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Attention: Dan Johnson

Subject: Jericho Diamond Mine
Reply to NWB
Review Comments to Jericho West Dam Design

EBA Engineering Consultants Ltd.'s (EBA's) replies to questions and comments in NWB Letter dated September 12, 2006 regarding the Jericho West Dam Design are presented below. The original NWB comments are in italics. EBA's reply follows each comment.

a. Foundation Conditions (Section 2.2) According to the drawings it appears that the north, not the south abutment consists of a relatively steep bedrock slope.

The North abutment is a relatively steep bedrock slope.

b) Slope Stability Analysis (Section 4.2) No graphical presentations of the slope stability analysis are provided. Information about the critical slip surfaces and instability mechanisms should be included. In addition, clarification of the two analytically methods described should be included, in particular the following statement "… analyzed for both undrained thawed effective strength parameters …". According to general engineering practice, slope stability analyses have to be carried out for the undrained (short term) condition as well as the drained (long term) condition in the thawed state. These analyses are conducted as a total stress analysis for the first case and using an effective stress analysis for the second. It is not clear in the report how the analysis was conducted and what strength parameters were used.

Graphical representations of the slope stability analyses are attached.

The analyses included in the report assumed drained strength parameters for the granular fill materials. Drained strength parameters are appropriate for the coarse grained run-of-mine material and 200 mm minus materials.

The GCL shear strength is a result of the fibres between the upper and lower fabrics of the GCL and the bentonite infilling. The GCL has a high peak strength as a result of the fibres; once the fibres tear, the strength is governed by the bentonite strength. Conservative parameters were used in the analyses ignoring the peak strength and applying the large displacement strength parameters.

Slope stability analyses were carried out for both an undrained and drained strength parameters of the foundation as described in the report.

The analyses presented in the report assumed drained strength parameters of the frozen core (20 mm minus material). Subsequently, the sensitivity of undrained strength parameters of the

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frozen core was analyzed. The undrained strength of the frozen core was based on Weaver and Morgenstern (1981) for long-term cohesion of a ice-poor. The undrained strength was assumed to be 200 kPa. The stability analysis indicated that undrained strength parameters of the core did not control the stability analyses (i.e. higher factors of safety were calculated, and the critical slip surface did not pass through the core.)

c. Creep (Section 5.0) The reviewers agree with EBA's conclusion that low creep movements will occur under these circumstances. However, no detailed information about the ice content within the foundation is presented other than "… relatively low." The Board request additional discussion regarding the foundation ice content to explain the comparison term "relatively low". What is this relative to? Additionally, further detail and discussion is requested to explain what site conditions exists and assumption have been made to justify the "risk of creep movement" to be "low"?

Frozen ground is described in terms of excess ice. Excess ice is the ice content not associated with the pore ice of the soil. The definition of low ice contents varies, but is generally less than 10 or 15% volumetric excess ice content.

The frozen till in the foundation had moisture contents ranging from 10 to 14%. A portion of this moisture is pore ice. The moisture content of the unfrozen soils is up to 10%. If it is assumed that the pore moisture content in the frozen soils is 10%, the moisture content due to excess ice is 0% to 4%. This is equivalent to excess ice contents of 0% to 9%. This is considered a low excess ice content.

Creep movement that would have an adverse effect on the dam is not anticipated given the foundation conditions. The performance of the dam will be monitored (visually and by survey) to determine if movement is occurring.

d. Thermal Performance (Section 7.0) Section 7 describes the thermal performance of the frozen core dam. The design report only refers to the SRK 2004 report, which was not available to the reviewers, and thermal boundary conditions used for the additional thermal analysis were not included in the report. More details and clarifications of the thermal analysis carried out to justify the predicted performance should be provided.

A memo describing the thermal analyses is appended to this letter.

e. Design of Thermosyphons (Section 7) Construction drawings of horizontal pipes for thermosyphons are included in the report (Drawings WD-9 & WD-10), which will be activated in the future if required. However, no analysis or details about their design is included in the report.

Details of the thermal analyses of the thermosyphons are appended to this letter.

f. Foundation Preparation (Section 10.4) According to the design report Section 10.4 "the key trench must be excavated into the permafrost so that the GCL liner system is keyed into permanently frozen ground." This definition is vague, since permafrost is defined by temperature and not ice content. A more precise requirement such as a minimum depth and particular ground temperature that ensures a proper adfreezing of the GCL liner to the frozen foundation soils should be specified.

The base of the key trench is placed in competent rock or ice saturated frozen ground. The required depth of the key trench is determined prior to construction using perculation tests (falling head tests) along the key trench location. Drill holes are filled with water to determine the level that water stabilizes at after 24 hours. It is assumed that the rock or frozen ground is ice saturated below this level. The key trench elevation is set below this level. The condition of key trench base is observed after key trench excavation and cleaning.

g. Monitoring (Section 11.2) Thermal monitoring is recommended via the use of horizontal as well as vertical ground temperature cables. More specific recommendations about the thermistor spacing and a recommended reading interval as well as the need for regular review of the temperature recordings to ensure the requirements of the design are being achieved throughout operational life of the structure.

A total of 12 ground temperature cables have been specified and shown on the construction drawings. The thermistor cable configurations are summarized in Table 1. The ground temperature cables will be read on a monthly basis. The ground temperatures will be submitted to the NWB monthly and summarized in the annual geotechnical inspection report.

TABLE 1: THERMISTOR CABLE SUMMARY

Station	Elevation	Total Cable Length (m)	Bead Spacing within the core (m)	Total number of beads
0+040	513	113	2	16
0+040	515	109	2	12
0+040	522	51	2	12
0+080	515	94	2	16
0+080	517	92	2	12
0+080	522	51	2	12
0+120	518	75	2	15
0+120	520	73	2	12
0+120	522	51	2	12
0+040	Vertical	16	1	16
0+080	Vertical	16	1	16
0+120	Vertical	16	1	16

h. Monitoring (Section 11.3) The surveying for both the dam construction and for future monitoring of the deformation of the dam requires a stable and permanent reference point adjacent to the dam. In summary, the design report and construction specifications for the PKCA West Dam contain most of the necessary design requirements. However, some clarifications are required, in particular related to the slope stability analysis. The general design as well as the material parameters selected for the analysis are conservative. This design and the selected configuration for the dam are safe, i.e. the effective factors of safety are higher than the minimum standards. It is believed that frozen core will remain frozen for the lifetime of the PKCA West Dam, even under potential warming climatic conditions. The *possibility of installing thermosyphons in the future adds to the safety of the dam design. The surveying and monitoring program recommended is crucial for a successful design and operation of the dam. It is therefore advised to further address these issues in the design report. The Board request additional detail on how survey points will be anchored to avoid long-term movements or damage to the liner. Additional detail is requested to address how the monitoring program will be reviewed by a qualified geotechnical engineer and communicated to the NWB.*

A detail of the settlement monitoring points is shown on drawing WD-8. The settlement points are 1 m above the dam liner to avoid liner damage during the installation of the points. The settlement points will be monitored on a monthly basis for the first two years. The monitoring schedule will be reviewed after that time to determine an appropriate schedule after that time. The settlement data will be reviewed and reported in the annual geotechnical inspection report.

i. Design Intent (Lake Level Projections - Section 2.3) The Board requests additional detail and discussion on the amount of freeboard between the maximum allowable water level and top of liner. Has consideration been given to dam settlement and wave action?

The "maximum operating water level" for the PKCA has been defined as elevation 523 m. The water level may rise above this level while flood waters are discharged and will also be higher due to waves and wave run-up. The maximum wave height for the West Dam is estimated to be 0.5 m. The "maximum water level" that includes waves and a temporary rise during flood routing has been defined as 524 m for the PKCA. The difference between the "maximum operating water level" and "maximum water level" is the freeboard.

The water retention elements in the dams have been specified to be at elevation 524 m. The top of the frozen core of the West Dam is 524 m and the top of the GCL liner is 523.5 m. Negligible settlement is expected at the frozen core crest based on observations at similar structures.

j. Settlement (Section 6.0) TDC states that the water level in the PKCA will be maintained at a low level to minimize foundation thaw and settlement and that the a settlement should be less than 20 cm. The NWB request additional detail and discussion on what water elevation "low level" corresponds to and the analysis completed to assess the amount of expected settlement.

The water impounded at the upstream dam slope will effect the foundation settlement. Projected water levels are presented in the PKCA management plan. The water levels will vary depending on the actual inputs, and discharge; however the during a mean year the water levels are projected to vary between elevation 514 and 518 m; as oppose to a full supply level of 523 m. Maintaining the water at this level limits the amount water adjacent to the upstream shell; and thus minimizes the amount of thaw and settlement under the upstream shell.

The settlement refers to the amount of settlement of the ice rich frozen overburden under the upstream shell. An estimate of settlement was based on an average thickness of ice rich overburden observed in the boreholes (1.3 m), and an excess ice content of 8%. Upon thaw this material may settle 8% resulting in a settlement of approximately 10 cm. The value of 20 cm was quoted to account for uncertainties in the geotechnical conditions.

k. Material Properties (Slope Protection – 9.1) TDC proposes to use run-of-mine rock on the upstream dam shell. It is stated that this material should have a size larger than the minimum requirements of rip-rap for slope protection; however, this minimum size is not provided in the construction specifications. TDC should include this information in the West Dam construction specifications document.

The D50 required for slope protection is 300 mm. The run-of-mine used for slope protection will have a D50 greater than this. An amendment will be issued to the West Dam construction specifications to reflect this.

l. TDC has included design drawings in the West Dam Design Report. The NWB requests signed and stamped design drawings from TDC.

Copies of the signed drawings will be forwarded to the NWB.

We trust this addresses the NWB questions comments. We welcome the opportunity to discuss them further at the scheduled meeting between NWB, EBA and Tahera.

Regards,
EBA Engineering Consultants Ltd.

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Appendix A: Jericho West Dam Thermal Analysis
Appendix B: West Dam Stability Analysis Plots

APPENDIX

APPENDIX A JERICHO WEST DAM THERMAL ANALYSIS

TO:	Bill Horne	DATE:	February 2, 2006
FROM:	Gordon Zhang	FILE:	1100060.004
SUBJECT:	**Thermal Analysis of West Dam Jericho Diamond Mine, Nunavut**		

1.0 INTRODUCTION

The Jericho West Dam was designed as a zoned dam with a frozen core and a frozen key trench over ice-saturated permafrost soil or rock (EBA, 2005). The design intent is to maintain the core, key trench, and the underlying soil or rock in a frozen condition over the mine life.

Thermal analyses were carried out to predict the short and long-term thermal conditions of the West Dam under various assumed conditions. The thermal model was calibrated using the measured ground temperatures at the site and considered the thermal impacts of nearby lakes on the initial ground temperatures within the dam footprint. This memo summarizes the input data and results of the thermal analyses.

2.0 THERMAL ANALYSES METHODOLOGY

Analyses were carried out using EBA's proprietary two-dimensional finite element computer model, GEOTHERM. The model simulates transient, two-dimensional heat conduction with change of phase for a variety of boundary conditions. The heat exchange at the ground surface is modelled with an energy balance equation considering air temperature, wind velocity, snow depth, and solar radiation. The model facilitates the inclusion of temperature phase change relationships for saline soils, such that any freezing depression and unfrozen water content variations can be explicitly modelled.

3.0 CLIMATIC DATA FOR THERMAL EVALUATIONS

3.1 MEAN CLIMATIC CONDITIONS

Climatic data required for the thermal analyses includes monthly air temperature, wind speed, solar radiation, and snow cover. There has been no meteorological station at the Jericho Diamond Mine site. The closest meteorological station is at Lupin/Contwoyto Lake, which is approximately 30 km south of the mine site. The climatic data for air temperature, snow cover, and wind speed were obtained from Environment Canada's meteorological station at Lupin/Contwoyto Lake, which has been operating since 1959. Mean monthly air temperatures for the thermal analyses were based on the 1971–2000 climatic normals at Lupin/Contwoyto Lake (data from Environment Canada's webpage). Monthly wind speed data were based on the 1951-1981 climatic normals at Contwoyto Lake (Environment Canada, 1982a). Month end snow cover data were based on the 1961-1991 climatic normals at Contwoyto Lake (Environment Canada, 1993). The solar radiation data were obtained from the meteorological station at Norman Wells, which is at a similar latitude as that for the Jericho mine site. The solar radiation data were based on the 1951-1980 climatic normals at Norman Wells (Environment Canada, 1982b). Table 1 summarizes the climatic conditions used for the thermal analyses.

TABLE 1: SUMMARY OF CLIMATIC DATA USED IN THERMAL ANALYSIS

Month	Monthly Air Temperature (°C)		Monthly Wind Speed (km/h)	Month-End Snow Cover (m)	Daily Solar Radiation (W/m²)
	Mean (1971-2000)	1 in 100 Warm			
January	-30.4	-25.2	20.2	0.44	5.4
February	-28.5	-23.6	13.3	0.52	31.6
March	-24.9	-20.6	13.8	0.60	97.3
April	-15.9	-13.2	14.3	0.65	179.2
May	-5.7	-4.7	16.5	0.30	233.1
June	6.5	9.2	14.6	0	267.2
July	11.5	16.3	16.8	0	234.5
August	8.8	12.5	18.8	0	166.8
September	1.8	2.5	23.0	0.02	93.9
October	-8.6	-7.1	19.8	0.15	32.5
November	-20.7	-17.1	16.9	0.28	9.6
December	-26.8	-22.2	16.3	0.37	2.0
Mean Annual	-11.1	-7.8			
Freezing Index (°C-days)	4884	4044			
Thawing Index (°C-days)	878	1243			

3.2 1 IN 100 WARM YEAR AIR TEMPERATURES

A probabilistic analysis was carried out to determine the mean monthly temperatures representative of a 1 in 100 warm year. The freezing index and thawing index for each year at Lupin/Contwoyto Lake from 1959 to 2004 were calculated. The freezing index for each winter was ranked in ascending order and plotted on probability paper. A "best-fit" line was drawn through the set of points to estimate the 1 in 100 warm year freezing index. A similar procedure was repeated for the summer temperatures to obtain the 1 in 100 warm year thawing index. Mean winter air temperatures were multiplied by the ratio of the 1 in 100 year freezing index to the mean freezing index to estimate the monthly winter air temperatures of a 1 in 100 warm year. Similarly, mean summer air temperatures were multiplied by the ratio of the 1 in 100 year thawing index to the mean thawing index to estimate the monthly summer air temperatures of a 1 in 100 warm year.

Monthly air temperatures for a 1 in 100 warm year are also listed in Table 1. As shown in Table 1, the 1 in 100 warm year annual air temperature is approximately 3.3°C warmer than the mean annual air temperature for the period of 1971 to 2000.

3.3 AIR TEMPERATURES CONSIDERING GLOBAL WARMING TRENDS

Measured air temperatures for the period of 1959 to 2004 indicate that there was generally a warming trend in the air temperatures at Lupin/Contwoyto Lake. Panel on Energy Research and Development (PERD) for Environment Canada (PERD, 1998) reported on estimates of temperature change due to global warming. The "best estimate" scenario and the pessimistic "high sensitivity" scenario were presented in the PERD (1998) report. The predicted temperature changes vary with month and latitude. Table 2 lists the estimated monthly air temperature increases per decade for the "best estimate" case and "high sensitivity" case at a latitude similar to that for the Jericho Diamond Mine site (N65.8°) based on the data from PERD (1998).

TABLE 2: PREDICTED AIR TEMPERATURE CHANGE BY SEASON PER DECADE AT N65.8° LATITUDE

Year	December January February	March April May	June July August	September October November
Best Estimate	0.51	0.38	0.12	0.10
High Sensitivity	0.89	0.63	0.19	0.17

4.0 CALIBRATION THERMAL ANALYSIS

4.1 MODELLED SOIL PROFILE AND PROPERTIES

A thermistor cable was installed in borehole BH-03-08 at the south abutment within the footprint of the West Dam during the 2003 geotechnical program conducted by SRK Consulting. The subsurface soil profile for BH-03-08 consists of a thin (0.1 m) organics layer overlying 5.4 m thick till over granite bedrock. The till is silty sand and gravel with cobbles and boulders. The index properties for the soils were estimated based on the geotechnical data from the site investigation and past experience. Thermal properties of the soils were determined indirectly from well-established correlations with soil index properties (Farouki 1986; Johnston 1981). Table 3 summarizes the material properties used in the calibration thermal analysis.

TABLE 3: MATERIAL PROPERTIES USED IN CALIBRATION THERMAL ANALYSIS							
Material	Water Content (%)	Bulk Density (Mg/m³)	Thermal Conductivity (W/m-K)		Specific Heat (kJ/kg°C)		Latent Heat (MJ/m³)
			Frozen	Unfrozen	Frozen	Unfrozen	
Moss/Organics	200	1.20	1.38	0.52	1.96	3.36	267
Till	12	2.24	2.59	1.90	0.88	1.10	80
Bedrock	1	2.53	3.00	3.00	0.75	0.77	8

4.2 THERMAL MODEL CALIBRATION AND ANALYSIS RESULTS

One-dimensional calibration thermal analyses were carried out to calibrate the thermal model with the measured ground temperature at BH-03-08. Input data such as snow properties, ground surface conditions and evapotranspiration factor were modified in the calibration analyses to obtain a good agreement between the modelled and measured ground temperatures. Table 4 compares the calibrated ground temperatures with those measured on October 18, 2005 at BH-03-08.

TABLE 4: MEASURED AND MODELLED GROUND TEMPERATURES ON OCTOBER 18, 2005		
Depth below Ground Surface (m)	Measured at BH-03-08 (°C)	Modelled at BH-03-08 (°C)
0.5	-0.7	-0.3
3.5	-2.3	-2.4
7.5	-4.9	-5.3
14.5	-6.0	-6.1

Table 4 indicates that there is generally a good agreement between the measured and calibrated ground temperatures for BH-03-08.

5.0 INITIAL GROUND TEMPERATURES IN CENTRAL LOW-LYING AREA BENEATH DAM FOOTPRINT

It is expected that the initial ground temperatures in the central low-lying area beneath the West Dam footprint are warmer than those measured at BH-03-08 because of two nearby lakes and a small stream flowing intermittently between them through the area during the spring and summer. In addition, a thicker snow cover is expected in the area due to snow drifting off the slope adjacent to the north abutment.

A single-bead thermistor cable was installed on the dam centreline at a depth of 4 m at Station 0+060 in early November 2005. The measured ground temperature was –0.8°C on November 11, 2005. Another single-bead thermistor cable was installed at a depth of 6 m at Station 0+040 in December 7, 2005.

A thermal analysis was carried out to evaluate the thermal influence of the nearby lakes and a thicker snow cover on initial ground temperatures in the low-lying area. The snow depth was assumed to be twice of the mean snow cover. The lakes were simulated as temperature boundaries with assumed lake water temperatures similar to those measured at northern lakes. The soil profile and properties used in the analysis were the same as listed in Table 3.

The thermal analysis estimated that the ground temperature was –0.62°C at a depth of 4 m on November 11 and –0.95°C at a depth of 6 m on December 11. The estimated temperature was almost identical to the measured at the same depth at Station 0+040 but 0.2°C warmer than the measured at Station 0+060, which is further away from the south-facing slope and the stream than Station 0+040.

As a comparison, ground temperatures near lakes at the EKATI Diamond Mine were considered. EBA (2002) reported that a thermistor cable was installed at a location (Borehole BDD-05) near a small stream between two relatively large lakes at EKATI. Table 5 lists both the measured ground temperatures at the EKATI cable and the estimated temperatures from the current thermal analysis on June 5. Table 5 indicates that the estimated ground temperatures are very close to the measured at EKATI but slightly warmer.

TABLE 5: MEASURED AND ESTIMATED NEAR LAKE GROUND TEMPERATURES

Depth below Ground Surface (m)	Measured at Borehole BDD-05 at EKATI on June 5, 2002 (°C)	Estimated on June 5 (°C)	Estimated on January 15 (°C)
-2	-2.9	-2.6	-0.2
-6	-1.9	-1.6	-0.9
-10	-1.3	-1.3	-1.3
-15	-1.7	-1.5	-1.5

In summary, a good agreement between the measured and estimated ground temperatures suggest that the initial ground temperatures in the low-lying area close to the stream is reasonably estimated in the current thermal analysis. The estimated initial ground temperatures on January 15 are also listed in Table 5. These data were adopted as the initial ground temperatures on January 15 prior to the placement of the core for the thermal analyses for the West Dam described in the following sections.

6.0 THERMAL EVALUATION OF WEST DAM

6.1 SOIL INDEX AND THERMAL PROPERTIES

The soil index properties for the construction materials and native soils were estimated based on the geotechnical data from the site investigation and past experience. Thermal properties of the soils were determined indirectly from well-established correlations with soil index properties or based on past experience. Table 6 summarizes the material properties used in the thermal analyses.

TABLE 6: MATERIAL PROPERTIES USED IN THERMAL ANALYSES

Material	Water Content (%)	Bulk Density (Mg/m³)	Thermal Conductivity (W/m-K)		Specific Heat (kJ/kg°C)		Latent Heat (MJ/m³)
			Frozen	Unfrozen	Frozen	Unfrozen	
Shell - Run-of-Mine (unsaturated)	3	2.16	1.66	1.82	0.77	0.83	21
Core – 20 mm Minus	11	2.28	2.94	2.19	0.87	1.07	75
Till Fill (unsaturated)	7	2.14	1.69	1.66	0.82	0.96	47
Transition – 200 mm Minus (unsaturated)	4	2.18	1.84	1.93	0.79	0.87	28
Overburden Till	14	2.17	2.49	1.78	0.90	1.16	89
Bedrock	1	2.53	3.00	3.00	0.75	0.77	8
Shell – Run-of-Mine (saturated)	10	2.31	3.00	2.27	0.86	1.05	70
Till Fill (saturated)	13	2.26	2.77	94	0.89	1.13	87
Transition – 200 mm Minus (saturated)	10	2.31	3.00	2.27	0.80	1.05	70

6.2 CASES SIMULATED AND ASSOCIATED ASSUMPTIONS

A vertical cross-section perpendicular to the axis of the West Dam through its lowest original ground surface (at an elevation of approximately 515.0 m) was simulated in the thermal analyses.

Two cases were evaluated: Case 1 simulated the West Dam without operation of the thermosyphons and Case 2 simulated the West Dam with thermosyphons, as designed in EBA (2005). Table 7 summarizes final cases and runs evaluated in this study. Each of the two cases was evaluated under three climatic scenarios. Runs No. 1 to 4 assumed mean climatic conditions. Run No. 5 evaluated the global warming impacts on the long-term thermal conditions of the dam. Air temperatures associated with the "high sensitivity" scenario of the global warming were used in the analyses. Run No. 6 estimated the maximum thaw depth after two consecutive 1 in 100 warm years. Runs No. 1 to 4 were analyzed to simulate gradual rises of the upstream water elevation with time after the completion of the dam construction (assumed on April 15, 2006). All analyses assumed that the upstream water elevation was maintained at its highest possible level. This is a conservative assumption, as it results in warmer ground temperatures. The operation water levels are expected to be lower than that assumed.

TABLE 7: CASES SIMULATED AND ASSOCIATED ASSUMPTIONS

Case	Run No.	Simulated Time Period	Upstream Water Elevation (m)	Downstream Water Elevation (m)	Air Temperature Assumed
1 (without Thermosyphons)	1	Apr. 15, 2006 to Jun. 1, 2006	≤515.4	≤515.4	Mean
	2	Jun. 1, 2006 to Jun.1, 2007	518.0	≤515.4	
	3	Jun. 1, 2007 to Jun.1, 2008	521.0	≤515.4	
	4	Jun. 1, 2008 to Jun.1, 2016	523.0	≤515.4	
	5	Jun. 1, 2008 to Jun.1, 2016	523.0	≤515.4	"High Sensitivity" Global Warming
	6	Jun. 1, 2008 to Jun.1, 2010	523.0	≤515.4	1 in 100 Warm
2 (with Thermosyphons)	1	Apr. 15, 2006 to Jun. 1, 2006	≤515.4	≤515.4	Mean
	2	Jun. 1, 2006 to Jun.1, 2007	518.0	≤515.4	
	3	Jun. 1, 2007 to Jun.1, 2008	521.0	≤515.4	
	4	Jun. 1, 2008 to Jun.1, 2016	523.0	≤515.4	
	5	Jun. 1, 2008 to Jun.1, 2016	523.0	≤515.4	"High Sensitivity" Global Warming
	6	Jun. 1, 2008 to Jun.1, 2010	523.0	≤515.4	1 in 100 Warm

A water/ice temperature boundary was applied on both the upstream and downstream sides of the original ground and dam surfaces below the assumed water elevations. The assumed water temperature was based on measured lake water temperatures in northern lakes and past experience in design some frozen core dams at EKATI Diamond Mine (EBA, 2003). Table 8 lists assumed water temperatures for shallow lakes (≤ 1.5 m deep) and deep lakes (> 1.5 m deep).

TABLE 8: ASSUMED WATER TEMPERATURES IN THERMAL ANALYSES												
Lake Depth	Mid-Month Lake Water Temperature (°C)											
	J	F	M	A	M	J	J	A	S	O	N	D
≤ 1.5 m	0	-1	-1	-1	1	3	15	14	5	2	1	0.5
> 1.5 m	2	2	2	2	2	4	10	14	7	3	2	2

Climatic conditions were applied at the surfaces exposed to air. The snow cover on the dam was assumed to be affected by wind and snow drifting from the top nearby south-facing slope and estimated based on past experience. The assumed snow cover on the dam crest was 50% of the mean monthly snow cover and on the downstream slope increased linearly to six times the mean monthly snow depth at the downstream toe. The assumed snow cover on the upstream slope varied due to the presence of the bench at the elevation of 524.0 m. The snow cover varied from 50% at the crest to four times at the toe of the slope above 524.0 m bench and one times at the crest of the 524.0 m bench to four times at the lower toe of the upstream slope.

The initial temperatures of the dam construction materials on April 15, 2006 were assumed to be -2°C, which is similar to the measured frozen core temperatures at the Outlet Dam at EKATI (EBA, 1998). The actual fill temperatures will vary depending on the construction sequence and climatic conditions during the dam construction. The initial temperatures for the original ground on April 15, 2006 were estimated in a separate thermal analysis based on the initial temperatures on January 15, 2006 presented in Table 5 and an assumed constant fill temperature of -2°C from January 15 to April 15, 2006. Prior to impoundment, the upstream shell (run-or-mine), till fill, and upstream transition zone (200 mm minus) materials are mostly in frozen conditions; however, water will infiltrate the upstream dam shell as water rises against the dam. It was assumed that impounded water will seep through the shell and till fill into the originally unsaturated transition zone in front of the frozen core, thereby raising the temperature of these materials. The temperatures of these materials upon initial submergence were assumed to be 0.5 °C on June 1.

6.3 THERMOSYPHON SIMULATION

A thermosyphon is a passive heat transfer device that operates by convection through vaporization and condensation. It consists of a sealed vessel with an upper part working as a condenser and a buried part in the ground functioning as an evaporator. Heat transfer is driven by the temperature difference across the unit. For ground cooling applications, thermosyphons remove heat from the ground beneath a structure and release it to the outside ambient air, as long as the air is colder than the ground. A more detailed description of thermosyphon technology is presented in Yarmak and Long (2002).

The thermosyphons were simulated as convective heat flux boundary. The inside diameter of the evaporators was assumed to be 20 mm. The convective heat transfer characteristics of the thermosyphons were based on empirical expressions established from laboratory experiments of full-scale horizontal thermosyphons (Haynes and Zarling, 1988). A convective heat transfer coefficient of 11.5 W/(m^2. ^{o}C) was calculated based on an effective horizontal evaporator length of 206 m in the south abutment area, a radiator size of 39 m^2, and a design wind speed of 5 km/h. This coefficient was used in the thermal analyses for Runs No. 2 to 6 of Case 2. It was assumed that thermosyphons are not in operation until the 2006 winter. The evaporator length for the thermosyphons in the north abutment area is shorter which may result in a higher value of the convective heat transfer coefficient and therefore colder ground temperatures.

6.4 RESULTS AND DISCUSSION

6.4.1 Results for Case without Thermosyphons

The thermal analyses indicate that the ground temperatures of the core and key trench fill were the warmest in early December for the Runs without thermosyphons (Case 1 and Run No. 1 of Case 2). The predicted temperature distributions under mean climatic conditions in early December 2006, 2008, and 2014, respectively, for Case 1 are shown in Figures 1 to 3. The results indicate that the trench fill, the upstream portion of the core, and the underlying till overburden and bedrock gradually warm with time by the end of 2008 due to gradually rising of the upstream water level. However, there is a slightly cooling trend with time after that time, as indicated in Figures 2 and 3. The predicted temperatures in the core and trench fill are colder than 0^{o}C through the life of the mine (2014). The predicted temperatures are generally colder than -1^{o}C in the trench fill in 2006 but warmer than -1^{o}C in the upstream portion of the trench in December after 2006.

Figure 4 shows the predicted temperature distribution in early December of 2014 under the "high sensitivity" global warming conditions for Case 1. The predicted ground temperatures for global warming case are slightly warmer than those for the mean climate case (Figure 4 compared to Figure 3).

Thermal analysis results indicate that the thaw depth below the dam surface will be deepest in early October. The predicted ground temperatures in early October of 2009 after two consecutive 1:100 warm years are shown in Figure 5. The top of the core remains in frozen conditions at its warmest time. The predicted maximum thaw depth below the dam surface at the top core centerline is 3.2, 3.4, and 3.8 m under the air temperatures of mean, "high sensitivity" global warming, and 1:100 warm year conditions, respectively.

6.4.2 Results for Case with Thermosyphons

The thermal analyses indicate that the ground temperatures of the core and key trench fill were generally the warmest in early October for the Runs with thermosypnons (Runs No. 2 to 6 of Case 2). Figures 6 and 7 present predicted temperature distributions under mean climatic conditions in early October 2008 and 2014, respectively, for Case 2. The results suggest that the core, trench fill, and the underlying till overburden and bedrock become colder with time. The predicted temperatures in the majority of the core and trench are colder than -1°C in 2006 and -1.5°C after 2006. The predicted temperatures in the downstream portion of the core and trench fill are colder than –2.0°C after 2006.

Figure 8 shows the predicted temperature distribution in early October of 2014 under the "high sensitivity" global warming conditions for Case 2. The predicted ground temperatures for global warming case are slightly warmer than those for the mean climate case (Figure 7). Nevertheless, the core and trench fill still cool with time under the global warming scenario.

The predicted maximum thaw depths below the dam surface at the top core centerline for Case 2 are slightly less than those for Case 1 and 3.1, 3.2, and 3.7 m under the air temperatures of mean, "high sensitivity" global warming, and 1:100 warm year conditions, respectively.

Figure 9 compares the predicted temperature history at the middle of the trench bottom for Case 1 with that for Case 2. This figure clearly shows the trends of the predicted temperature at the selected location for the two cases.

6.4.3 Discussion on Results

Preliminary thermal analyses and past experience suggest that the assumed initial temperatures of both the original ground and fill materials greatly affect their predicted temperatures in later years. In the current thermal analyses, the assumed initial temperatures are generally conservative for the following reasons:

- The section simulated has the warmest initial ground temperatures prior to the dam construction. The initial ground temperature at other sections along the dam axis would be colder.
- The initial ground temperature in the area adjacent to the open trench would be colder than the assumed because of the extended period of time when the ground exposed to cold air and snow clearing after the trench excavation but before the fill placement.
- The initial fill temperature can be colder than the assumed depending on the actual climatic conditions and specific construction sequence during the dam construction.

The water elevation assumptions in Table 7 are generally conservative. The actual upstream water elevation is expected to be lower than the assumed values. As a result, the actual ground temperatures for the upstream portion of the dam would be colder than predicted.

6.5 CONCLUSIONS AND RECOMMENDATION

Thermal analysis results indicate that the predicted temperatures in the majority of the core and trench fill are warmer than –1.5°C at their warmest period of time for the West Dam without operation of the thermosyphons. The predicted warm temperatures may not meet the design thermal criterion of –2.0°C for the critical zone in the core and trench. The operation of the as-designed thermosyphons during and after the 2006 winter can maintain the critical zone cold enough throughout the mine life and meet the design criterion.

The assumptions used in the thermal analyses are generally conservative. The actual ground temperatures can be colder. Therefore, it is recommended that the as-designed thermistor cables be immediately installed after the completion of the shell fill placement. The dam temperatures be monitored and then reviewed prior to the 2006 winter. If the measured data indicate that the actual dam temperatures are much colder than the predicted, further thermal analyses can be conducted using the measured temperatures as initial inputs to evaluate the long-term dam thermal conditions without the operation of the thermosyphons.

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FIGURES

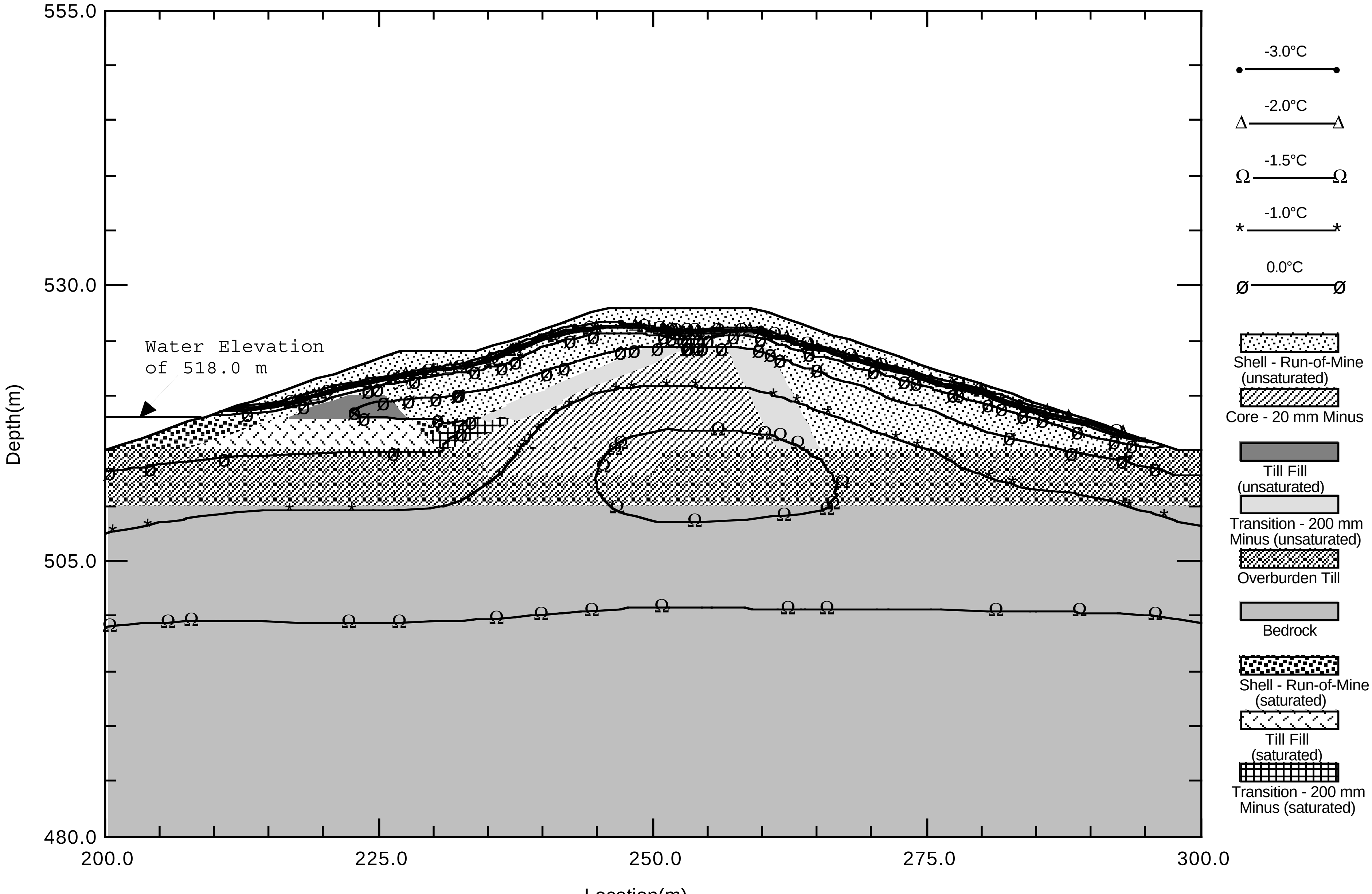

Figure 1

Predicted Isotherms in Early December of 2006
West Dam without Thermosyphons under Mean Climatic Conditions

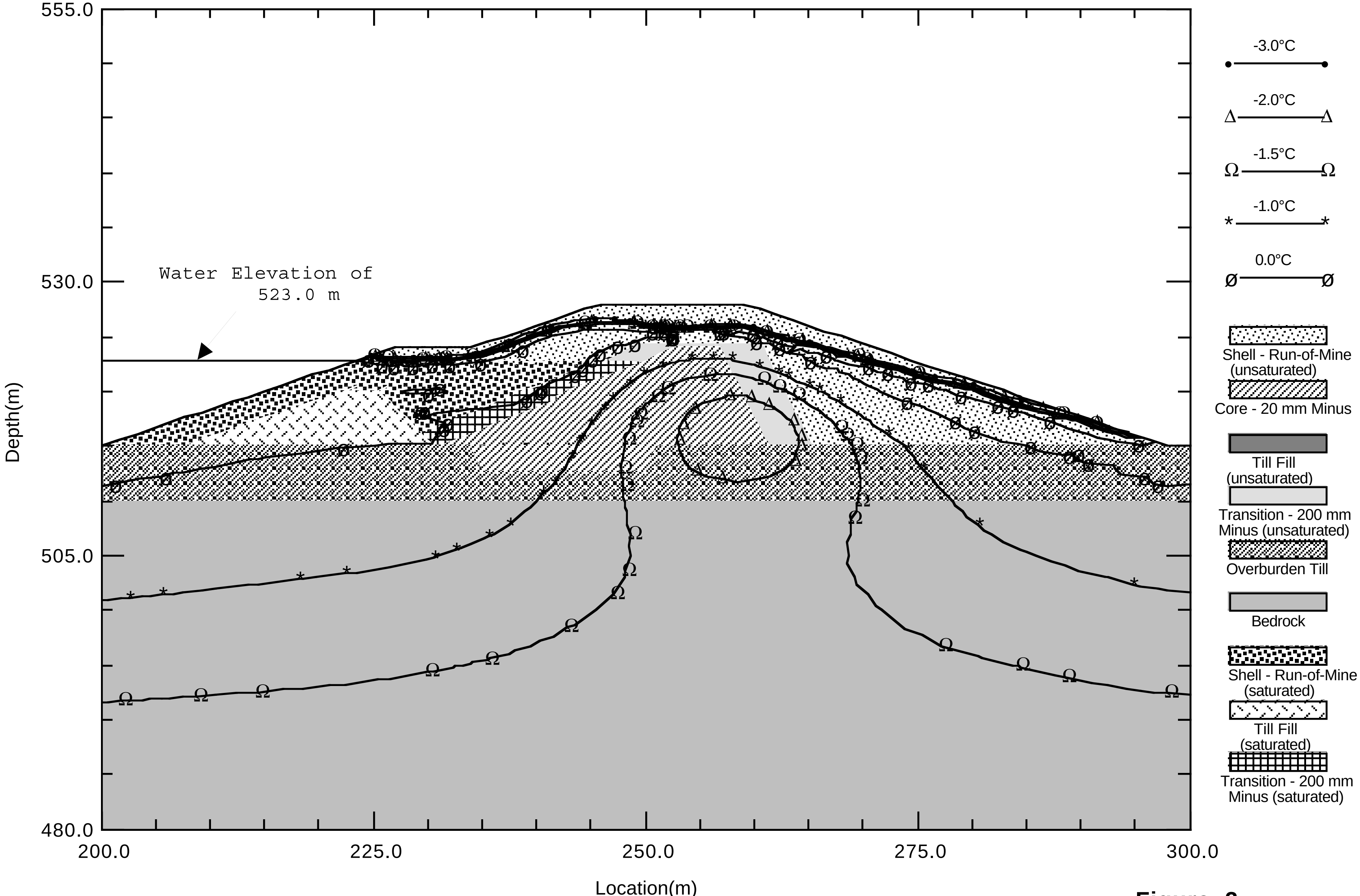

Figure 2

Predicted Isotherms in Early December of 2008
West Dam without Thermosyphons under Mean Climatic Conditions

eba

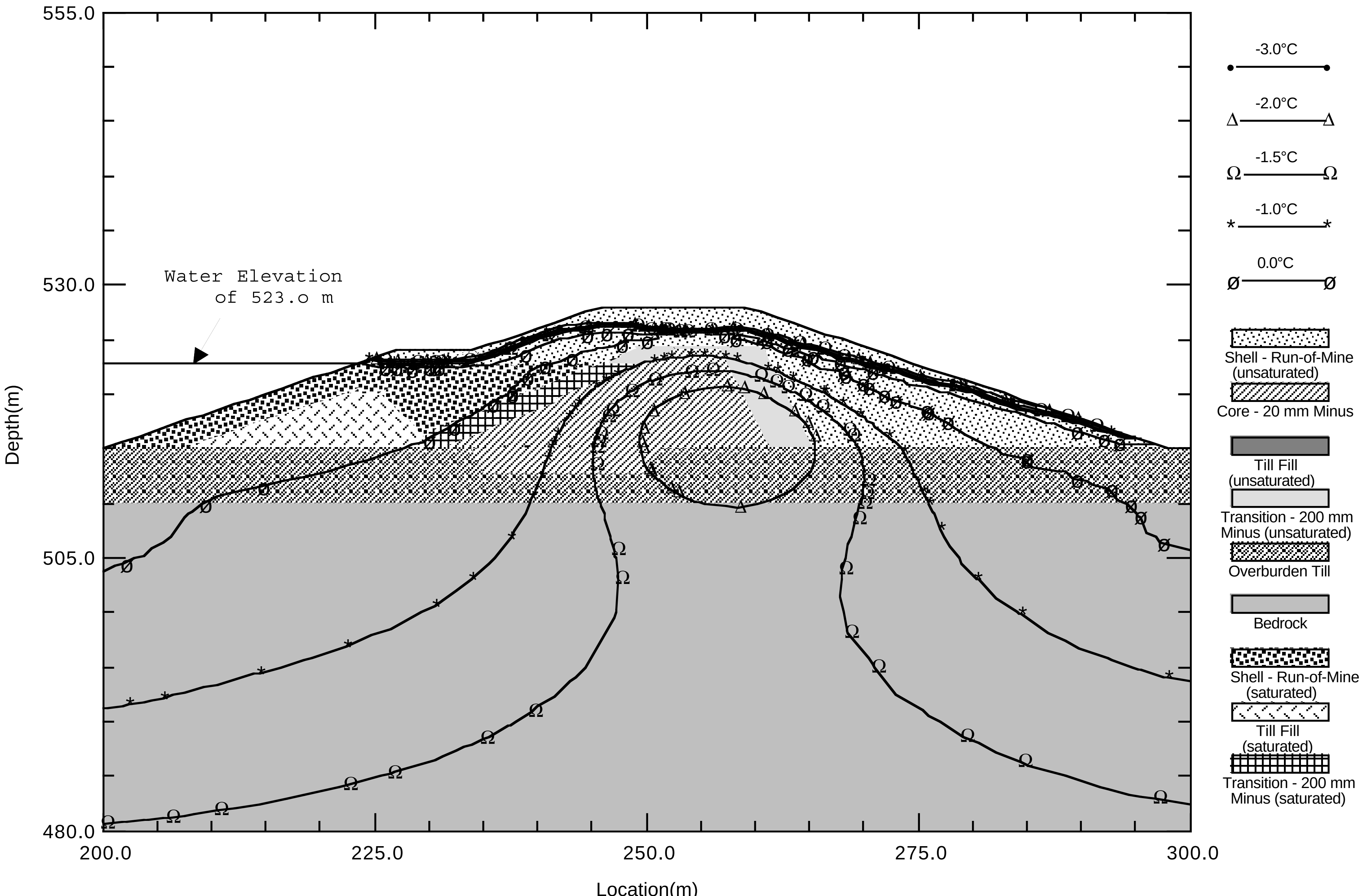

Figure 3

Predicted Isotherms in Early December of 2014
West Dam without Thermosyphons, under Mean Climatic Conditions

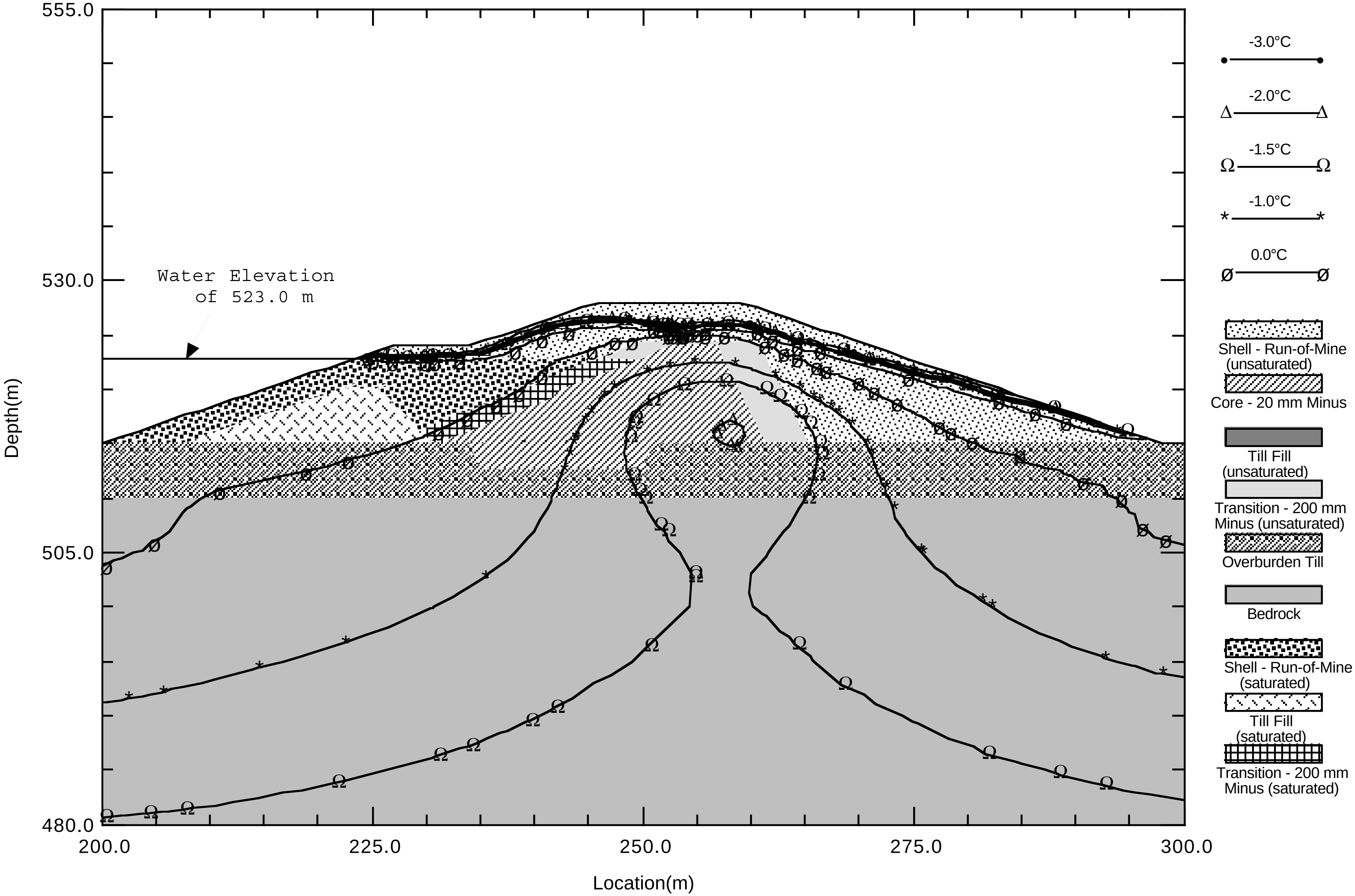

Figure 4

Predicted Isotherms in Early December of 2014
West Dam without Thermosyphons under "High Sensitivity" Global Warming Conditions

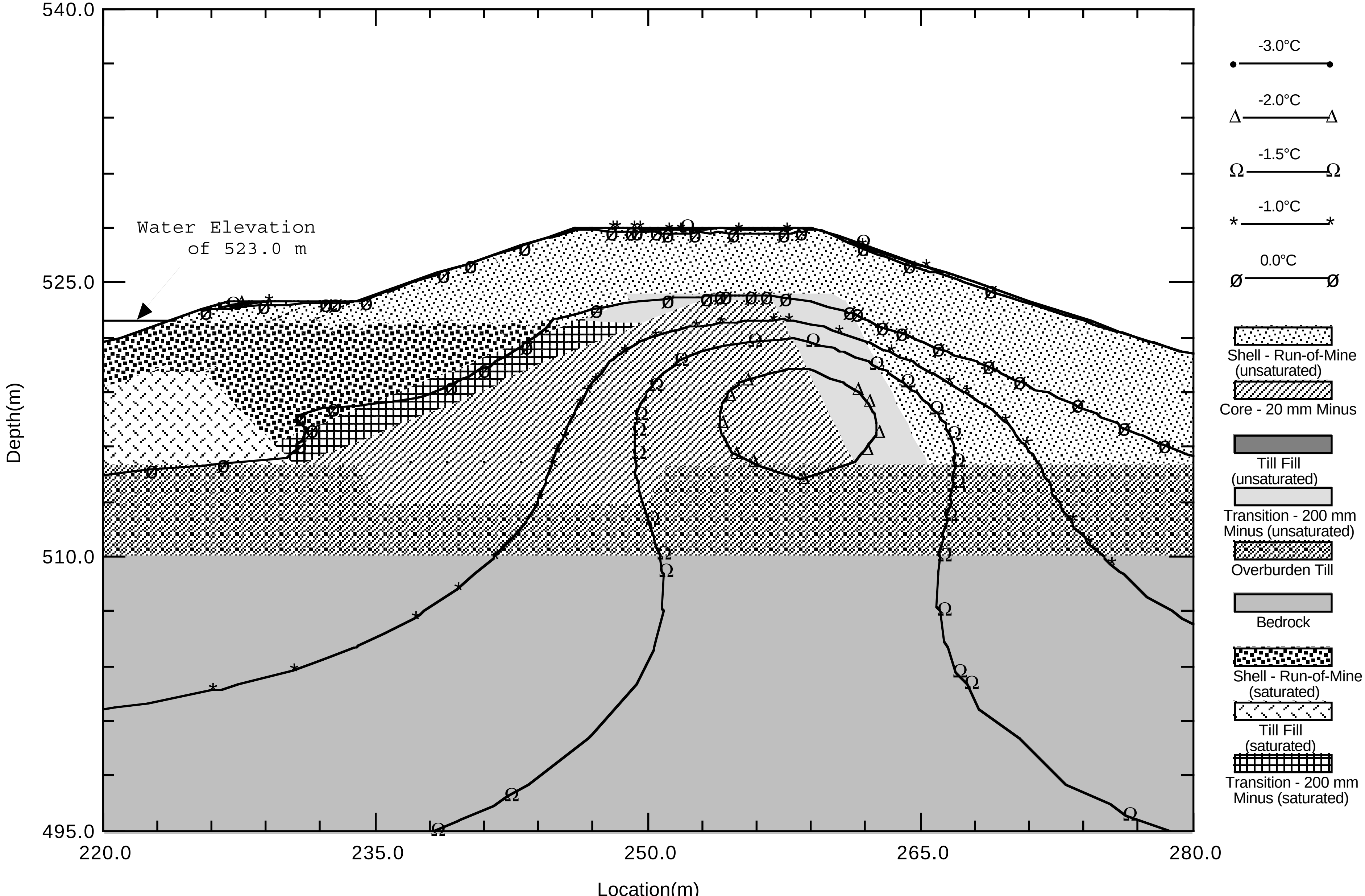

Figure 5

Predicted Isotherms and Maximum Thaw Depth in Early October of 2009
West Dam without Thermosyphons under Two Consecutive 1:100 Warm Years after June 1, 2008

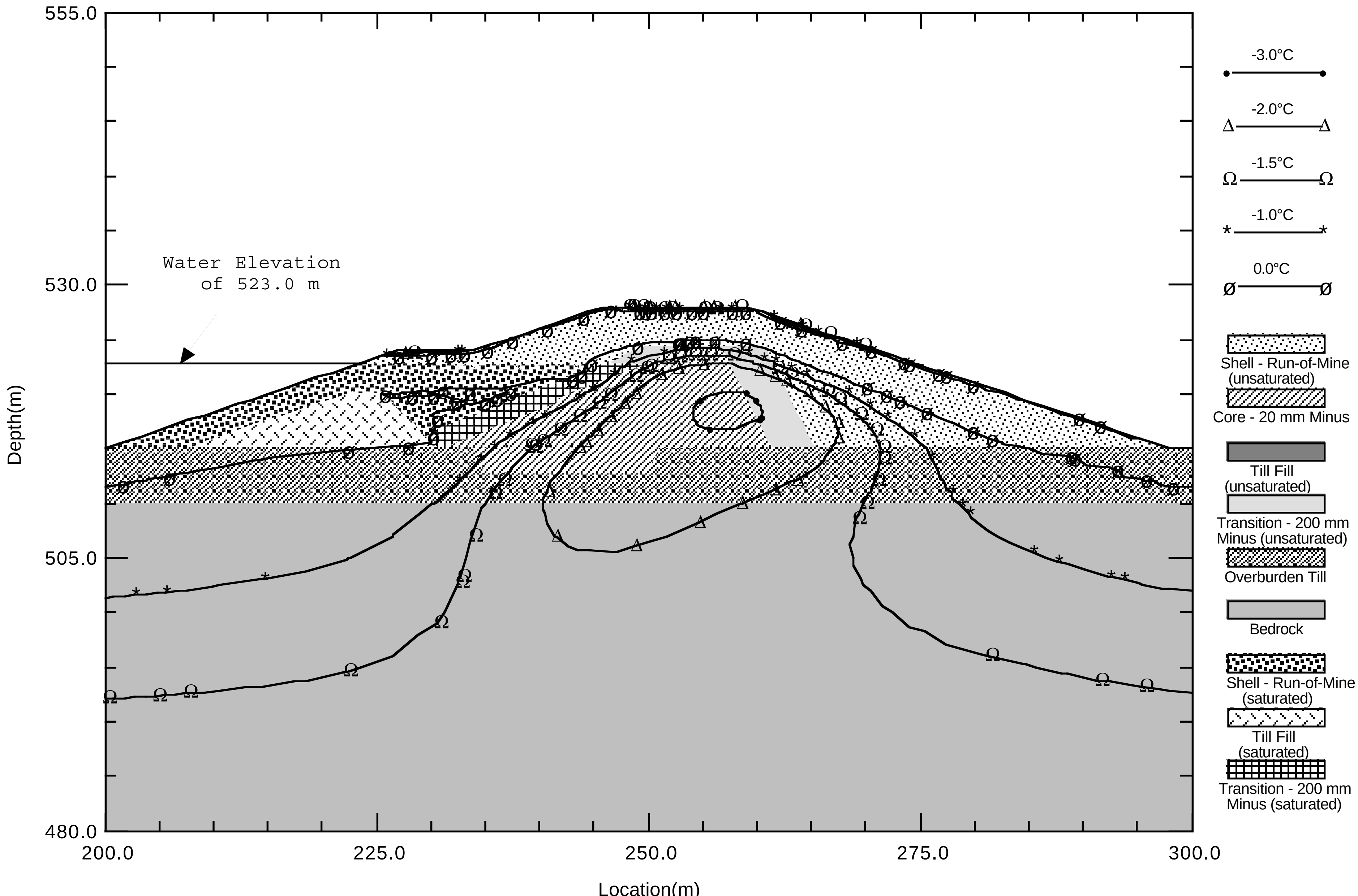

Figure 6

Predicted Isotherms in Early October of 2008

West Dam with Operation of Thermosyphons after 2006 Winter under Mean Climatic Conditions

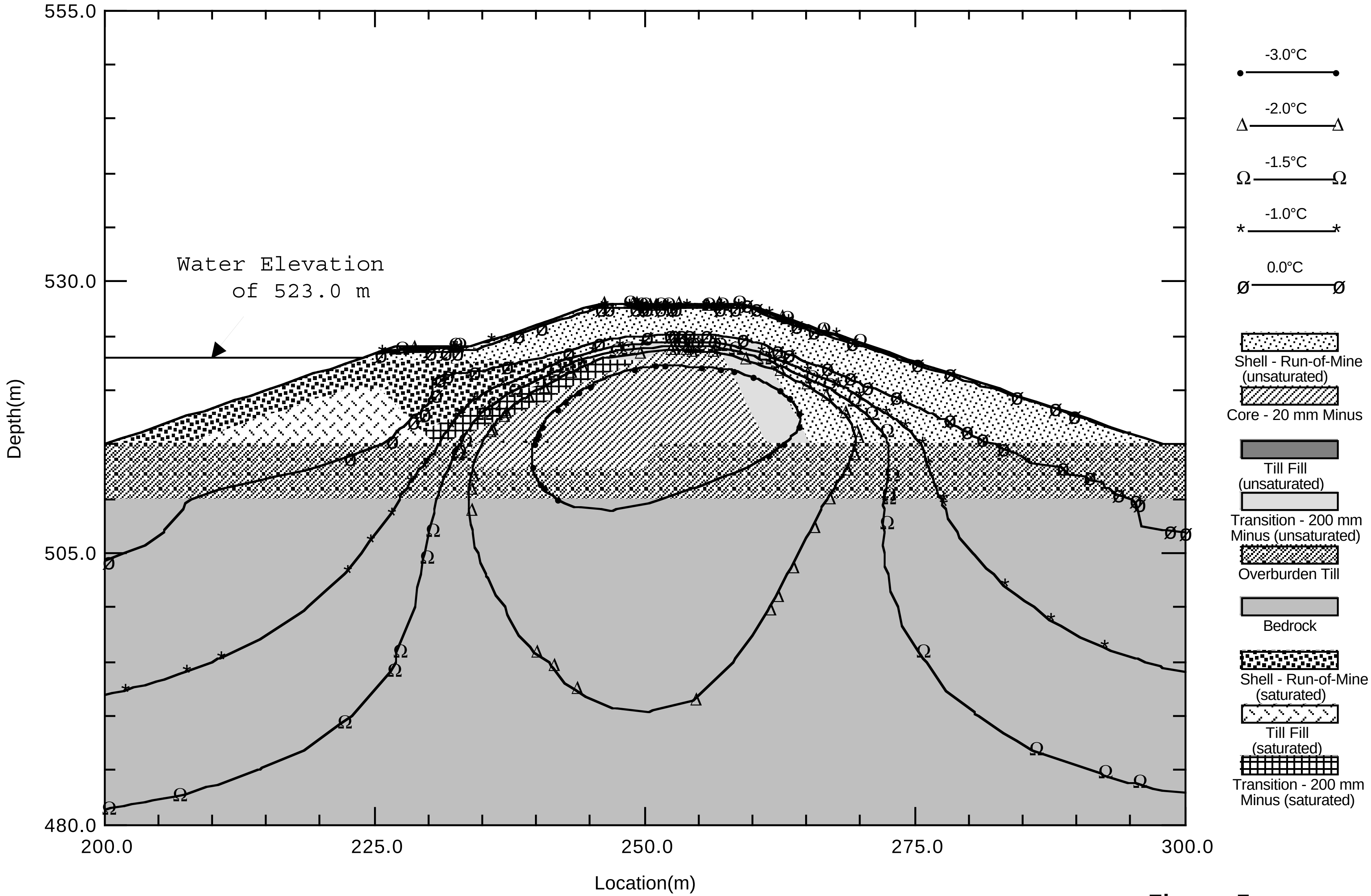

Figure 7

Predicted Isotherms in Early October of 2014

West Dam with Operation of Thermosyphons after 2006 Winter under Mean Climatic Conditions

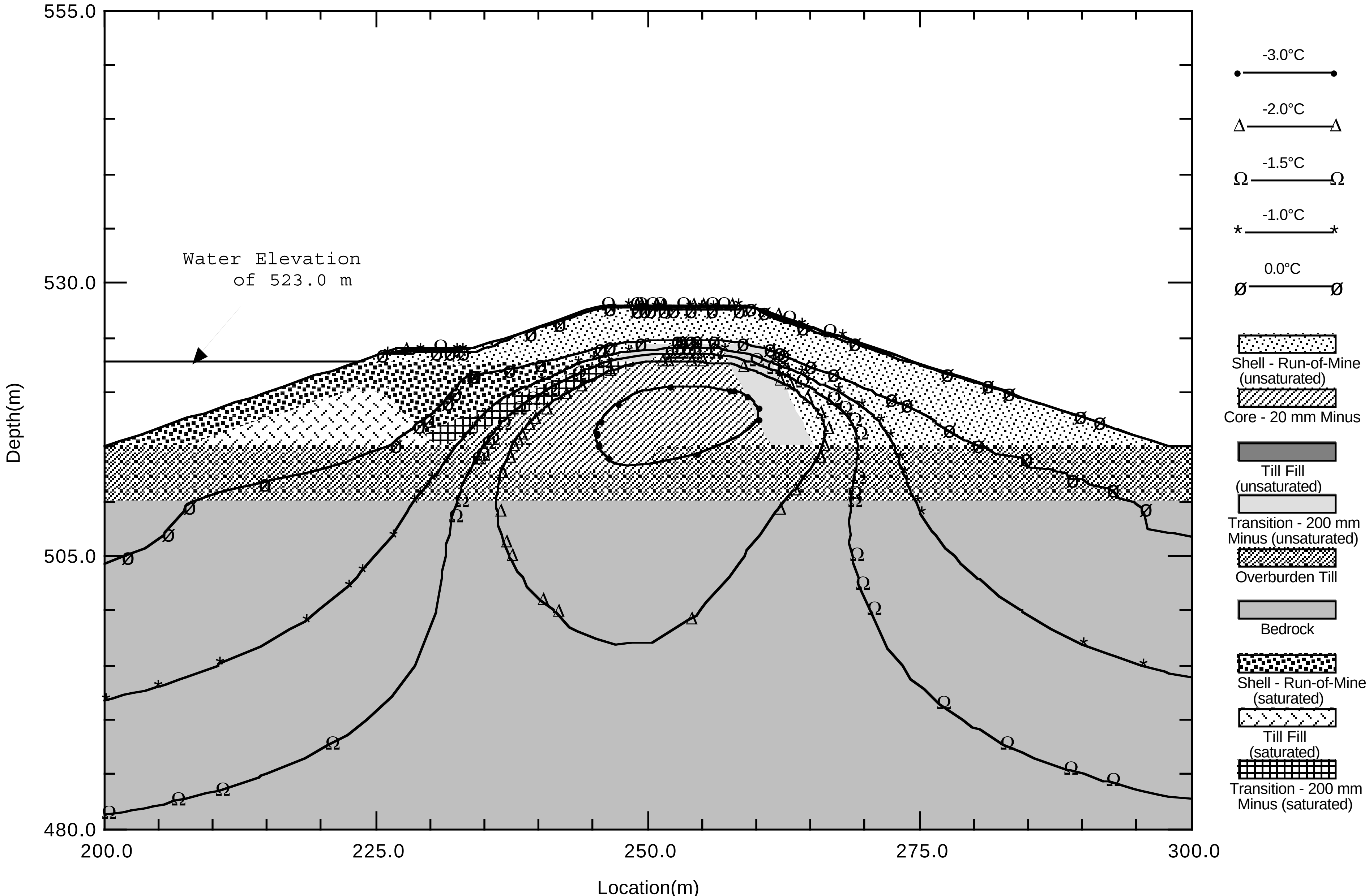

Figure 8

Predicted Isotherms in Early October of 2014

West Dam with Operation of Thermosyphons after 2006 Winter under “High Sensitivity” Global Warming Conditions

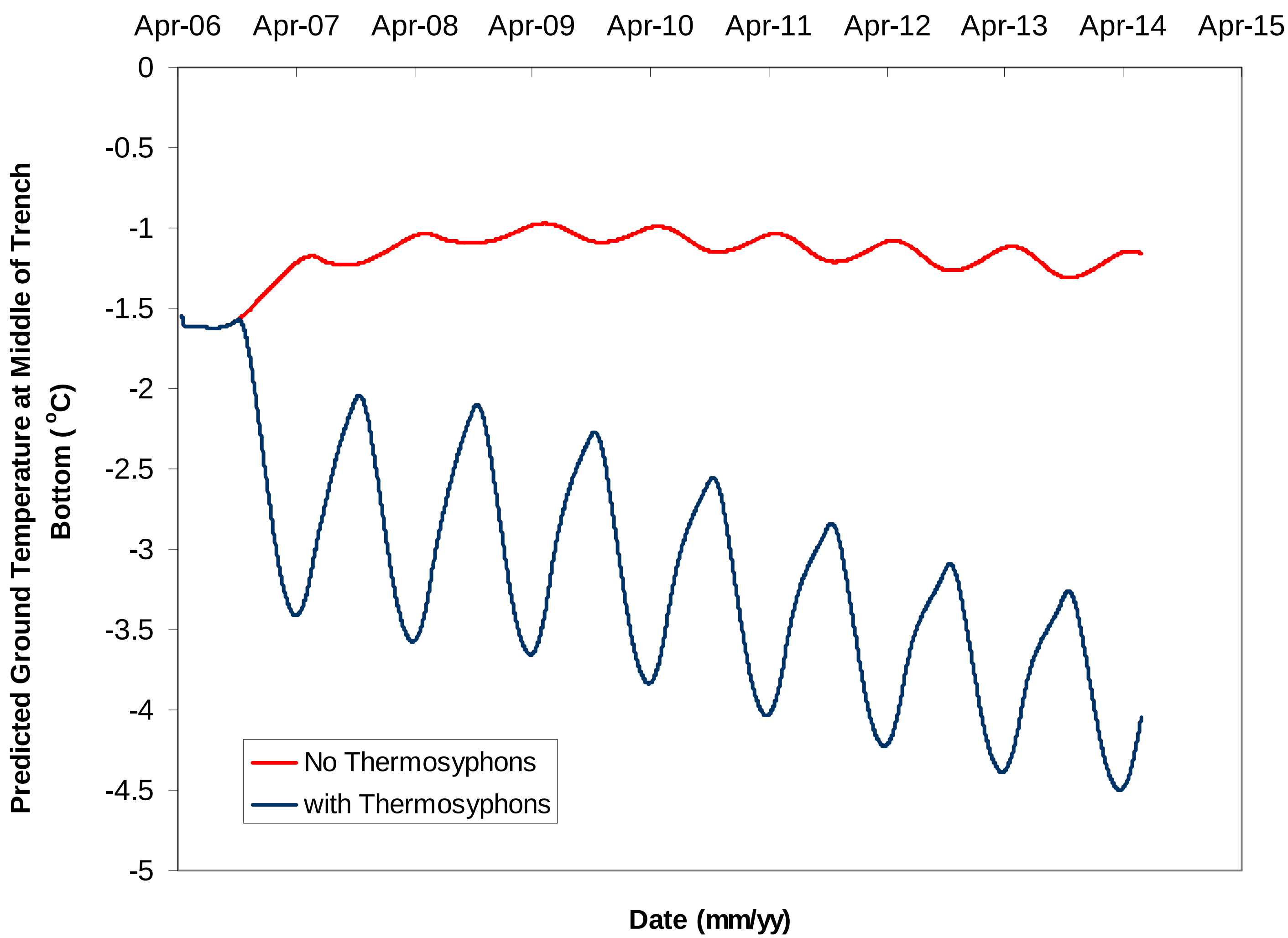

Figure 9
Comparison of Predicted Temperature History at Middle of Trench Bottom for West Dam Without and With Thermosyphons

APPENDIX

APPENDIX B WEST DAM STABILITY ANALYSIS PLOTS

(Note: Plots are for analyses described in Jericho West Dam Design Report (EBA, 2005).)

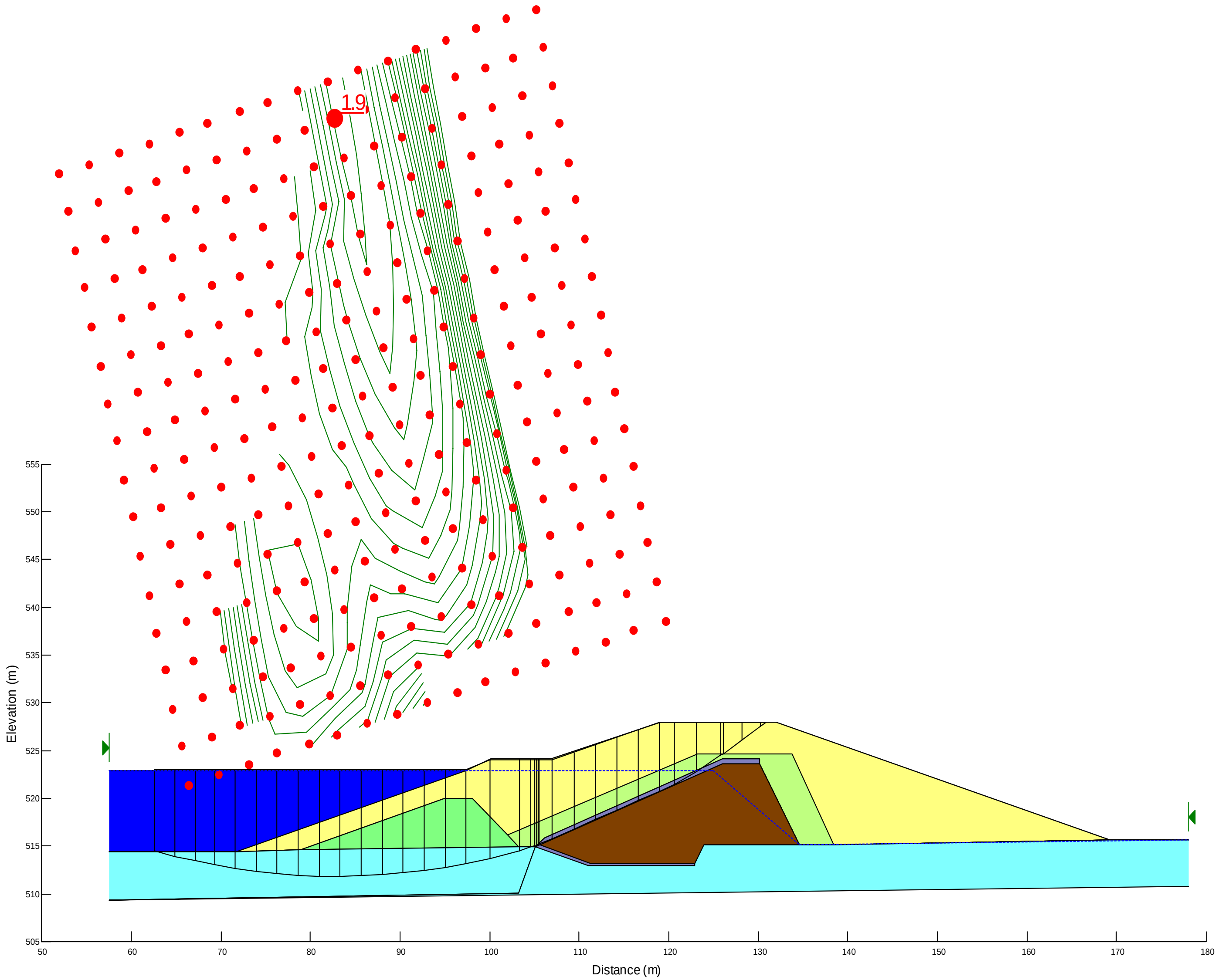

Figure 1

Stability Analysis - Upstream, Static, Effective Stress for Foundation Till

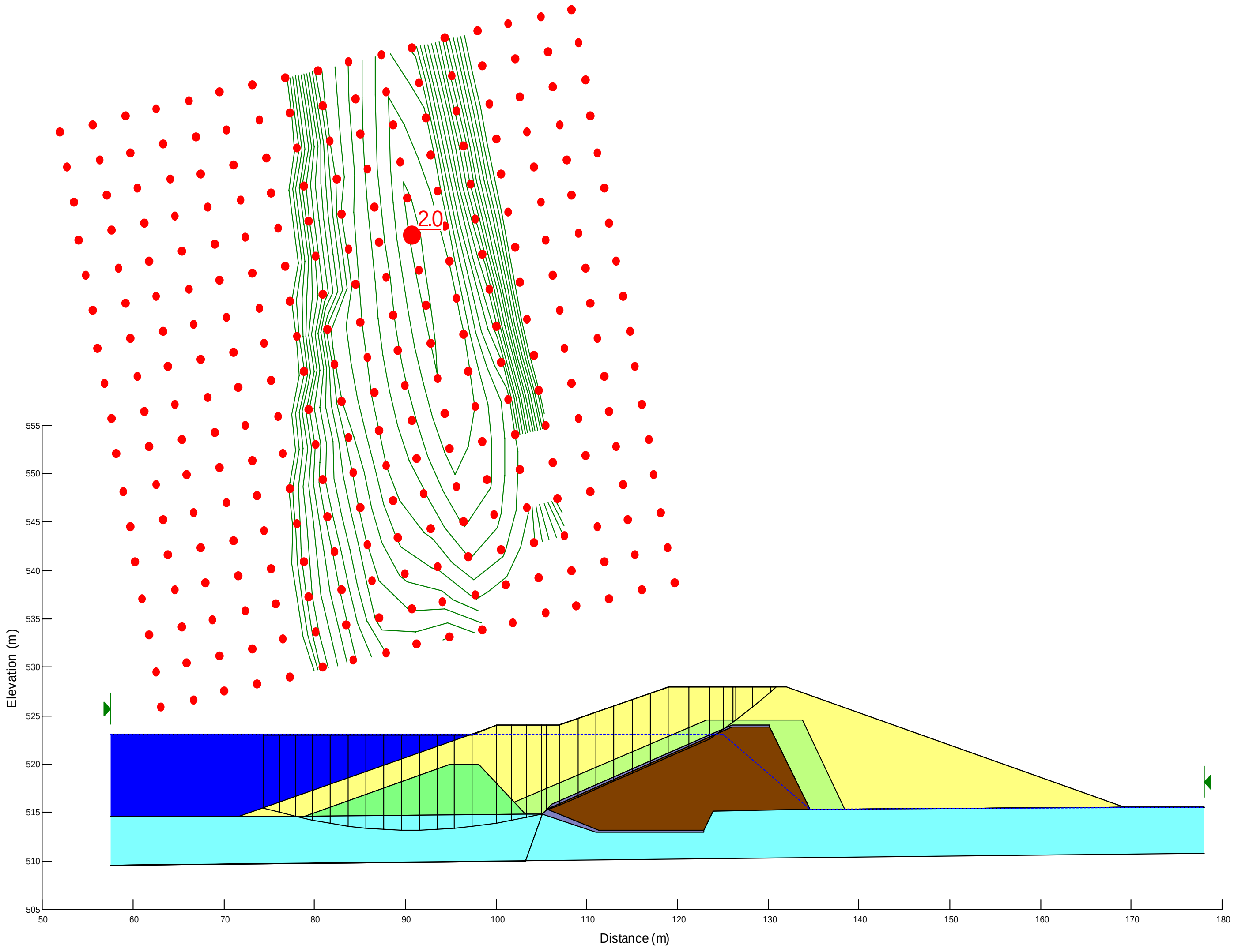

Figure 2

Stability Analysis - Upstream, Static, Total Stress for Foundation Till

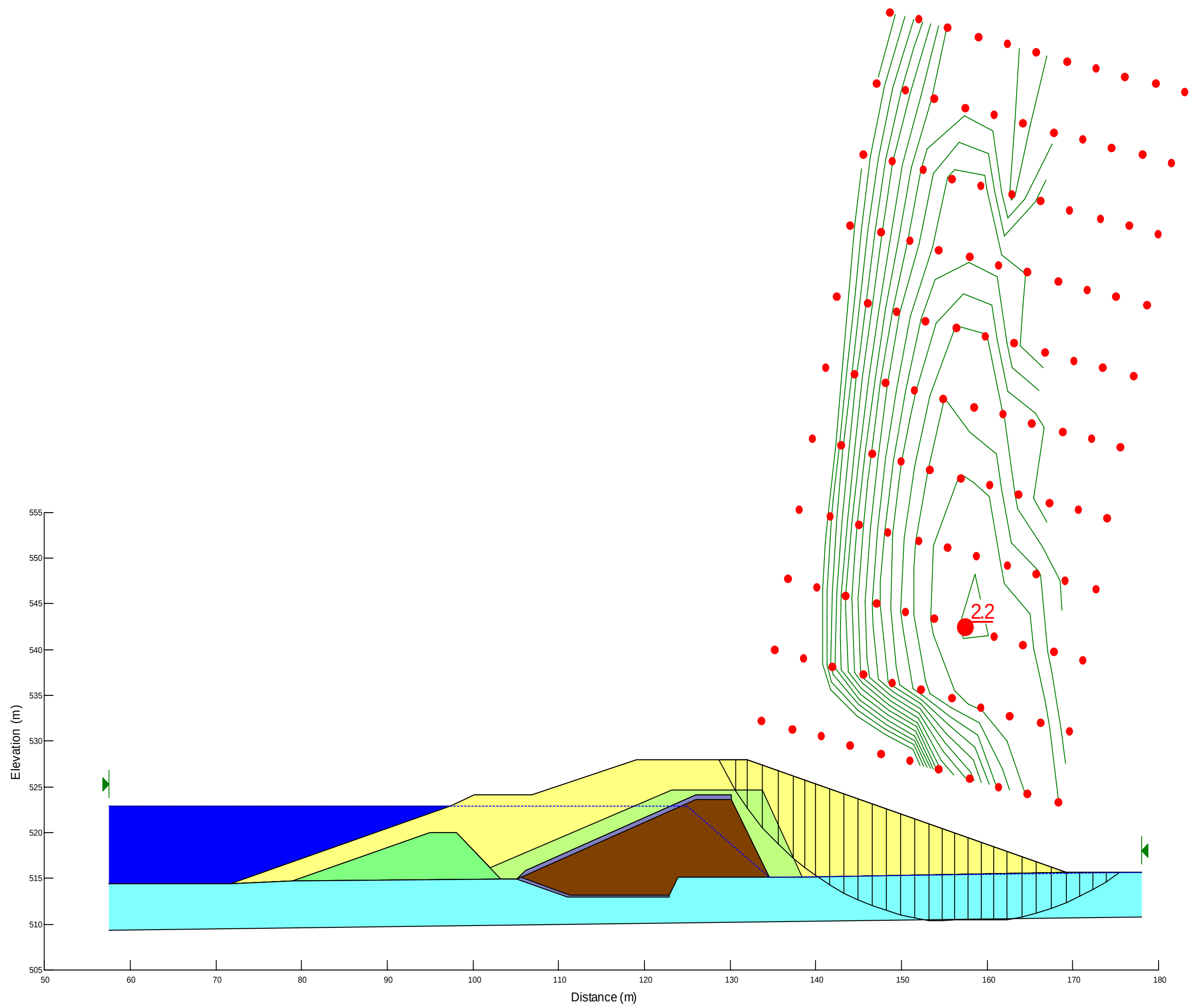

Figure 3

Stability Analysis - Downstream, Static, Effective Stress for Foundation Till

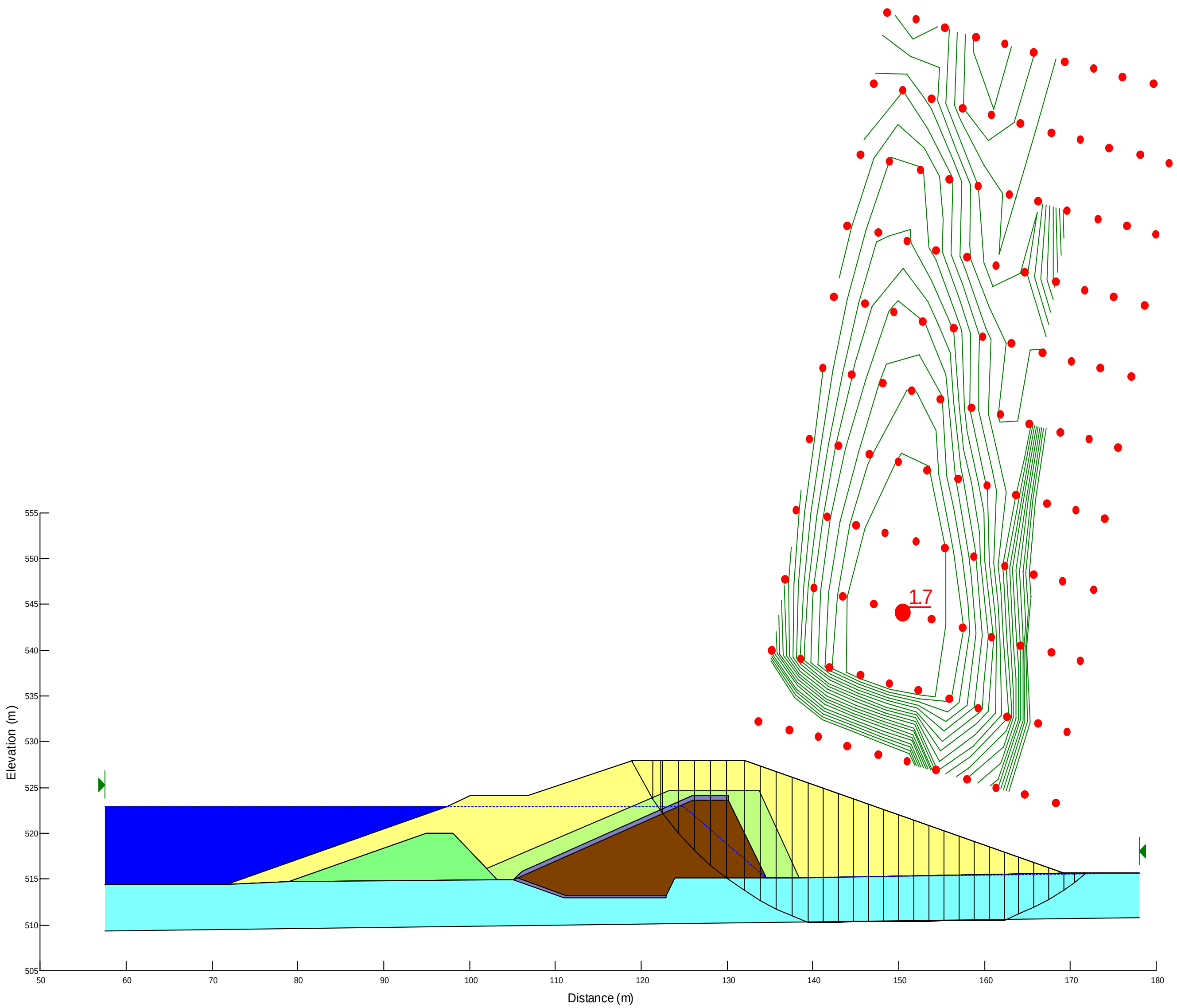

Figure 4

Stability Analysis - Downstream, Static, Total Stress for Foundation Till

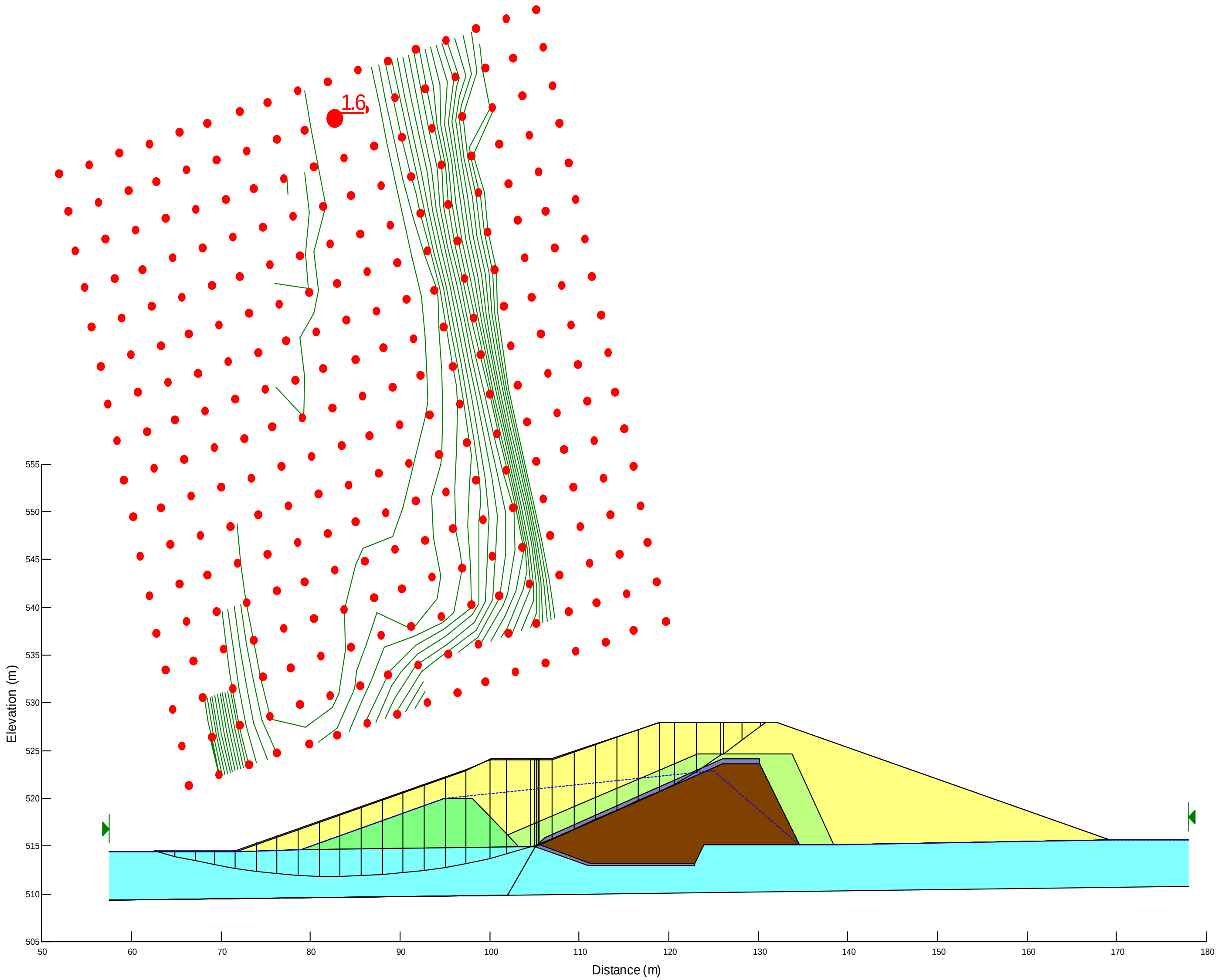

Figure 5

Stability Analysis - Upstream, Static, Rapid Drawdown of Reservoir, Effective Stress for Foundation Till

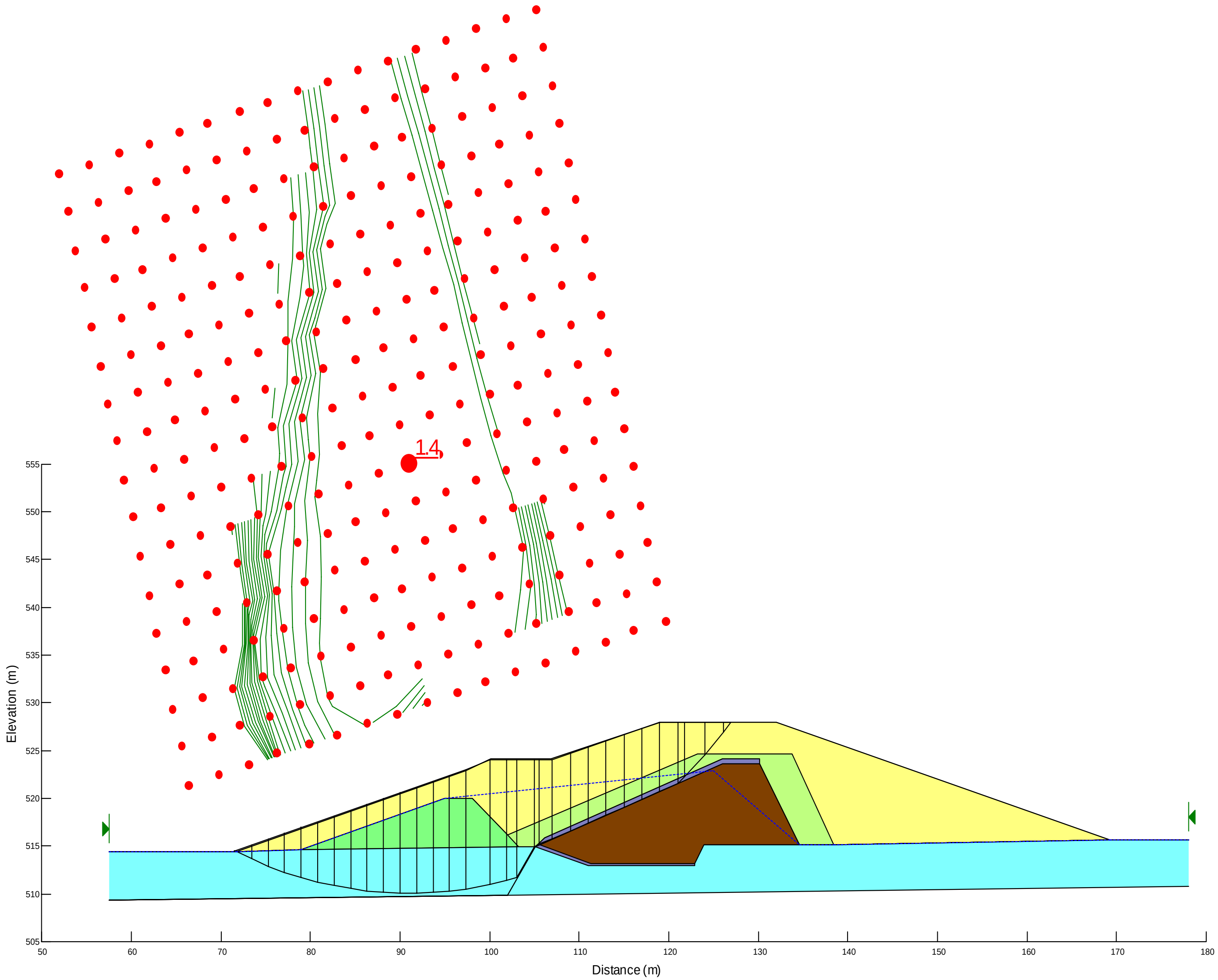

Figure 6

Stability Analysis - Upstream, Static, Rapid Drawdown of Reservoir, Total Stress for Foundation Till

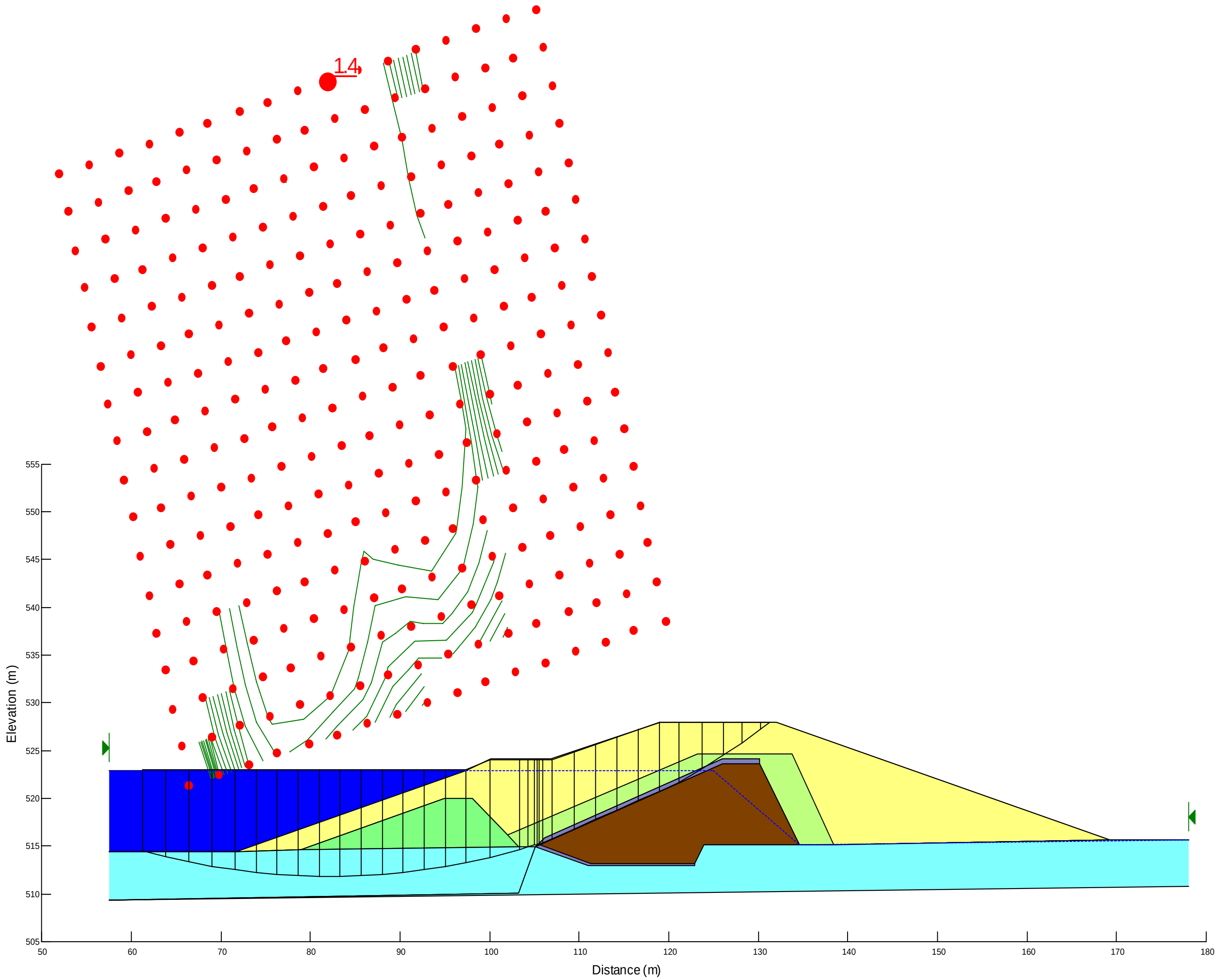

Figure 7

Stability Analysis - Upstream, Seismic, Effective Stress for Foundation Till

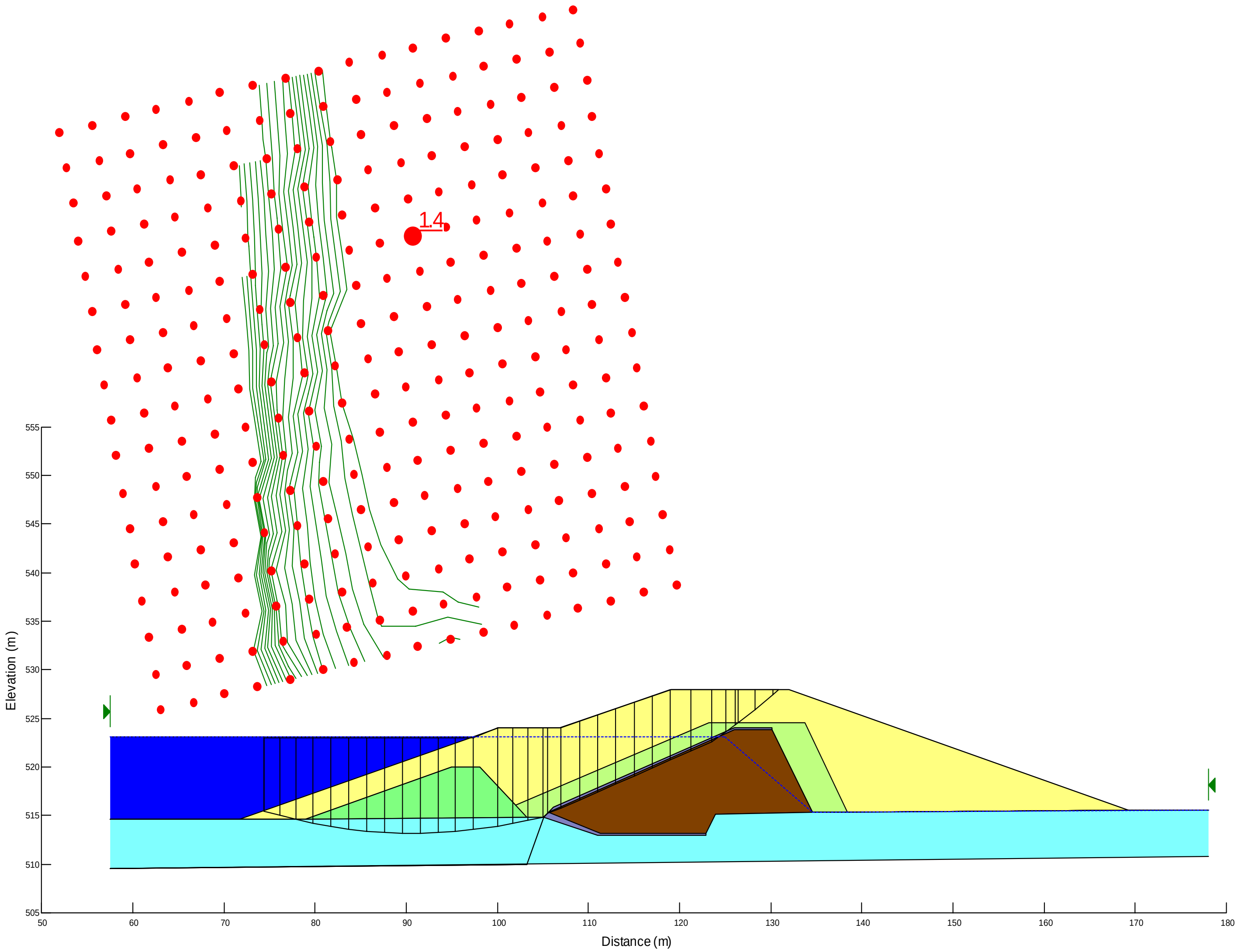

Figure 8

Stability Analysis - Upstream, Seismic, Total Stress for Foundation Till

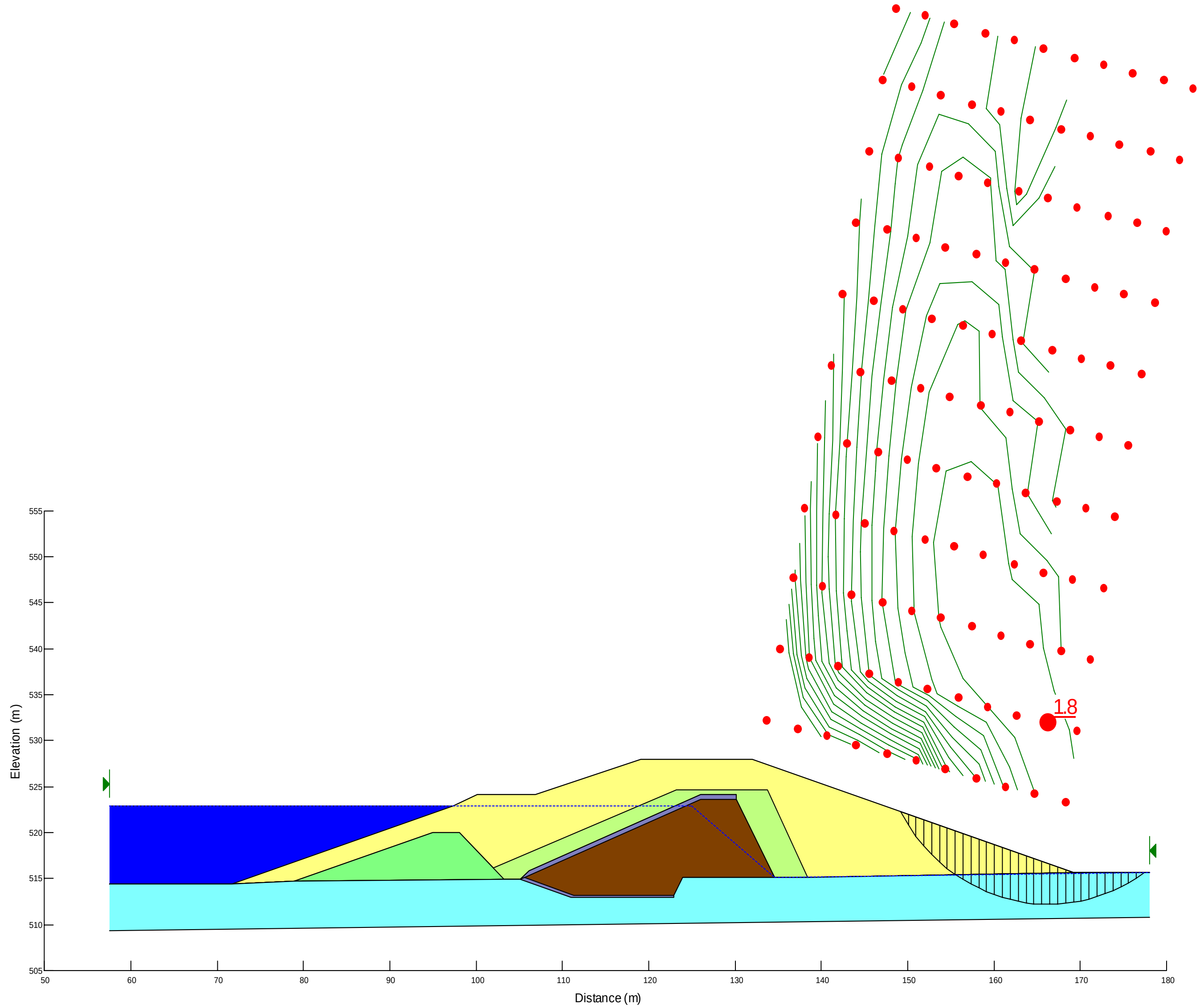

Figure 9

Stability Analysis - Downstream, Seismic, Effective Stress for Foundation Till

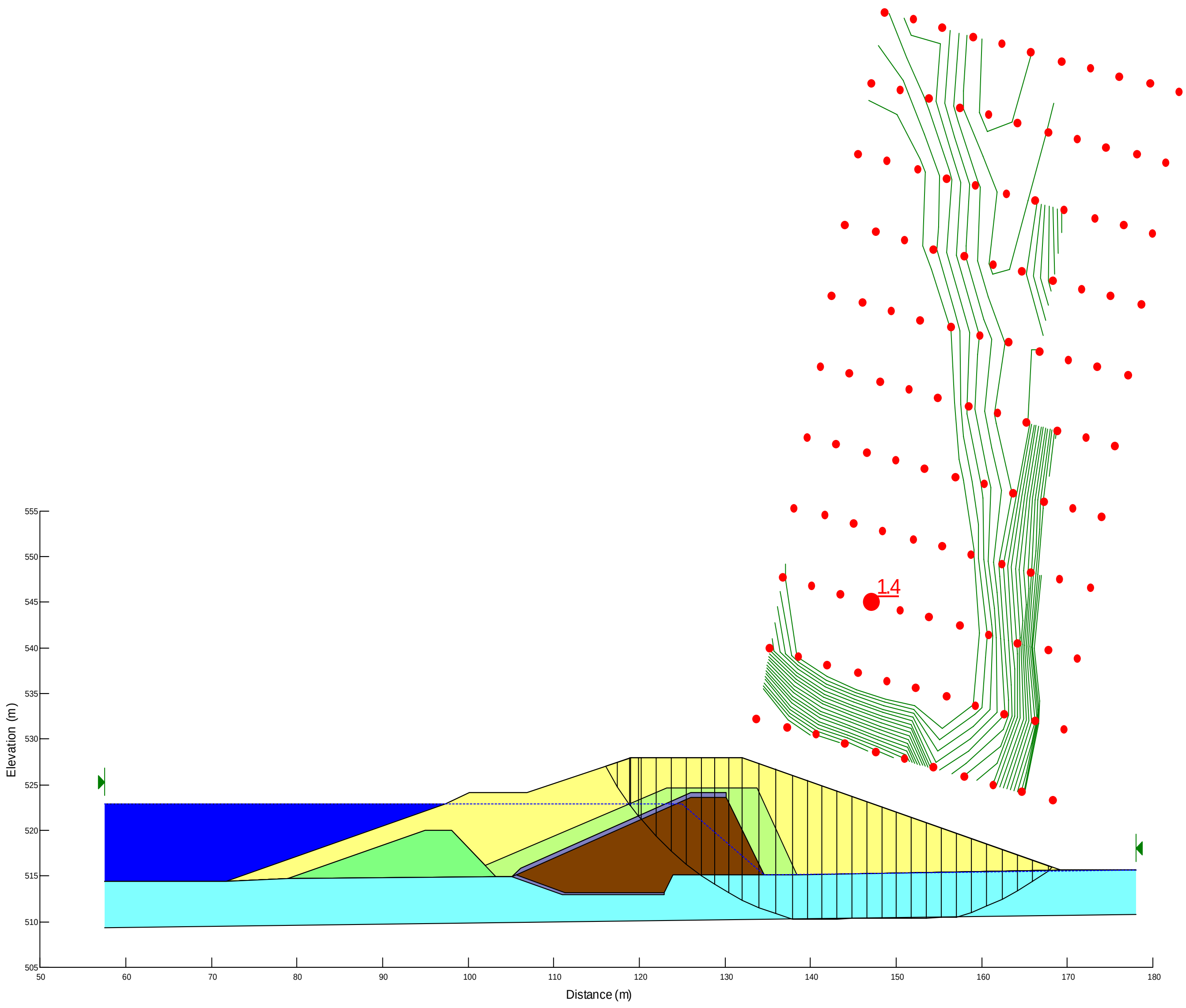

Figure 10

Stability Analysis - Downstream, Seismic, Total Stress for Foundation Till