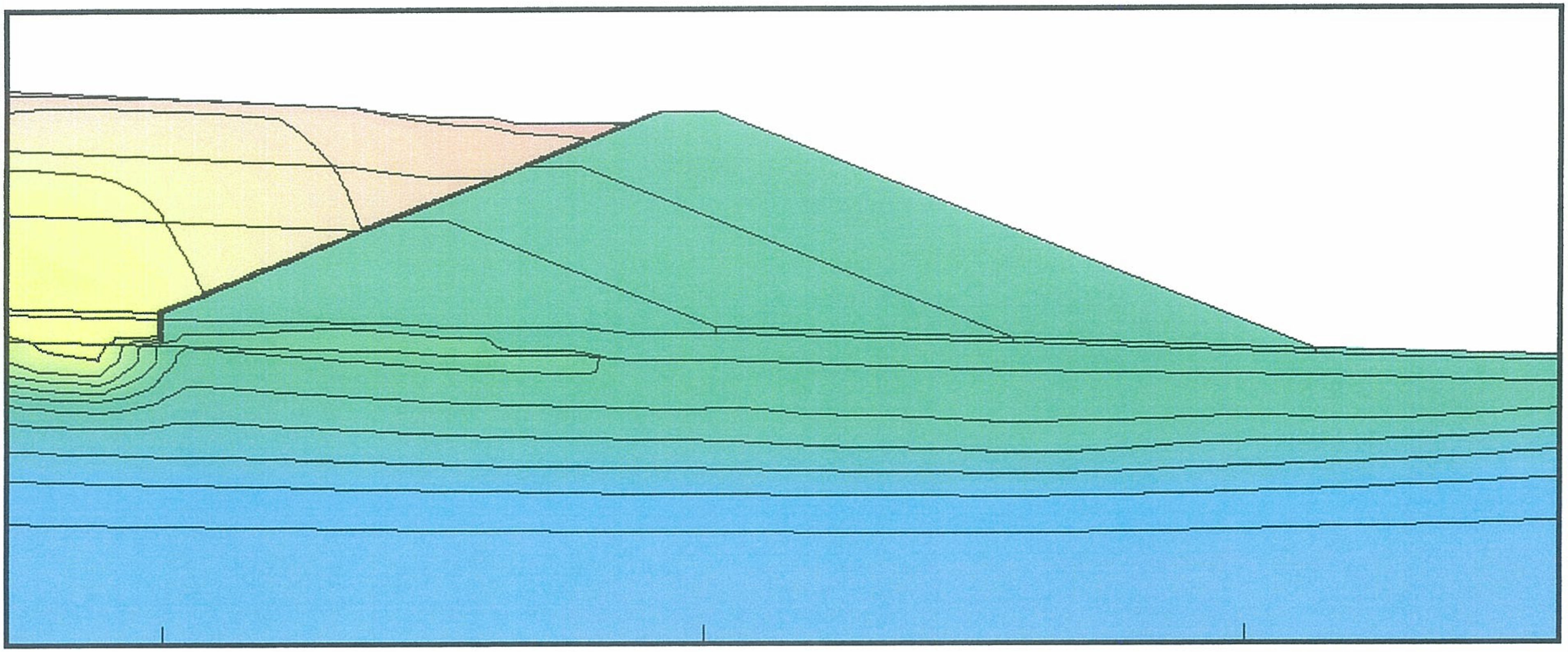
I-12h

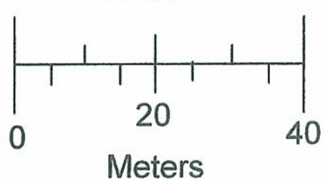


Thermal Contour Map
Scenario 2 – Phase 3 – Time step 900
Mar 15 / 05

Rock Creek Dam,
Nome, Alaska

I-12t

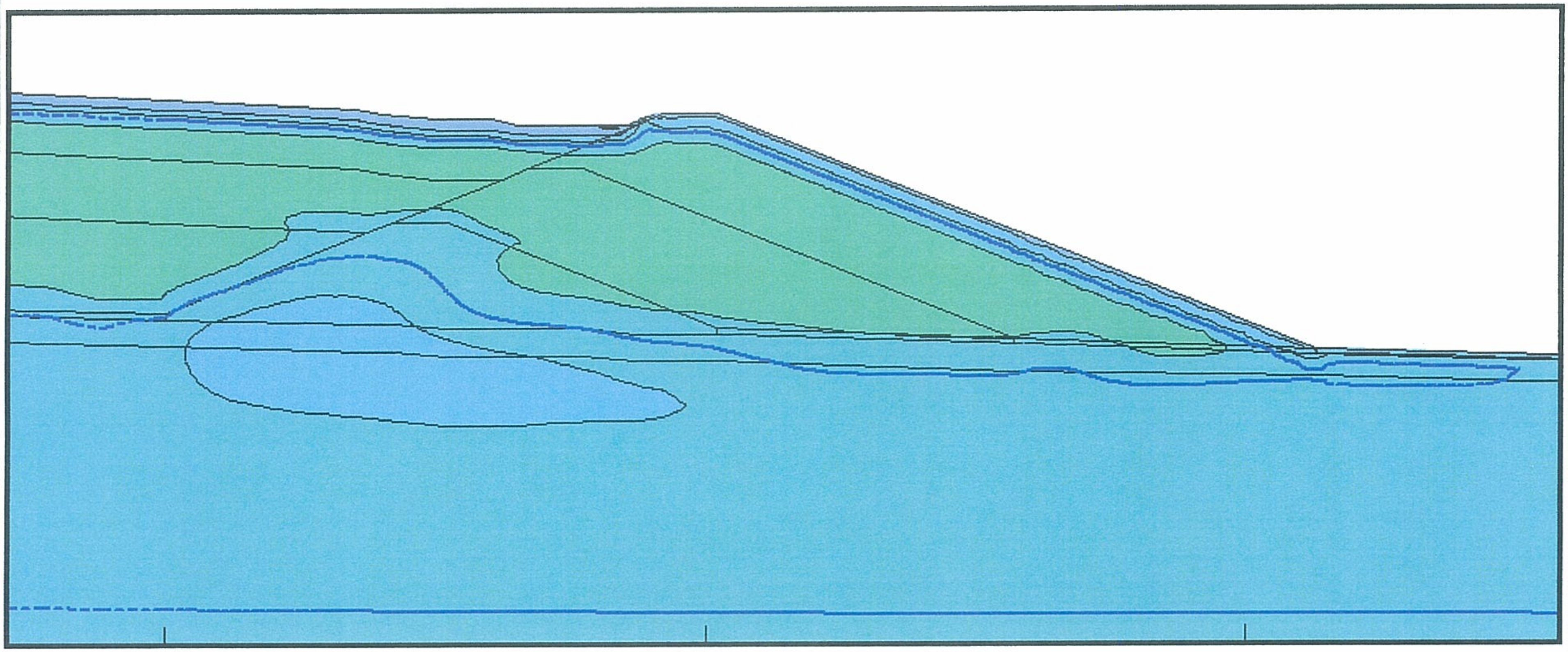


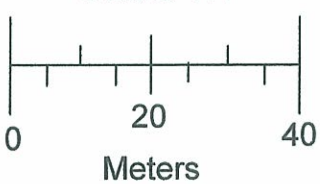


Hydraulic Head Contour Map
Scenario 2 – Phase 3 – Time step 980
Apr 5 / 05

Rock Creek Dam,
Nome, Alaska

I-13h

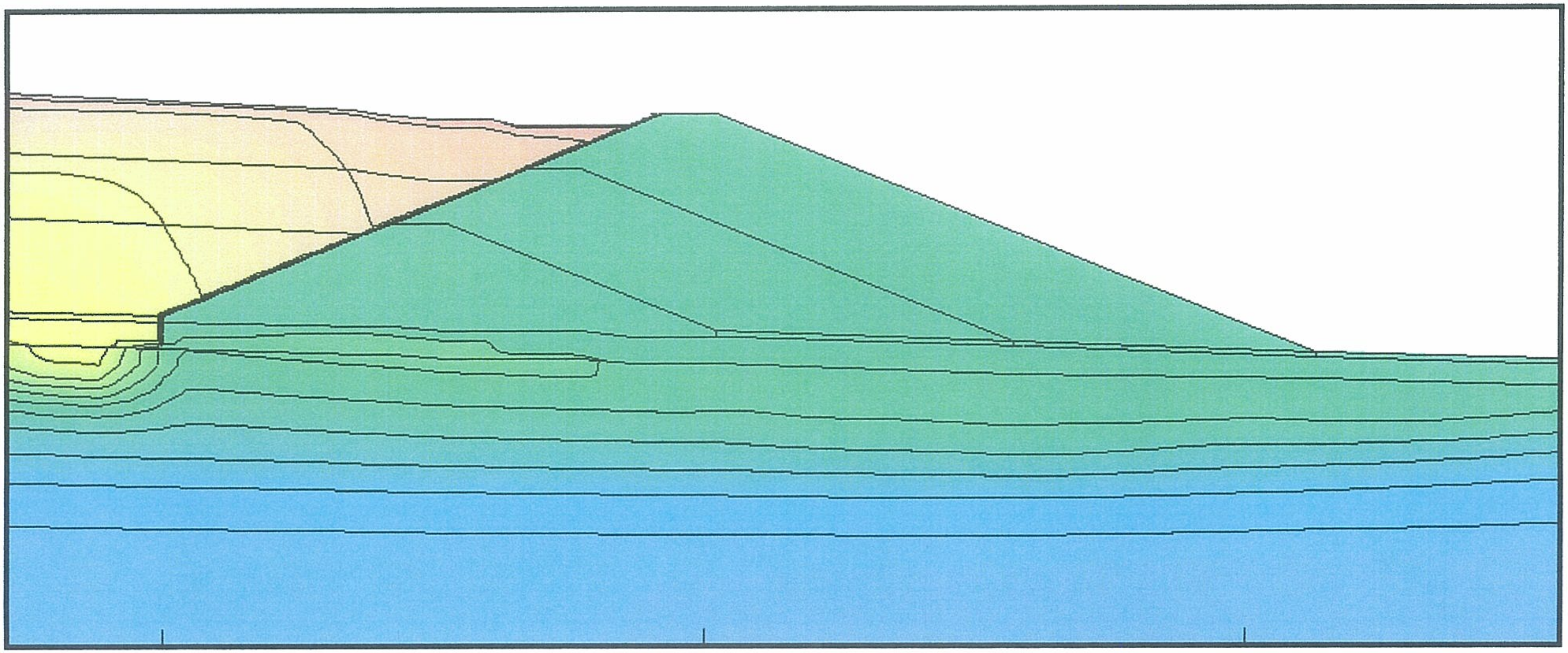


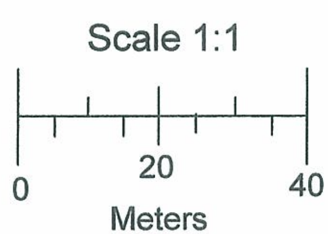


Thermal Contour Map
Scenario 2 – Phase 3 – Time step 980
Apr 5 / 05

Rock Creek Dam,
Nome, Alaska

I-13t

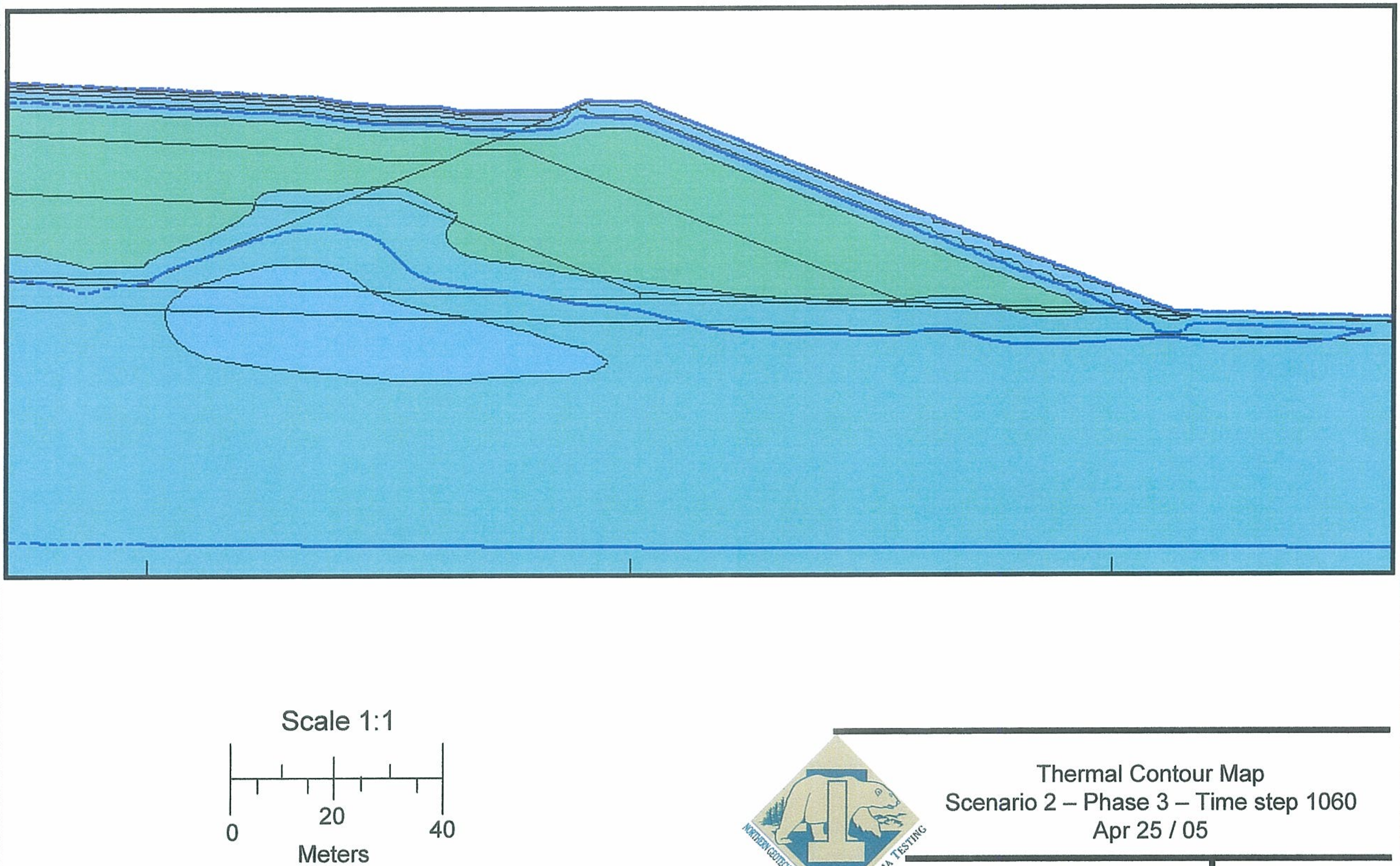




Hydraulic Head Contour Map
Scenario 2 – Phase 3 – Time step 1060
Apr 25 / 05

Rock Creek Dam,
Nome, Alaska

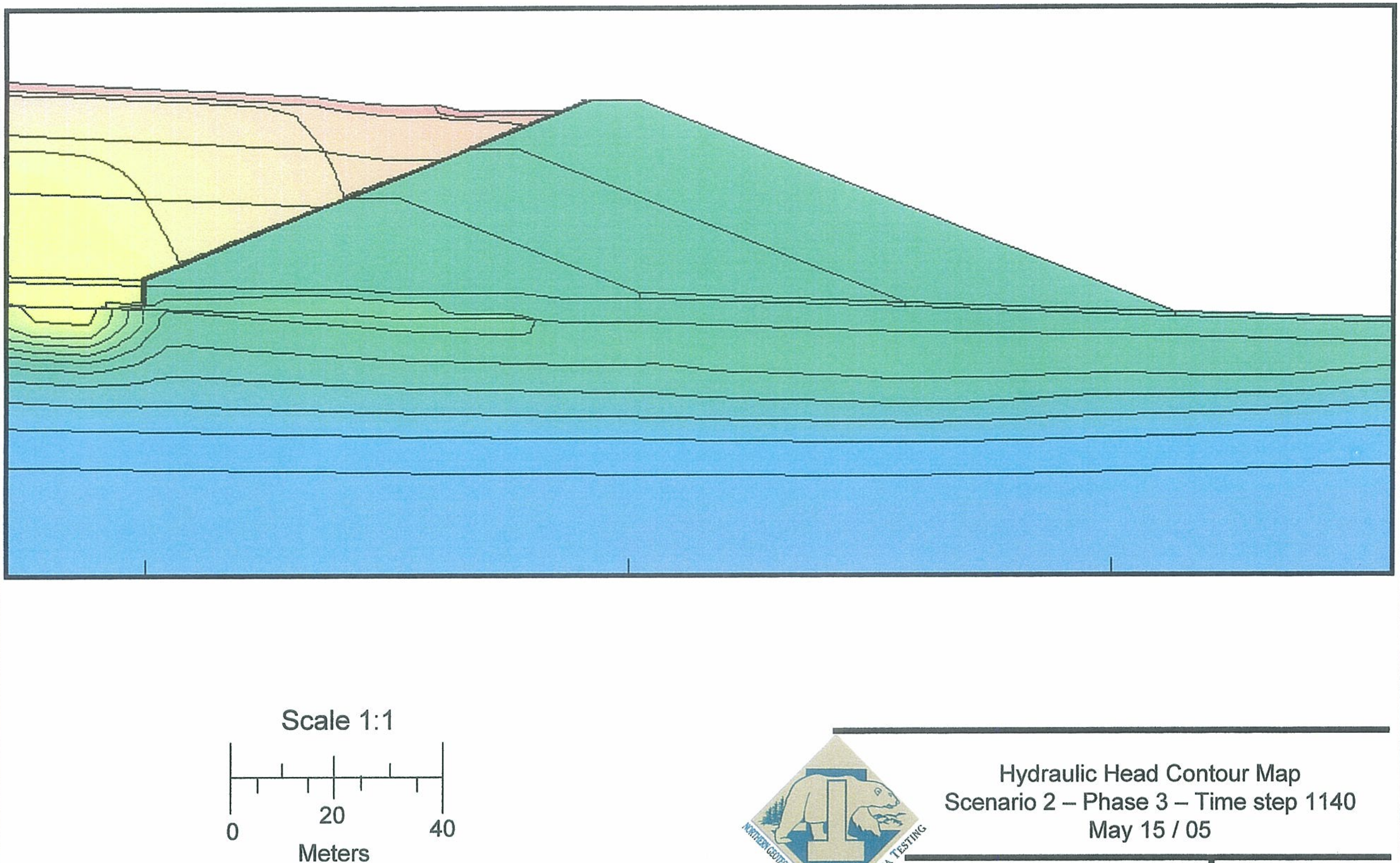
I-14h



Thermal Contour Map
Scenario 2 – Phase 3 – Time step 1060
Apr 25 / 05

Rock Creek Dam,
Nome, Alaska

I-14t

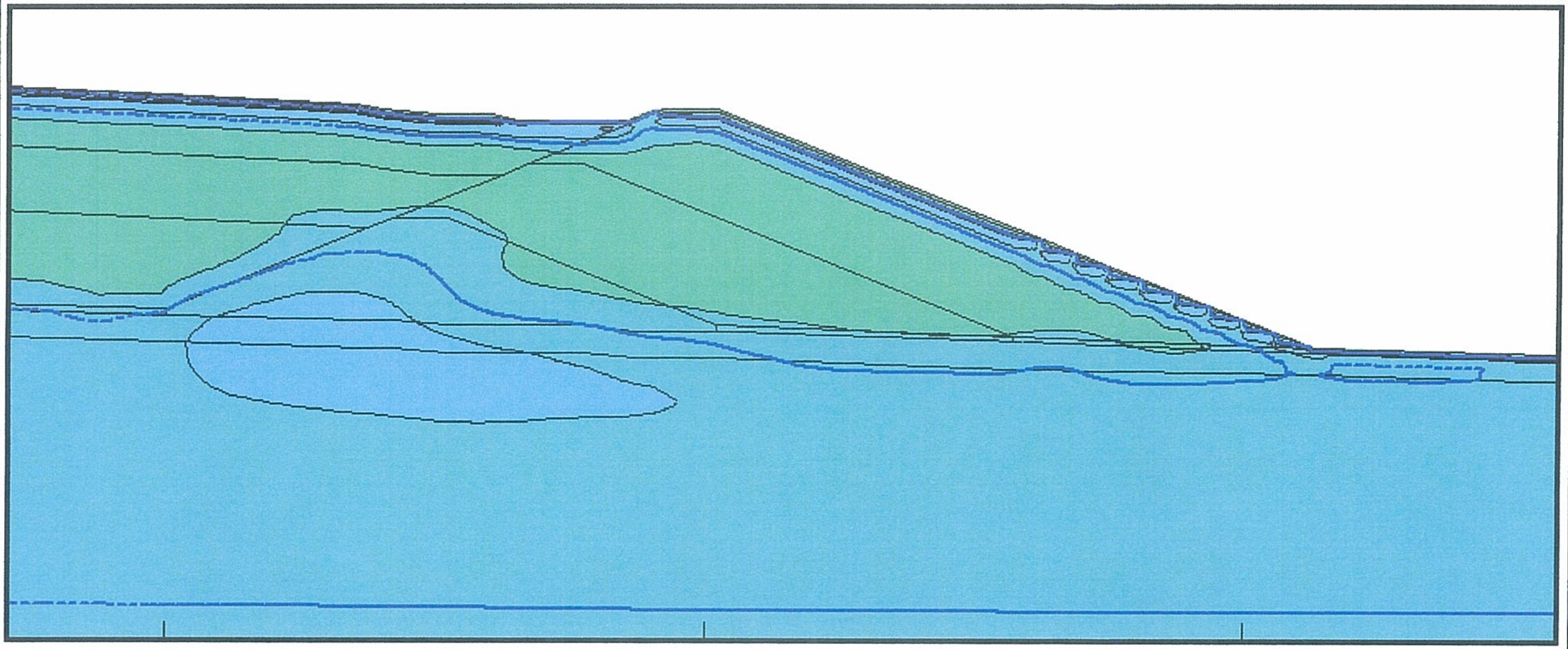


Hydraulic Head Contour Map
Scenario 2 – Phase 3 – Time step 1140
May 15 / 05

Northern Geotechnical Engineering, Inc. Terra Firma Testing

Rock Creek Dam,
Nome, Alaska

I-15h



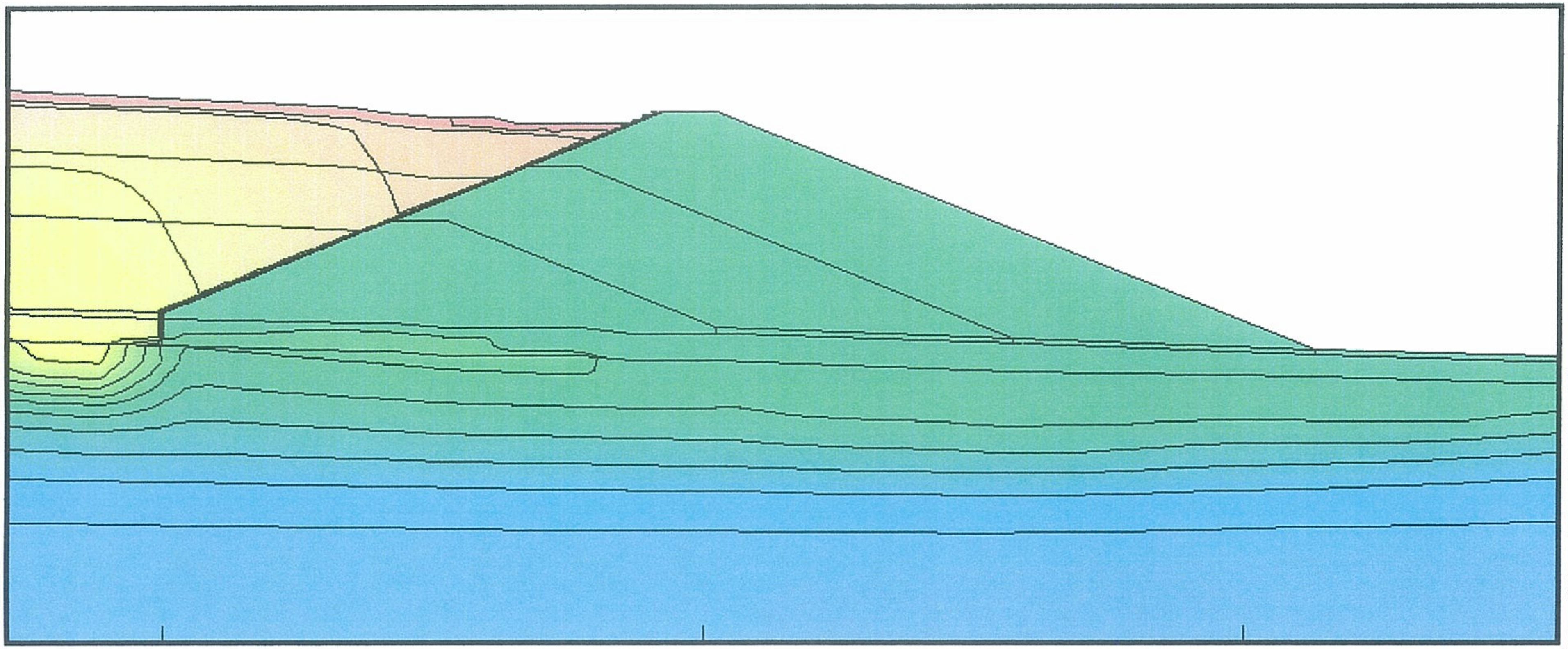
Scale 1:1

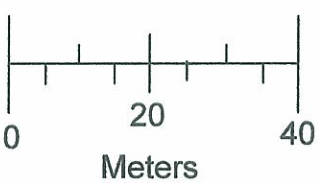
0 20 40
Meters

Thermal Contour Map
Scenario 2 – Phase 3 – Time step 1140
May 15 / 05

Rock Creek Dam,
Nome, Alaska

I-15t

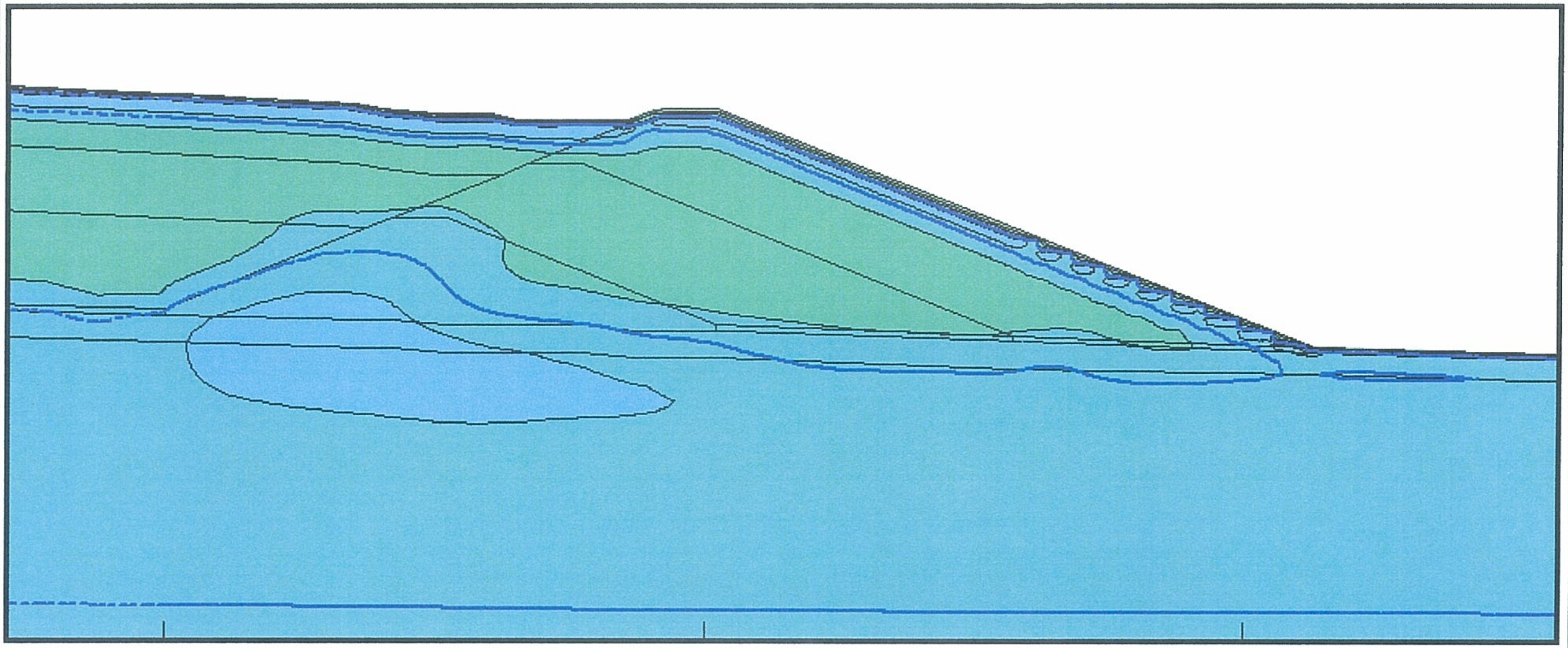




Hydraulic Head Contour Map
Scenario 2 – Phase 3 – Time step 1220
Jun 5 / 05

Rock Creek Dam,
Nome, Alaska

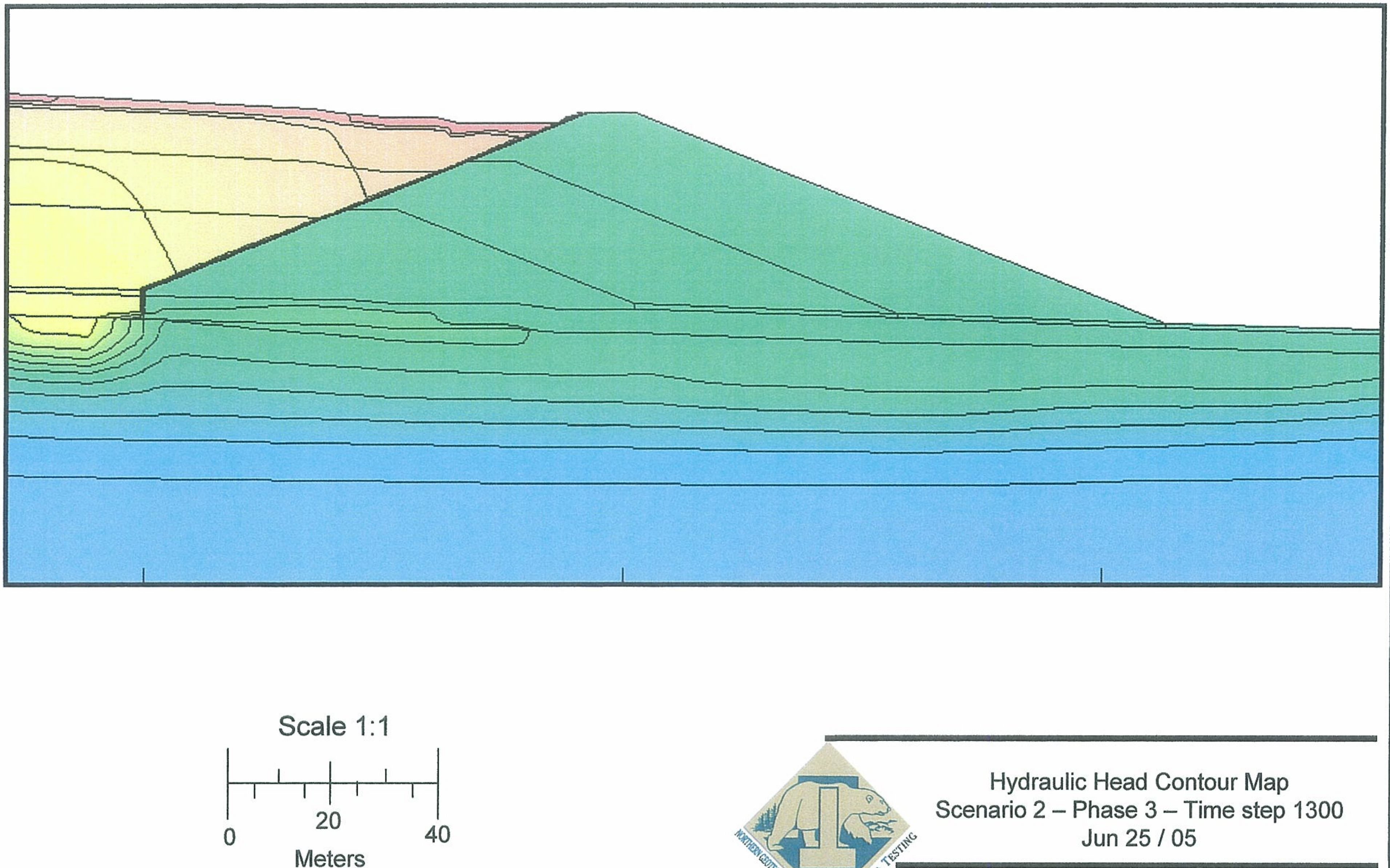
I-16h



Thermal Contour Map
Scenario 2 – Phase 3 – Time step 1220
Jun 5 / 05

Rock Creek Dam,
Nome, Alaska

I-16t

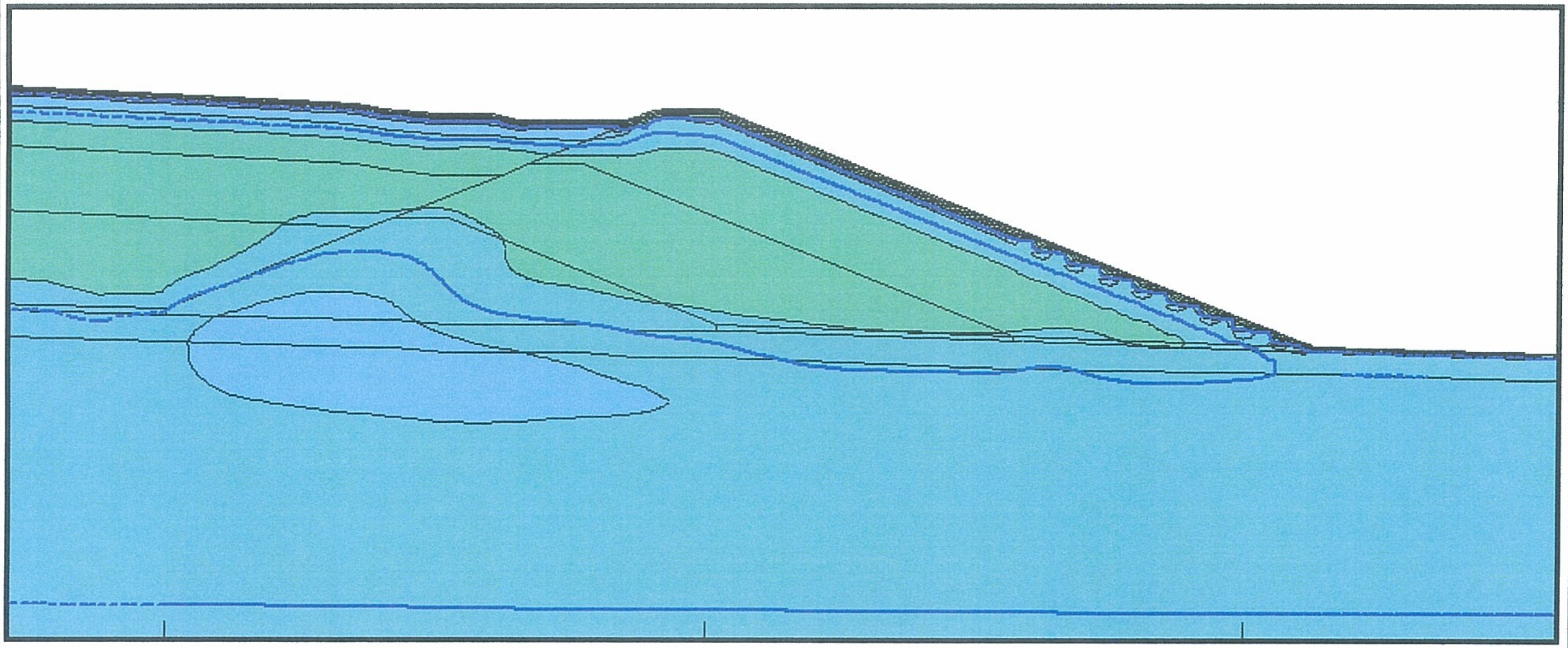


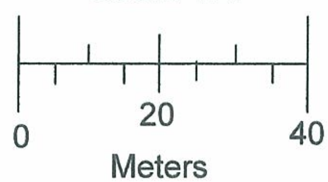
Hydraulic Head Contour Map
Scenario 2 – Phase 3 – Time step 1300
Jun 25 / 05

TERRA FIRMA TESTING
NORTHERN GEOTECHNICAL ENGINEERING, INC.

Rock Creek Dam,
Nome, Alaska

I-17h

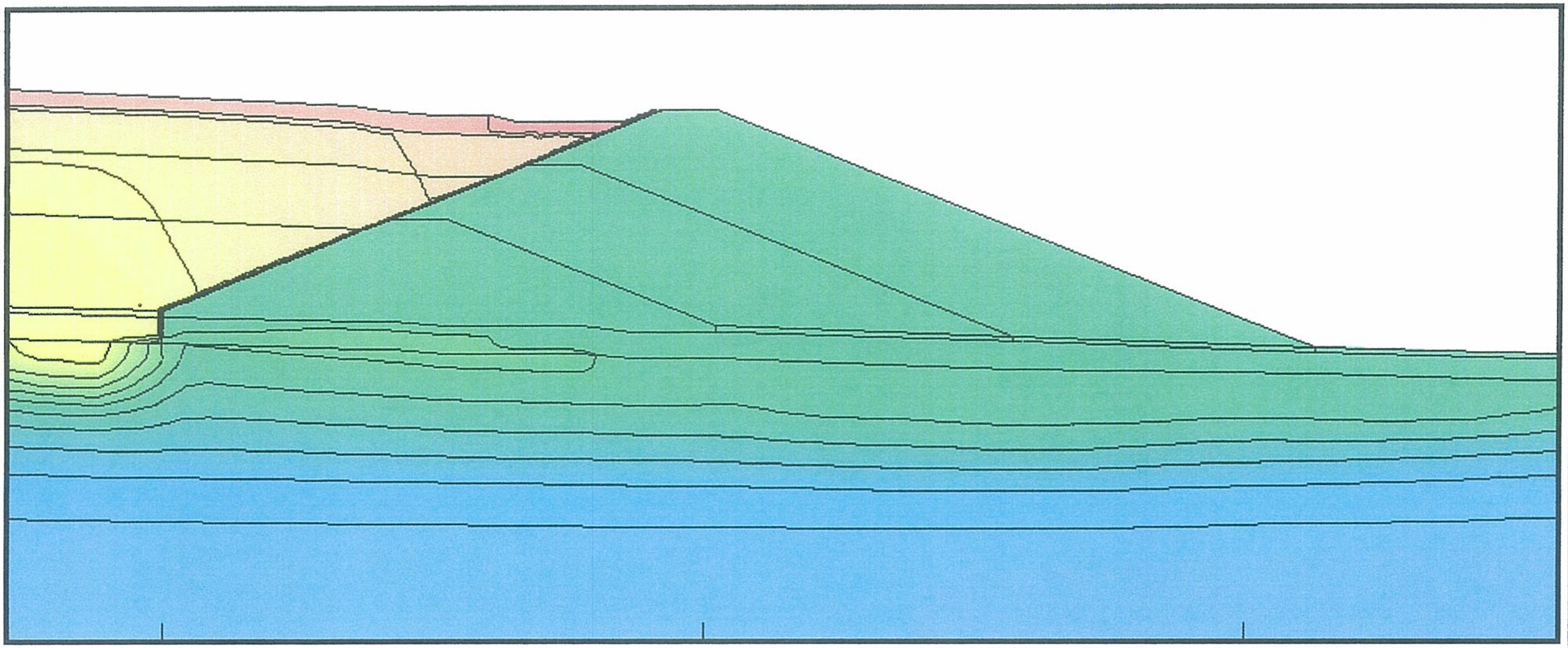


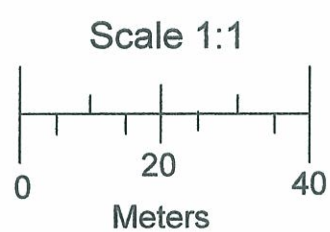


Thermal Contour Map
Scenario 2 – Phase 3 – Time step 1300
Jun 25 / 05

Rock Creek Dam,
Nome, Alaska

I-17t

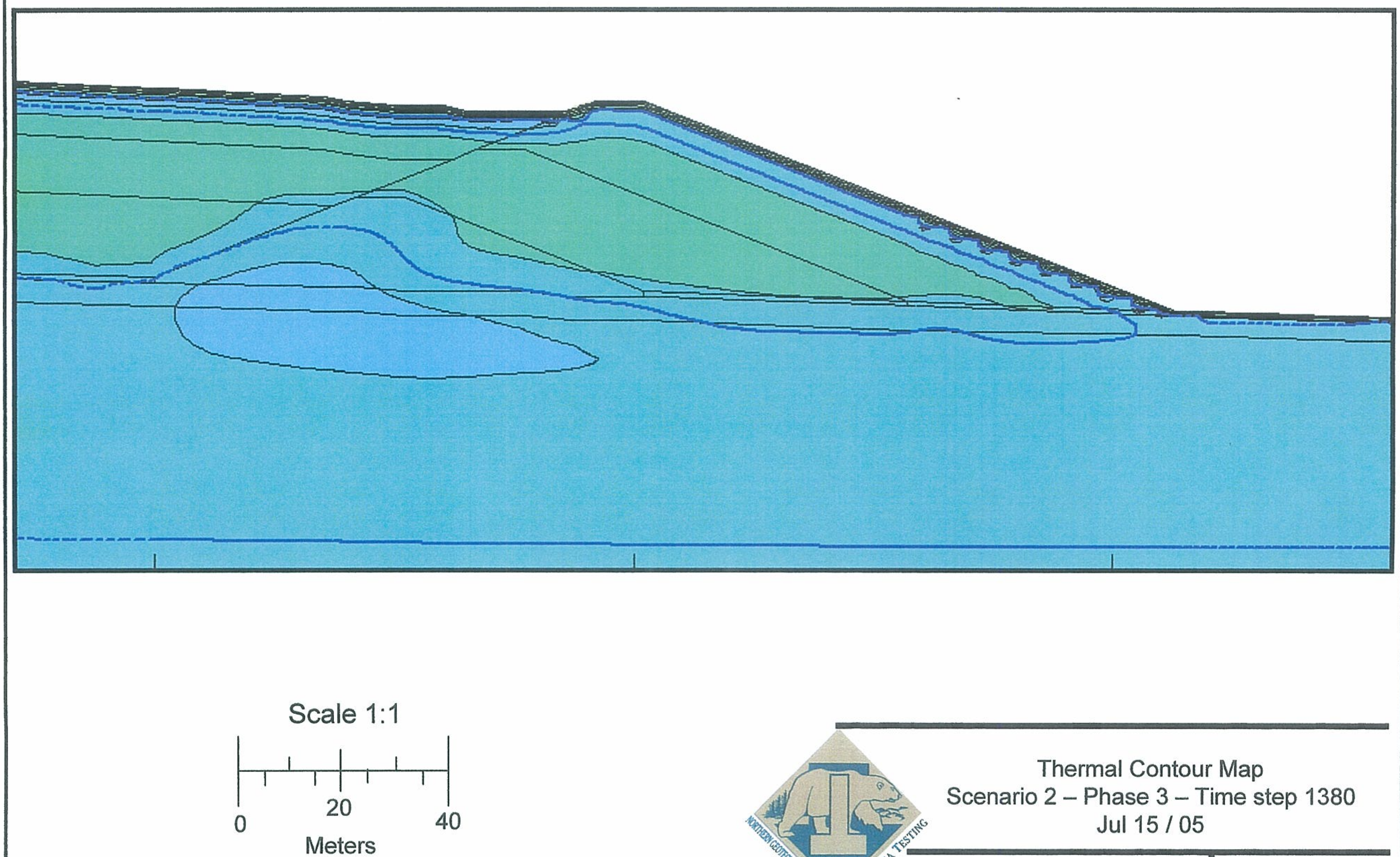




Hydraulic Head Contour Map
Scenario 2 – Phase 3 – Time step 1380
Jul 15 / 05

Rock Creek Dam,
Nome, Alaska

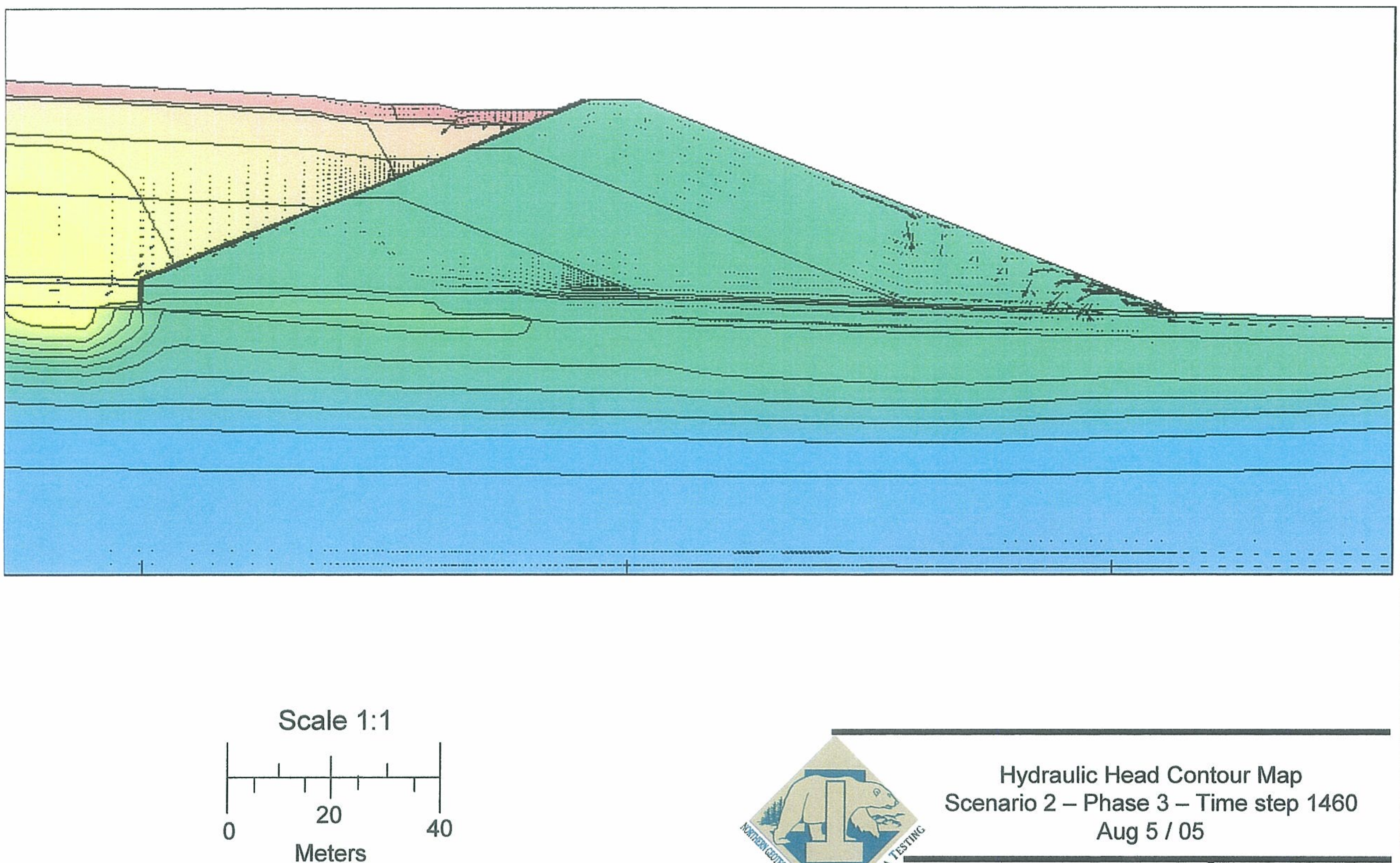
I-18h



Thermal Contour Map
Scenario 2 – Phase 3 – Time step 1380
Jul 15 / 05

Rock Creek Dam,
Nome, Alaska

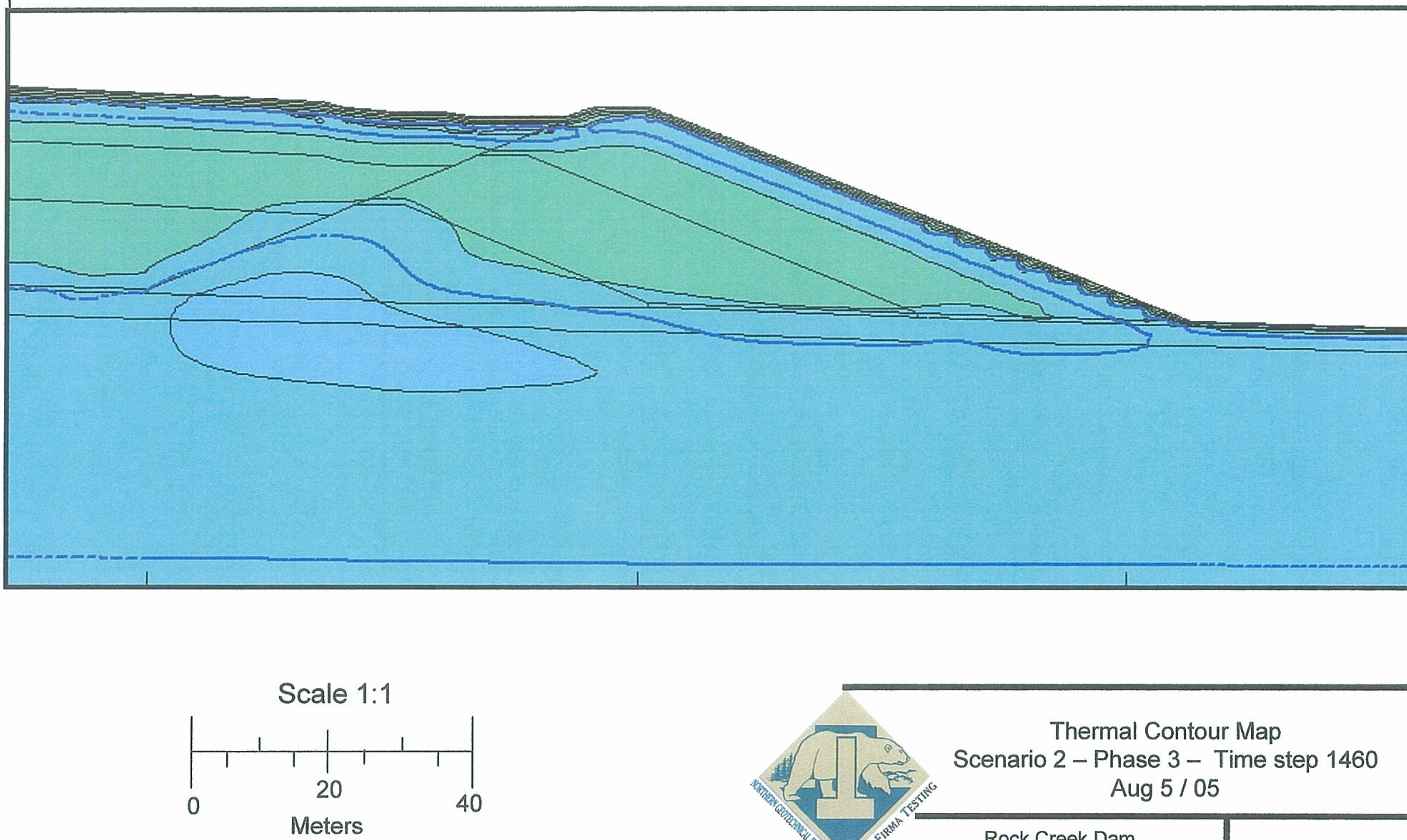
I-18t



Hydraulic Head Contour Map
Scenario 2 – Phase 3 – Time step 1460
Aug 5 / 05

Rock Creek Dam,
Nome, Alaska

I-19h



Thermal Contour Map
Scenario 2 – Phase 3 – Time step 1460
Aug 5 / 05

Rock Creek Dam,
Nome, Alaska

I-19t