

A Summary of Modeling Studies of the South Bay Mine Site

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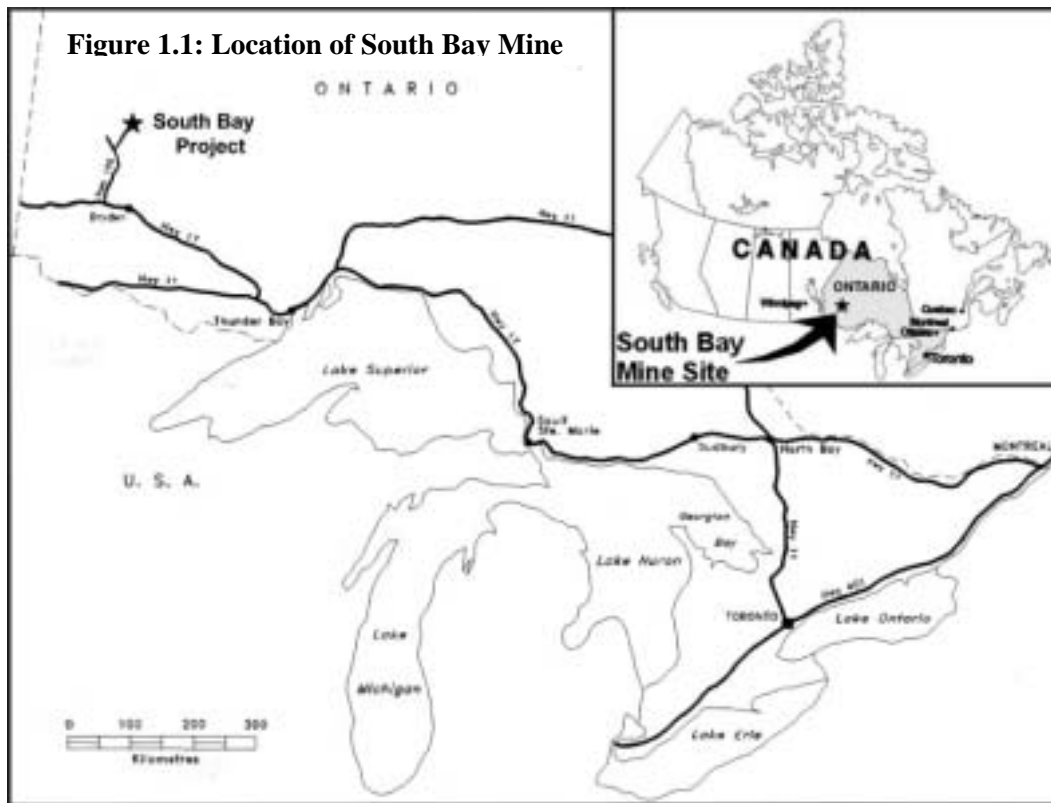
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A Summary of Modeling Studies of the South Bay Mine Site

1.0 Background

The former Cu/Zn base-metal mine at South Bay, Ontario (Figure 1.1) adjacent to Confederation Lake north of Ear Falls, Ontario has been shut down since 1985. Presently the mine site is undergoing decommissioning using ecological engineering and bioremediation technology.



An extensive monitoring program initiated in 1985 has been in effect at the South Bay mine site. The results of this monitoring program have been used to provide direction for several remedial actions on the site. In addition, it has been used to monitor the effectiveness of these actions and focus future remedial work. As part of the investigations on the site, predictive modeling was used in 1988 to attempt to predict the movement of contaminants in the groundwater, using a hydrogeological model developed for the site at that time and the CHINTEX model. During the ensuing years, as the result of further hydrogeological investigations, it was discovered that the main seepage pathway from the tailings was not into Confederation Lake (as had been previously thought) but rather into Mud Lake through a large deposit of gravel in a bedrock canyon (named the “Kalin canyon”).

In 1998, the software package, Visual Modflow, was used to construct a numerical model of the larger drainage basin bounded by Confederation Lake to the south and west and north of Amanda Lake and to the surface water divide in the east, east of Bush Rabbit Lake which flows into Lena lake. This three-dimensional groundwater flow model has become an industry standard and has been subject to extensive verification and validation studies. It is used by many consulting firms as well as by USGS and USEPA. In addition, more detailed models were constructed of the tailings area (in 1998 and refined in 1999) and the town site (in 2000). These models utilized the increased database collected since 1995 and several reinterpretations of the site hydrogeology based on the collected data. The models were calibrated and used to assess to following:

- The groundwater flow characteristics (volumes, velocities, directions) in the various stratigraphic units and areas of the site,
- The release and transport of contaminants from the tailings,
- The effectiveness of various remedial alternatives, such as installing a ditch, creating an impermeable cap, lowering the decant pond water level.

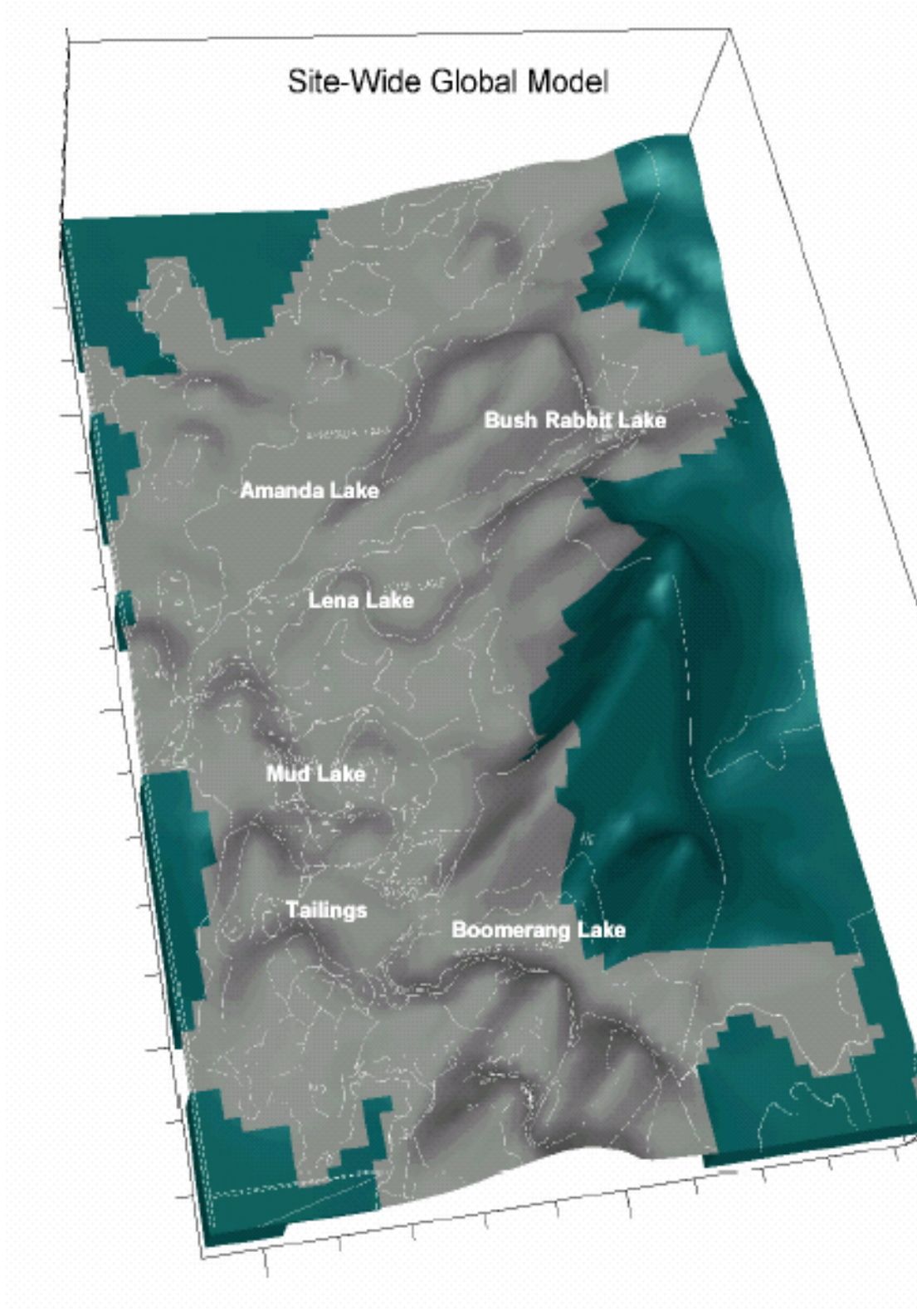
The following report summarizes the setup and results of the various models, previously reported in SCIMUS, 1998, SCIMUS, 1999, Boojum 2000a, and Boojum 2000b.

The model setup, assumptions and major input parameters required by both of the models are summarized in Chapter 2. The results of the *global site-wide model* and the calibration and results of the *tailings area model* and the *town-site model* are given in Chapter 3.

2.0 Model Setup

2.1 Global Site-Wide Model Setup and Assumptions

A model was developed encompassing the major watersheds, comprising the mine and tailings sites and the adjacent areas. A three dimensional perspective of the modeled area is shown in Figure 2.1. The *global site-wide model* was used to describe the groundwater flow regime and estimate flows in the various components of the local watershed. These flows can be used to determine the dilution that can be expected for the seeps from the tailings area.



**Figure 2.1: Global Site-Wide Model - Ground Surface Topography
(Vertical Exaggeration, 25:1)**

The entire modeled area was delineated on a *200 ft x 200 ft* grid according to the following characteristics: forest, water, muskeg, bedrock outcrop, tailings and overburden. The boundaries of the modeling domain in the vertical direction were delineated using determined ground surface elevations and bedrock elevations at each of the grid points. Ground surface elevations were read from topographic maps, whereas bedrock elevations were estimated using the available borehole logs, geophysical surveys, ground truthing measurements, visible outcrops and “educated guesses” in the regions where no data was available. The vertical domain was divided into *five* equally spaced layers. The bedrock surface was adjusted in some locations, to ensure contact between adjacent cells. It was assumed that the bedrock represented a no flow boundary. The layer immediately above the bedrock was usually assigned a relatively high hydraulic conductivity. This layer takes into account the flow in the fractured bedrock, which constitutes the upper few feet of the bedrock.

The Golden Software SURFER computer program was used to generate surfaces at the desired grid spacing for both the ground surface and the top of the bedrock. The ground surface along with the site map superimposed is shown in Figure 2.1. There is an exaggeration of about 25:1 in the vertical direction. These surfaces were imported into Visual MODFLOW to define the modeling grid. The grid, the constant head nodes (red), and the wall nodes (orange) (5 feet thick with a hydraulic conductivity of 10^{-6} cm/s used to simulate the tailings dam) are shown in Figure 2.2.

2.2 Tailings Area Model Set-up and Assumptions

The tailings area model was set up in a manner similar to the global site-wide model. The area modeled, however, was smaller, encompassing the tailings and Decant pond, Mud Lake, a portion of Boomerang Lake and a portion of the shore of Confederation Lake. The modeled domains as well as the locations of monitoring wells are shown in Figure 2.3. Confederation Lake was assigned a constant head of 1351 fasl and defined the eastern and part of the southern and northern boundary of the modeled region. The remainder of the northern boundary was based on the level of the standing water in the swampy region at this location. A constant head of 1351.5 also represented Boomerang Lake. The remainder of the boundary was assumed to be a no flow boundary since it represented a topographic high.

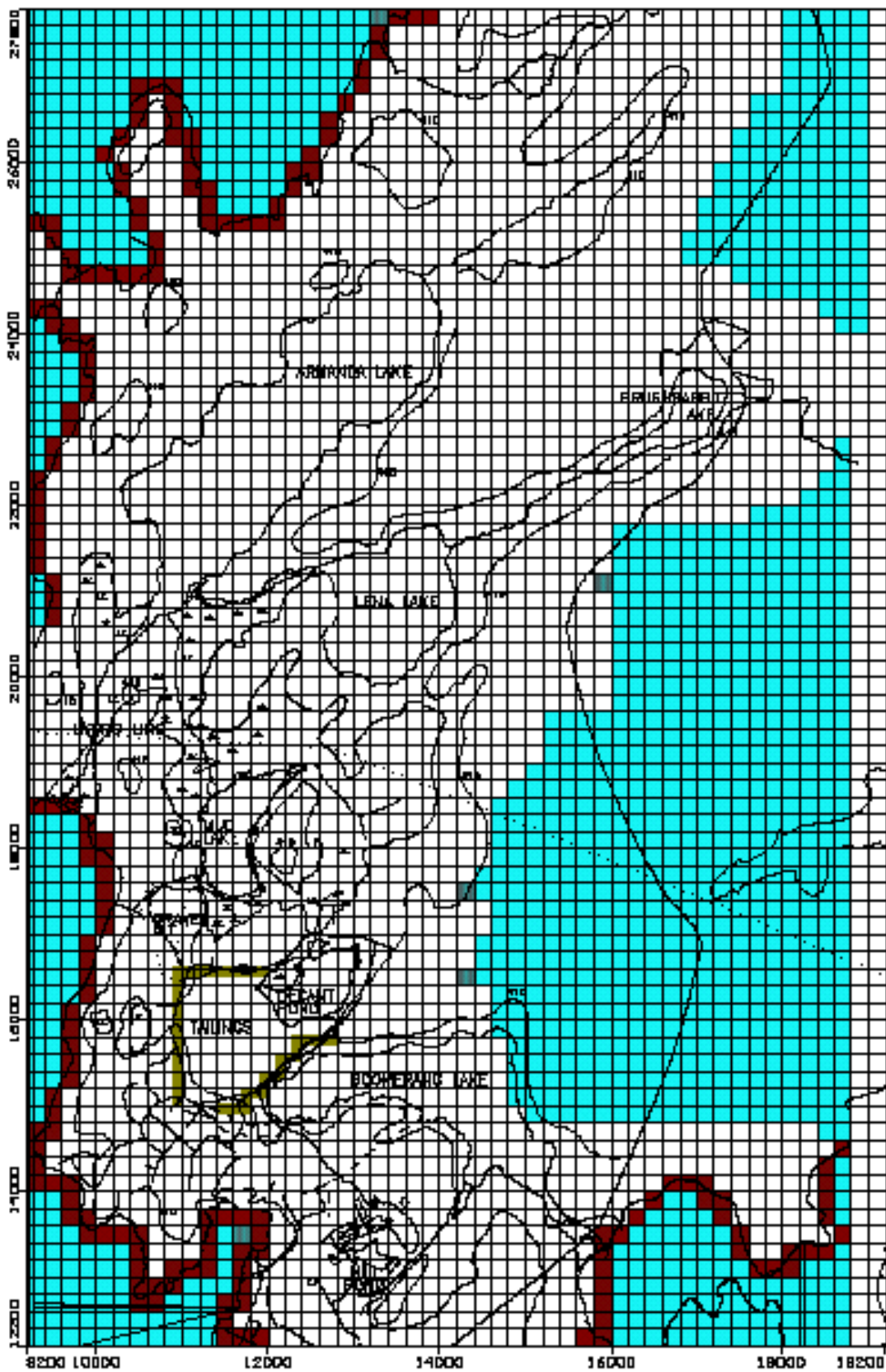
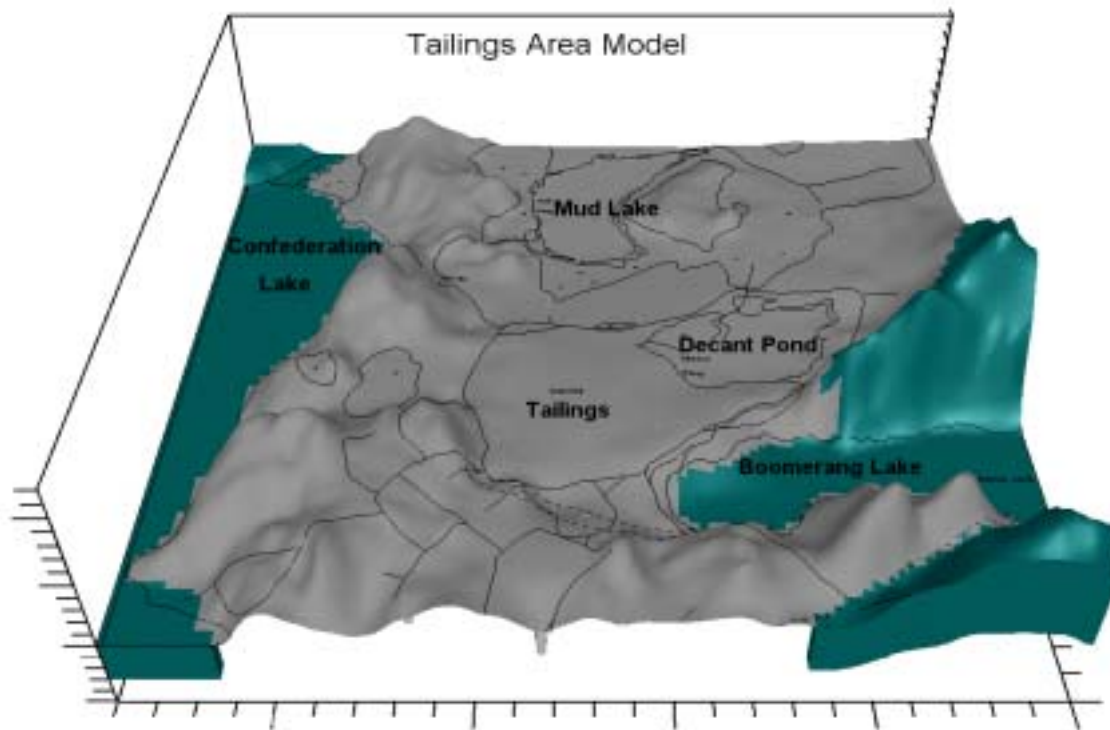


Figure 2.2: Figure 2.2: Global Site-Wide Model - Grid, Constant Head, and Wall Nodes



**Figure 2.3: Tailings Area Model - Ground Surface Topography
(Vertical Exaggeration, 10:1)**

The ground surface topography for the entire tailings area was input into the model from topographic maps using a *50 ft x 50 ft* grid. An aerial survey had been flown for the project in 1986 by Airquest to arrive at topographic contours for the tailings and mine site with intervals of 5 ft. Bedrock elevations were estimated using the available borehole logs, geophysical surveys; ground truthing measurements, visible outcrops and “educated guesses” were used in the regions where no data was available. Refinements were made to the model in several stages:

- First six equally spaced layers were defined between the ground surface and bedrock surface and hydraulic conductivities were assigned similar to those for the global site-wide model (SCIMUS, 1998)
- Borehole log stratigraphic data from 73 monitoring wells were used to define *four* distinct layers between the ground surface and bedrock surface throughout the modeled area and measured hydraulic conductivities in the various stratigraphic units (SCIMUS, 1999)
- Further refinements were made to model the town site as described in Section 3.4.

As with the Global Site wide Model, it was necessary to adjust the position of the bedrock surface in some locations to ensure that adjacent cells were in contact with one another. The layer immediately above the bedrock was usually assigned a relatively high hydraulic conductivity. This layer takes into account the flow in the fractured bedrock that constitutes the upper few feet of the bedrock. In the region outside of the areas in which boreholes are located, the bedrock was assumed to be 30 feet below ground surface. In these regions, the four layers were equally spaced. Borehole data was used to define the positions of the boundaries of the four layers in the vertical plane, as was done with the site wide model. The Golden Software SURFER model was used to interpolate surfaces at the desired grid spacing for each of the layers and the top of the bedrock from the borehole logs.

The diversion ditch south of the tailings impoundment was represented by a series of drain nodes (gray color) starting at an elevation of 1355 immediately south of the tailings to an elevation of 1351.5 at Boomerang Lake. The tailings dam between the tailings impoundment and Boomerang Lake was represented by a series of wall nodes (gold color) (Figure 2.4).

2.3 Model Input Parameters

The assumed infiltrations (net precipitation minus runoff) used in all models are given in Table 2.1.

Table 2.1: Modeled Recharge

Area of Recharge	Annual Recharge (mm/a)
On treed land areas	150
On lakes, muskeg, rock outcrops, steep slopes	0
Non-vegetated Overburden	200
Tailings	200 (150 in detailed models)

In the areas of standing water (i.e. lakes and muskeg) and in areas with steep slopes, it was assumed that any net precipitation would contribute immediately to surface water run-off and thus would not contribute to the groundwater system. These areas were assigned an infiltration of 0 mm/a.

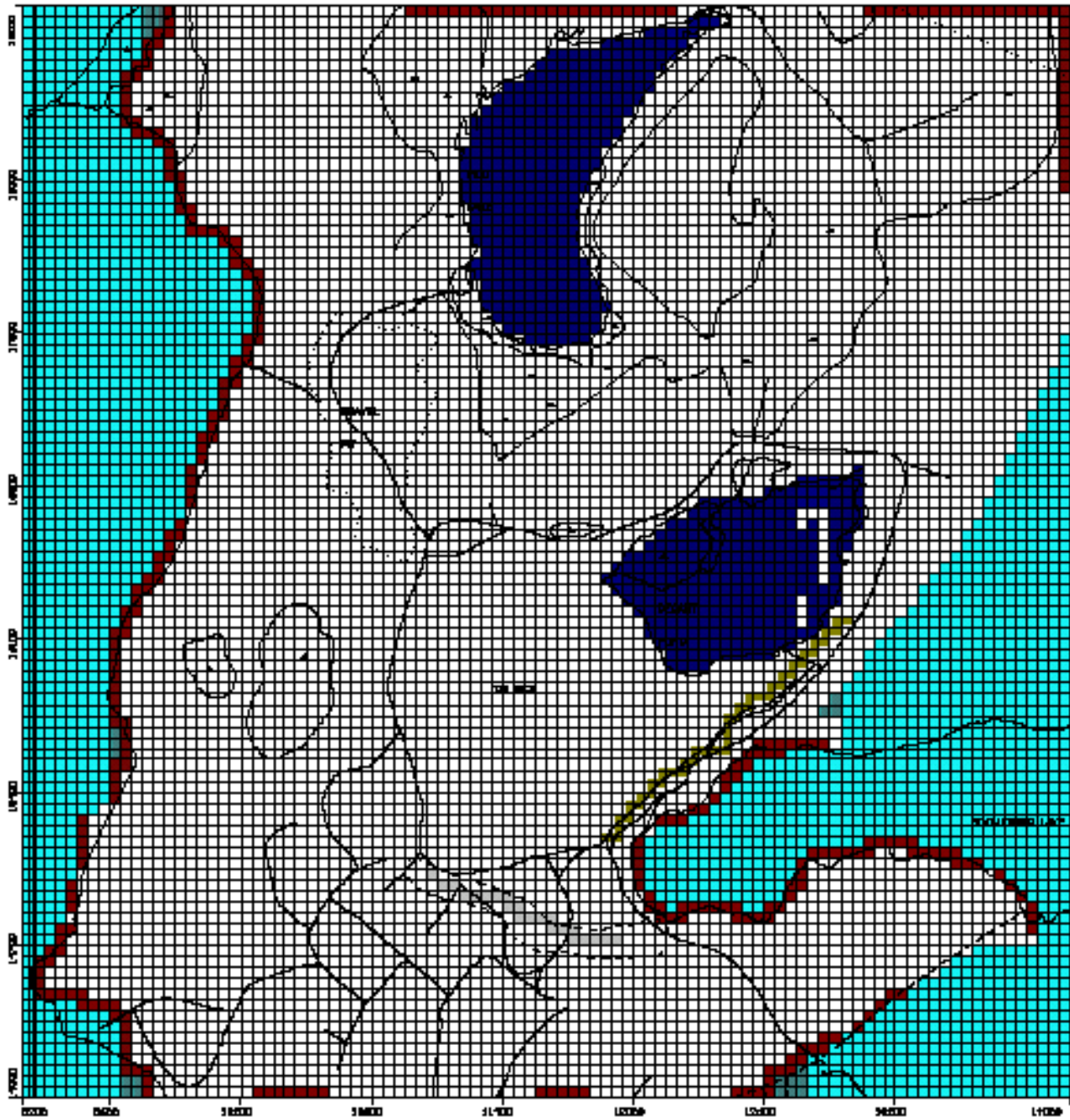


Figure 2.4: Tailings Area Model - Boundary Conditions In Layer 2

The existing hydraulic conductivities measured at the various monitoring wells on site were grouped according to their locations and their depth. These are shown in Appendix A of SCIMUS, 1998. In the global model, the tailings area was divided into 4 conductivity zones depending on elevation and the Kalin Canyon was divided into two zones. The median hydraulic conductivity for each of the

zones was used in the model. The median values were used since large areas were modeled with a limited database. The values used and the color-coding for each hydrogeologic unit modeled in the site-wide model is shown in Table 2.2. A plan view of the hydraulic conductivities in Layer 5 is shown in Figure 2.5. The color codes used for the various hydraulic conductivity values were given in Table 2.2. The vertical hydraulic conductivities were assumed to be between 10% and 20% of the horizontal values except in the case of the highly permeable gravels found in the Kalin canyon. Here the vertical hydraulic conductivity was expected to be similar to the values in the horizontal plane.

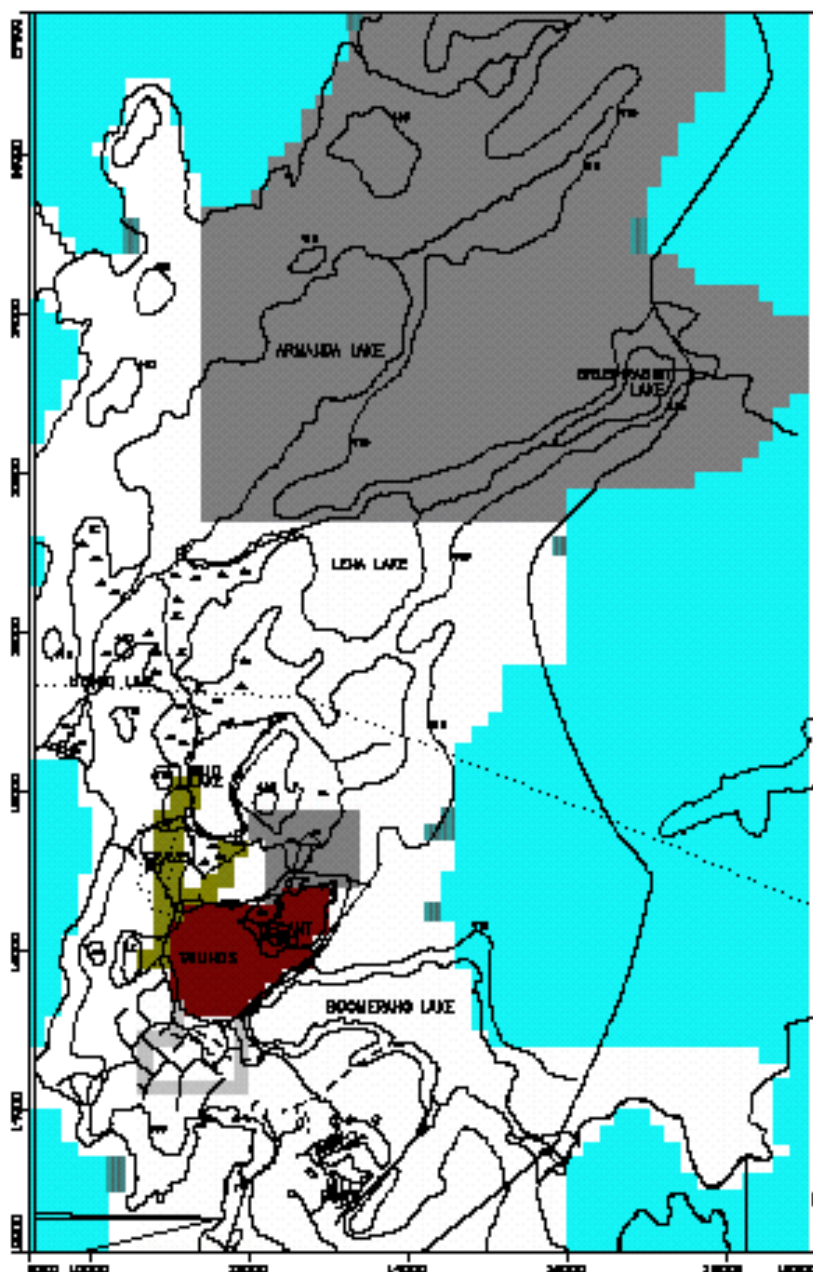


Figure 2.5: Global Site-Wide Model – Hydraulic Conductivities In Layer 5

Table 2.2: Hydraulic Conductivities Used in Global Site-Wide Model

Site Area	Hydraulic Conductivity (cm/s)		Model Colour Code
	xy-plane	z-plane	(Figure 2.5)
General region	0.001	0.0002	White
Tailings (Zone 1, Upper)	0.00014	0.00002	Dark Blue
Tailings (Zone 2)	0.000071	0.000002	Green
Tailings (Zone 3)	0.00017	0.00001	Light Blue
Tailings (Zone 4, lower)	0.00718	0.0007	Orange
Kalin Canyon Upper Zone	0.016	0.01	Purple
Kalin Canyon Lower Zone	0.093	0.09	Yellow
Mine Site Flow Restriction	0.00004	0.000002	Light Gray
South Mud Lake Permeable Zone	0.005	0.0005	Dark Gray

In the case of the detailed models for the Tailings Area and the Town Site, the geometric means of the conductivity zones were used. The geometric mean is the appropriate value to use in an area where there are sufficient data to characterize the stratigraphic units. The values used and the color coding for each hydrogeologic unit modeled in the detailed models and the hydraulic conductivities assigned for a cross-section of the tailings area and Mud Lake are shown in Figure 2.6.

Each of the lakes was assigned a constant head, depth, and a conductance representing the rate of recharge to the groundwater system. The assigned elevation and depths are given in the Table 2.3. The conductance of the lake bottoms was chosen such that the properties of the surrounding groundwater system, not the lake bottom would govern the rate of recharges or discharge. The Decant Pond was also assigned constant head nodes similar to those for the Lakes.

Table 2.3: Properties of Lakes

Lake	Water Elevation (fasl)	Depth (ft)
Boomerang Lake	1351.5	6.5
Mud Lake	1357	3
Decant Pond	1365	3
Bush Rabbit Lake	1358	3
Lena Lake	1356	6
Amanda Lake	1352	7

Confederation Lake was assigned a constant head of 1351 fasl and defined the majority of the boundary of the modeled region in the global site-wide model. The remainder of the northern boundary was interpolated between the water level in Confederation Lake and a water level of 1364 fasl for the Lake in the northeast corner of the modeled domain, taking into account the topography. The remainder of the boundary was assumed to be a no flow boundary since it represented a topographic high.

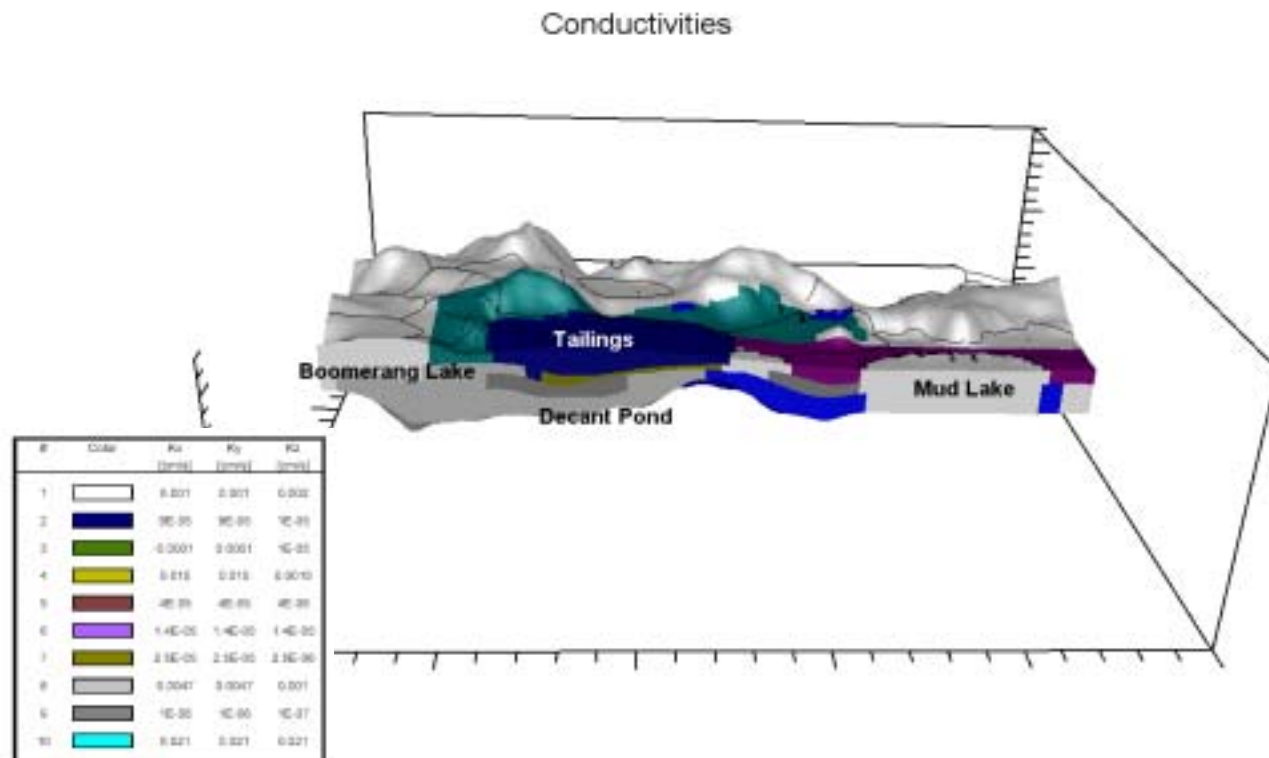


Figure 2.6: Tailings Area Model - Hydraulic Conductivities (Vertical Exaggeration, 10:1)

3.0 Modeling Results

3.1 Global Site-Wide Modeling Results

The equipotentials and the direction of flow are shown in Figure 3.1. The equipotentials generally follow the contours of the land, as can be expected. The flow direction is perpendicular to the equipotentials.

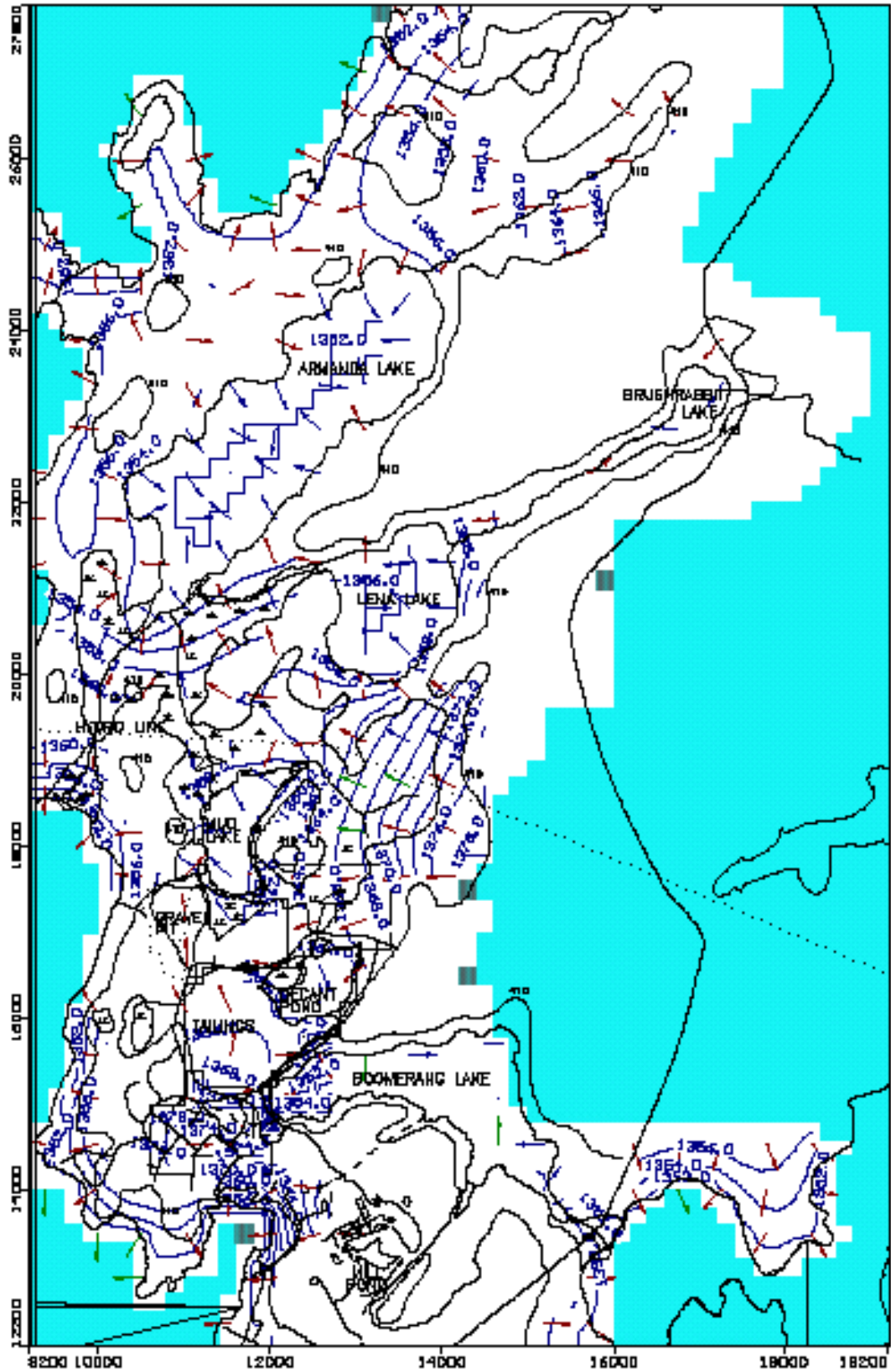


Figure 3.1: Global Site-Wide Model - Equipotentials and Flow Direction In Layer 1

The Amanda Lake watershed accounts for a discharge of 382,500 m³/a into Confederation Lake from the groundwater system. Of this, 218,600 flow directly from the groundwater system into Confederation along its shoreline and 163,900 discharges first into Amanda Lake and subsequently flow into Confederation Lake via surface water. All of this water is uncontaminated by the mining/milling operations.

Lena Lake drains into Amanda Lake and thus the major output from the Lena Lake watershed to the Amanda Lake watershed is about 131,300 m³/a of groundwater that discharges into Lena Lake and then continues as surface water into Amanda Lake. About 23,700 m³/a of groundwater from the Lena Lake watershed flows directly into the Amanda Lake watershed. All of this water is uncontaminated by the mining/milling operations.

The Mud Lake watershed has a mixture of contaminated and uncontaminated water. The tailings impoundment is contained within this watershed and a significant percentage (about 25% as calculated from the more detailed tailings area model) of the 102,000 m³/a of groundwater discharging into Mud Lake originates from this impoundment. This is the potentially contaminated portion. The majority, about 75,000 m³/a of the groundwater, that flows into Mud Lake as well as all of the 56,000 m³/a of groundwater that flow directly into Confederation Lake are uncontaminated. In addition, there are 36,500 m³/a of uncontaminated groundwater that flow into the Lena Lake watershed and 18,900 m³/a (most of which is uncontaminated) that flow into Boomerang Lake. Most of the 6,800 m³/a of groundwater that flows to the Northern Mine Site watershed is also uncontaminated. In total, only about 31,000 m³/a of the 224,000 m³/a of the groundwater discharged from the Mud Lake watershed have a potential for contamination.

The Northern and Southern Mine Site watersheds and Boomerang Lake all have large portions of contaminated water. At present this contaminated water is isolated from the groundwater discharging along the Confederation Lake shoreline and thus the 167,000 m³/a of groundwater that is discharging into Confederation Lake is at present uncontaminated. Significant volumes of potentially contaminated water, about 115,000 m³/a, are discharging into Boomerang Lake. In Boomerang Lake an ecological engineered treatment system is in operation relegating Zn to the sediments and stabilizing the acidification.

The totals flows of uncontaminated water from the groundwater system in the watersheds studied that available for dilution is estimated to be about 900,000 m³/a.

3.2 Calibration of Tailings Area Model

The model calculated a steady-state flow regime. Figure 3.2 and Table 3.1 show a comparison of the calculated versus observed heads at each of the monitoring wells. All of the heads agree within 3 ft, with the exception of M-22, M-42, M-78A, B, M-71, and M-44. Water levels in M-22 and M-71 are anomalous. Monitoring wells M-42 and M-78A, B are adjacent to the diversion ditch while M-44 is adjacent to the tailings dam and thus the water levels in these cannot be calibrated with the present grid spacing, because of the steep guidance caused by the man-made structures. Most of the heads agree within 2 ft. This is considered to be an excellent agreement given the complexity of the terrain and the large unknowns in parameter values. With the present model calibration, a good representation of the volume of flows and flow directions should be possible.

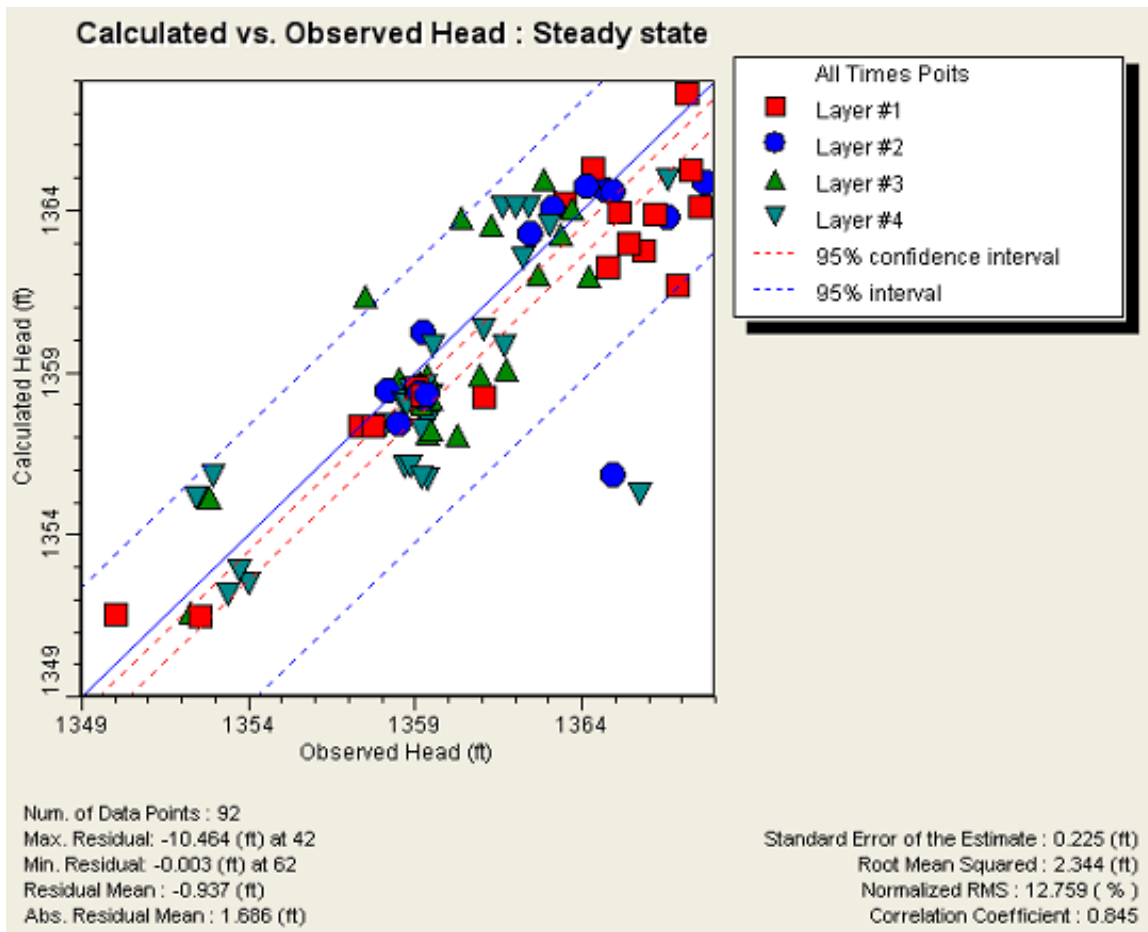


Figure 3.2: Flow Model Calibration, Calculated vs Observed Heads for Tailings Area Model

Table 3.1: Comparison of Calculated and Observed Heads in Tailings Area Model

Monitoring Well	Observed Heads (ft)	Calculated Heads (ft)	Difference (ft)	Monitoring Well	Observed Heads (ft)	Calculated Heads (ft)	Difference (ft)
M42	1365.72	1356.33	-9.4	M79	1358.62	1358.28	-0.3
M22	1364.93	1356.2	-8.7	M66B	1359.24	1358.9	-0.3
M78A	1358.69	1355	-3.7	M3	1359.02	1358.68	-0.3
M78B	1358.89	1355.82	-3.1	M34	1359.05	1358.72	-0.3
M33	1367.74	1364.93	-2.8	M66A	1359.14	1358.88	-0.3
M41	1366.58	1363.79	-2.8	M63	1357.72	1357.46	-0.3
M28	1360.26	1357.69	-2.6	M27C	1359.03	1358.81	-0.2
M90	1361.04	1358.48	-2.6	M40B	1362.68	1362.48	-0.2
M64	1361.74	1359.35	-2.4	M5N	1358.89	1358.72	-0.2
H1	1366.2	1363.85	-2.3	M2	1364.73	1364.61	-0.1
M30	1364.23	1361.95	-2.3	M5W	1363.37	1363.26	-0.1
M60B	1359.47	1357.27	-2.2	M9	1360.96	1360.86	-0.1
H6	1365.83	1363.8	-2	M62	1357.32	1357.22	-0.1
H5	1367.56	1365.55	-2	M26A	1364.94	1364.92	0
M60A	1359.23	1357.27	-2	M72B	1359.36	1359.45	0.1
M24N	1359.37	1357.56	-1.8	M39	1358.18	1358.63	0.4
H7	1365.38	1363.61	-1.8	M65	1364.18	1364.69	0.5
M47	1353.38	1351.68	-1.7	H8	1368.4	1368.96	0.6
M31	1366.59	1365.03	-1.6	M67	1363.7	1364.32	0.6
M8	1354.04	1352.48	-1.6	M4	1358.51	1359.17	0.7
M24W	1358.53	1357.06	-1.5	M40A	1362.46	1363.15	0.7
M58	1359.17	1358.03	-1.1	M27S	1363.13	1363.87	0.7
M59	1359.29	1358.16	-1.1	M43	1363.03	1363.82	0.8
M76	1359.48	1358.4	-1.1	H4	1367.13	1368.18	1
M53	1352.56	1351.5	-1.1	M7N	1363.5	1364.79	1.3
M73	1359.18	1358.23	-1	M46	1361.07	1362.36	1.3
M69	1359.51	1358.62	-0.9	M27N	1364.36	1365.67	1.3
M83B	1359.32	1358.47	-0.9	M75	1359.57	1360.89	1.3
M89	1359.38	1358.59	-0.8	M32	1361.69	1363.09	1.4
M24E	1358.13	1357.34	-0.8	M10	1359.39	1361.12	1.7
M5E	1359.05	1358.32	-0.7	M26B	1362.42	1364.32	1.9
H2	1364.76	1364.07	-0.7	M82	1359.23	1361.15	1.9
M52	1352.27	1351.59	-0.7	M25	1362.85	1364.92	2.1
M88	1359.22	1358.57	-0.6	M77B	1352.85	1355	2.2
M20B	1359.36	1358.72	-0.6	M68	1362.03	1364.19	2.2
M74	1359.31	1358.7	-0.6	M56	1350.03	1352.19	2.2
M83A	1359.07	1358.47	-0.6	M61	1361.28	1363.56	2.3
M45	1353.72	1353.14	-0.6	M1	1361.61	1364.06	2.4
M72A	1359.18	1358.62	-0.6	M7S	1362.26	1364.73	2.5
M39A	1359.15	1358.62	-0.5	M77A	1352.46	1355	2.5
M80	1358.83	1358.3	-0.5	M21	1359.36	1362.25	2.9
M86	1359.16	1358.66	-0.5	M50	1352.92	1355.93	3
M81	1358.73	1358.23	-0.5	M71	1360.39	1363.75	3.4
M85	1359.06	1358.69	-0.4	M44	1357.52	1361.37	3.9
H3	1365.1	1364.75	-0.4				

3.3 Tailings Area Modeling Results

3.3.1 Groundwater Flows under Existing Conditions

The equipotentials, path lines, and the direction of the velocity vectors in the various layers as shown in Figures 3.3 to 3.6 describe the flow pattern. There is evidence of a local water table mounding in the upper layers near the southwest corner of the tailings impoundment. This is consistent with field observations of water pooling at the surface in this area. This effect disappears in the lower layers.

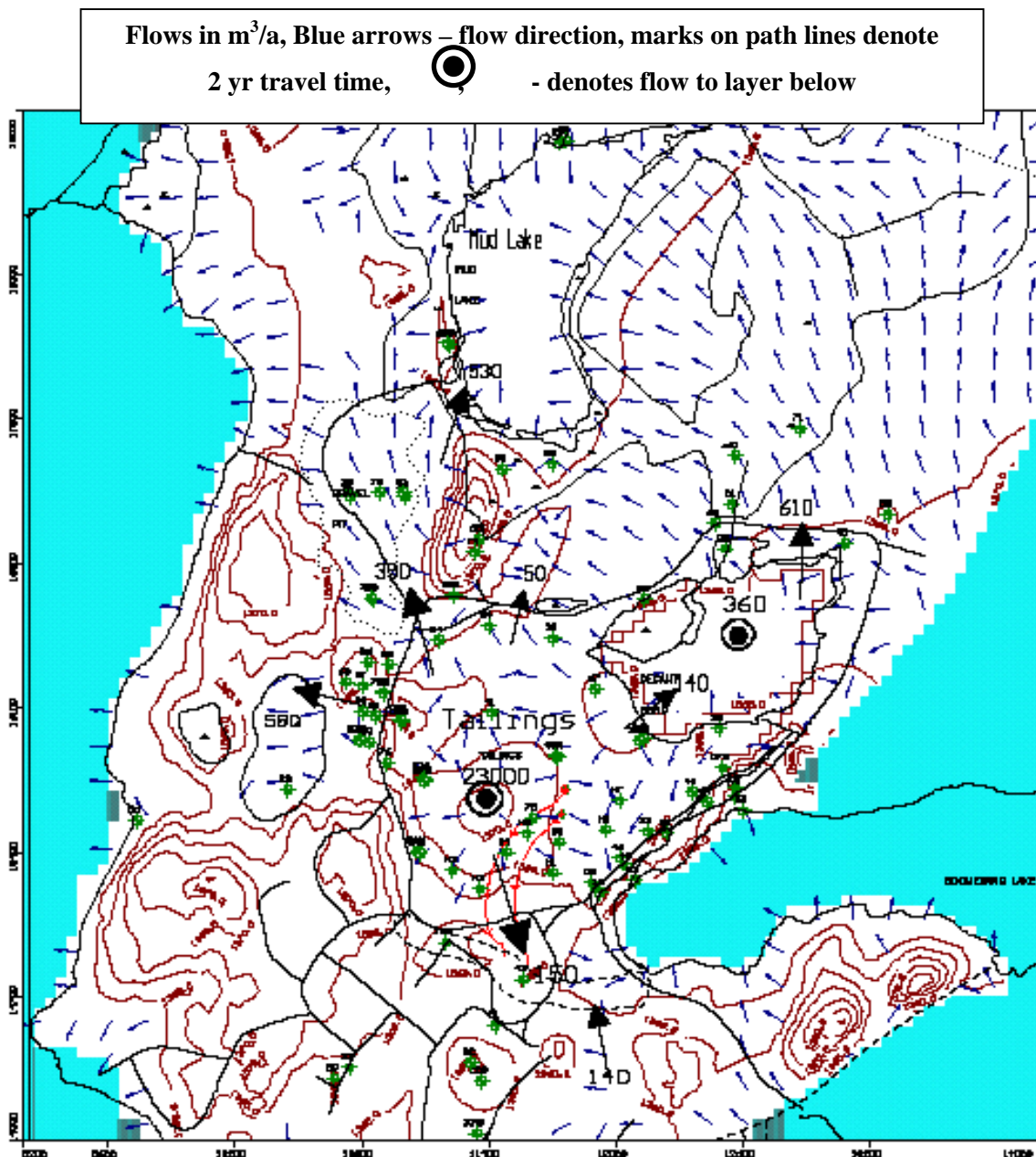


Figure 3.3: Tailings Area Model - Equipotentials, Flows, and Path lines In Layer 1

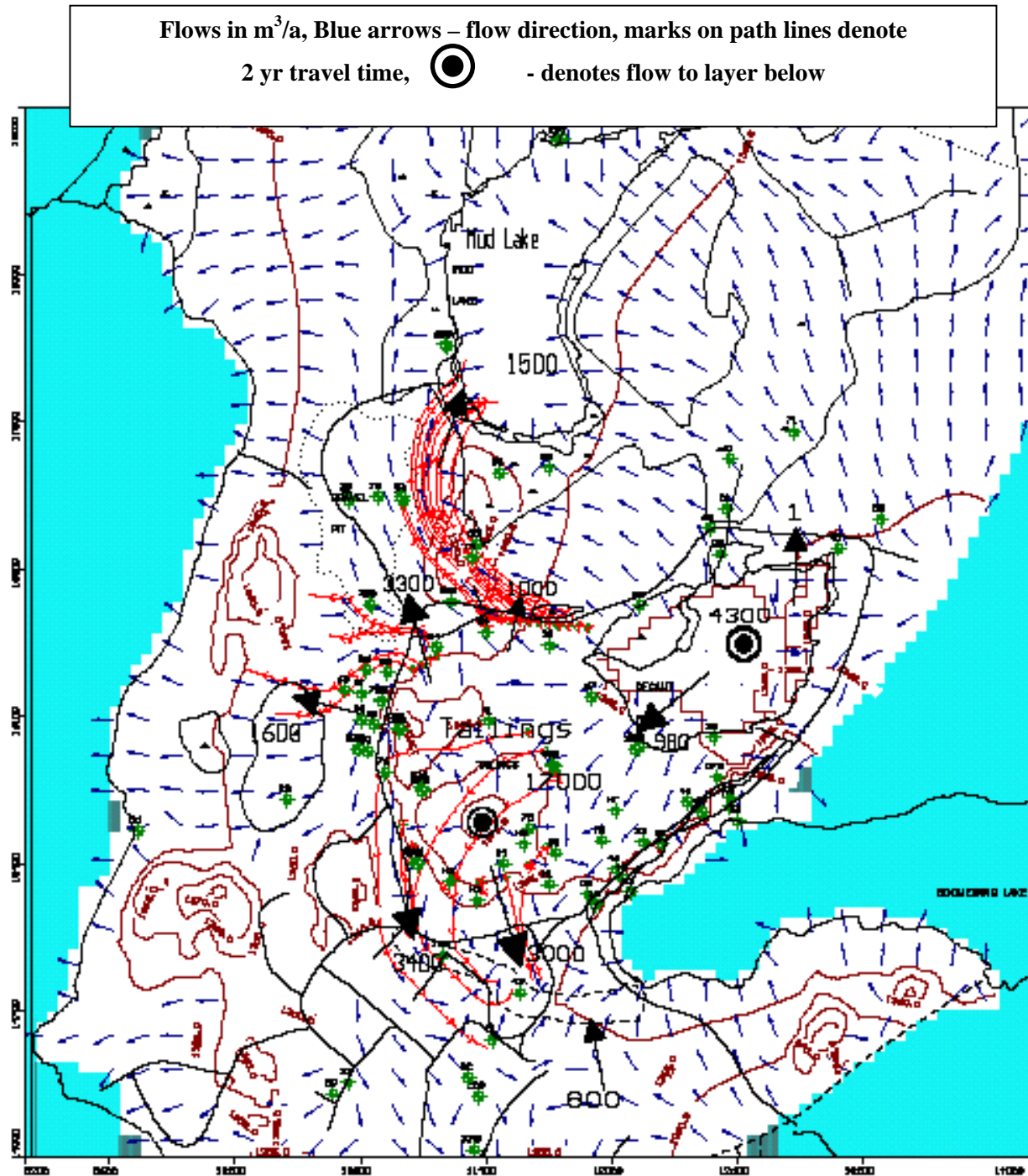


Figure 3.4: Tailings Area Model - Equipotentials, Flows, and Path lines In Layer 2

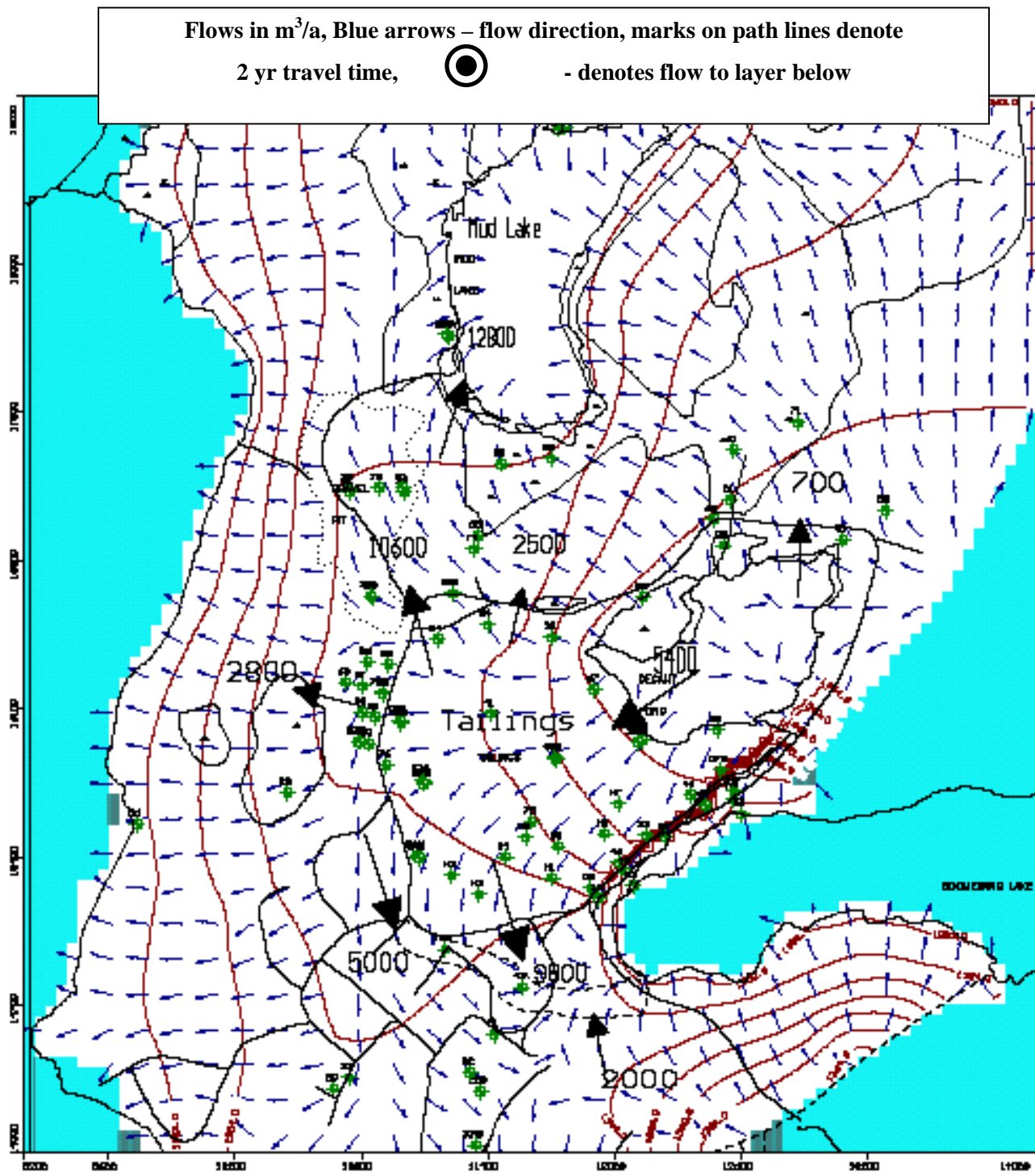


Figure 3.6: Tailings Area Model - Equipotentials, Flows, and Path lines In Layer 4

The diversion ditch to the south of the tailings impoundment creates an effective hydraulic trap. This is clearly shown in the velocity vectors, Figures 3.3 to 3.6, as water flows towards the ditch from the north from Kalin canyon and the tailings and from the south from the town site. The predominant flow directions from the tailings area are clearly defined as one observes the flow pattern in the lower layers, Figure 3.5 and 3.6. The predominant flow direction from the tailings impoundment is towards the diversion ditch, rather than to Kalin canyon. The water flows mainly either west to the Kalin canyon and then to the ditch or directly south from the tailings to the ditch. Only water from the northern tip of the tailings flows north to Mud Lake through the Kalin Canyon.

Decant Pond serves as the major recharge area for water moving through the tailings impoundment. Most of the groundwater discharging into the Decant Pond originates from the high ground to the east.

The annual flows in each of the various zones are also shown in Figures 3.3 to 3.6. Figure 3.7 shows a cross-section of the various equipotentials, path lines, and velocity vectors along the predominant direction of travel from the tailings to Mud Lake. From the calculated flow volumes, the following observations can be made:

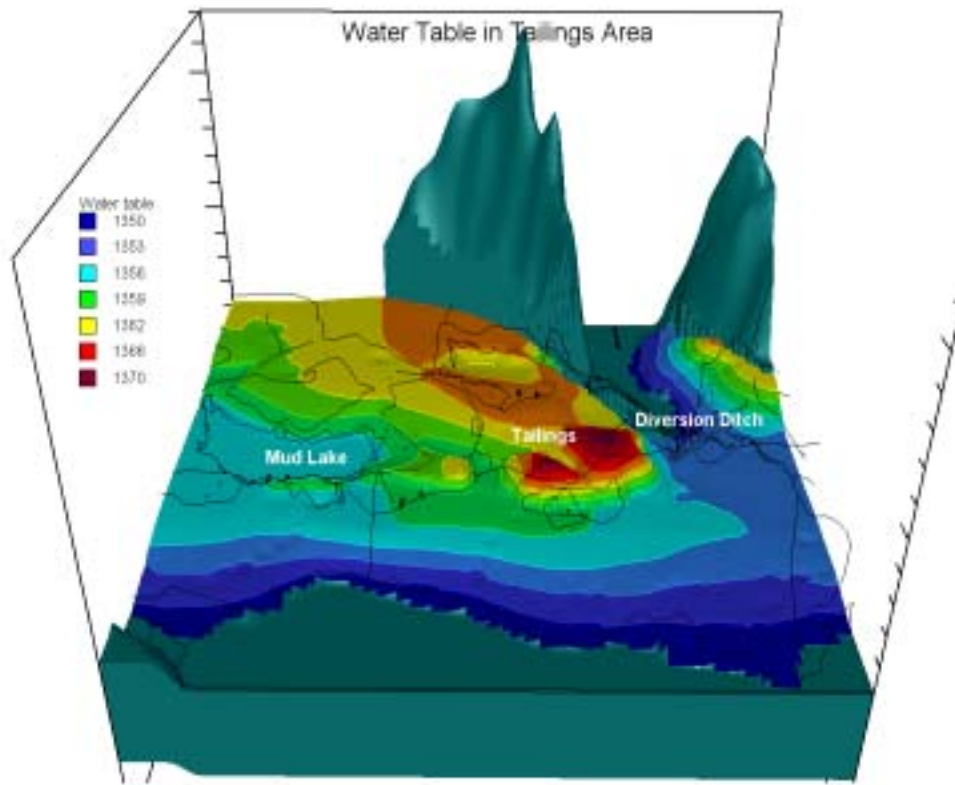


Figure 3.7: Water Table in the Vicinity of the Tailings (Vertical Exaggeration, 10:1)

- The total recharge from precipitation on the tailings impoundment is about 24,000 m³/a, whereas that coming from the Decant Pond (in the lower layers) is about 16,000 m³/a. About 1700 m³/a move directly north from the northwest portion of the Decant Pond towards Mud Lake.
- A net flow of 18,000 m³/a move from under the tailings into the sand/gravel zone in the Kalin canyon.
- A net flow of about 14,000 m³/a moves directly from the tailings area into the diversion ditch.
- A net flow of about 6,000 m³/a moves from the north side of the tailings area north directly to Mud Lake.
- About 8,700 m³/a flow from Kalin Canyon into Boomerang Lake.
- About 13,000 m³/a flow from Kalin Canyon into the diversion ditch.
- About 26,000 m³/a flow from the Kalin Canyon to Mud Lake

In the tailings, the major flow is vertically downward into the lower layers. About 23,000 m³/a of water flows from the tailings into layer 2 directly beneath it. Beneath the tailings, about 12,000 m³/a flows vertically from layer 2 to layer 3 and about 16,000 m³/a flows from layer 3 to layer 4. Since all contaminated water originates from the tailings, one can see a progressive dilution of almost nothing in layer 2, about 44% in layer 3 and a further 34% in layer 4 from water originating from the Decant Pond.

The flow into Kalin Canyon from the Tailings Area originates mainly from layers 2, 3 and 4 whereas water from Kalin Canyon enters Mud Lake mainly in layers 3 and 4. This water is likely contaminated by the seepage from the tailings area.

3.3.2 Lowering Decant Pond

The model was used to simulate the effect of lowering the water level of the Decant Pond. This would be accomplished if the existing beaver dam is breached. The water level would be expected to drop from 1565 fasl to 1563.5 fasl. The resulting changes in flows are shown in Table 3.2.

Table 3.2: Change in Flows with Lowering of Decant Pond

Flow Direction	Annual Flows (m ³ /a) With Decant Pond		
	At Original Level	At Lowered Level	Decrease (%)
Decant Pond To Tailings Area	11400	8000	3400 (30%)
Tailings Area to Diversion Ditch	14000	13000	1000 (7%)
Tailings Area to Kalin Canyon	19000	16600	2400 (13%)
Tailings Area to Mud Lake	6000	4600	2400 (40%)

The lowered Decant Pond resulted in a 30% decrease in the flow of water from the Pond to the Tailings. This in turn resulted in the above decreases in flows from the Tailings area to Mud Lake, the diversion ditch and the Kalin Canyon. An effort was made to lower Decant pond in 1998.

3.3.3 Covering Tailings with Infiltration Barrier

The effect of an infiltration barrier on the tailings was simulated using the model. It was assumed that a covering of phosphate on the tailings would effectively eliminate all infiltration causing the water to run off into Decant Pond. The weir at the outlet of the Pond will maintain the level at 1565 fasl, thus it is not necessary to change the model parameters describing the Pond. The infiltration barrier is simulated by change of the net infiltration into the tailings to zero. The resulting flows are shown in Table 3.3. Almost double the water is expected to enter the tailings from the Decant Pond; however, the flow from the tailings area is expected to decrease between 20 and 40%.

Table 3.3: Change in Flows with Infiltration Barrier on Tailings

Flow Direction	Annual Flows (m ³ /a) To/From Tailings Area		
	With Original Cover	With Infiltration Barrier	Decrease (%)
Decant Pond To Tailings Area	11400	22100	-10700 (-94%)
Tailings Area to Diversion Ditch	14000	9700	4300 (31%)
Tailings Area to Kalin Canyon	19000	10800	8200 (43%)
Tailings Area to Mud Lake	6000	4600	1400 (23%)

3.3.4 Effect of Water Level Rise in Mud Lake and the Validation of the Tailings Area Model

As a result of beaver activity in the Mud Lake area, the water level of Mud Lake increased gradually by about 0.5 m during the late summer/early fall of 1999. At the same time, water level measurement intensity was increased in the tailings area, allowing the monitoring of the effect of the water level rise on the ground water regime. It was found that the water level in the monitoring wells upstream from Mud Lake in the Kalin Canyon rose about one foot as a result of the higher water level in Mud Lake. The changes for individual wells are shown in Table 3.4.

Table 3.4: Change in Water Level in Specified Monitoring Wells Following Water Level Rise of 0.5 m in Mud Lake

Monitoring Well	Water Level Rise in Monitoring Wells (feet)			
	Original Observed WL	Original Calculated WL	Change in Observed WL	Change in calculated WL
M69	1359.51	1358.62	1	0.9
M72A	1359.18	1358.62	1	0.9
M79	1358.62	1358.28	0.7	1.3
M80	1358.83	1358.3	0.9	1.3
M81	1358.73	1358.23	0.8	1.3
M83A	1359.07	1358.47	1	0.8

In order to test whether the Tailings Area Model correctly predicts this change, the level of Mud Lake was increased by 0.5 m in the model and a new steady state water table was calculated. The predicted change in each of the monitoring wells measured is given in Table 3.4. As can be seen the agreement is excellent given that the calculated changes are based on an average annual level, whereas the observed changes are the changes between the water levels of March, 1999 and March, 2000, a single point in time.

3.3.5 Effect of Injection Well Near Mud Lake

In order to predict the effects of a pilot test to inject urea and sugar into monitoring well M60A seepage in the flow regime in the vicinity of Mud Lake, a well injecting water at the rate of 1 L/s was simulated in the model. The well removed 1 L/s from the lowest layer (layer 4 at artesian conditions) and injected the water into the uppermost layer (layer 1). The changes in flows from Kalin Canyon (the location of M60A) into Mud Lake are as shown in Table 3.5. It is reasonable to conclude that the passive injection of these relatively small amounts of water, although highly contaminated, into layer 1 does not affect the ground water regime extensively.

Table 3.5: Change in Flows into Mud Lake with Injection Well

Layer	Annual Flows (m ³ /a) To/From Kalin Canyon into Mud Lake		
	Original	Injection of 1 L/s (Single well)	Injection of 1 L/s (Three wells)
Layer 1	530	700	680
Layer 2	1500	1530	1550
Layer 3	11300	10300	10300
Layer 4	12800	10900	10900

3.3.6 Contaminant Transport Modeling in Tailings Area

Transport of contaminants from the tailings was simulated using the contaminant transport portion of Visual MODFLOW. The transport of contaminants used zinc as a conservative contaminant. Concentrations of zinc in the various piezometers that are screened in the tailings were reviewed in order to develop a source term for the model. From the results of the field measurements between 1986 to the present, it was determined that the zinc concentration in the tailings was best represented by a constant value of 700 mg/L. No retardation and a longitudinal dispersion of 10 ft were assumed. Twenty years of transport were simulated. The Zn concentration contours are shown in colour in layer 3 at 10 and 20 years and in layer 4 at 20 years in Figures 3.8 to 3.10. A cross-section in the direction of flow is shown in Figure 3.11.

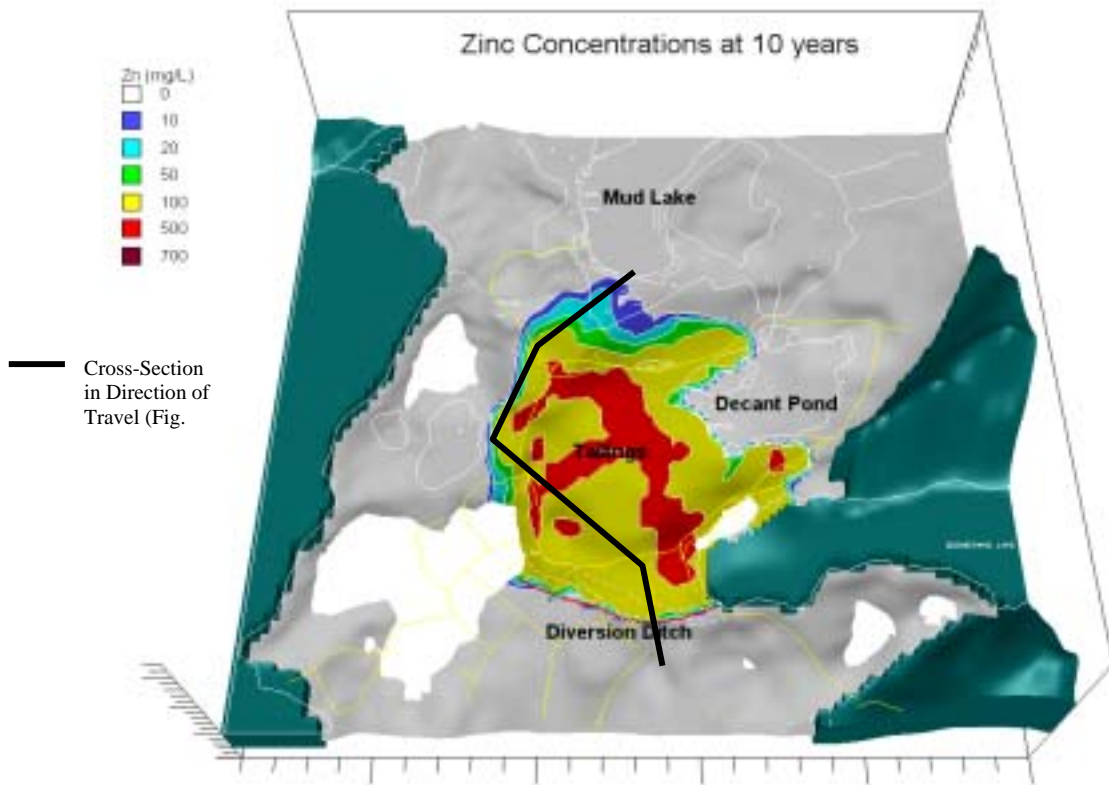


Figure 3.8: Contaminant Plume in Third Layer from Tailings After 10 Years (Vertical Exaggeration, 10:1)

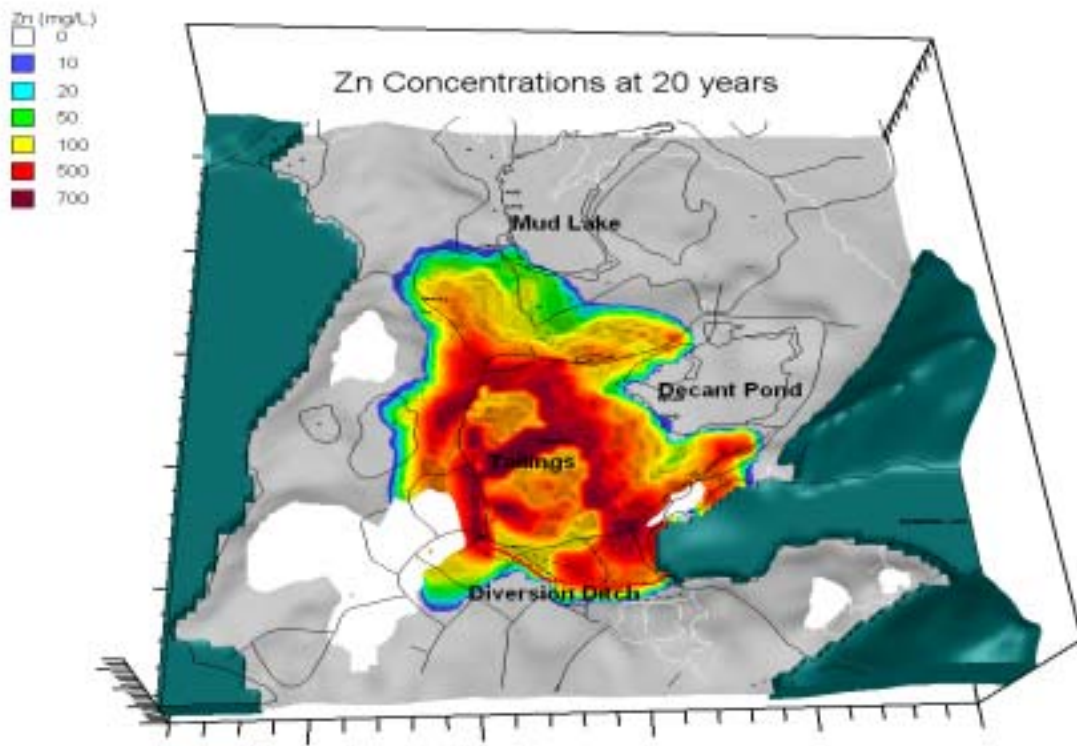


Figure 3.9: Contaminant Plume in Third Layer from Tailings After 20 Years (Vertical Exaggeration, 10:1)

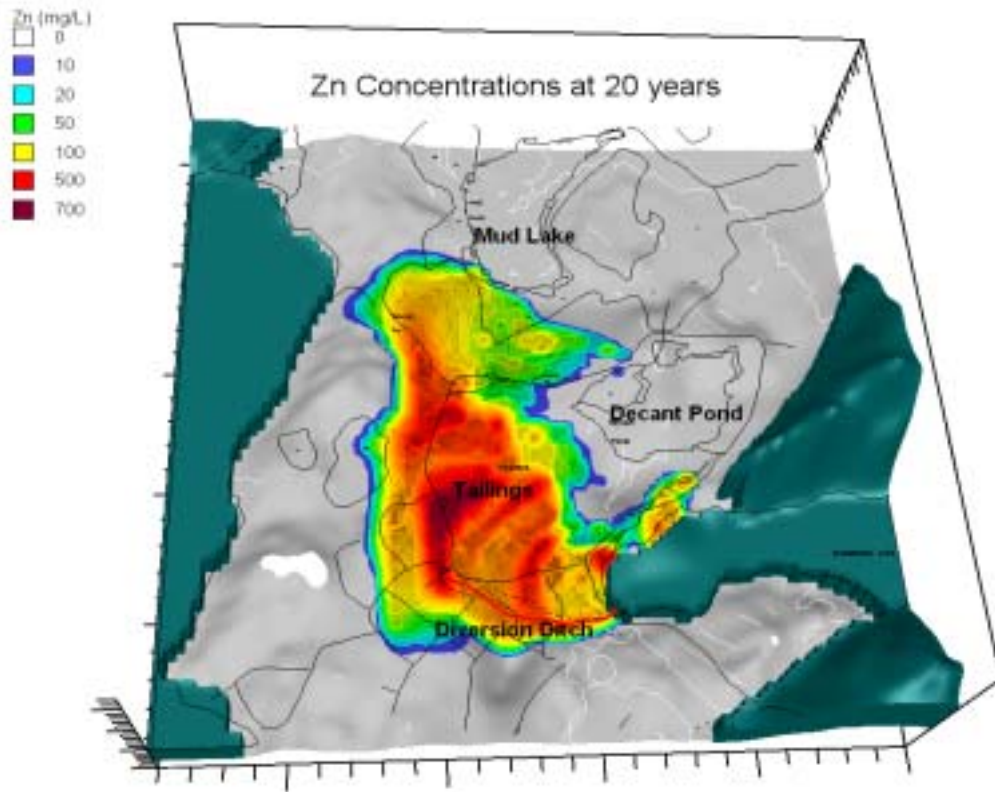


Figure 3.10: Contaminant Plume In Fourth Layer from Tailings After 20 Years (Vertical Exaggeration, 10:1)

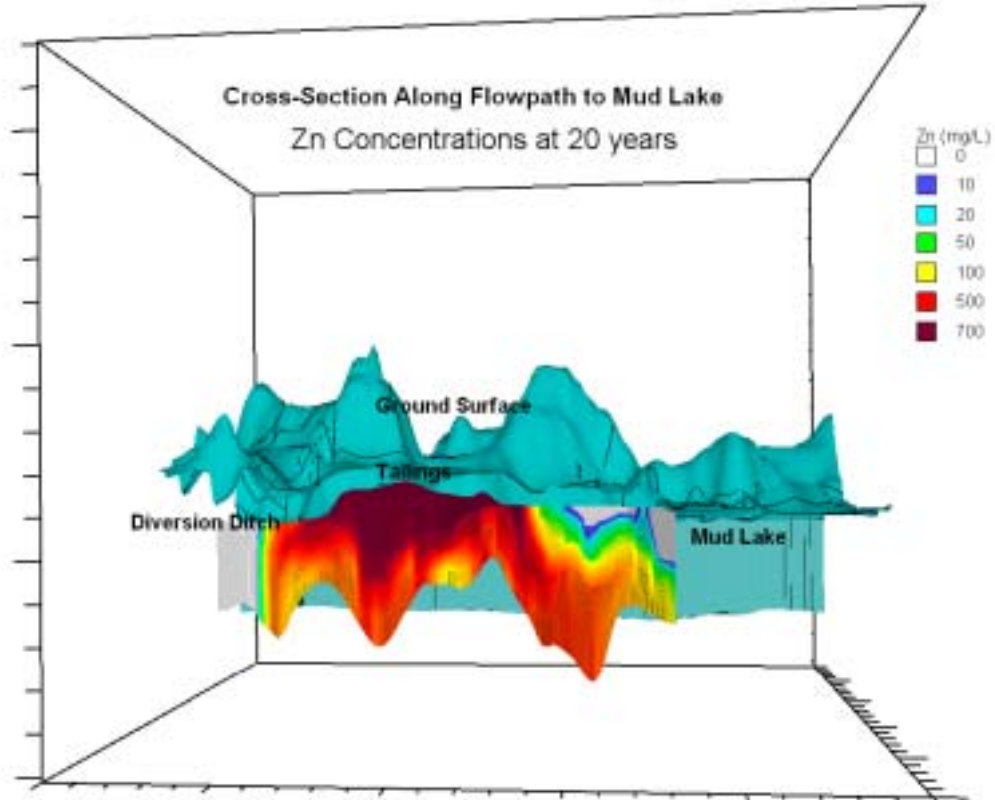


Figure 3.11: Cross-Sectional View of Contaminant Plume After 20 Years in Primary Flow Direction (Vertical Exaggeration, 25:1)

One main contaminant pathway is towards Mud Lake via the Kalin Canyon and zinc contamination is predicted to arrive at Mud Lake within the twenty years modelled. For Monitoring wells, the predicted zinc concentrations after 20 years are shown in Table 3.6. The monitoring wells on the western side of the Kalin Canyon (M79, M80, M81) demonstrate excellent agreement between measured and estimated zinc concentrations. Those on the eastern side (M74 and M66A) predict higher concentrations than measured mainly because they are adjacent to a stratigraphic unit of lower hydraulic conductivity and the actual movement of the contaminant plume is slower than predicted. For M60A, located adjacent to Mud Lake, the 110 mg/L contour of the predicted contaminant plume is only 100 m distant, and thus the rate of movement of the contaminant plume is slightly under predicted in this region. The model also indicates the movement of minor amounts of contamination towards Confederation Lake and this is expected to reach Confederation Lake in small amounts within 30 years.

Table 3.6: Comparison of Measured [Zn] with Predicted [Zn]

Monitoring Well	Stratigraphy	Depth, m	[Zn], mg/L	
			Measured	Predicted
M66A	Gravel	8.21	100	500
M74	Gravel	12.35	3	60
M60A = East	Mud Lake	16.43	110	10
M79	Gravel	17.46	160	180
M80	Gravel	19.21	230	220
M81	Gravel	20.51	75	180

The other main contaminant plume is south directly from the tailings and from the tailings via Kalin Canyon towards the town site. Most of the zinc flowing towards the town site is completely intercepted by the diversion ditch and there is very little movement beyond the ditch in the twenty years modelled. The results indicate that the diversion ditch is effective in containing the contaminant plume from the tailings areas in all depths of the overburden. A zinc concentration of 150 mg/L would be predicted at 20 years from the isopath generated from the transport model at monitoring well M78A and 20 mg/L at monitoring well M42. The measured zinc concentrations at M78A were 198 mg/L in

1995, 170 mg/L in 1996 and 150 mg/L in 2000. At M42, zinc concentrations of 0.11 mg/L in 1986, 16 mg/L in 1996 and 19 mg/L in 2000 were measured. These concentrations are in excellent agreement with the predictions from the transport modeling.

From Figure 3.10, it can be seen that there is a component of the contaminant plume in the lowest layer that bypasses the ditch and continues towards the town site. This component is not predicted to reach monitoring well, M22, within the 20-year modelling period. M22 reported 0.15 mg/L in 1996, again in good agreement, but unfortunately the piezometers is no longer functioning.

In order to more accurately simulate the flow in this region, the hydraulic conductivities of the various layers in the region of the diversion ditch and the former town site were refined based on a data collection made over the past decade. It was found that most of the southward moving contamination in the lowest layer will likely return to the ditch based on the direction of the velocity vectors in this layer; however, there is a small slow moving component that may eventually reach Confederation Lake.

The effectiveness of an infiltration barrier on the tailings on the contaminant plume from the tailings is shown in Figure 3.12. Although the plume is slightly retarded in its movement, it still moves along the primary flow directions and reaches Mud Lake and the diversion ditch within 20 years, and will eventually reach Confederation Lake (about 30 years).

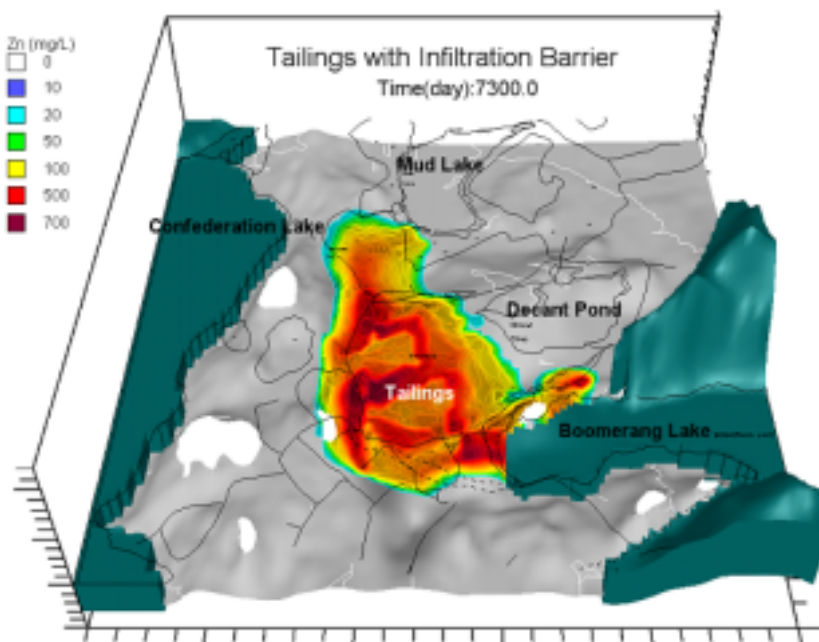


Figure 3.12: Contaminant Plume from Tailings with Infiltration Barrier After 20 Years (10:1 vertical)

4.0 Summary and Conclusions

Several observations can be made from the above modeling study.

The global site-wide model provided a first estimate of the dilution potential from the groundwater system of the various watersheds surrounding the mine and tailings sites. It was determined that there are about 900,000 m³/a of uncontaminated groundwater available for diluting about 150,000 m³/a of groundwater in the mine site and tailings areas that could eventually become contaminated.

The flow from the tailings to the Kalin Canyon is about 18,000 m³/a. Most of this flows north to Mud Lake and some flows south to the diversion ditch. Considerable flow (about 14,000 m³/a) moves south from the tailings into the diversion ditch. There is only minimal flow south that bypasses the diversion ditch toward the town site and west toward Confederation Lake. The flow estimates generated by the model agree well with the trend in interpretation of available hydrogeological information in recent years.

The diversion ditch is the major receptor of contaminated water from the tailings. The zinc loading into the diversion ditch which flows into Boomerang Lake can be estimated to be about 5.6 Tonnes/a from as early as 10 years after the start of the modeling. Modeled zinc concentrations near the diversion ditch agree well with measured concentrations.

The results of the transport modeling using zinc as the representative contaminant indicated a breakthrough of contamination into Mud Lake about 10 years and a predicted concentration of zinc of 30 mg/L at the inflow of this groundwater into Mud Lake after 10 years and about 100 mg/L after 20 years. These predictions agree well with the field observations made to date. The estimated loading of zinc into Mud Lake is 0.78 Tonnes/annum after 10 years and 2.6 Tonnes/annum after 20 years. This value agrees with the observed Zn concentrations in Mud lake using the surface water flows into and out of Mud Lake. This is a very conservative assumption since it assumes that all the water entering Mud Lake from Kalin canyon is contaminated, whereas only the southern portion of the Lake receives contaminated water within the time frame modeled.

From the present modeling results, it is shown that there is a small flow of contaminants from the

tailings into Confederation Lake from the Kalin canyon. Total flows from Kalin Canyon toward Confederation are estimated to be about 7000 m³/a. Of this about 140 m³/a in layer 4 is contaminated with zinc at 10 mg/L after 20 years. This amounts to a loading of about 1.4 Kg/a of zinc into Confederation Lake after 20 years, a loading too small to be detected in Confederation lake.

Flow beyond the diversion ditch is small and is estimated to be only 3 m³/a and at a zinc concentration of 10 mg/L after about 30 years. This amounts to a loading of less than 0.1 Kg/a, a negligible amount.

The modeling has provided a good description of the groundwater flow system, consistent with field measurements. The modeling has demonstrated that the major contaminant pathways are south to the diversion ditch to Boomerang lake and north via the Kalin Canyon to Mud Lake. All other pathways are insignificant.

5.0 References

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