I. Holubec Consulting Inc.

GEOTECHNICAL, SEEPAGE AND WATER BALANCE

Volume I

Of

SEEPAGE AND WATER QUALITY FOR RECLAIMED TAILINGS CONTAINMENT AREA

Lupin Operation

Report prepared for:

Kinross Gold Corporation

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1.0 INTRODUCTION

A closure plan for Tailings Containment Area (TCA), Lupin Operation, Kinross Gold Corporation was prepared with the assistance of I. Holubec Consulting Inc., January 2005. A closure design that protects the environment in both continuous permafrost and no-permafrost for the tailings containment is required because climate warming is raising the air temperature at the site. As such, the closure plan was designed for the permafrost conditions that currently exist, as well as for a later period, should permafrost thaw due to climate warming.

Seepage and Water Quality assessment for the reclaimed Tailings Containment Area are given in three volumes, namely: I) Geotechnical, Seepage and Water Balance; II) Water Management after Closure, and III) Geochemistry and Water Quality. Information that is presented in these three reports is:

I) Geotechnical, Seepage and Water Balance

- Description of the tailings containment area (TCA), tailings' physical properties, closure design and water management, after TCA reclamation is completed.
- Seepage analyses through thawed tailings to estimate the volume of unsaturated tailings.

II) Water Management after Closure

- Shows the direction of flows within the TCA after closure
- Estimates the maximum design flows at key points after closure
- Shows the location of discharge channels and provides cross section designs

III) Geochemistry and Water Quality

- Geochemistry and water quality of the present TCA.
- Geochemistry of the unsaturated tailings and seepage water quality.
- Water quality throughout the TCA and prediction of the water quality at the discharge point of the TCA.
- Assessment of the water quality on the downstream aquatic life.

This report represents Volume I of the 3 volumes.

2.0 TCA and tailings properties

2.1 TCA

The TCA was developed in an area with numerous shallow lakes and marsh-like depressions. The drainage pattern is poorly defined but ultimately the streams drain to Contwoyto Lake. The location of the TCA and its drainage towards Contwoyto Lake are shown in Figure 1.

The construction of two relatively small dams on the west side and a saddle dam on the east side created an enclosed watershed with an area of 616 ha. The watershed contained 18 small lakes varying in surface area from about 0.6 ha to 19.7 ha illustrated in the pre-construction air photo shown in Figure 2.

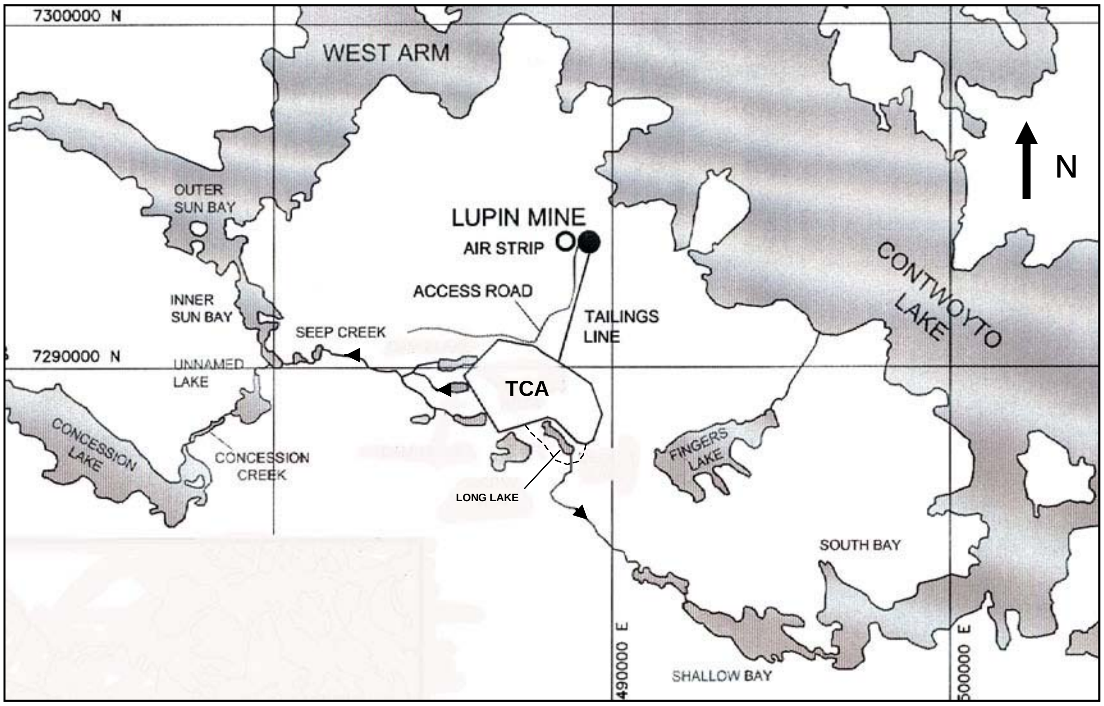


Figure 1. Location of TCA within Contwoyto drainage system

The Tailings Containment Area (TCA) was developed in 1981 by the construction of two main dams, Dam 1a and Dam 2, on the west side of the tailings watershed (Holubec et al 1982). Dam 1a was constructed across the watershed outlet stream and Dam 2 across an adjacent low saddle. Ore milling commenced in 1982 and the tailings slurry was discharged from the northern edge of the TCA to form one large pond against Dams 1a and 2 as shown in a photograph in Figure 2. This operation strategy continued until 1985. Increased production of ore resulted in the adoption of a revised tailings management strategy that deposited the tailings within cells. Excess water from these cells is directed into two ponds in series within the TCA that improves the water quality before discharging. Since 1985, water has been discharged from a downstream polishing pond to control the water level within the ponds. This tailings management strategy has remained in practice to this date. Progressive reclamation of the filled cells started in 1988, when Cell 1A was covered with a layer of esker sand/gravel. About 75 percent of the tailings areas are covered with at least 1m of sand/gravel. The remaining tailings were to be covered in 2006 but, because of the premature closing of the winter supply road to fuel deliveries, the cover program has been delayed until 2007.

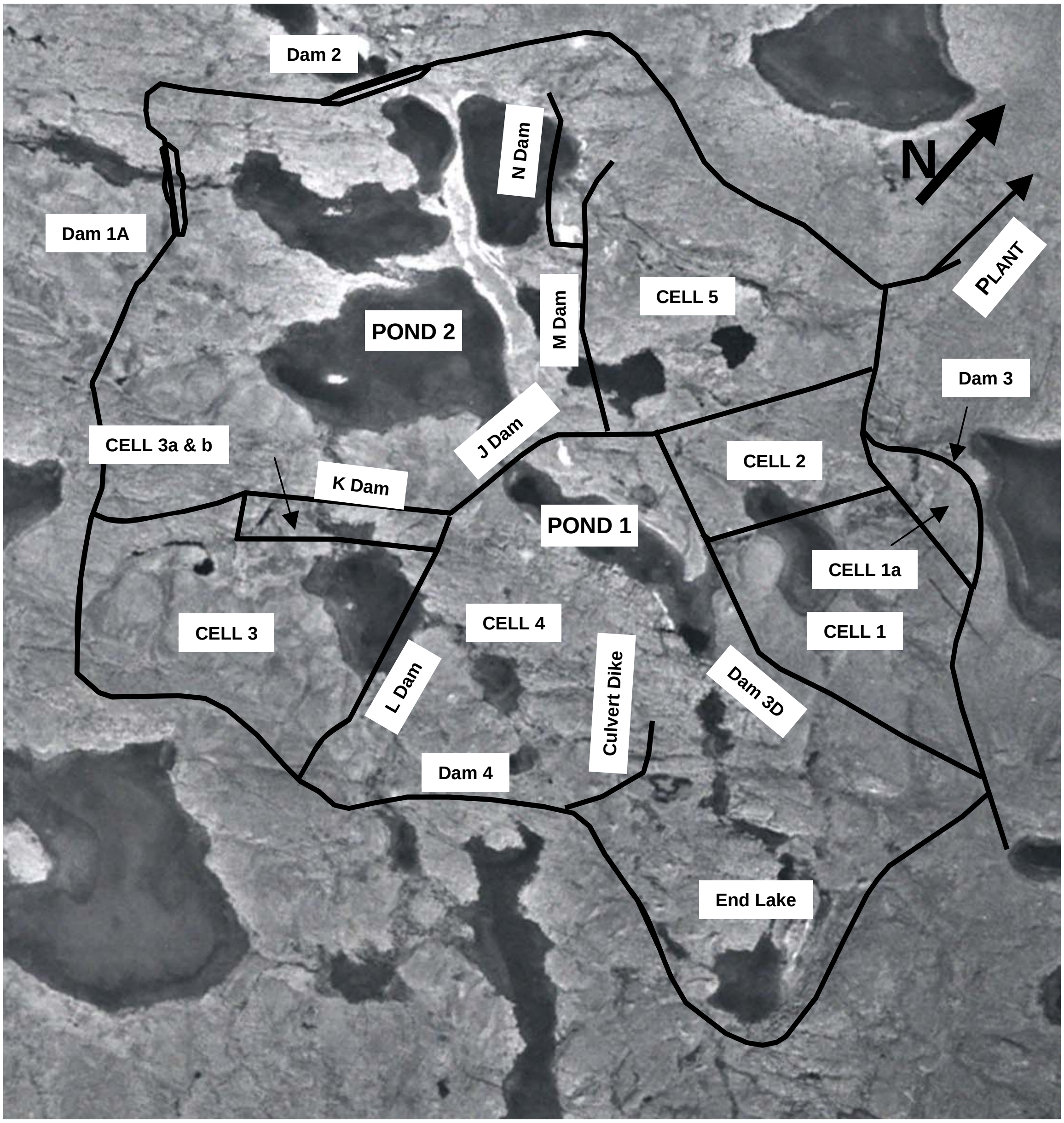


Figure 2. Locations of TCA dams, ponds and cells

Detailed history of the development of the TCA, along with the design and construction of the dams are given in the document entitled "Closure Plan for Tailings Containment Area" (Holubec, January 2005).

From the start of the Lupin operation in 1982 to the end of 2004 approximately 5,120,000 m^3 of tailings were stored within the TCA. The tailings were stored in four major cells (Cells 1, 2, 3 and 5) and one smaller Cell N. These cells occupy an area of about 145 ha within the total TCA watershed area of about 616 ha. Estimated statistics of the cells and contained tailings are given in Table 1.

Table 1. Statistics of cells and contained tailings

Cell	Cell's Watershed, ha	Tailings surface area ha	Mean tailings thickness, m	Tailings volume stored, m3
Cell 1a	6	6.3	1.7	107,000
Cell 1	41	36.1	3.5	1,263,000
Cell 2	21	15.0	3.0	450,000
Cell 3	67	50.0	4.0	1,724,000
Cell 4	No tailings			
Cell 5	56	34.3	4.5	1,544,000
Cell N	3	3.0	1.0	32,000
Totals	194	144.7		5,120,000

Cross sections drawn through the major cells illustrate the ground leading from the containment dams 3D, M and K to drainage divides. The locations of the sections are shown in Figure 3. The three cross sections are given in Appendix A. The sections in Appendix A were drawn to show the greatest thicknesses of tailings in the three cells. This occurs in areas that were previously underlain by small lakes (See Figure 2). These sections show that the maximum thickness of the tailings is about 5m, 10m and 10m in Cells 1, 3 and 5 respectively. The thicknesses given in Table 1 were estimated from the volume of tailings and the area of each cell.

A section through Cell 1 (Figure 4) was taken as a representative for seepage analyses discussed in the next Chapter.

3.0 CELL 1 STRATIGAPHY DESCRIPTION

3.1 Stratigraphy

Tailings were deposited within an area that formerly contained a small lake and generally sloped towards the south. This area is presently called Pond 1. The ground is underlain by a relatively thin cover of silty sand till, about 1 m thick, over phyllite bedrock. The bedrock is greatly fractured near the surface with this fracturing decreasing with depth.

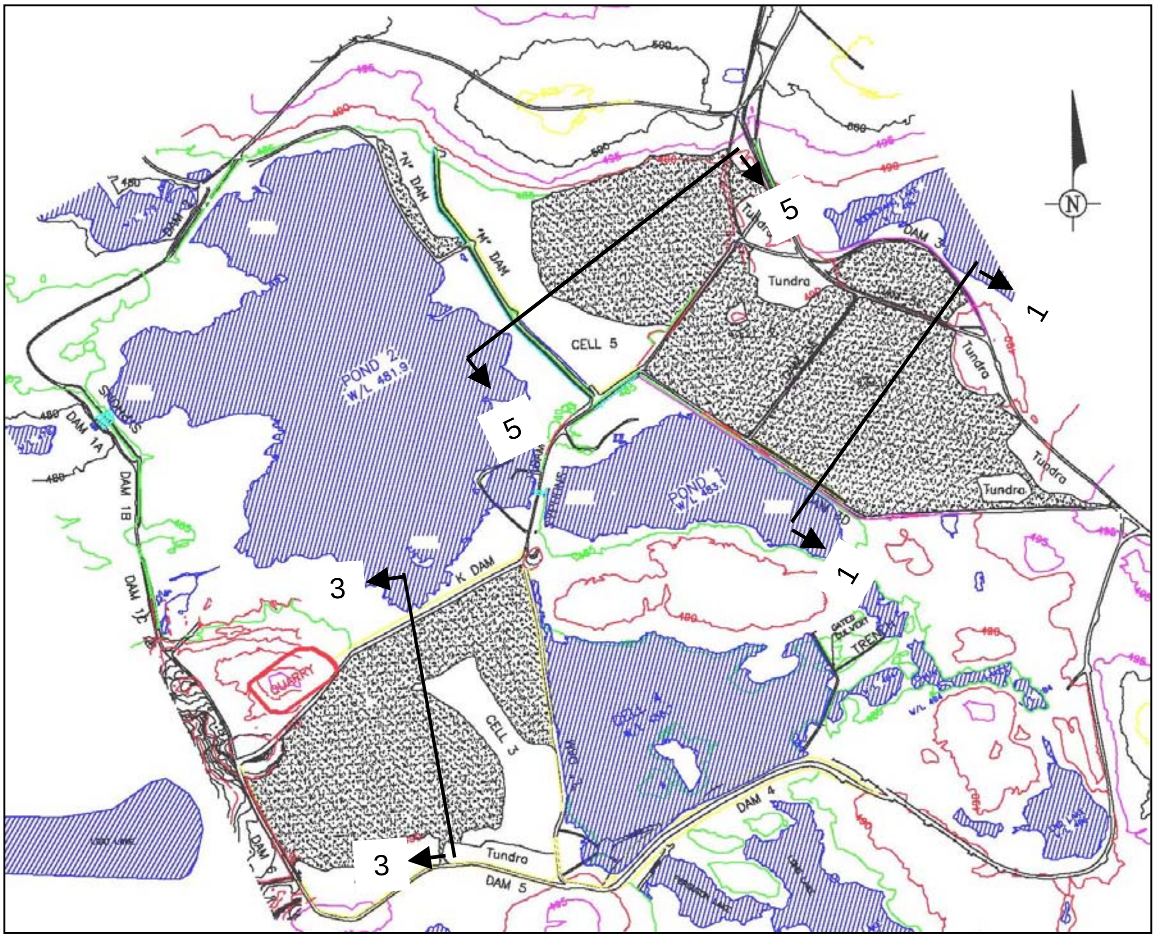


Figure 3. Locations of cross sections through main tailings cells

Cell 1 was formed by the construction of 3D Dam. Dam 3D was constructed from gravelly sand that was formed into a broad, 555-metre long embankment with a 10 to 15-metre wide crest. During operation a mine rock buttress was added to prevent sloughing of the sand/gravel material at the dam toe. Tailing slurry was discharged predominantly from dams 3C and 3D and finally 3D. Tailings discharge was stopped in 1992 and the tailings surface covered with sand/gravel material.

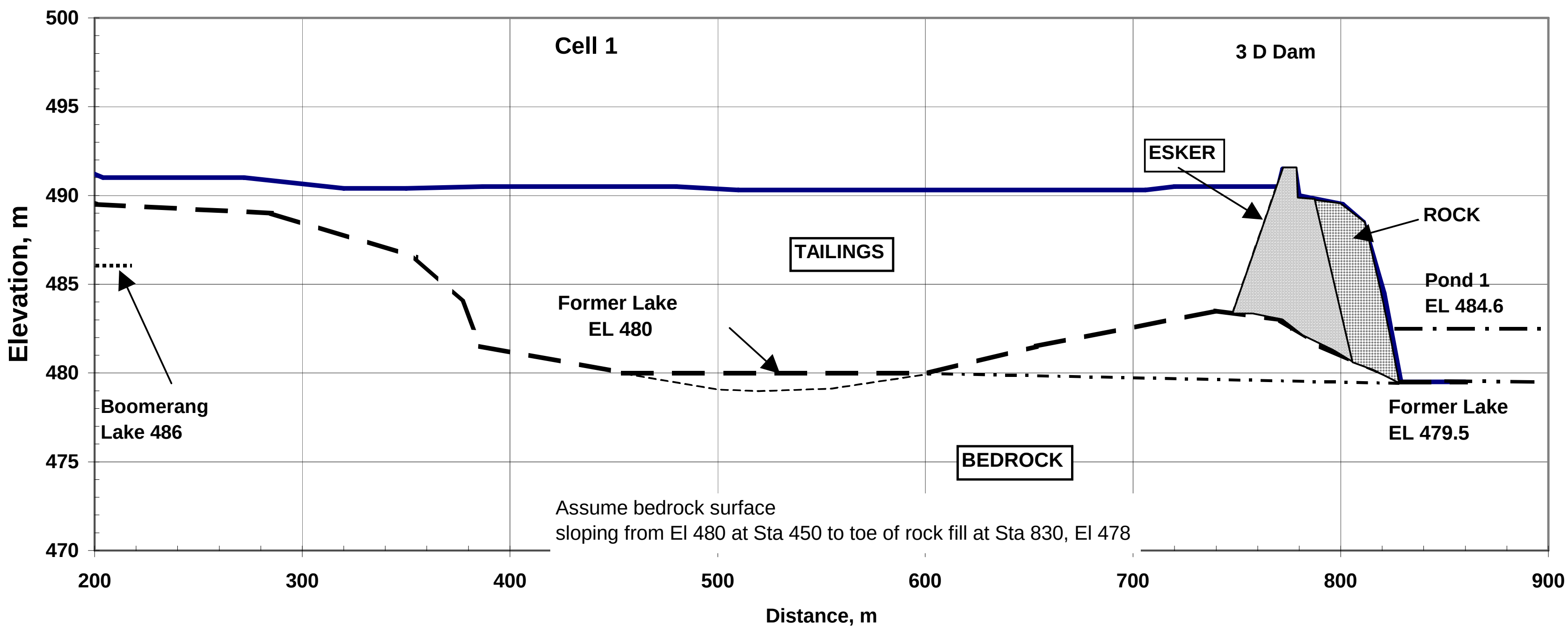


Figure 4. Representative tailings cross section at Cell 1

3.2 Material Properties

Descriptions of the materials are given from the surface, starting with the tailings cover.

3.2.1 Esker sand/gravel material

Six samples were taken during the 2004 test pit program and sieve analyses were conducted. The particle size distribution curves of the total samples are given in the Closure 2005 report. The results of these total samples given in percentage of gravel, sand and silt sizes are given in Table 2. It is assumed that the particle size distribution for 3D Dam is similar.

Table 2. Particle size distribution of the sand/gravel cover material

Location	Particle sizes in %			Material Description
	Gravel	Sand	Silt	
Cell 1 - Top	40	58	2	Gravelly sand
Cell 1 - Base	48	50	2	Gravelly sand
Cell 3	30	68	2	Gravelly sand
Cell 3b	38	60	2	Gravelly sand
Cell 1a	50	47	3	Sandy gravel
Cell 2	25	69	6	Gravelly sand, silty
Average	39	59	3	

Moisture contents were determined from four samples that varied from 7.2% to 9.8%. These moisture contents represent the unsaturated sand/gravel material since the samples were taken above the saturated zone.

Table 3. Sand/gravel cover material water content measured in 2004

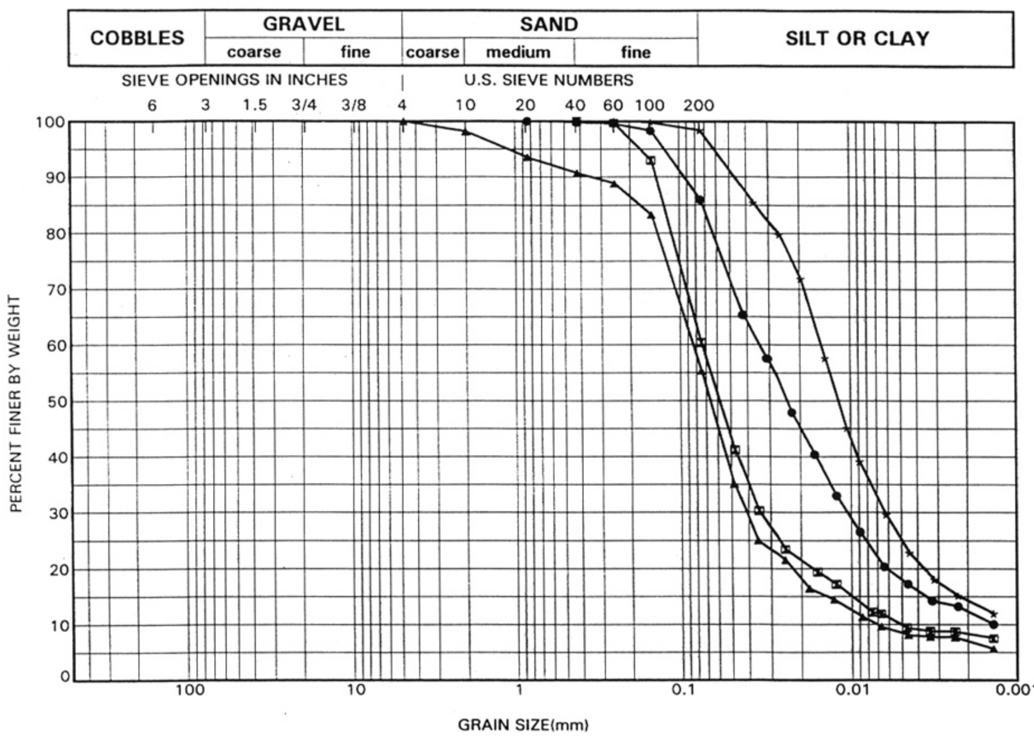
Location	Water content %
Cell 1a-1	8.1
Cell 1a-2	7.2
Cell 2-1	9.8
Cell 2-2	8.5

Based on the above particle distributions and using the Hazen formula, it is estimated that the hydraulic conductivity of the sand/gravel cover material is a $3x10^{2}$ cm/s.

3.2.2 Tailings

The most extensive sampling of tailings was done in 1994 (Klohn-Crippen, 1995). During this program 42 tailings samples were taken at various locations from the tailings slurry discharge point to the centre of the pond. Particle analyses show the tailings to have predominantly silt-sized particles, representing 73% of the material. Typical tailings gradation curves are shown in Figure 5. The well-graded shape of the gradation curves and the fact that the sand particles are floating in a silt/clay matrix would suggest a very low hydraulic conductivity.

Figure 5. Typical tailings gradation (Klohn-Crippen, 1995)



Gradation results from Klohn-Crippen (1995 Rpt) and published index & engineering properties (Lambe & Whitman 1969) and (Vick 1983), and a recent paper dealing with laboratory properties of mine tailings (Qiu & Sego 2001), were used to estimate water contents of the tailings in a state of full saturation and unsaturated and the likely range of hydraulic conductivities.

The following properties were estimated based on the above references:

Property	Value
Specific gravity	3.17
Void ratio	0.82
Saturated water content	28%
Unsaturated water content	20%

Hydraulic conductivities from various references are given in Table 3.

Table 3. Hydraulic conductivities from published material

Author(s) & type	Hydraulic conductivity	
Wilson, 1981	k, cm/s	k, cm/s
Copper slimes	6.3E-07	
Copper slimes	8.0E-07	
Lead-Zinc slimes	1.9E-06	
Molybdenum slimes	4.0E-06	
Avg		2.E-06
	k, cm/s	k, cm/s
Qiu & Sego 2001	2.7E-05	
	6.7E-05	
Avg		5.E-05
Lambe & Whitman 1969	k, cm/s	k, cm/s
Silty sand (3)	3.0E-08	
Silt - Boston (9)	6.0E-08	
Silt - Boston (16)	1.0E-08	
Silt - Boston (17)	4.0E-08	
Silt - North Carolina (21)	2.0E-05	
Avg		4.E-06
Hough 1957	k, cm/s	k, cm/s
Uniform Silt	5.E-06	5.E-06
All values	Avg	1.E-05

Based on the above values, it is estimated that the tailings have a hydraulic conductivity ranging from about 1E-05 to 5E-05 cm/s.

3.2.3 Phyllite bedrock.

Estimation of the hydraulic conductivity is difficult because no measurements could be done in the past because any fractures in the bedrock would be filled with ice and frozen. It is known that the hydraulic conductivity will be very high near the bedrock surface and will decrease with depth in the thawed state. The hydraulic conductivity was modelled based on experience from other sites. Also two different values were used for the top bedrock zone.

Estimated bedrock hydraulic conductivities are given in Table 4.

Table 4. Estimated bedrock hydraulic conductivities

	Hydraulic conductivity range, cm/s	
Depth, m		
0 to 3	1E-03	1E-04
3 to 12	1E-04	1E-04
12 to 15	1E-05	1E-05

4.0 POTENTIAL TAILINGS SEEPAGE

4.1 General

Tailings at Lupin were observed to have a potential for acid drainage if the tailings were exposed to prolonged weathering (Klohn-Crippen 1995).

Lupin has adopted a saturated granular zone cover design for the tailings. This design is based on the studies in southern climate areas that show only a very small depth of water over the surface of tailings is necessary to practically stop any oxidation of tailings.

Lupin has selected to cover the tailings with 1.0 m of sand/gravel that will maintain a small depth of a saturated water zone at its base. The overlying cover layer will minimize evaporation of water from this zone and the low permeability of the fine tailings, being more than 73 percent silt size, will prevent dropping of the groundwater level within the tailings due to future thawing.

The tailings cover design has to meet two objectives:

1) Prevent the oxidation of the tailings and release of metal seepage during the period when air temperatures maintain the tailings frozen. Permafrost will be present.
2) Ensure that when climate warming thaws the permafrost, the oxidation of the tailings will be minimal and such that seepage released from the unsaturated tailings will not be harmful to the downstream environment.

The physical parameters, seepage from the tailings covers and thermal conditions of the cover and underlying tailings were presented in the Closure Report (2005). The geochemistry and quality of the water released from the tailings are discussed in the accompanying report.

The saturation level and seepage geometry of tailings after climate warming has thawed the permafrost is presented here-in. It describes the seepage analyses that were conducted to establish the zone of the unsaturated tailings under various assumptions.

4.2 Analyses method

Seepage analyses were conducted using MODFLOW-2000. The reference for MODFLOW-2000 is a model published and maintained by the USGS. The Visual MODFLOW was developed by Waterloo Hydrogeologic Inc.

4.3 Geometry

The cross section for the seepage model was taken from the Cell 1 section shown in Figure 4. In this model the sand/gravel cover and the silty sand till over the bedrock zone were neglected. The reasons being:

a) The sand/gravel cover has a high hydraulic conductivity with respect to the underlying tailings and it is only 1m thick.
b) Silty sand till is about 1m thick and has a hydraulic conductivity similar to the overlying tailings.
c) Only the sand/gravel portion of the dam section was modeled. The mine rock has voids too large to contain any seepage.

Seepage analyses were conducted in a 2D space with the section being 1m wide.

4.4 Hydrology

Table 5 provides the most recent climate Normals from Environment Canada.

It is anticipated that in the long-term time frame, when climate warming has raised the air temperatures to a level that the permafrost has thawed, winter will experience much smaller snowfalls. As a result it is conservative to assume that at this time all precipitation will fall as rain and that 80 percent of this precipitation infiltrates into the esker cover. This rate of infiltration rate was used because the tailings cover surface has little slope and the sand/gravel material is relatively permeable. It was assumed that there is no evaporation loss because the saturation would be within the base of the cover or lower, as determined by the seepage model.

Precipitation was introduced at the tailings surface and constant head boundaries were used at the left and right ends of the seepage section.

Table 5. Precipitation Normals from Environment Canada Web (1971 to 2000)

(mm of water equivalent; 1 cm snow = 1 mm water)

Month	Rain	Snow	Total
Jan		9.4	9.4
Feb		8.4	8.4
Mar		11.3	11.3
Apr	0.1	13.7	13.8
May	6.2	12.3	18.5
Jun	25.5	3.6	29.1
Jul	42.7	0.4	43.1
Aug	56.8	3.3	60.1
Sep	27.7	18.0	45.7
Oct	1.9	28.2	30.1
Nov		15.2	15.2
Dec		14.4	14.4
Total	160.9	138.2	299.1

Seepage analyses were conducted for two precipitation models.

a) Base case – using the 2005 precipitation Normals.
b) Increased precipitation by 50% to model increased precipitation anticipated that will accompany climate warming.

4.5 Seepage analyses models

Six seepage analyses were conducted to show:

- Groundwater surface through the section.
- Groundwater flow through the tailings and bedrock.
- Establish the magnitude and surface length of the unsaturated tailings zone.
- Hydraulic conductivities of the mid and lower bedrock zones were kept constant in all runs.

4.6 Seepage cases.

Six seepage analyses were conducted to determine the possible range of unsaturated tailings zones. These are given in Table 6.

4.7 Seepage analyses results

4.7.1 Groundwater surface & unsaturated tailings area

The results of the seepage analyses are given in Figures A8 to A13 in Appendix A and in terms of the geometrics of the unsaturated zone in Table 7. The geometrics are given in terms of volume of unsaturated tailings per metre section and the length of unsaturated tailings on the surface. These terms are explained schematically in Figure 6.

Table 6. Hydraulic conductivities used in seepage analyses

Case	Description	Precipitation	Tailings	Top bedrock
		% Normal	k, cm/s	k, cm/s
1	High tailings k, others normal	100	5E-05	1E-03
2	Decrease top bedrock k	100	5E-05	1E-04
3	As in 1, increase precipitation 50%	150	5E-05	1E-03
4	As Case 1, low tailings k	100	1E-05	1E-03
5	As Case 2, low tailings k	100	1E-05	1E-04
6	As Case 3, low tailings k	150	1E-05	1E-03

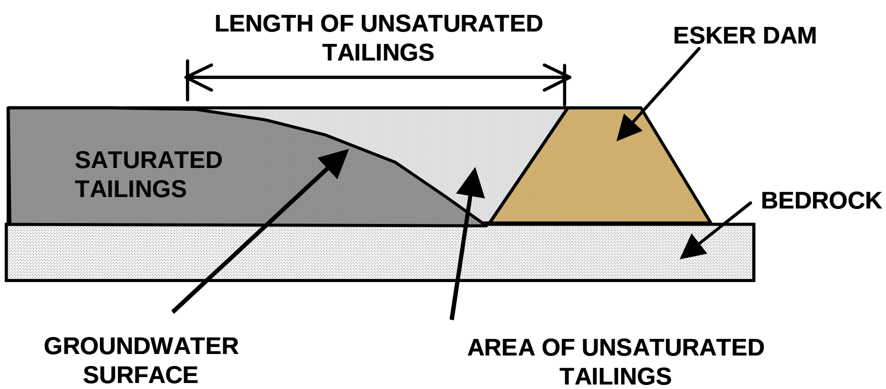


Figure 6. Schematic of seepage analyses results

Table 7. Unsaturated zone from seepage analyses

Case	Description	Unsaturated tailings zone, per m width			
Tailings k=5E-5 cm/s		Volume, m^3	% of total tailings	Surface Length, m	Of total Length, %
1	High tailings k, others normal	750	12	150	26
2	Decrease top bedrock k	170	3	30	5
3	As in 1, increase precipitation 50%	480	8	85	15
Tailings k=5E-5 cm/s					
4	As Case 1, low tailings k	710	11	130	23
5	As Case 2, low tailings k	120	2	20	4
6	As Case 3, low tailings k	390	6	80	14

4.7.2 Groundwater level fluctuation

The fluctuation of the groundwater during the yearly cycle was determined for higher tailings permeability Case 1. The groundwater fluctuations during the years, after the steady state was reached, are illustrated in Figure 7. This is shown by the upper curve that corresponds to the groundwater surface. Results in this figure indicate that the groundwater fluctuates about 0.3m during the year.

4.7.3 Volume of unsaturated tailings.

The volume of seepage water through the unsaturated zones is estimated from the following:

- Annual precipitation
- Runoff
- Length of unsaturated tailings zone
- Width (length) of tailings containment dams.

The annual precipitation is 299 mm and the runoff on the sand/gravel tailings cover is estimated as 0.80. This runoff is for the granular cover over the tailings. The length of the unsaturated tailings zone was determined in the seepage analyses and given in Table 7. The total width (length) of the dams is given by the sum of 3D, K and M dam widths. It should be noted that 3D Dam contains both Cells 1 and 2. The widths of these 3 dams is about 900m, 600m and 1000m respectively; for a total of 2,500m.

The total annual seepage from the unsaturated tailings zone is estimated to vary from 12,000 to a maximum of about 90,000 m^3 as shown in Table 8.

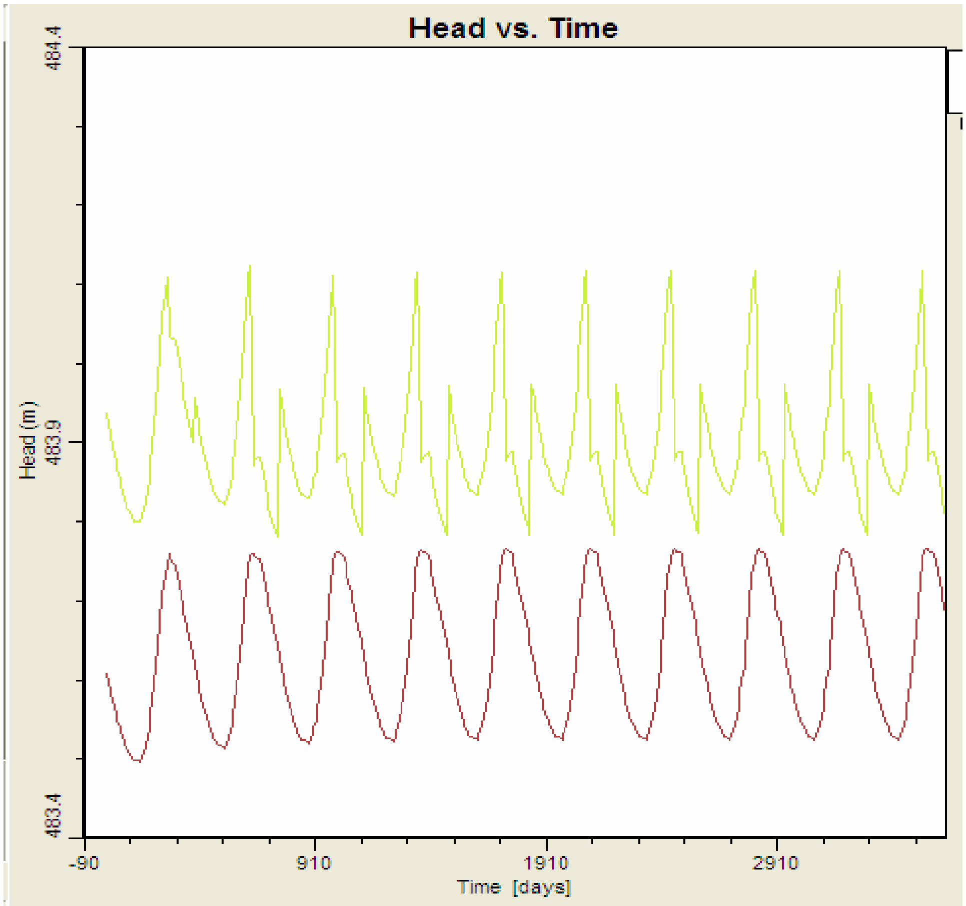


Figure 7. Groundwater fluctuation for Case 1 at steady state.

Note.. Head fluctuations represent groundwater surface changes as measured by the head of water at two depths. Upper curve (yellow) represents head (groundwater surface) and the lower curve (red) as measured about as measured about 1m and 4m below the mean groundwater surface respectively.

Table 8. Estimated seepage volumes through unsaturated tailings

Seepage Case	Length of unsaturated Tailings, m	Total width of dam face, m	Total area of unsaturated tailings, ha	Seepage through unsaturated tailings, m^3
1	150	2500	37.5	90,000
2	30	2500	20.0	18,000
3	85	2500	23.8	76,000
4	130	2500	32.5	78,000
5	20	2500	5.0	12,000
6	80	2500	20.0	58,000

5.0 SURFACE WATER BALANCE AT CLOSURE

Surface water balance estimates were prepared for the period when the ground and tailings are frozen and for the period after permafrost has thawed to a sufficient depth when it does not control the groundwater flows. It is estimated that the permafrost may start to thaw in about 2050 and become sufficiently thawed some 30 years later, i.e. about 2080.

The TCA area of about 616ha was subdivided into three categories: water surface, land, and tailings. Tailings were further subdivided into: frozen during the permafrost period, and saturated and unsaturated for the thawed state representing the condition after about 2080. The unsaturated tailings surface is based on being a reasonable area based on the results given in Table 8. The areas, precipitation, water evaporation and runoff values assumed for the water balance estimates are given in Table 9 and Table 10.

The results of the water balance analyses are given in Table 11. The impact of these results is discussed in Volume II.

Table 9. Land areas distribution during and after permafrost

Areas	Areas	Permafrost	
	ha	During, ha	After, ha
Water	72.6	72.6	72.6
Land area	398.7	398.7	398.7
Tailings	144.7		
Frozen		144.7	
Saturated			119.7
Unsaturated			25.0
Total TCA	616.0	616.0	616.0

Table 10. Precipitation, evaporation and runoff coefficients

Precipitation	299	mm	2,990	m3/ha
Evaporation	240	mm	2,400	m3/ha
Runoff coefficients				
Frozen		0.70		
Thawed				
Land			0.66	
Tailings			0.80	

Note: Evaporation value represents evaporation from water surface.

Table 11. TCA Water balance during permafrost and thaw conditions

Components	Regime			
	Permafrost		Thaw	
In	m^3	%	m^3	%
Water	42,834	4%	42,834	4%
Land	834,485	71%	786,801	67%
Tailings				
Frozen	302,857	26%		
Saturated			286,322	24%
Unsaturated			59,800	5%
Out	1,180,176	100%	1,175,756.9	100%

6.0 CLOSURE

This report was prepared to provide the basis for evaluation of the present water quality within the TCA and to predict the future water quality, as discussed further in Volume III.

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7.0 REFERENCES

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APPENDIX A

SUPPORTING FIGURES

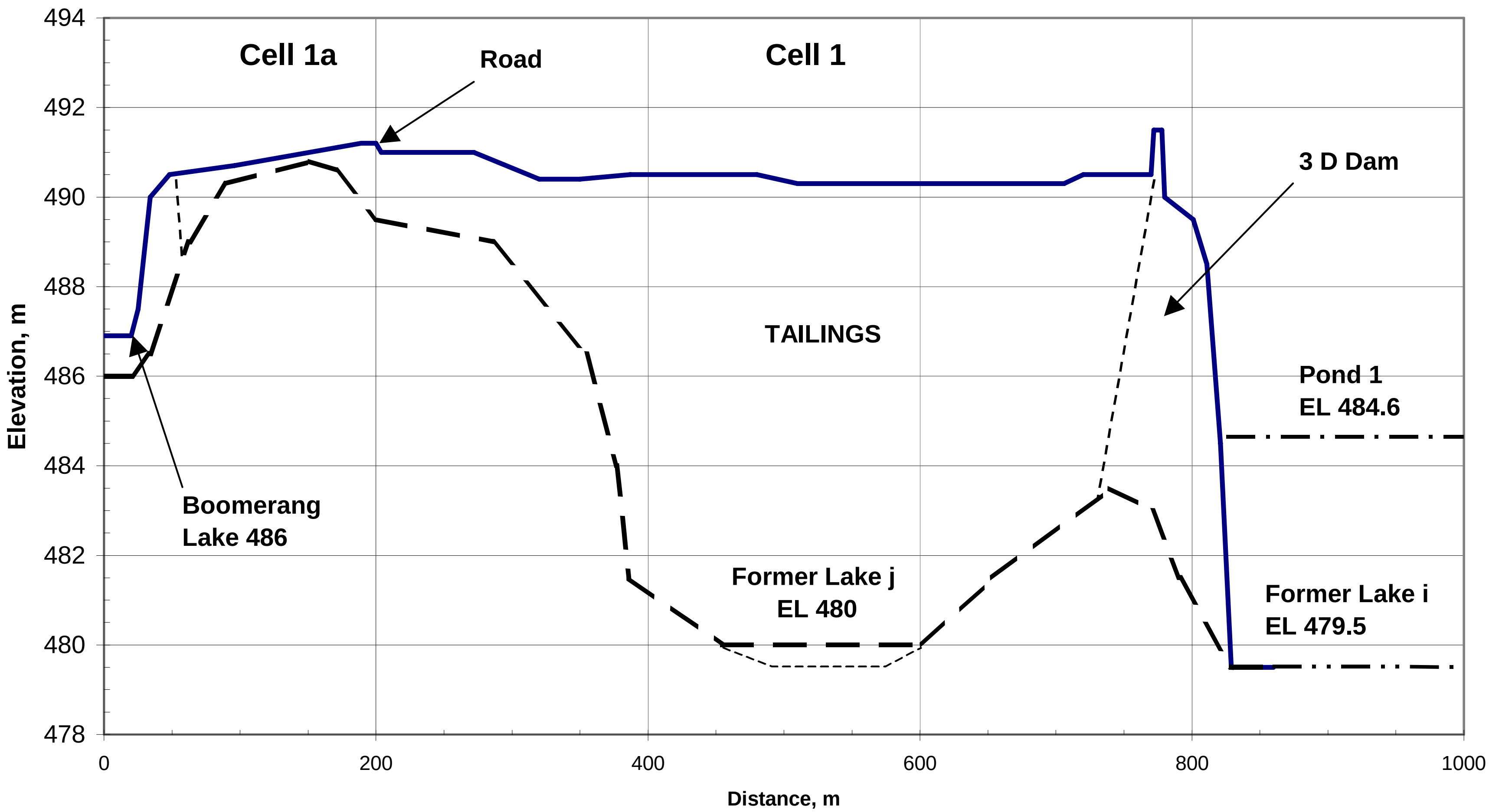

Figure A1.Tailings contained by Dam 3D, section normal to dam

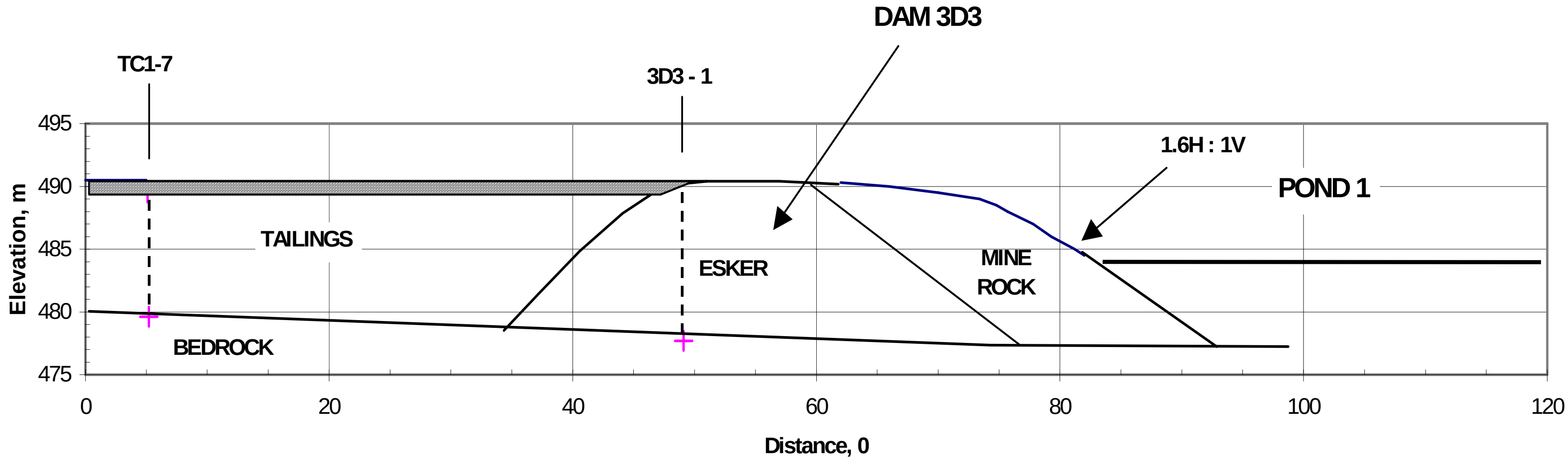

Figure A2.Dam 3D section, facing east

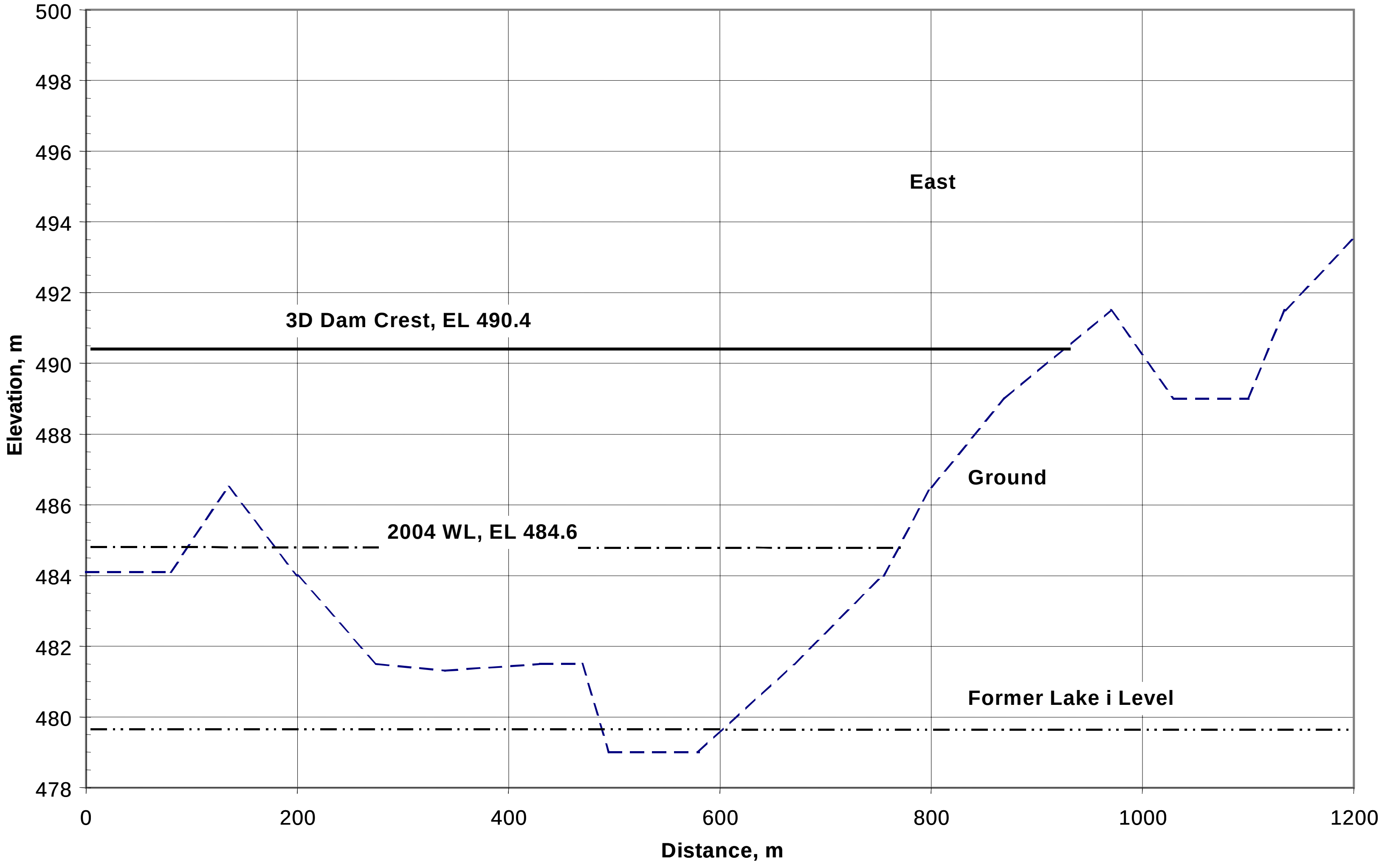

Figure A3. Dam 3D foundation profile (against Cell 1)

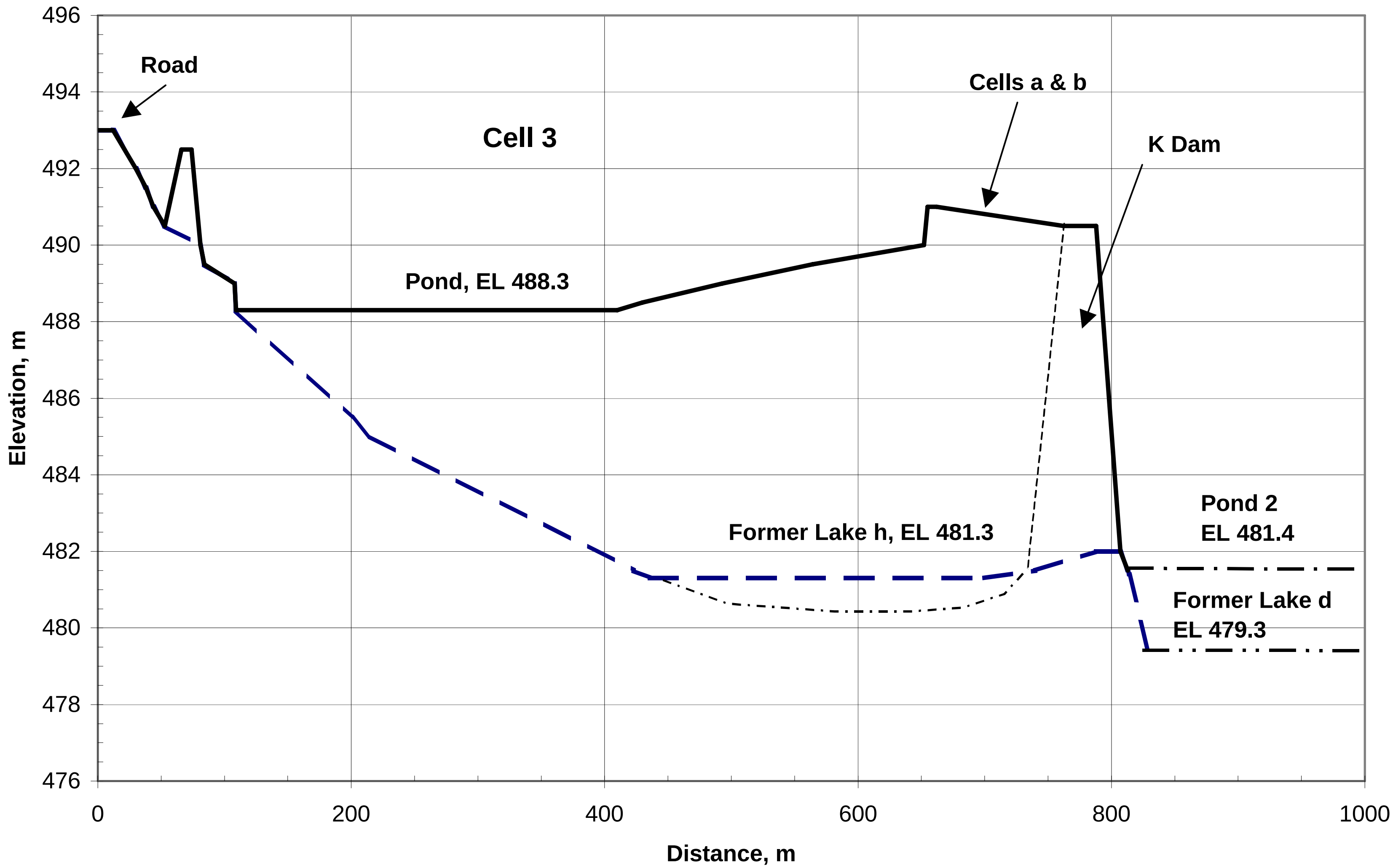

Figure A4.Tailings contained by K Dam , section normal to dam

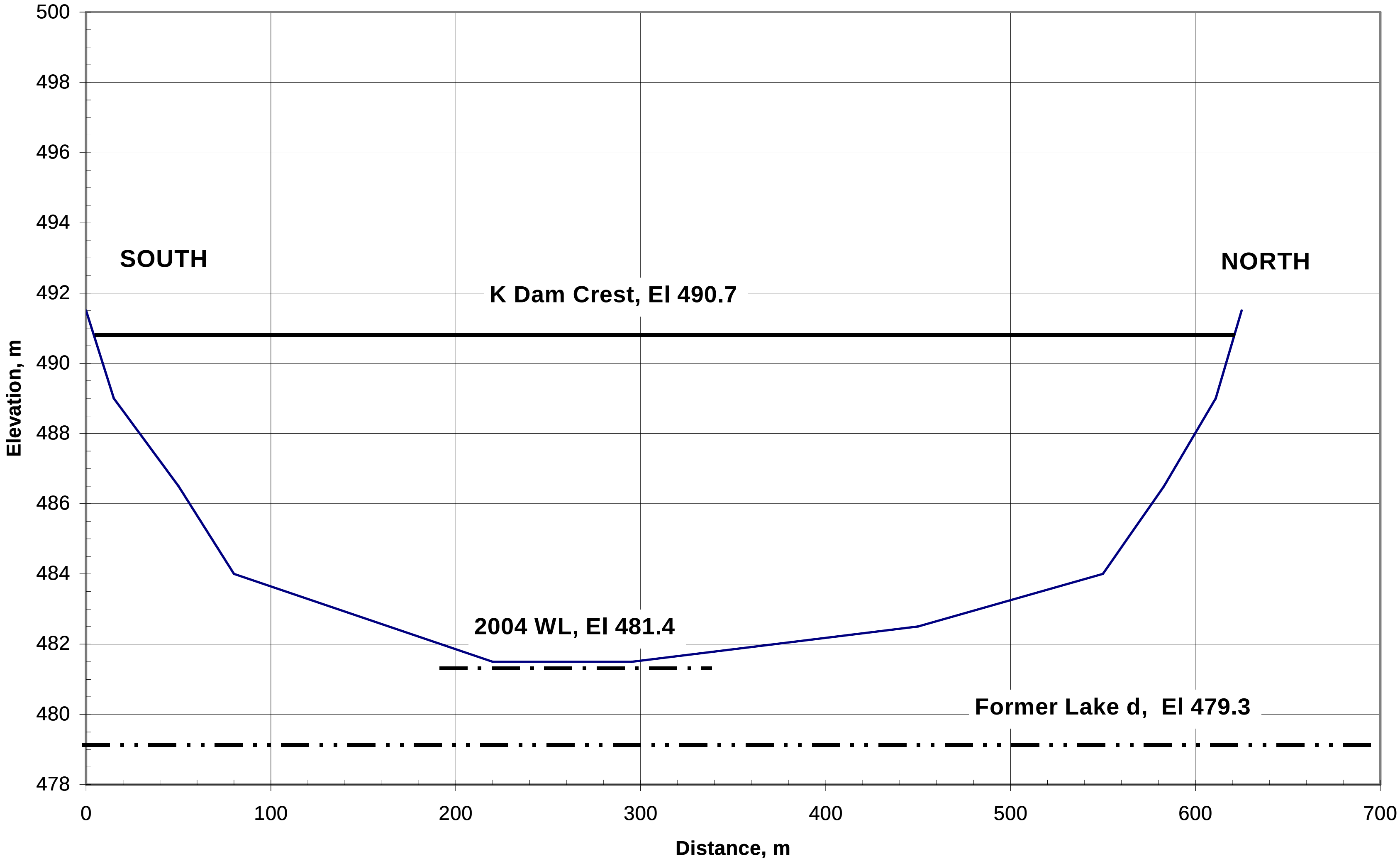

Figure A5.K Dam foundation profile, looking west

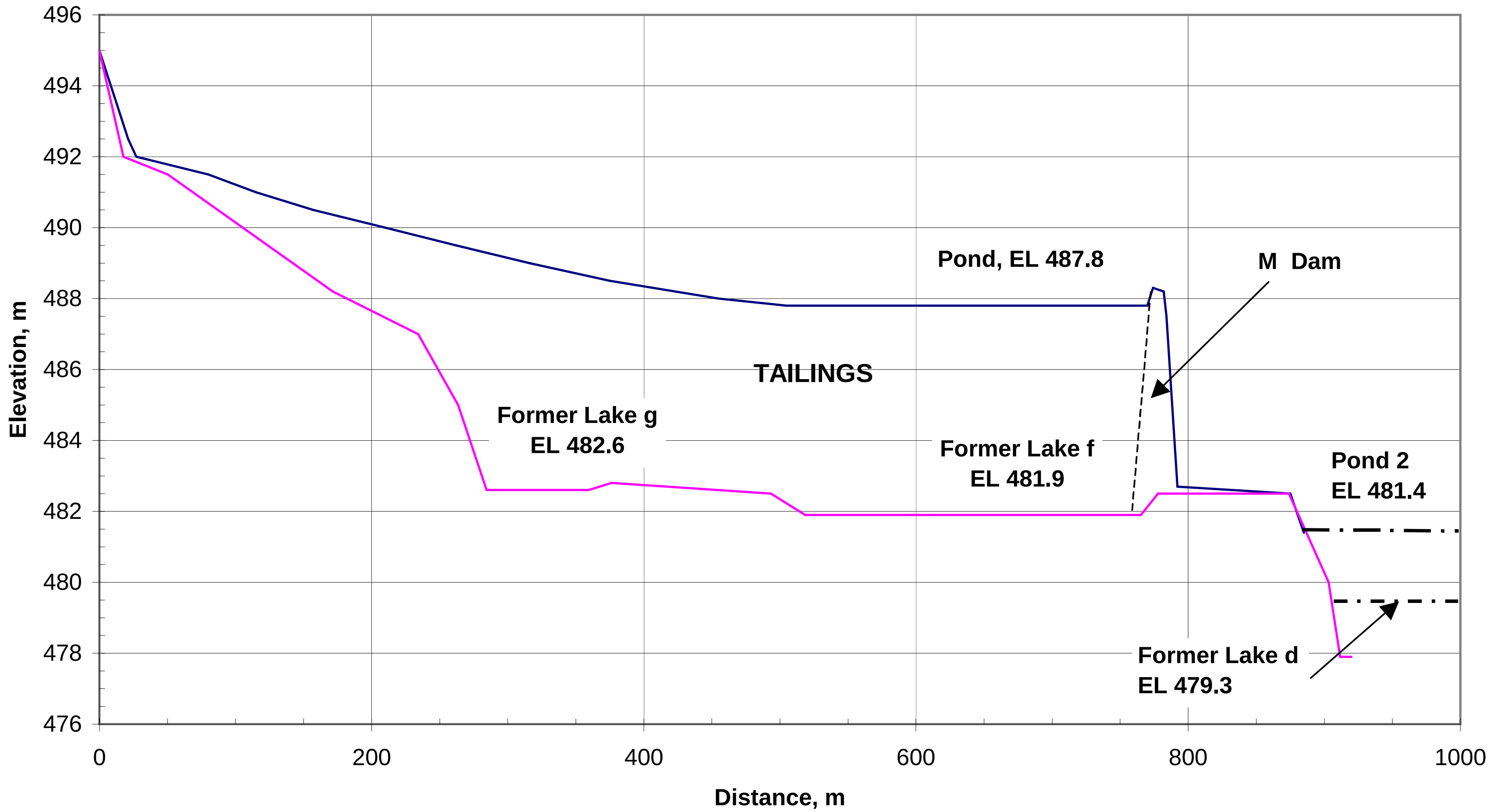

Figure A6.M Dam section with contained tailings, looking east

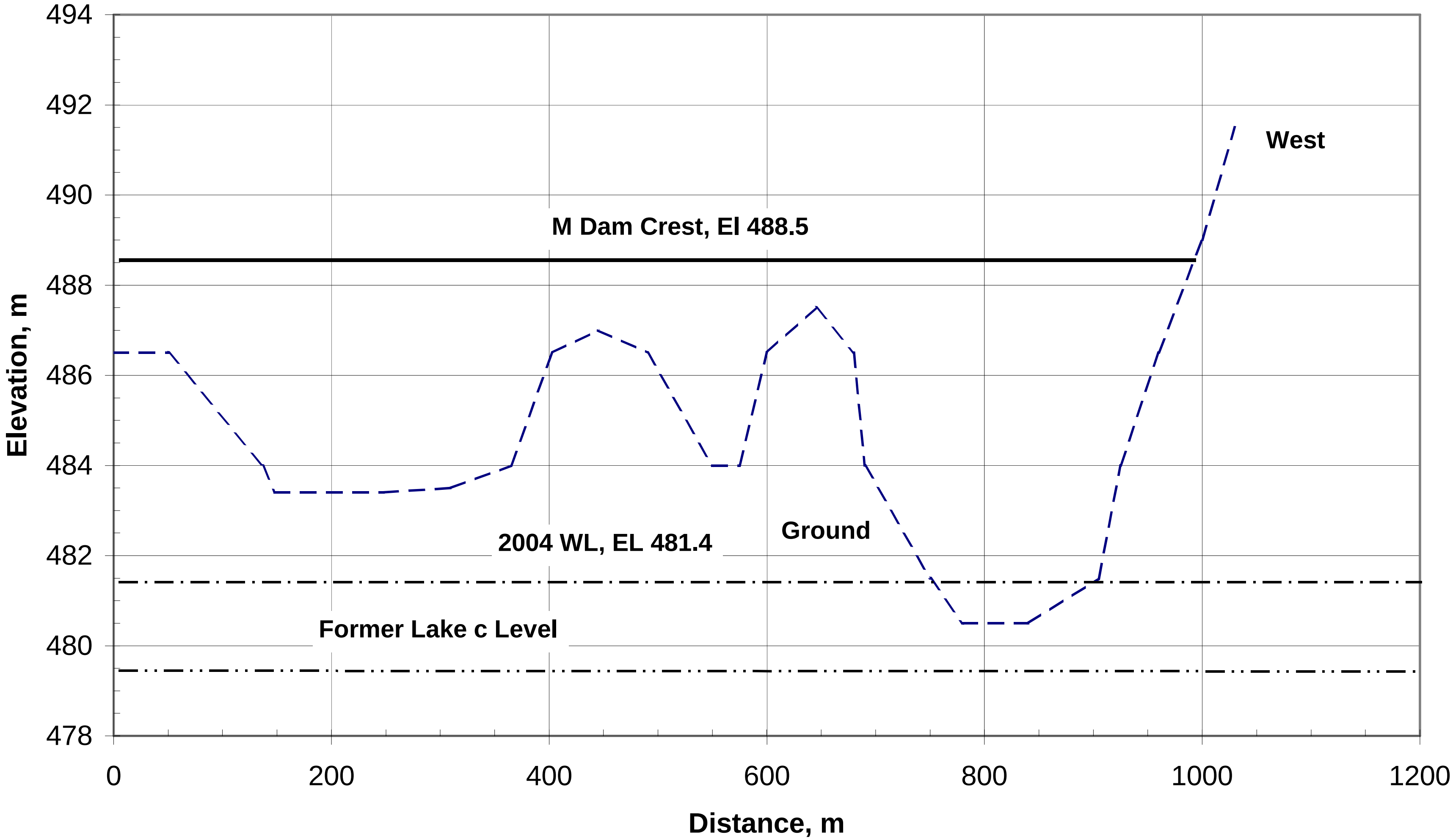

Figure A7.M Dam foundation profile

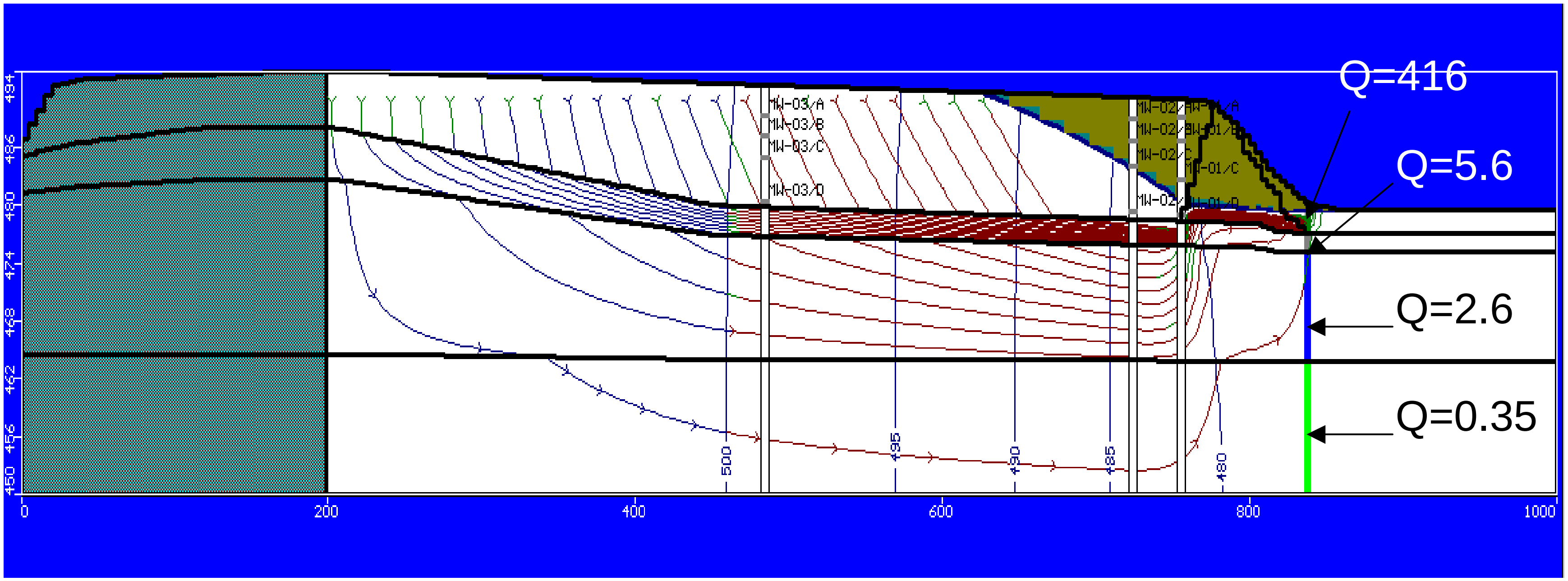

Figure A8. Case 1- Tailings, k=5E-5 cm/s, 3m thick surface bedrock k=1E-3

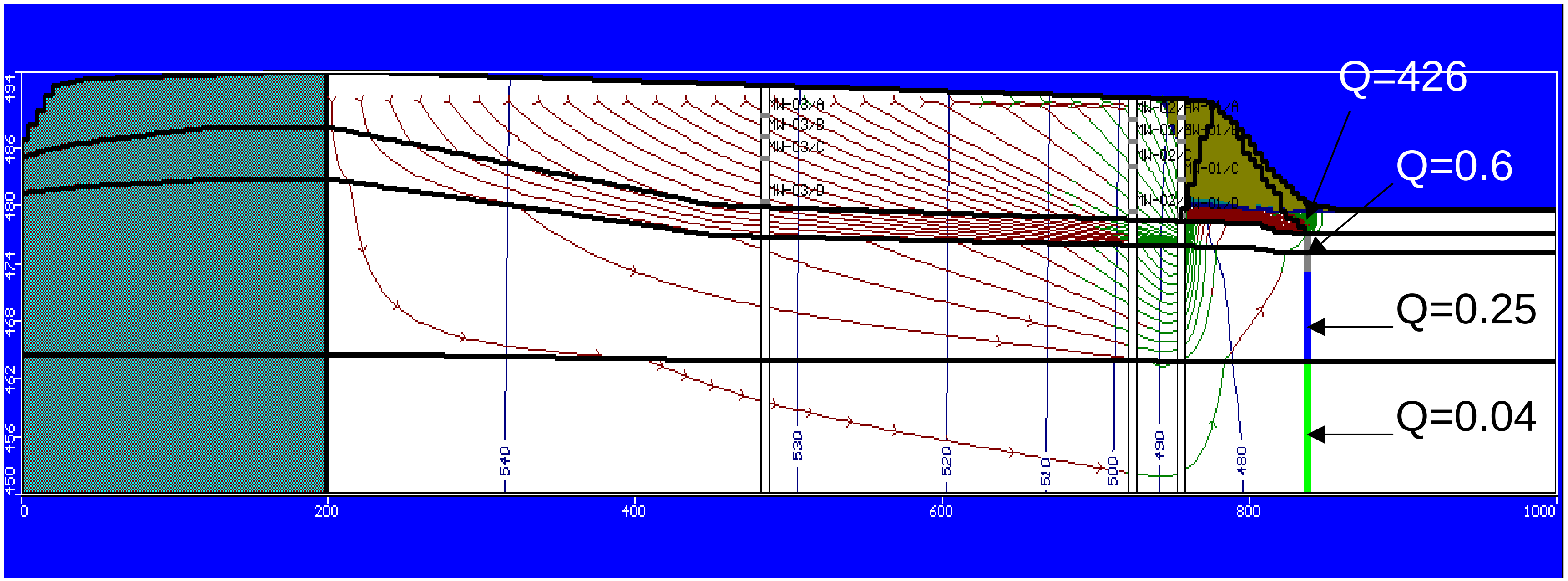

Figure A9. Case 2- Tailings, k=5E-5 cm/s, 3m thick surface bedrock k=1E-4

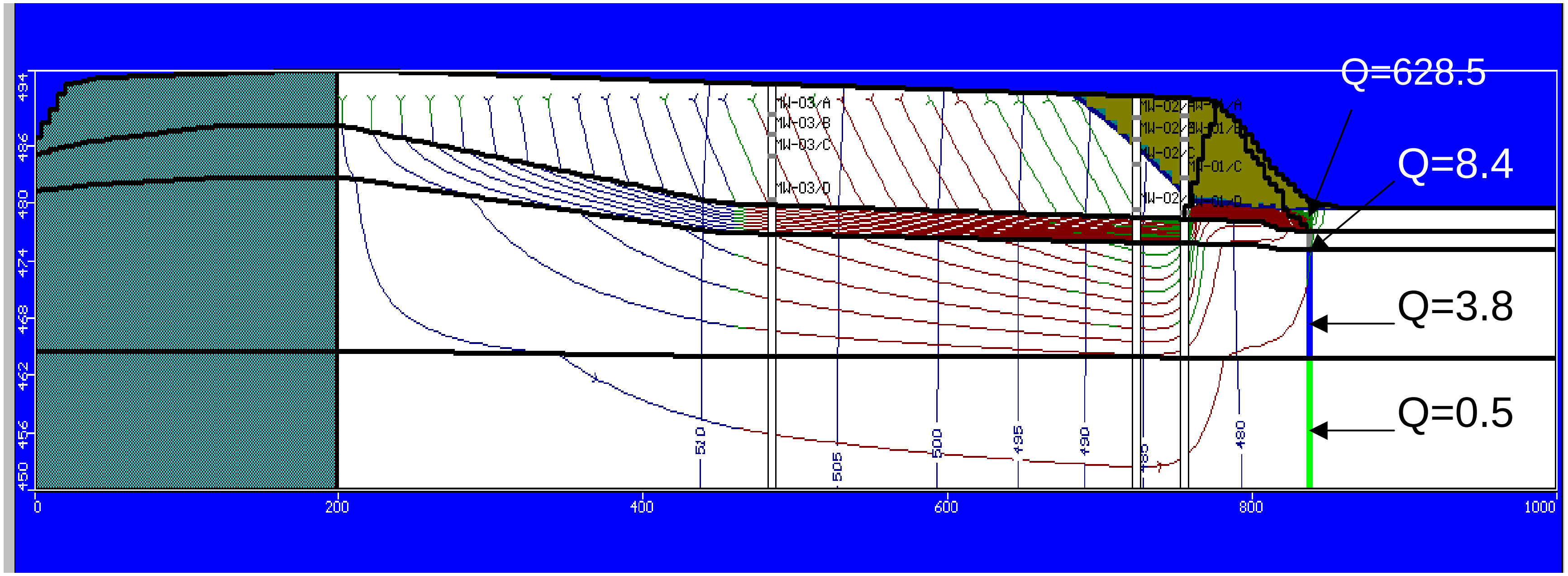

Figure A10. Case 3- As Case 1, increase precipitation 50%

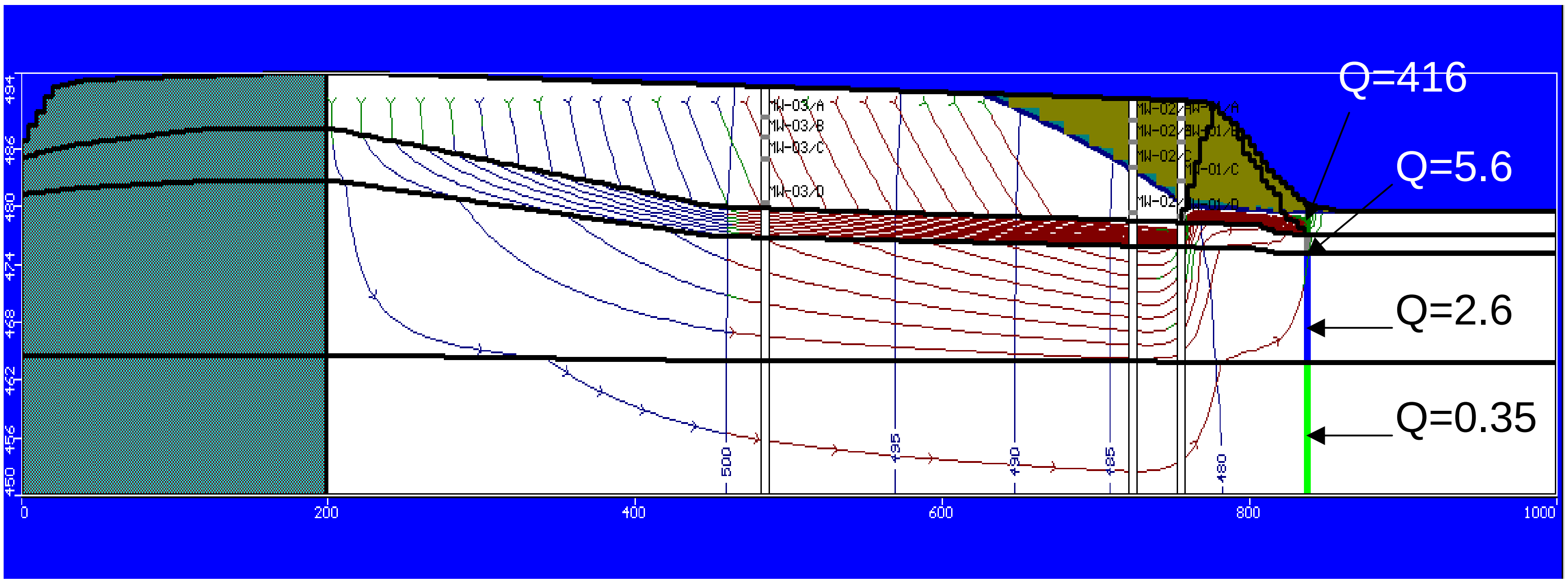

Figure A 11. Case 4, same as Case 1 but tailings k=1E-5cm/s

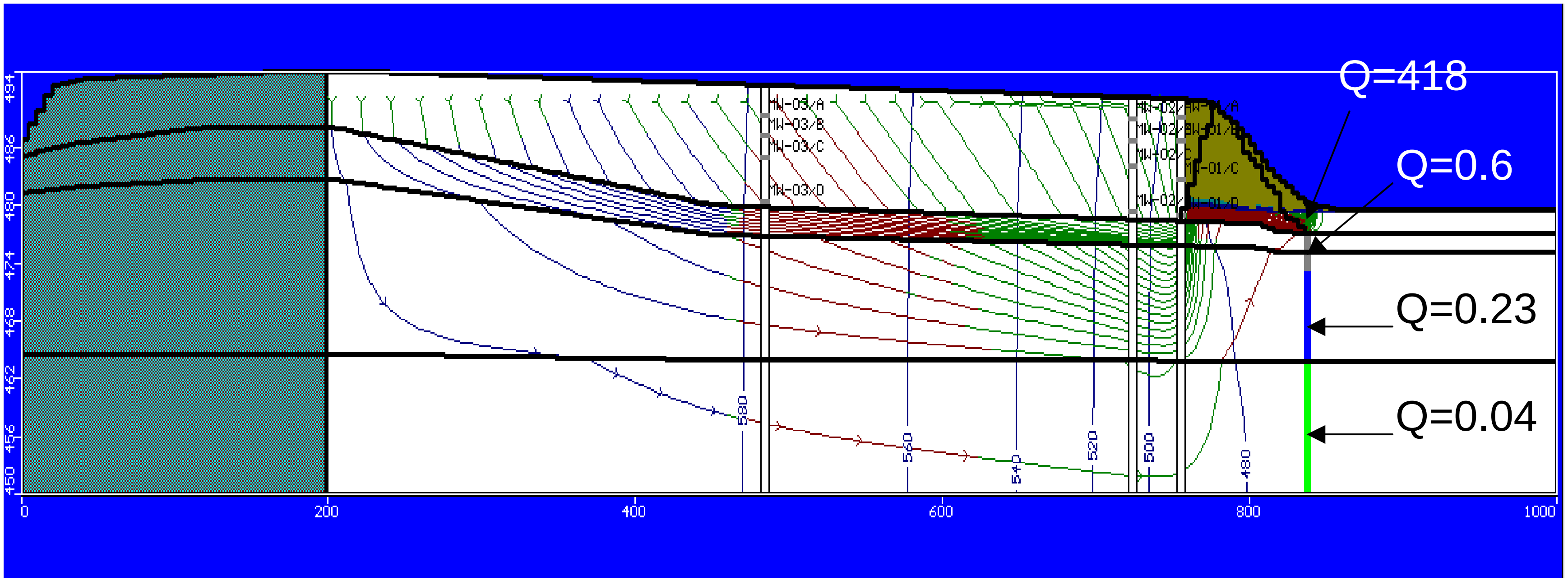

Figure A 12. Case 5, same as Case 2 but tailings k=1E-5cm/s

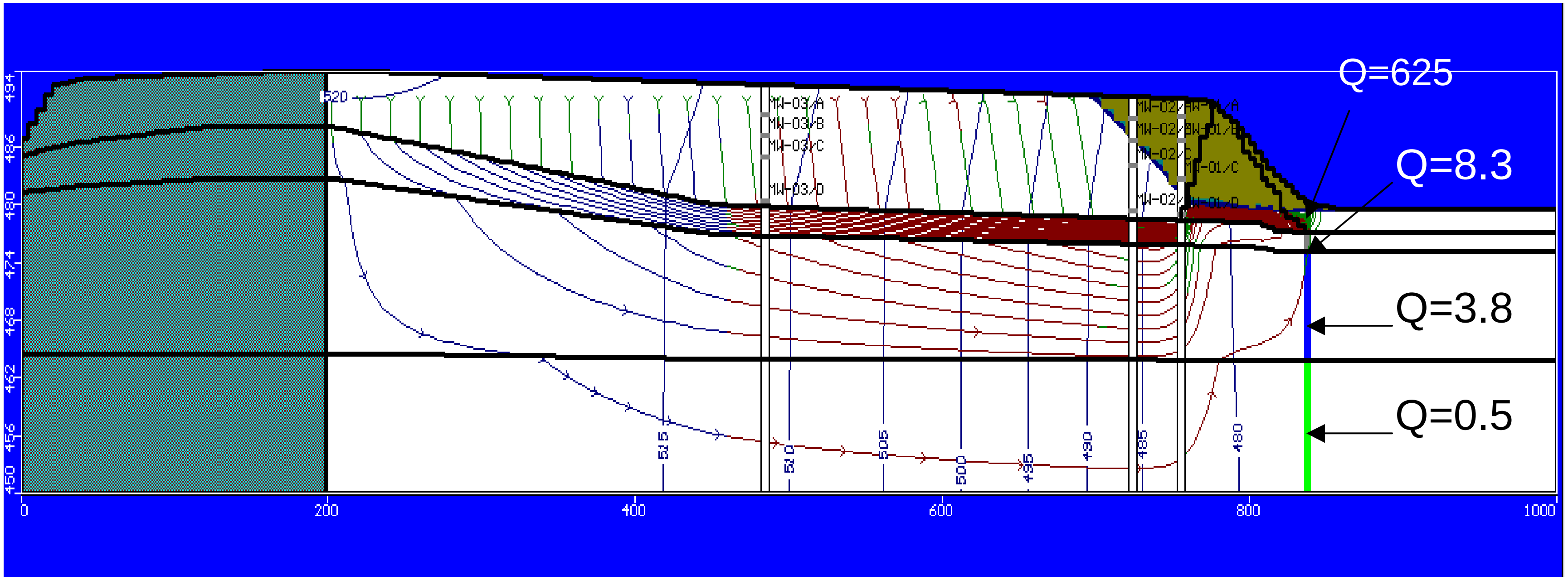

Figure A 13. Case 6, same as Case 3 but tailings k=1E-5cm/s