A Modelling Study of the South Bay Mine Site

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1.0 Background

The former gold mine at South Bay, Ontario adjacent to Confederation Lake north of Ear Falls, Ontario has been shut down for over 10 years. Presently the mine site is undergoing closeout using ecological engineering and bioremediation technology.

An extensive monitoring program has been in effect at the South Bay mine site for the past several years. 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 modelling was used in 1988 to attempt to predict the movement of contaminants in the groundwater, using the hydrogeological model developed for the site at that time and the CHINTEX model. During the ensuing years, it was discovered that the main seepage pathway from the tailings was not into Confederation Lake but rather into Mud Lake through a large deposit of gravel which was named the "Kalin canyon".

In light of the increased data base collected during the past ten years and the reinterpretation of the site hydrogeology, it was decided appropriate at this time to construct a numerical model that can be used to simulate the existing groundwater flow patterns and be used to predict contaminant movement. The model, once calibrated can be used to assess the effectiveness of the various remedial alternatives and to assess the impact of changing properties such as porosity and hydraulic conductivity as a result of some of the biological processes used in the remediation.

The three basic objectives of the Phase one modelling described in this report were the following:

- Develop a global site-wide model encompassing all of the significant water sheds in the vicinity of the site in order to determine the effective dilution via groundwater of contaminated water with water from uncontaminated areas. This can then be used together with measured surface water flows to determine expected contaminant concentrations in various water bodies.

- Use the results of the global site-wide model to construct a more detailed tailings area model and calibrate this model to simulate the measured existing flow patterns.

- Use the detailed tailings area model to simulate the release and transport of contaminants from the tailings area into the various receiving water bodies.

As stated above, two models were developed for this study, a global site-wide model and a more detailed ***tailings*** area model.

The major input parameters required by both of the models are summarized in Chapter 2 and the development and results of the global ***site-wide model*** are described in Chapter 3. The development and results of the ***failings area model*** are given in Chapter 4. Conclusions and recommendations for further work are given in Chapter 5.

2.0 Model Input Parameters

2.1 Infiltration

Net precipitation (precipitation minus evapotranspiration) was estimated to be the following for the South Bay Site:

On land areas 250 mm/a
On water bodies 175 mm/a

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

Table 2.1 Modelled Recharge

Parameter	Annual Recharge	Model Colour (Figures 3.4 and 4.4)
Infiltration		
On treed land areas	150 mm/a (5.9 in/a)	white
On lakes, muskeg, rock outcrops, steep slopes	0 mm/a (0 in/a)	blue
Non-vegetated Overburden	200 mm/a (7.9 in/a)	green
Tailings	200 mm/a (7.9 in/a)	green

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 were assigned an infiltration of 0 mm/a. (1)

2.2 Hydraulic Conductivities

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. 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 values used and the colour coding for each hydrogeologic unit modelled is shown in Table 2.2.

Table 2.2 Hydraulic Conductivites Used in Model

Site Area	Hydraulic Conductivity (cm/s)		Model Colour Code (Figures 3.5,3.6,4.5)
	xy-plane	z-plane	
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

The vertical hydraulic conductivities were assumed to between 0% 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.

2.3 Constant Head and Lake Nodes

Each of the lakes were assigned a constant head, depth, and a conductance representing the rate of recharge to the groundwater system. The assigned heads and depths are given in the Table 2.3. The conductances of the lake bottoms were chosen such that the properties of the surrounding groundwater system, not the lake bottom would govern the rate of recharge or discharge. The Decant Pond was also assigned constant head nodes similar to those for the Lakes. The modelled elevation of the Decant Pond was 1365 fasl.

Table 2.3
Properties of Lakes

Lake	Water Elevation (fasl)	Depth (ft)
Boomerang Lake	1351.5	6.5
Mud Lake	1357 .	3
Bushrabbit 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 modelled region. The remainder of the northern boundary was interpolated between the water level in Confederation Lake and a water level of 1364 fast for the Lake in the north-east corner of the modelled 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.

3.0 Site Wide Global Model

3.1 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 area modelled is shown in Figure 3.1.

The model was first set up as a two-dimensional problem using the finite difference planar model, FLOWPATH. Once set up, it was intended to use the finite element cross-sectional model, FLONET, to model some representative cross-sections. The intention was that once the model was developed to transfer the information to a three-dimensional model. After some preliminary calibration work, however, it was decided to go directly to the use of the three-dimensional finite difference model, Waterloo Hydrologic's Visual MODFLOW in order to reduce the total time required for model set-up and calibration.

To help assign properties, the entire modelled 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 modelling 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. In some cases, it was necessary to adjust the position of the bedrock surface in order to ensure that adjacent cells were in contact with one another. 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 model was used to generate surfaces at the desired grid spacing for both the ground surface and the top of the bedrock. These surfaces along with the site map superimposed are shown in Figures 3.1 and 3.2. There is an exaggeration of about 25:1 in the vertical direction.

These surfaces were imported into Visual MODFLOW to define the modelling 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 3.3. Figure 3.4 shows the various recharge zones that were identified in Table 2.1. A plan view of the hydraulic conductivities in Layer 5 is shown in Figure 3.5. The colour codes used for the various hydraulic conductivity values were given in Table 2.2.

Figure 3.1
Global Side-Wide Model - Ground Surface Topography

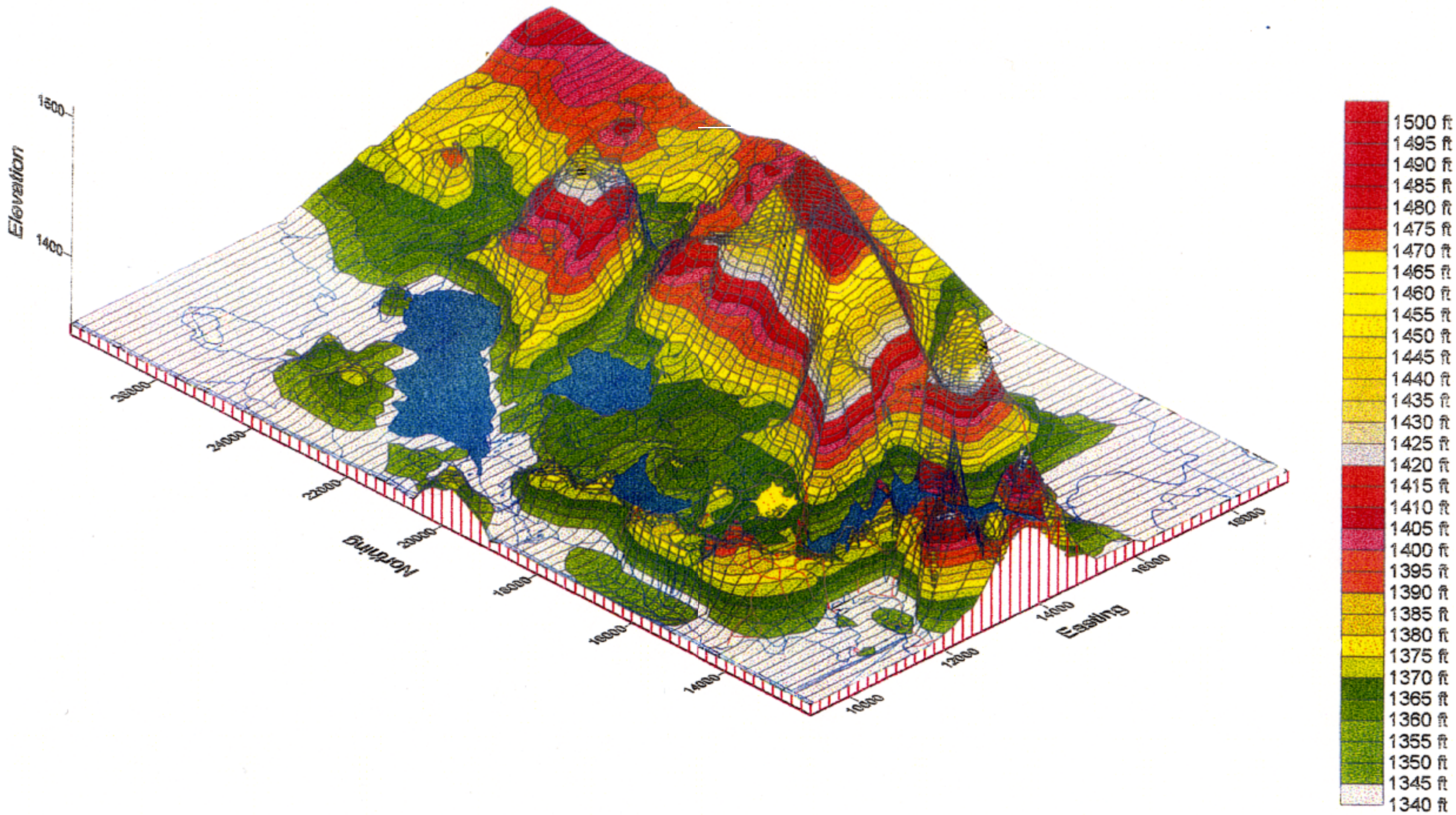
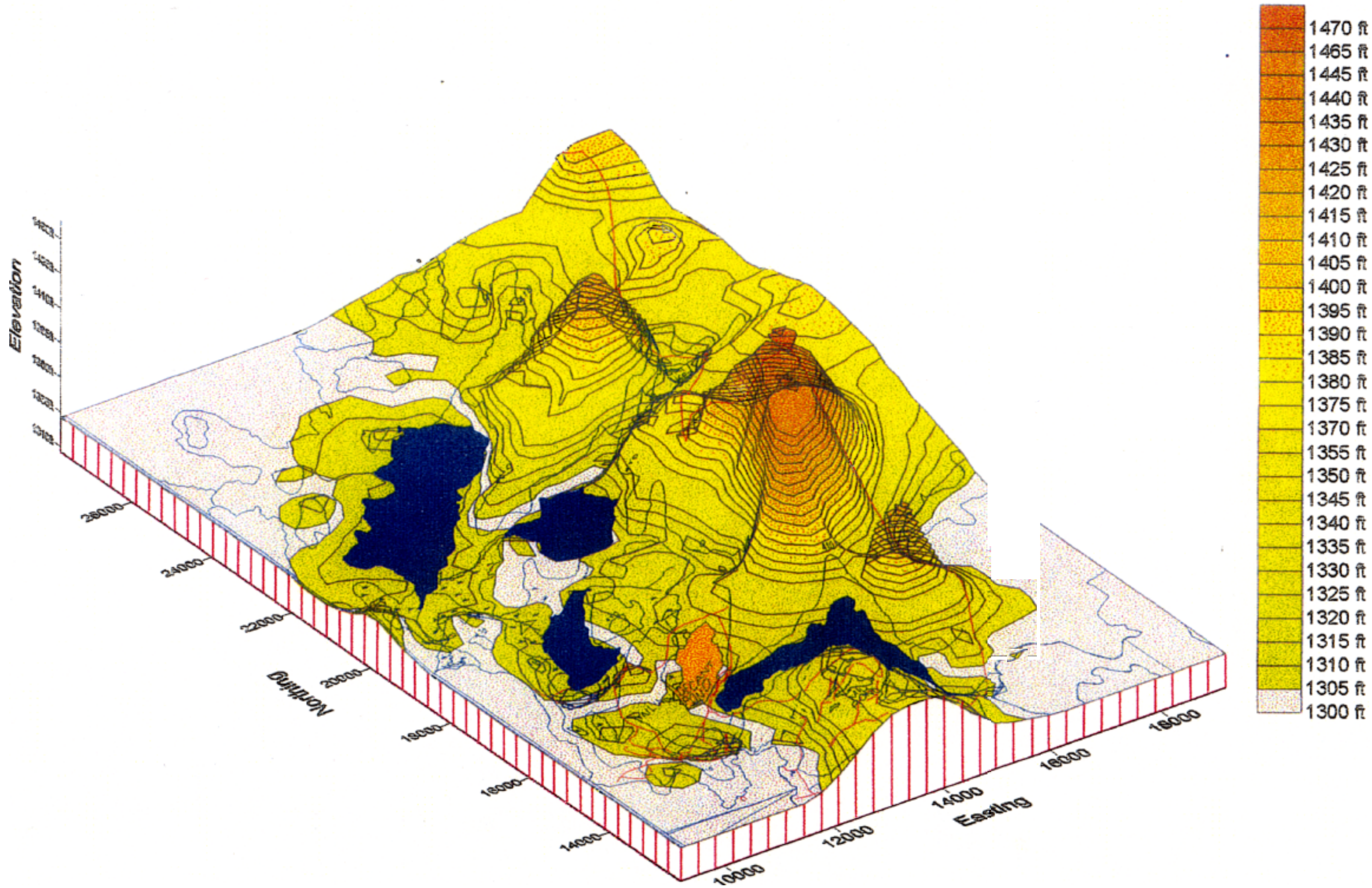


Figure 3.2
Global Site-Wide Model - Bedrock Surface Topography



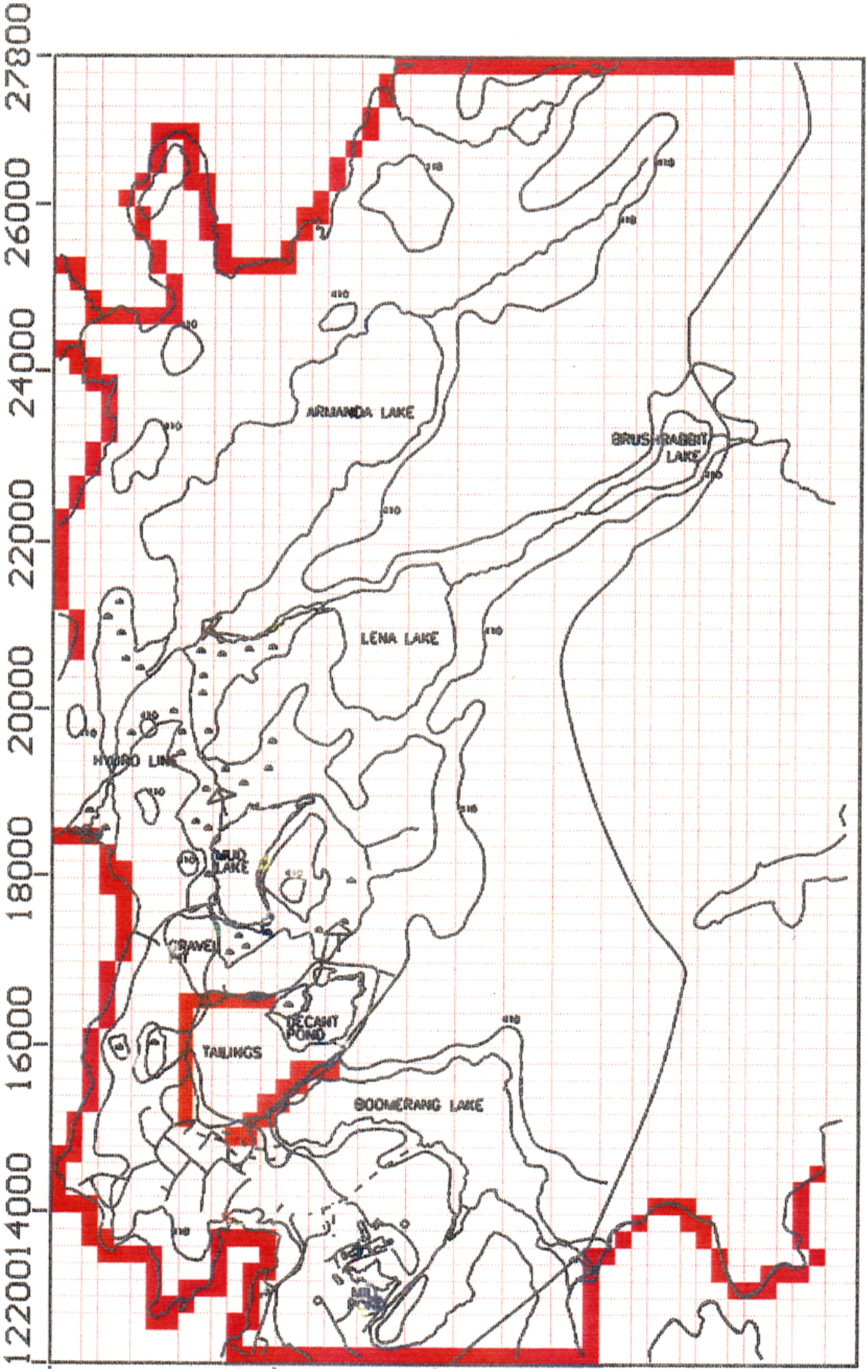


Figure 3. 3 Global Site-Wide Model Grid, Constant Head and Wall Nodes

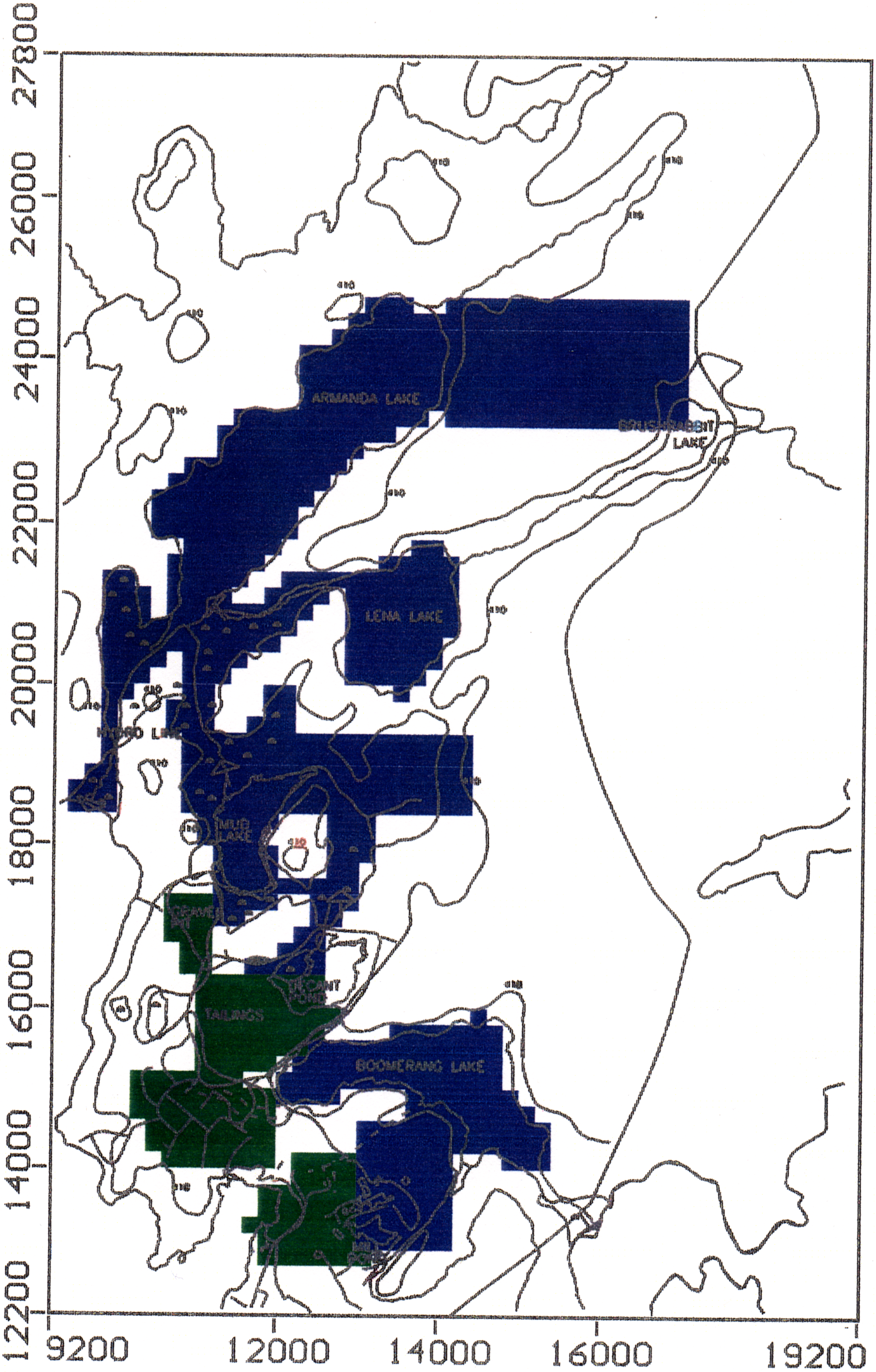


Figure 3.4 Global Site-Wide Model Recharge Zones

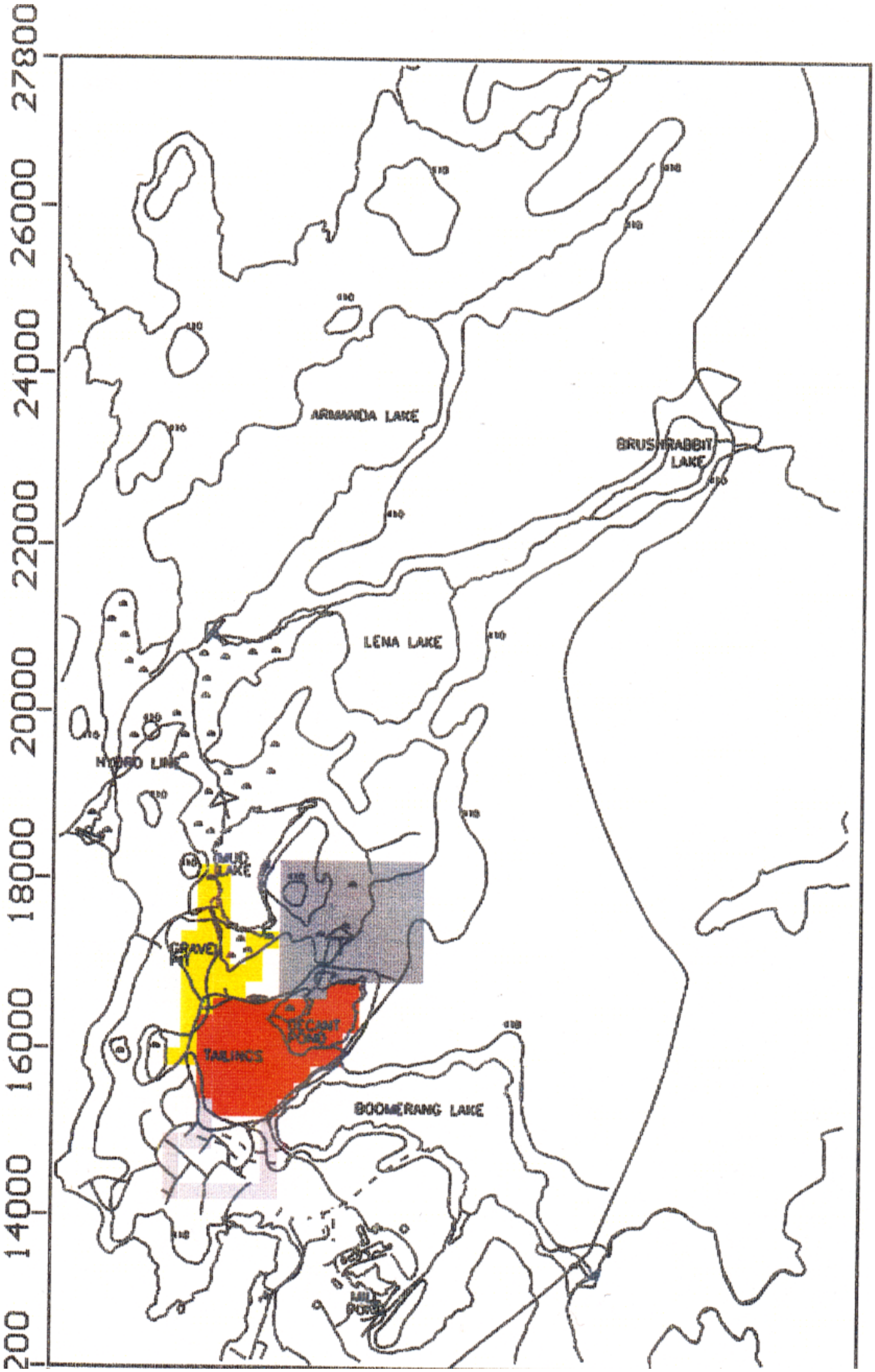


Figure 3.5 Global Site-Wide Model Hydraulic Conductivity Zones on the Lowest Layer

Figure 3.6 shows the conductivity zones in cross-sectional view in a cross-section through the tailings and the Kalin canyon. Only three of the four tailings zones were modelled in the global site-wide model. The various Flow Zones used to determine the flows into Confederation Lake from the groundwater system in the various areas of the site are shown in Figure 3.7 and summarized in Table 3.1. The flow zones correspond to the major watersheds within the modelled region.

Table 3.1 Modelled Flow Zones

Flow Zone	Model Colour	Characteristic
Zone 1 (Amanda Lake)	dark blue	uncontaminated
Zone 2 (Lena Lake)	green	uncontaminated
Zone 3 (Tailings Area)	light blue	mixed
Zone 4 (Northern Mine site)	gray	contaminated
Zone 5 (Boomerang Lake)	pink	mixed
Zone 6 (Southern Mine Site)	orange	contaminated

3.2 Modelling Results

The Equipotentials and the direction of flow are shown in Figures 3.8. As can be seen the equipotentials generally follow the contours of the land as can be expected. The flow direction is perpendicular to the equipotentials.

The flows to Confederation Lake from the various watersheds are summarized in Table 3.2. The various ***inflows*** are described as follows:

- Recharge refers to input into the groundwater system from the infiltration component of the net precipitation.
- The flows from the various lakes refers to the flows entering the groundwater system through the various lake nodes in order to maintain a constant lake water

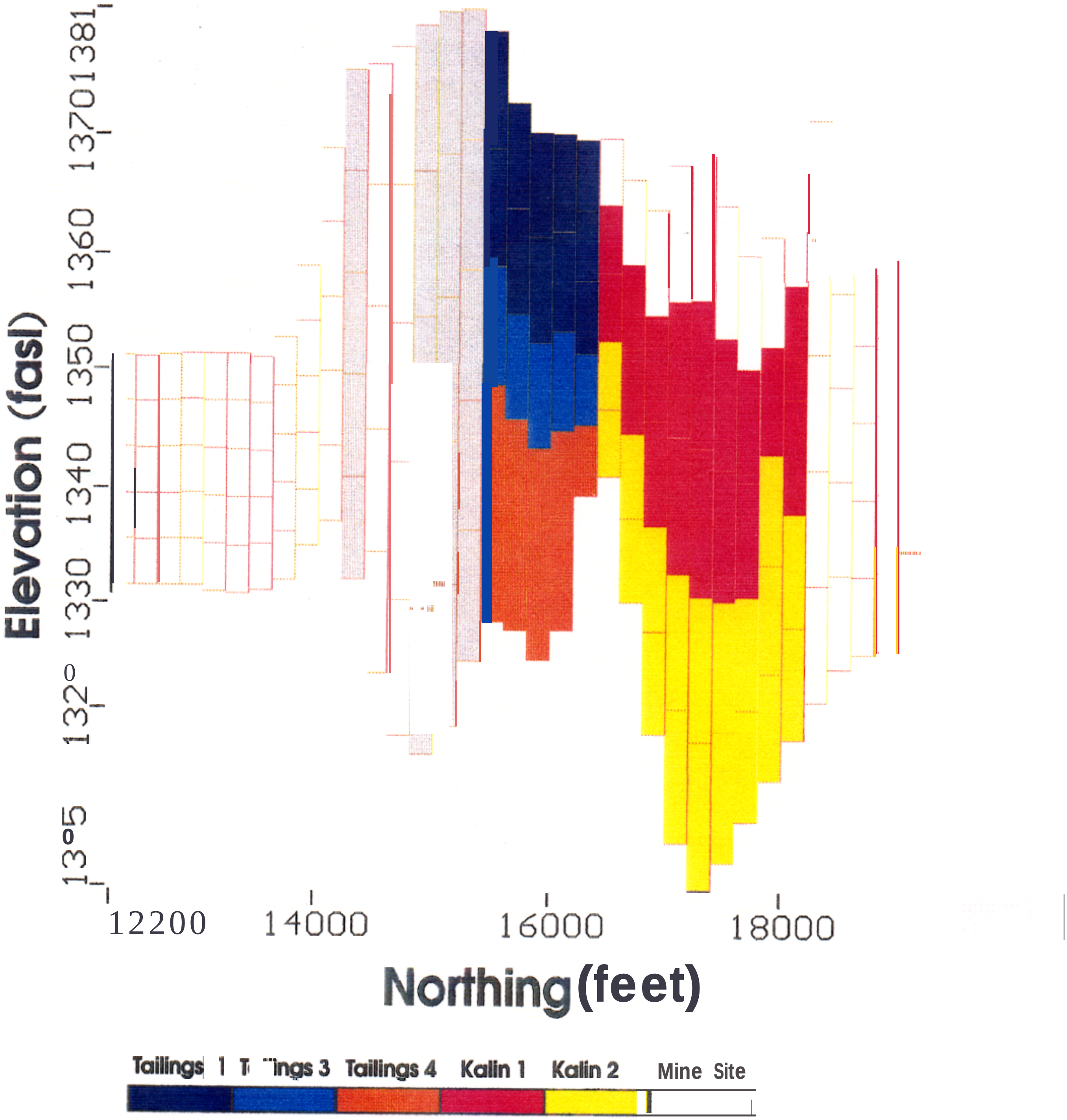


Figure 3.6 Hydraulic Conductivity Zones in Tailings - Kalin Canyon Area

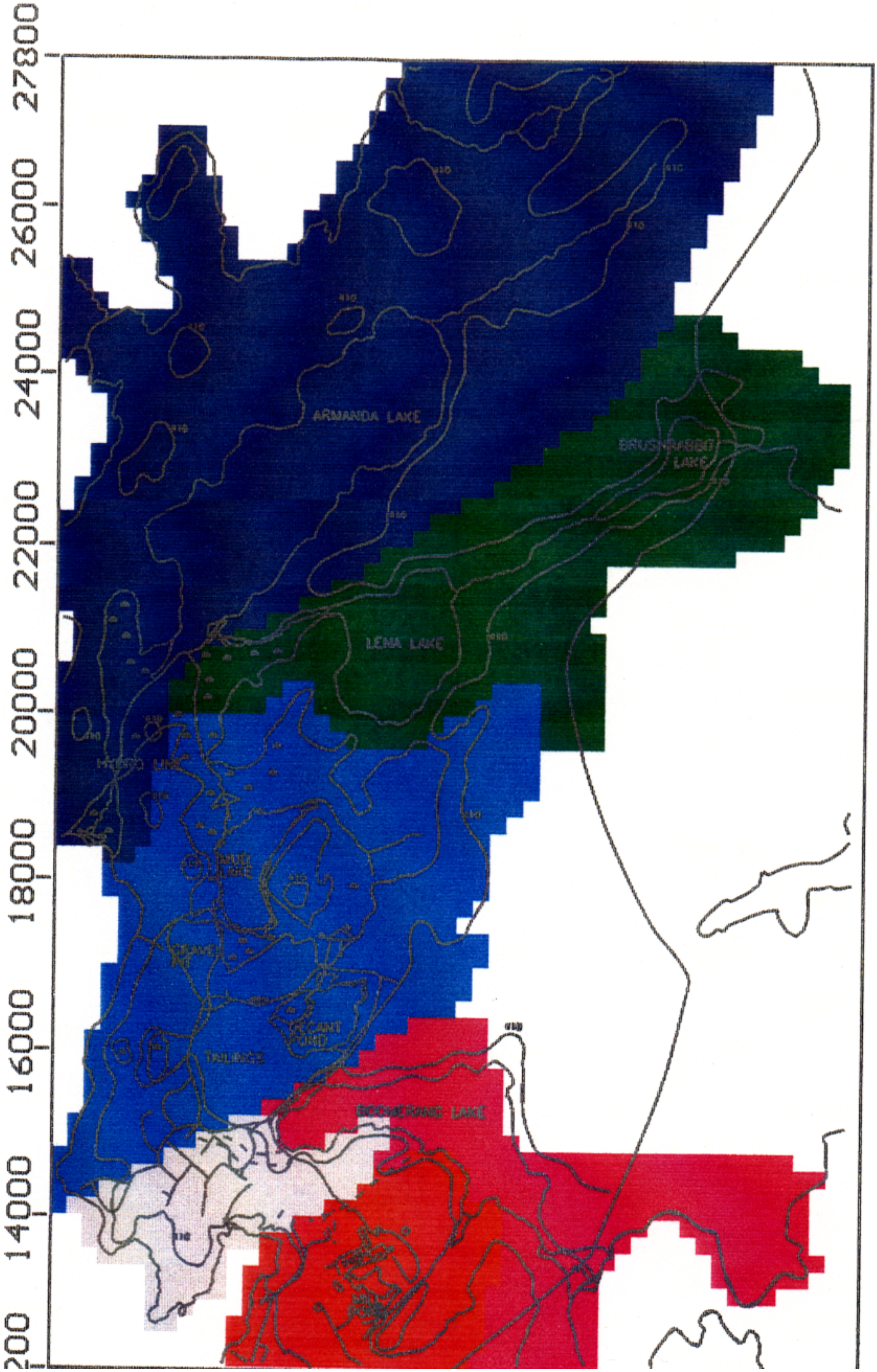


Figure 3.7 Global Site-Wide Model Flow Zones

elevation.

- The flows from adjacent watersheds are also identified.

The ***outflows*** are identified as follows:

- The flow to the various lakes represents the discharge from the groundwater system into the lake and the amount of water needed to maintain the lake node at its constant lake water elevation.
- The flow into adjacent watersheds via the groundwater system is identified by the watershed name.

Recharge from precipitation accounts for the major input into each watershed. The contributions of flows into groundwater system from Lena Lake and Bush Rabbit Lake are combined in the calculation of the flows. This was also done for the discharge from the groundwater system into the two lakes.

The Amanda Lake watershed accounts for a discharge of 382,500 m^3/a into Confederation Lake from the groundwater system. Of this, 218,600 flows directly from the groundwater system into Confederation along its shoreline and 163,900 discharges first into Amanda Lake and subsequently flows 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 m^3/a of groundwater that discharges into Lena Lake and then continues as surface water into Amanda Lake. About 23,700 m^3/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 m^3/a of groundwater discharging into Mud Lake originates from this impoundment. This is the potentially contaminated portion. The majority, about 75,000 m^3/a of the groundwater, that flows into Mud Lake as well as all of the 56,000 m^3/a of groundwater that flow directly into Confederation Lake are uncontaminated. In addition, there are 36,500 m^3/a of uncontaminated groundwater that flow into the Lena Lake watershed and 18,900 m^3/a (most of which is uncontaminated) that flow into Boomerang Lake. Most of the 6,800 m^3/a of groundwater that flows to the Northern Mine Site watershed is also uncontaminated. In total, only about 31,000 m^3/a of the 224,000 m^3/a of the groundwater discharged from the Mud Lake watershed have a potential for contamination.

Table 3.2

Groundwater Flows in the South Bay Site-Wide Global Model

Flow Parameters	Amanda Lake Watershed	Lena Lake Watershed	Mud Lake Watershed	Southern Mine Site	Boomerang Lake	Northern Mine Site
	1 *dark blue*	2 *green*	3 *light blue*	4 *orange*	5 *pink*	6 *light gray*
inflow						
Recharge	357000	116000	202300	75100	86800	59500
From Amanda Lake			4500			
From Lena Lake	23700					
From Mud Lake	3750	36500			18900	
From Southern Mine Site					19400	6800
From Northern Mine Site			14300	8200	16700	980
From Boomerang Lake			2100	15000		18700
Outflow						
To Confederation Lake	218600		56000	60200	60000	46500
To Mud Lake	4500		102000		2100	14300
To Amanda Lake	163900	23700	3750			
To Lena Lake		131200	36500			
To Southern Mine Site					830	8200
To Boomerang Lake			18900	19400	78900	17000
To Northern Mine Site			6800	18700	980	

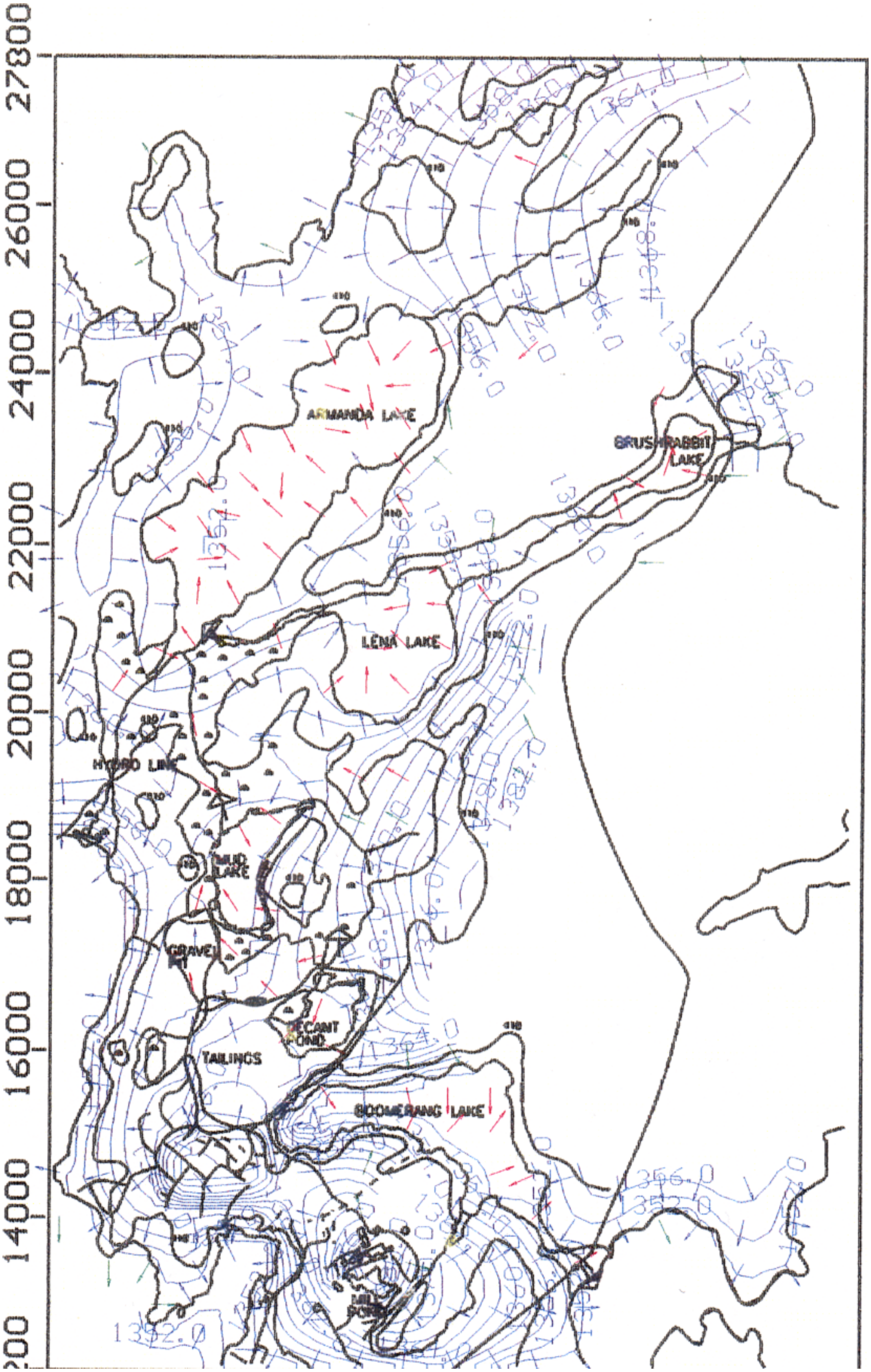


Figure 3.8 Global Site-Wide Model Equipotentials and Direction of Flaw

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 m^3/a of groundwater that is discharging into Confederation Lake is at present uncontaminated. Significant volumes of potentially contaminated water, about 115,000 m^3/a, are discharging into Boomerang Lake. There is presently a ecologically engineered treatment system in operation in Boomerang Lake.

The totals flows of uncontaminated water from the groundwater system in the watersheds studied that available for dilution are estimated to be about 900,000 m^3/a.

4.0 Tailings Area Model

4.1 Model Set-up and Assumptions

The tailings area model was set up in a manner similar to the global site-wide model. The area modelled, 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. A ***50 ft by*** 50 ***ft*** grid was used. Again, the SURFER model was used to generate surfaces at the desired grid spacing for both the ground surface and the top of the bedrock. These surfaces along with the site map superimposed are shown in Figures 4.1 and 4.2. There is an exaggeration of about 10:1 in the vertical direction.

The vertical domain was divided into six equally spaced layers. In some cases it was necessary to adjust the position of the bedrock surface in order to ensure that adjacent cells were in contact with one another.

The assumptions made and input parameters used are identical to those used in the global model. The locations of the various regions of recharge, hydraulic conductivity, constant head and wall nodes, and flow regions are shown in Figures 4.3 to 4.7. The flow zones are described in Table 4.1.

Table 4.1 Modelled Flow Zones

Flow Zone	Model Colour	Characteristic
Zone 1 (Kalin Canyon)	dark blue	contaminated
Zone 2 (Mud Lake)	green	initially uncontaminated
Zone 3 (Tailings Area)	light blue	contaminated
Zone 4 (Decant Pond)	orange	contaminated
Zone 5 (East to Confederation Lake)	pink	mixed
Zone 6 (South to Confederation Lake)	yellow	contaminated
Zone 7 (North to Mud Lake)	light gray	contaminated
Zone 8 (South to Boomerang Lake)	dark gray	contaminated

Figure 4.1
Tailings Area Model - Ground Surface Topography

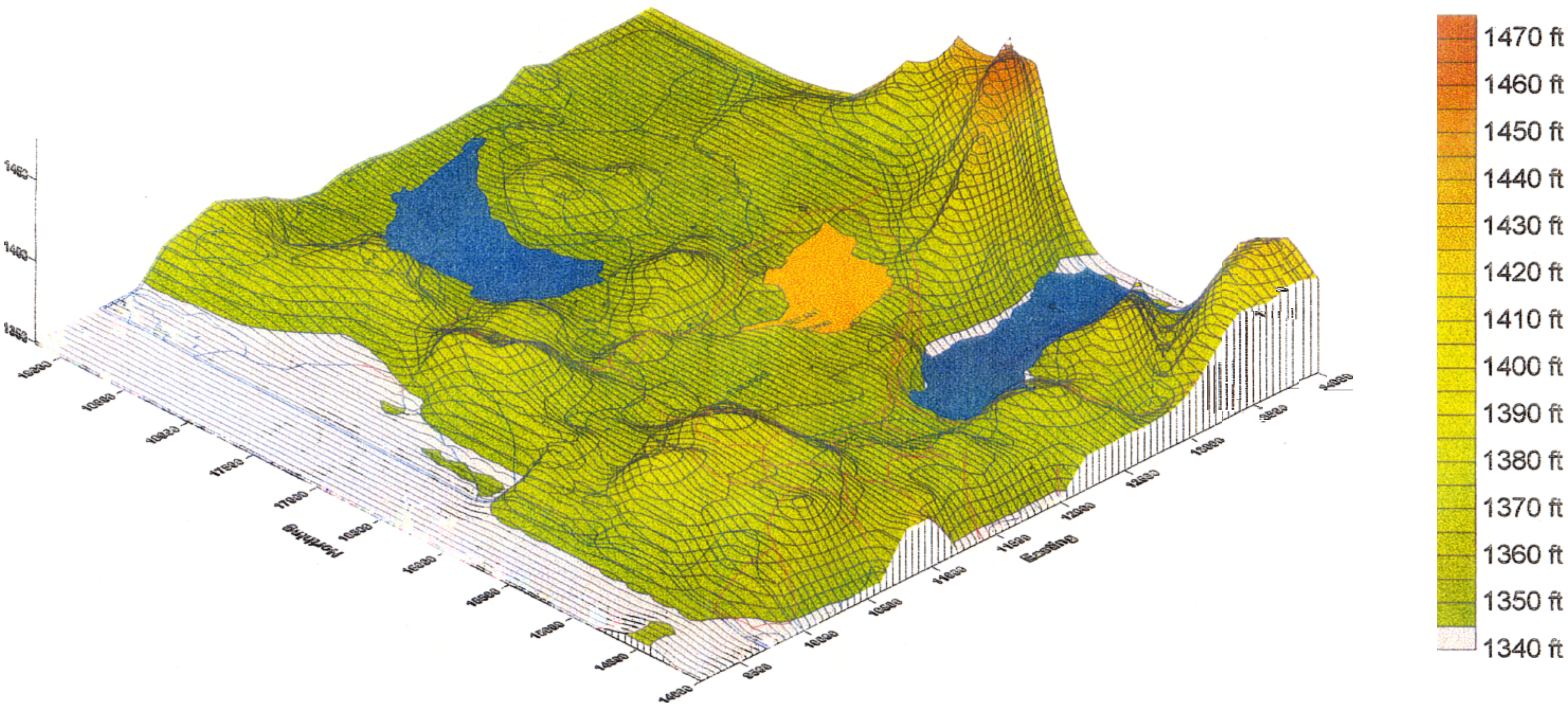
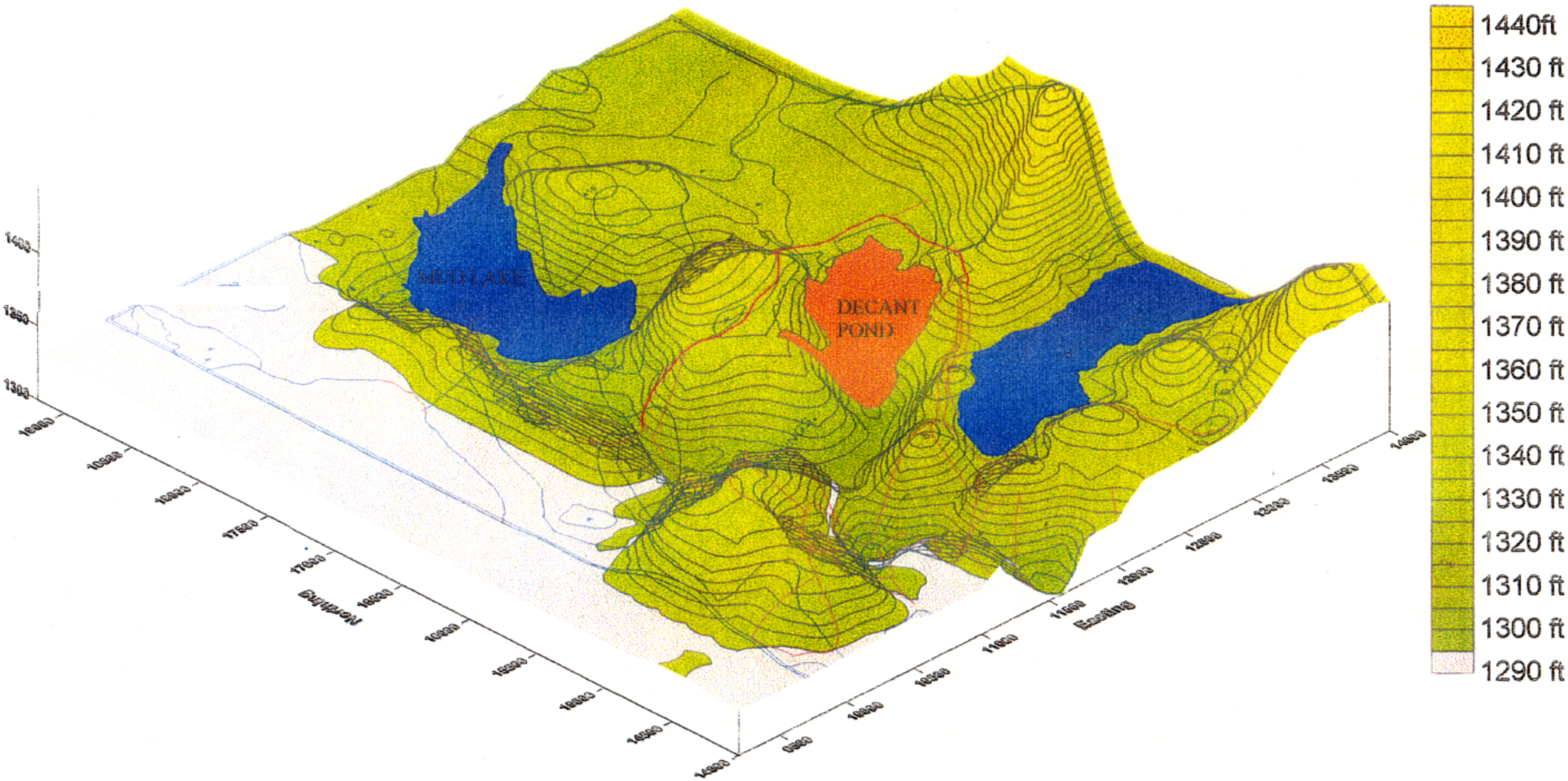


Figure 4.2
Tailings Area Model - Bedrock Surface Topography



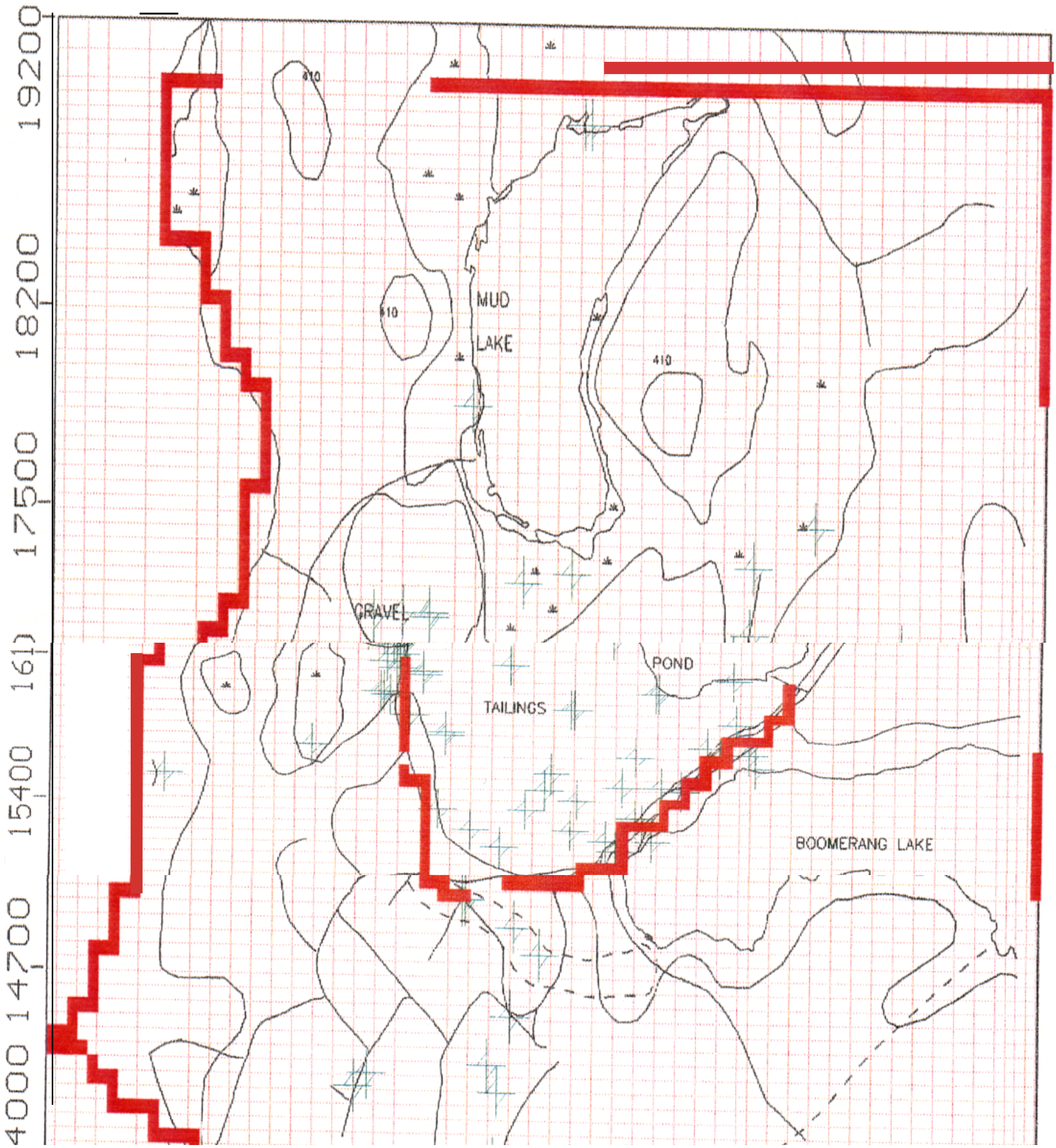


Figure 4.3 Tailings Area Model Grid, Piezometers and Constant Head and Wall Nodes

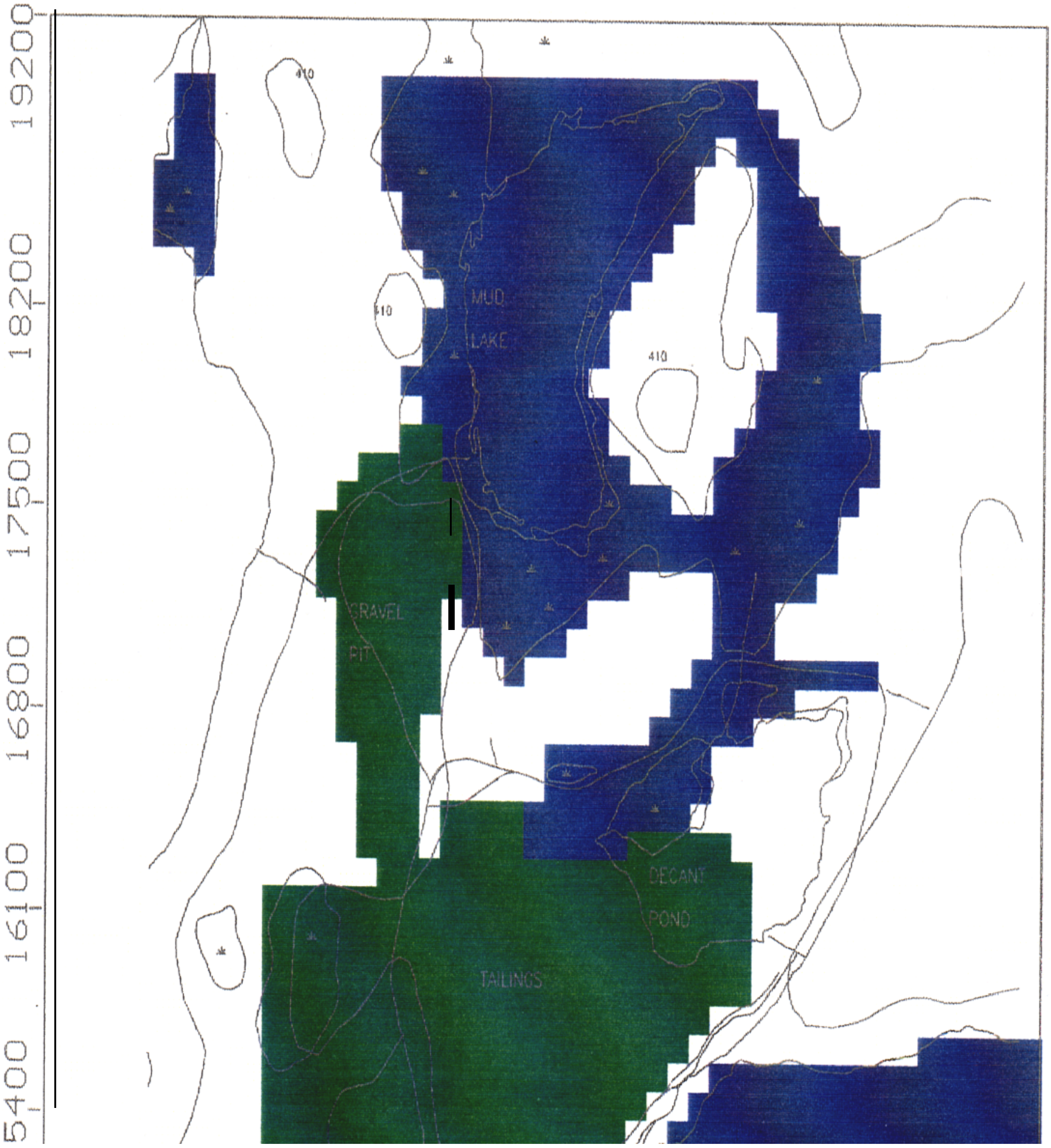


Figure 4.4 Tailings Area Model Recharge Zones

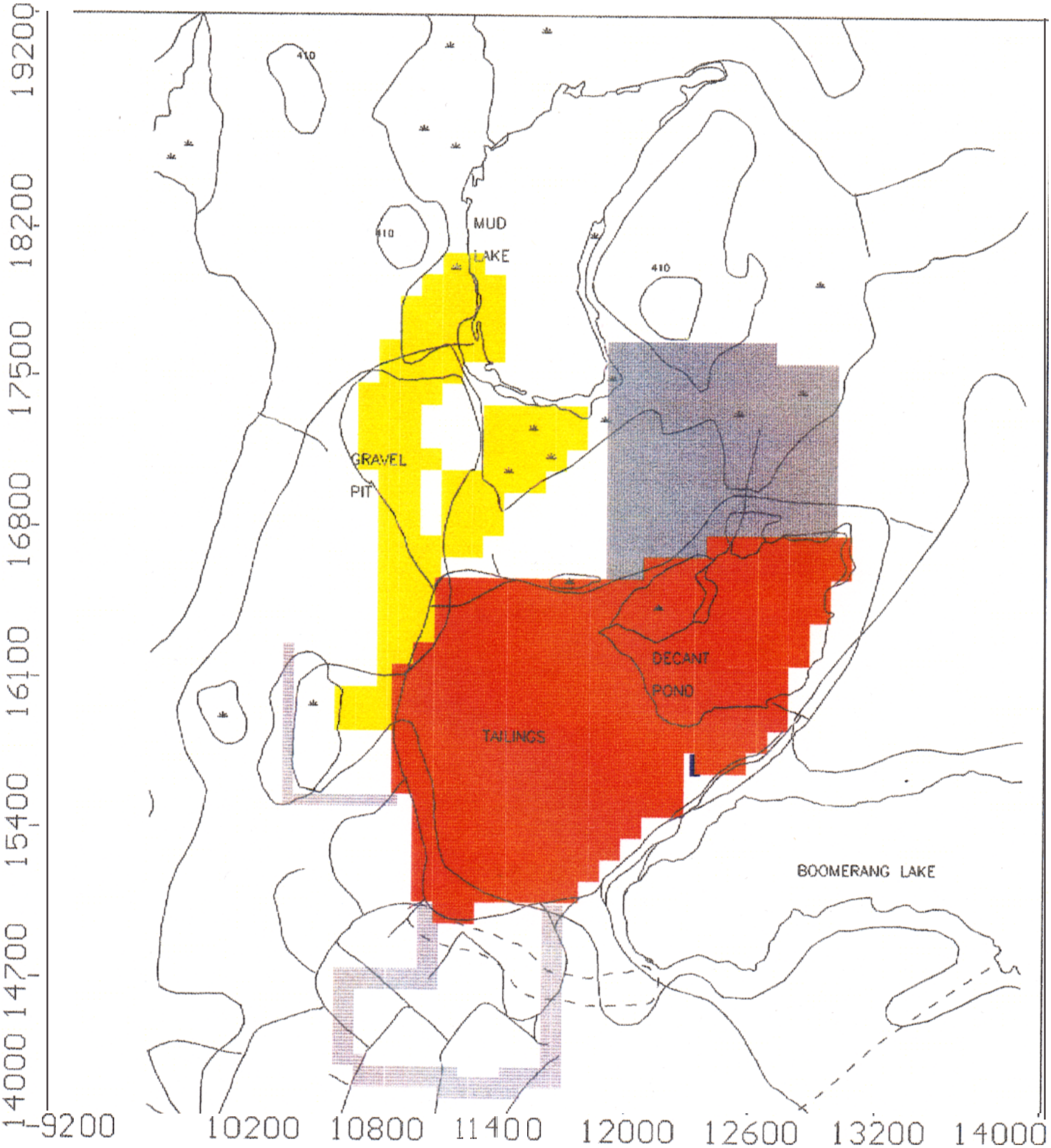


Figure 4.5 Tailings Area Model Hydraulic Conductivity Zones on Lowest Layer

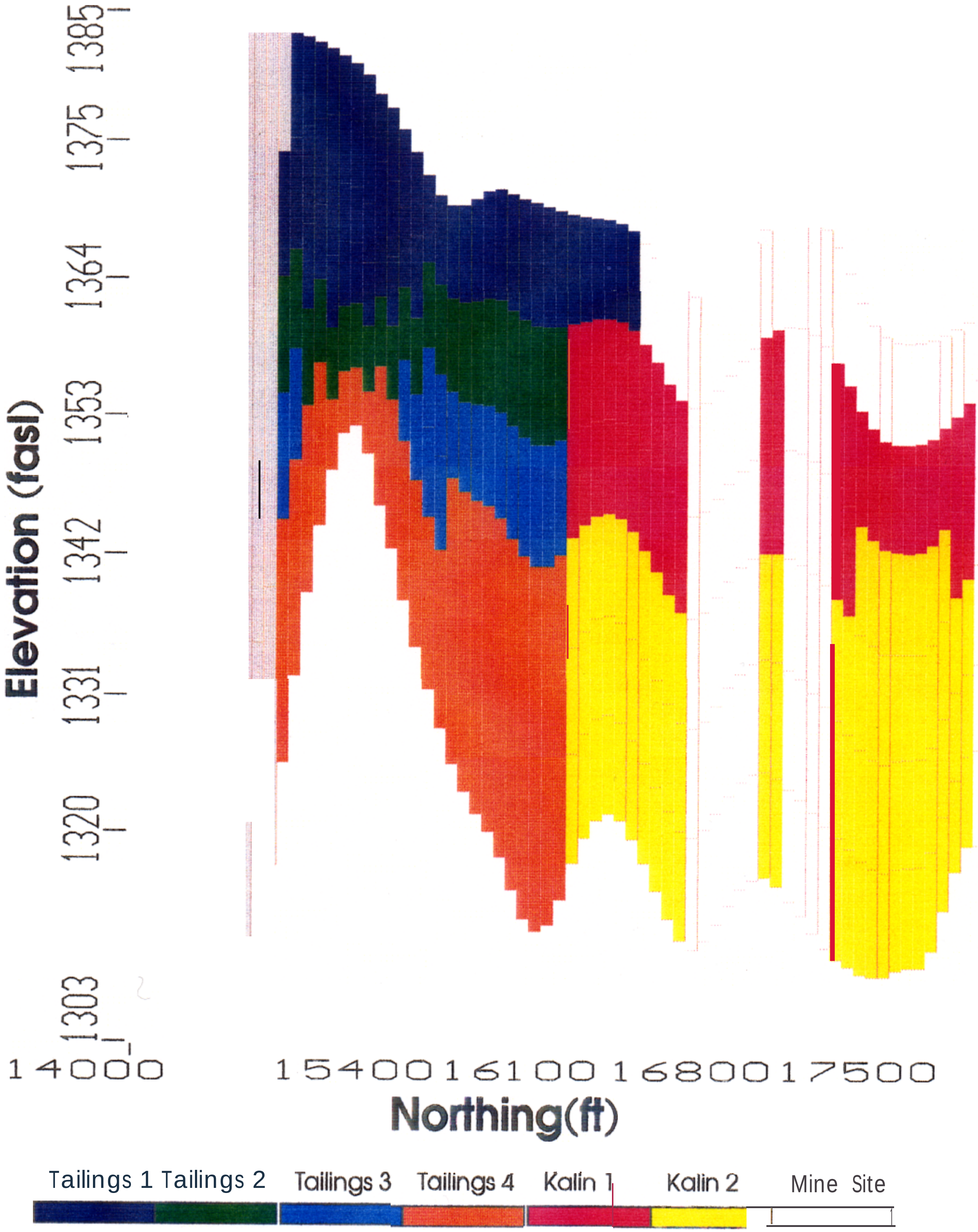


Figure 4.6 Hydraulic Conductivity Zones in Tailings-Kalin Canyon Area

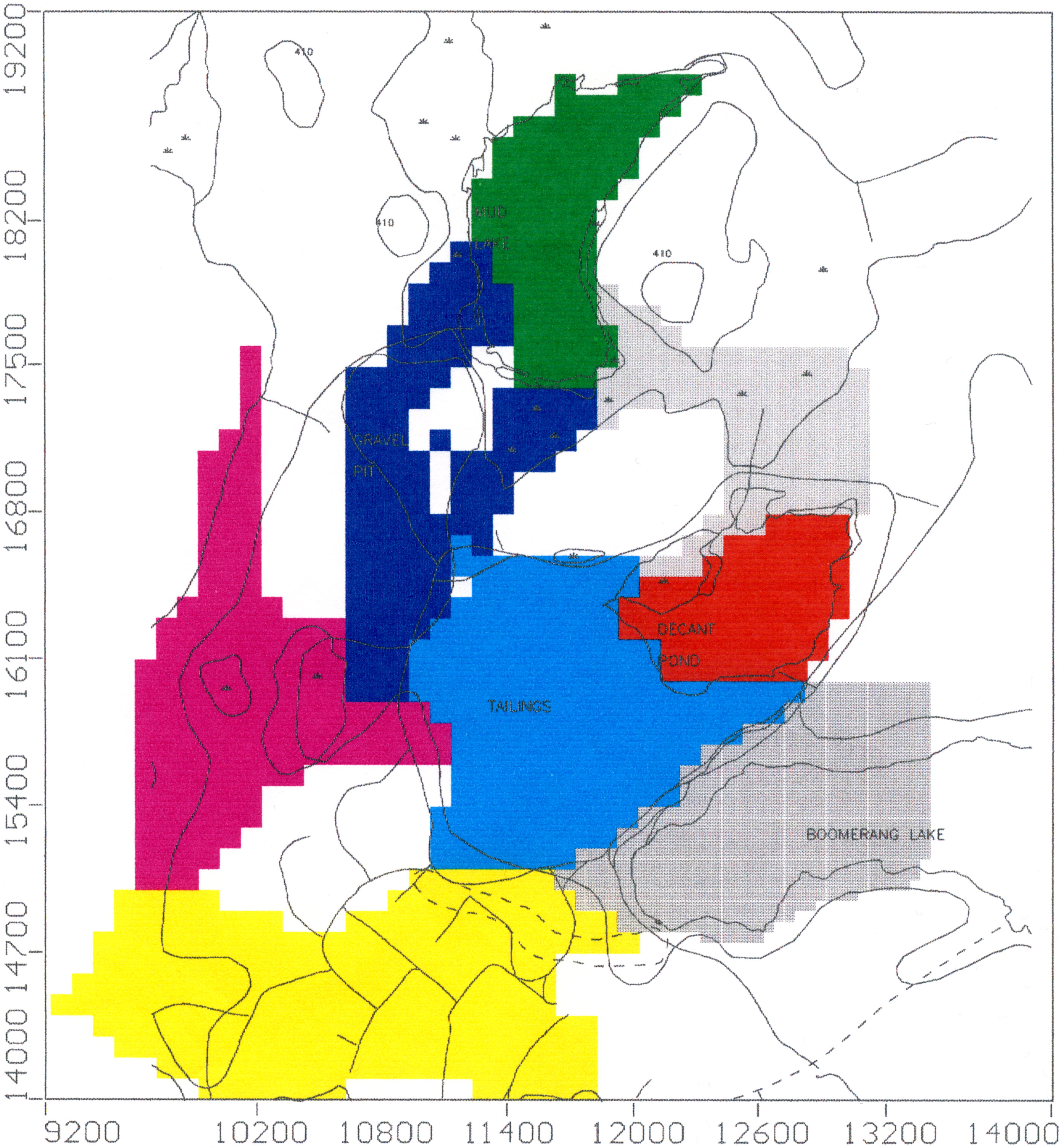


Figure 4.7 Tailings Area Model Flow Zones

4.2 Results of Tailings Area Modelling

The equipotentials and flow directions calculated by the tailings area model are shown in Figure 4.8. These agree closely with the values inferred from on-site monitoring data. Comparisons of the calculated and observed hydraulic heads in the various on-site piezometers are shown in Table 4.2 and Figures 4.9 and 4.10.

For the most part, the agreement between the calculated and observed heads is very good (within 0 - 2 ft). The calculated heads in several piezometers, however, show differences greater than 2.5 feet from the observed heads. These are discussed in the following.

Water levels in piezometers in the southwest corner of the tailings Pond (M24, M75, M27, M41) indicate that there is a very tight upper portion of tailings and a very permeable lower portion with strong downward vertical gradients. Thus, the calculated heads for the lower piezometers are too high and those for the upper piezometers are too low. More detailed delineation of the hydraulic conductivities are necessary in this area to improve the model calibration.

Water levels in piezometers along the edge of the tailings dam (M32, M46, M72, M76, M31, M51) show poor agreement because of the rapid variation of the heads in this region and the finite grid element size. Since the calculated water levels in this region agree well with that measured, the discrepancies noted can be ignored.

Several piezometers (M22, M42, M33, MSP13) are likely in areas exhibiting a perched water table and thus the calculated water levels are much lower than those observed. At this point, it is not thought to be important to try to model this effect.

The groundwater flows from the tailings area into various receiving bodies were also calculated. These are shown in Table 4.3 and Figure 4.11. It can be seen that the majority of the groundwater flow from the tailings is into the Kalin Canyon (72%). Recharge from precipitation accounts for 85% of the input into the tailings whereas recharge from the decant pond accounts for about 6%. The rest of the input is mainly from the southern portion of the Kalin canyon.

Most of the flow in the Kalin Canyon ends up in Mud Lake and about 27,000 m^3/a are discharged from Mud Lake into Confederation Lake. There is also significant flow from the decant pond towards Mud Lake both by discharge of groundwater to the surface water system (6200 m^3/a) and by groundwater movement (3100 m^3/a).

Discharge from the tailings into Boomerang Lake is small (1200 m^3/a) as is discharge to the region south of the tailings (2100 m^3/a) and to the east (3700 m^3/a).

Table 4.2
Comparison between Average Annual Water Levels and Model Predictions

Monitoring Well	Observed heads[fasl]	Calculated heads[fasl]	Difference
1	**1362.0**	**1361.7**	**0.3**
2	**1364.7**	**1362.7**	**2.0**
3	**1359.1**	**1357.9**	**1.3**
4	**1358.7**	**1360.1**	**-1.4**
5	**1359.2**	**1360.1**	**-0.8**
8	**1354.3**	**1353.4**	**0.9**
9	**1361.1**	**1361.6**	**-0.5**
10	1359.5	1361.4	- 19
21	1359.5	1359.4	01 .
22	1363.7	1357.4	6.3
24	1358.4	1362.0	-36 .
25	1363.5	1365.0	-15 .
28	1360.5	1357.7	28 .
30	1364.3	1363.2	11 .
31	1366.7	1363.7	29 .
32	1362.1	1365.6	-35 .
33	1368.1	1363.3	47 .
34	1359.2	1357.8	14 .
39	1358.5	1358.1	04 .
41	1366.8	1363.0	37 .
42	1365.9	1359.7	62 .
43	1363.3	1364.6	-13 .
45	1353.8	1354.3	-05 .
46	1361.3	1364.7	-34 .
47	1353.4	1352.9	05 .
49	1359.5	1360.1	-0 . 6
50	1353.1	1353.9	-0 . 8
51	1368.3	1365.8	25 .
52	1352.2	1352.5	-03 .
53	1352.6	1352.3	03 .
56	1350.7	1351.2	-0 . 5
58	1359.3	1357.7	16 .
59	1359.4	1357.7	17 .
61	1361.2	1360.9	03 .
62	1357.4	1357.0	04 .
63	1357.7	1356.9	09 .
64	1361.9	1360.6	13 .
65	1364.2	1364.7	- 05
67	1363.7	1364.9	-11 .
68	1362.1	1362.1	-0 . 1
69	1359.8	1358.4	14 .
71	1360.5	1361.4	-09 .
73	1359.3	1357.8	15 .
74	1359.4	1357.9	15 .
75	1359.7	1363.1	-34 .
76	1359.6	1362.0	-24 .
79	1358.7	1357.8	09 .
80	1358.9	1357.8	11 .
81	1358.7	1357.8	09 .
82	1359.4	1359.0	04 .
86	1359.3	1358.4	09 .

Table 4.2
Comparison between Average Annual Water Levels and Model Predictions

Monitoring Well	Observed heads[fasl]	Calculated heads[fasl]	Difference
88	1359.3	1358.5	0.8
89	1359.5	1358.5	0.9
90	1360.9	1358.6	2.4
OSN	1359.0	1360.0	-1.0
05W	1363.7	1361.9	1.7
07N	1363.7	1365.6	-1.9
07s	1362.4	1364.7	-2.3
20B	1359.5	1357.5	2.1
24N	1359.5	1361.9	-2.4
24W	1358.8	1362.0	-3.2
26A	1365.0	1365.7	-0.7
26B	1362.5	1364.5	-2.0
27c	1359.1	1361.1	-2.1
27N	1364.9	1361.4	3.5
27S	1363.3	1361.4	1.9
39A	1358.7	1358.1	0.6
40A	1362.8	1364.2	-1.4
40B	1362.8	1363.7	-0.8
60A	1359.4	1357.2	2.2
60B	1359.7	1357.2	2.4
66A	1359.2	1360.0	-0.8
66B	1359.3	1360.0	-0.7
72A	1359.3	1358.5	0.7
72B	1359.5	1360.0	-0.6
72C	1367.0	1362.1	4.9
77A	1352.5	1353.0	-0.5
77B	1353.0	1353.1	-0.1
78A	1358.8	1360.4	-1.5
78B	1359.0	1360.5	-1.5
83A	1359.2	1358.5	0.6
83B	1359.4	1358.5	0.9
HO2	1365.3	1365.7	-0.4
HO3	1365.3	1363.9	1.4
HO4	1367.0	1366.1	0.9
HO5	1367.6	1366.3	1.3
HO6	1366.0	1366.9	-0.9
HO7	1365.6	1367.4	-1.8
HO8	1368.5	1366.4	2.1

Table 4.3
Groundwater Flows in the South Bay Tailings Area Model

Flow Parameters	Kalin Canyon	Mud Lake	Tailings	Decant Pond	East to Confederation Lake	South to Confederation Lake	North to Mud lake	South to Boomerang Lake
	1 *dark blue*	2 *green*	3 *light blue*	4 *orange*	5 *pink*	6 *yellow*	7 *light gray*	8 *dark gray*
Inflow								
Recharge	5200	7900	22300	8600	2700	2700	1600	
From Tailings	18400			780	3700	2100		1200
From Decant Pond			1500				3100	
From Mud Lake							900	
From Kalin Canyon		7700	2200		1400			
From North Tailings Path		5000						
Unlabelled groundwater	9100	1200	160	400	1900	400	4400	100
Outflow								
To Tailings	2200			1500	2200			300
To Mud Lake	7700						5700	
To Decant Pond			780					
To Confederation Lake		13300			4500	4400		
To Kalin Canyon			18400		2600		1000	
To Boomerang Lake			1200			300		
South			2100					
East			3700					
North				3100				
To Surface Flow	13600			6200				2000
Unlabelled groundwater		8400	1600	60	400	500	3200	20

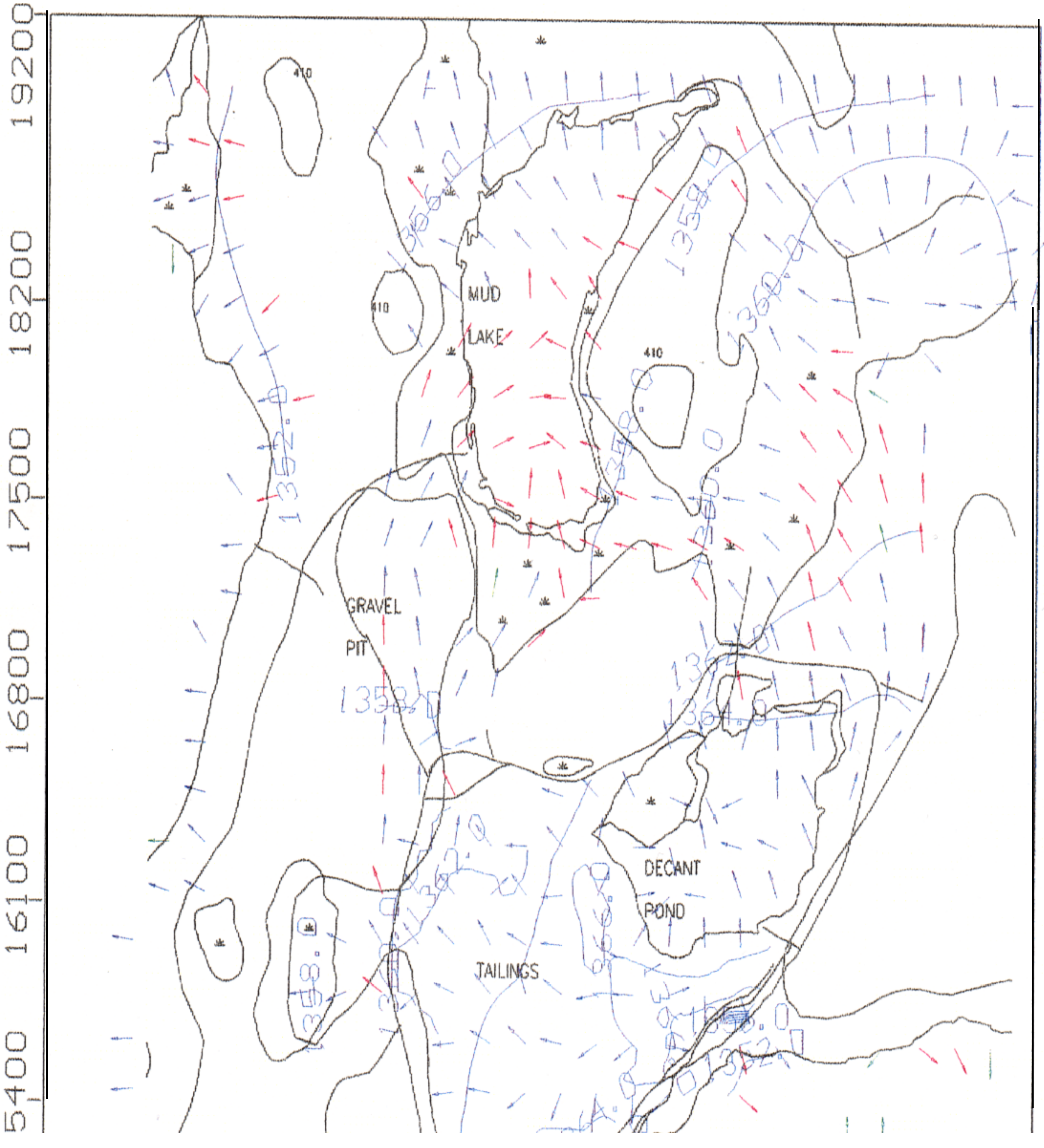


Figure 4.8 Tailings Area Model Equipotentials and Direction of Flaw

Figure 4.9
Calculated Heads in Tailings Area

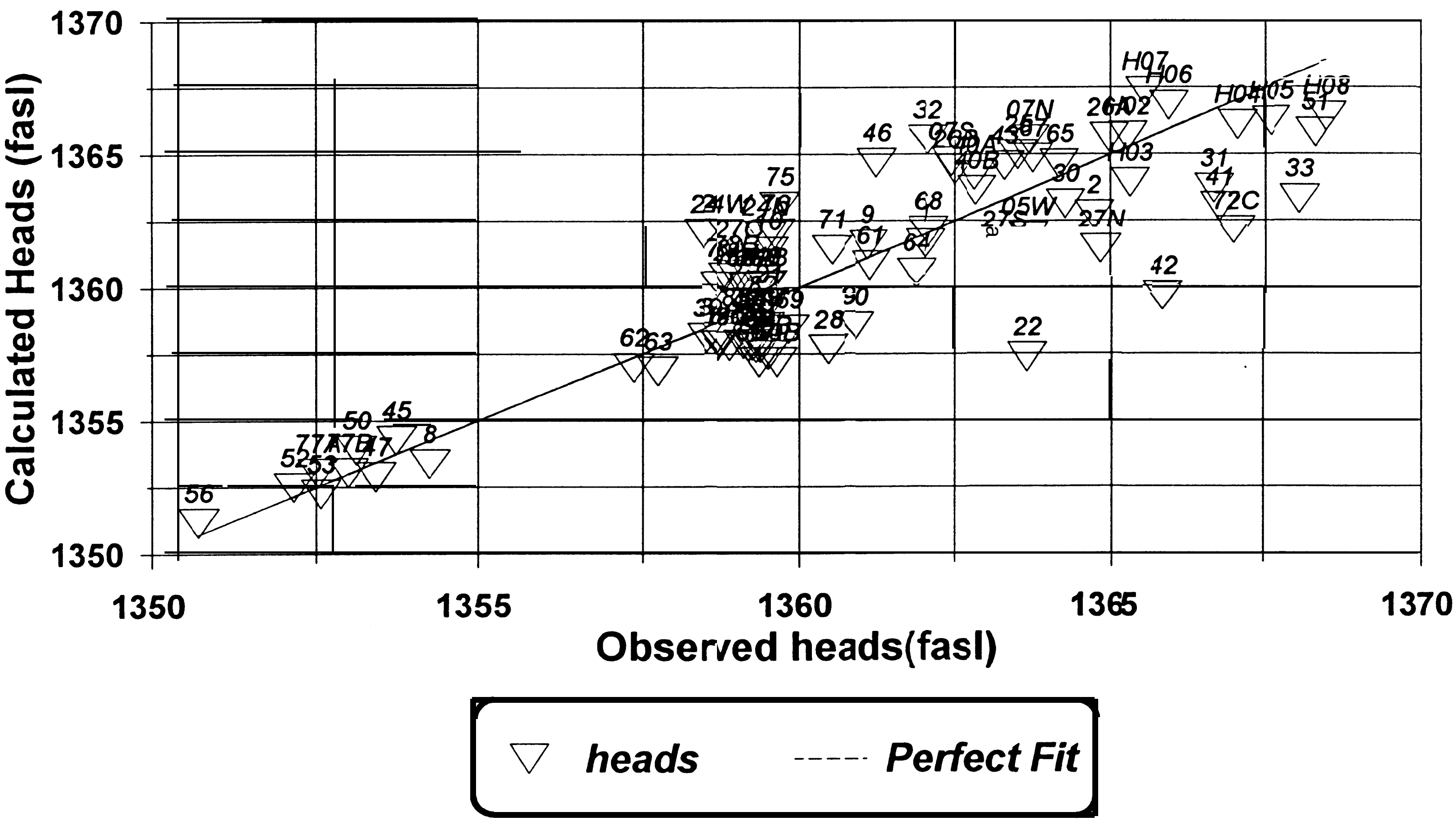
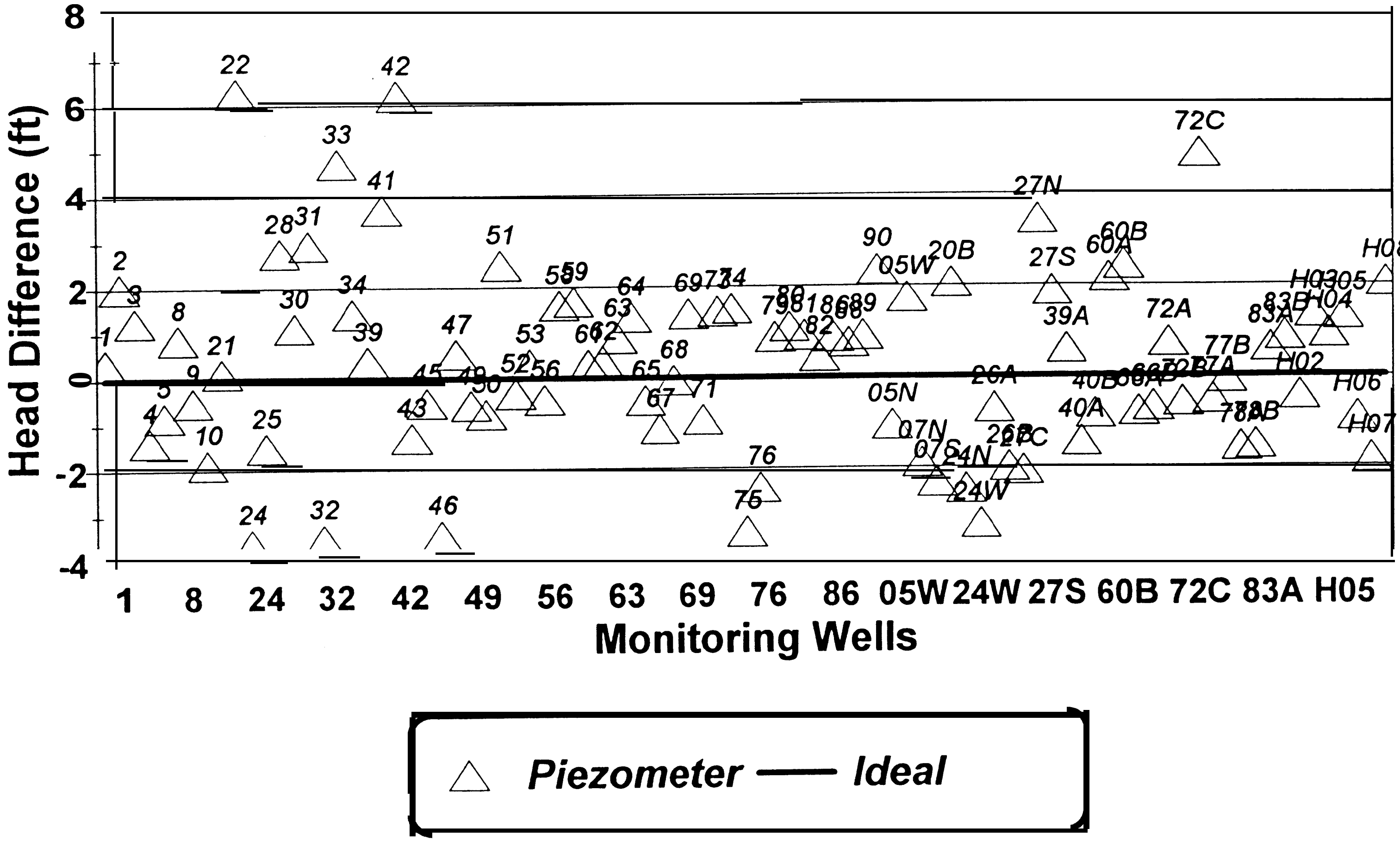


Figure 4.10
Observed minus Calculated Heads



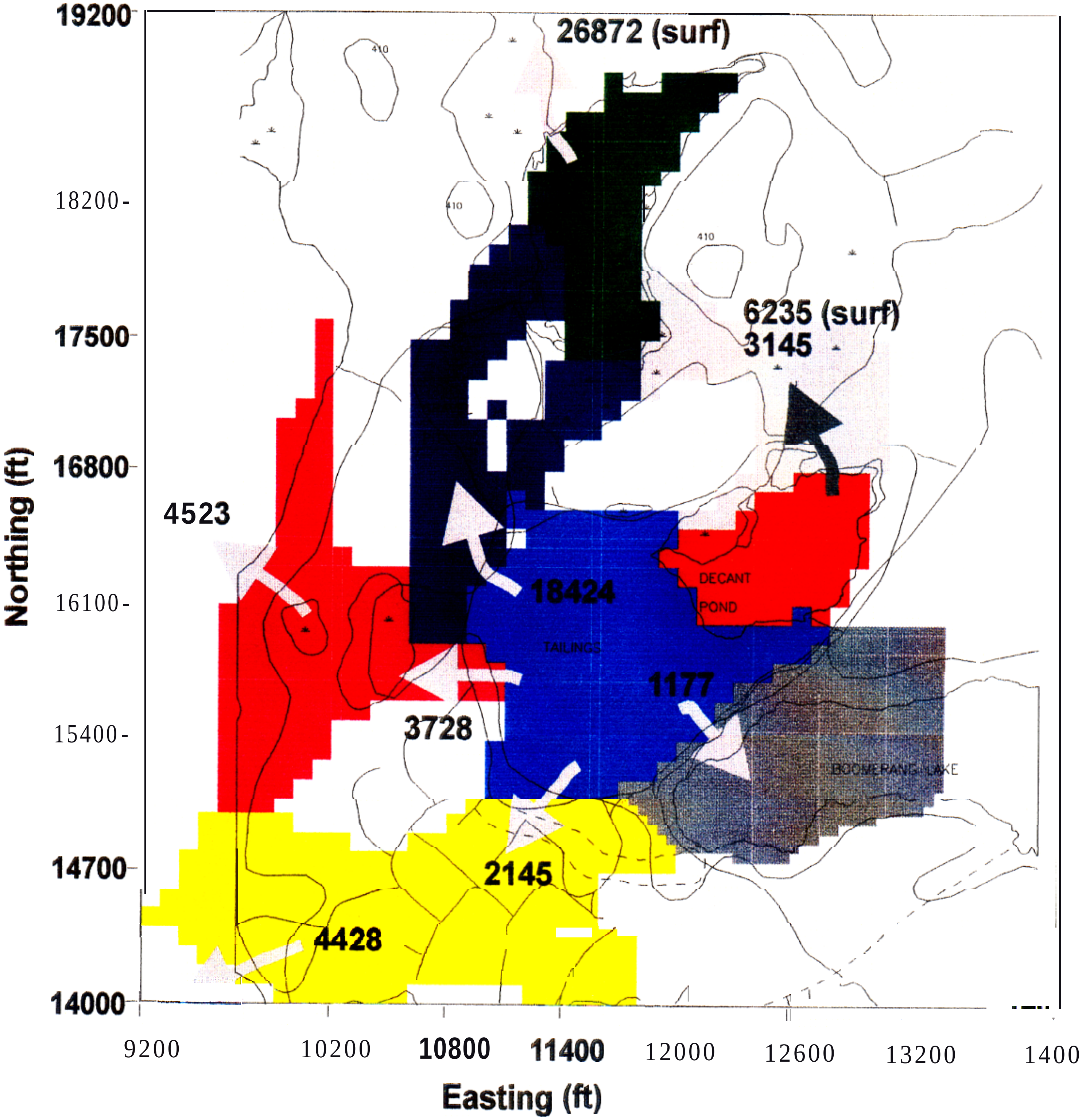


Figure 4.11 Flow System Modelled for South Bay Tailings Area (in m3/a)

The major pathway for seepage from the tailings appears to be the Kalin Canyon to Mud Lake. The total discharge from the tailings via all other pathways is about 7000 m^3/a.

This analysis agrees with the trend in the hydrogeological predictions made in the past. It is possible in future to further quantify some of the minor pathways that were identified in the present modelling study.

In order to investigate the rate of contaminant migration from the tailings area and the potential loading into Confederation Lake, the transport portion of Visual Modflow, MT3D was utilized. Zinc was used as the representative contaminant and a uniform initial concentration of 200 mg/L was assumed throughout the tailings pile. A longitudinal dispersivity of 20 ft was also assumed throughout the entire flow regime.

The contaminant concentrations were calculated at 5 and 10 years after the start of the modelling and the results are plotted in Figure 4.12. The contour lines plotted are at 20 mg/L intervals. The zinc concentrations decreased to less than 1 mg/L within 100 feet of the 20 mg/L contour. As can be seen from the figure, after 10 years, the concentration of zinc at the discharge of Kalin Canyon into Mud Lake was approaching 60 mg/L. The total amount of inflow into Mud Lake from Kalin canyon is 21300 m^3/a. This represents a loading of 1.275 Tonnes of zinc per annum into Mud Lake.

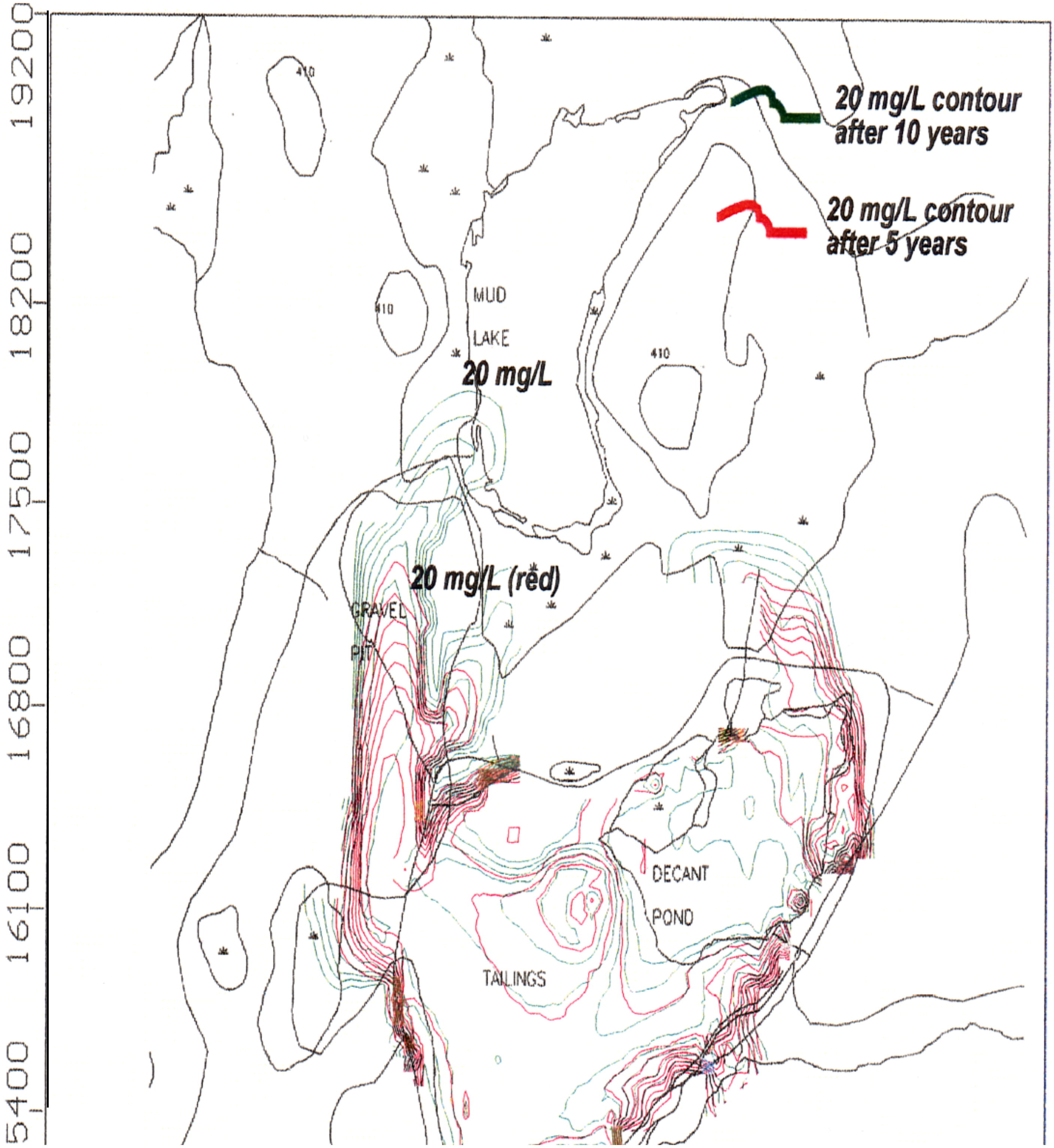


**Figure 4.12 Tailings Area Model
Zinc Concentrations
After 5 and 10 years**

5.0 Conclusions and Recommendations for Further Work

Several interesting observations can be made from the above modelling 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 m^3/a of uncontaminated groundwater available for diluting about 150,000 m^3/a of groundwater in the mine site and tailings areas that could eventually become contaminated.

The majority of flow from the tailings are via the Kalin Canyon to Mud Lake, about 18,000 m^3/a. The remaining flow paths account for 7,000 m^3/a. There are about 9,000 m^3/a flowing from the Decant Pond into Mud Lake. Most of this water is presently uncontaminated. The above flow estimates agree well with the trend in interpretation of available hydrogeological information in recent years.

The results of the transport modelling using zinc as the representative contaminant indicated a breakthrough of contamination into Mud Lake at between 5 and 10 years and a predicted concentration of zinc of 60 mg/L at the inflow of this groundwater into Mud Lake after 10 years. These predictions agree well with the field observations made to date. The estimated loading of 1.275 Tonnes of zinc per annum into Mud Lake can be compared to the 0.5 Tonnes/annum previously estimated for discharge into Confederation Lake by the CHINTEX model. At the time of the CHINTEX modelling, it was thought that a significant flow from the tailings was into Confederation Lake. The present loadings are very conservative, since it was assumed that an average concentration of 200 mg/L, representing the upper range of zinc concentrations within the tailings, was distributed throughout the tailings.

From the present modelling results, it is evident that the potential for migration of contaminants from the tailings directly into Confederation Lake is very small. Within the ten year study period, the contaminant plume has only moved about 200 feet from the tailings towards Confederation along the eastern pathway. Flows in this direction are about 3700 m^3/a.

The following are recommendations for further work:

- Update and refine the global site-wide model as new data becomes available. This would allow the refining of our understanding of the flow patterns and dilution potentials and allow a detailed look at the amount of clean and contaminated flows and the percentage of these flows in the mixing zones.
- Input detailed stratigraphic information into the tailings area model and conduct

further investigation on the effect of varying hydraulic conductivities in the south-western part of the tailings area in an attempt to duplicate the observed heads.

- Simulate an infiltration barrier on top of the tailings and determine the impact on zinc migration from the tailings.
- Determine the effect of deepening the ditch south of the tailings impoundment.
- Construct a detailed model of the mine site area to determine the flow system and predict contaminant movement.
- Review current literature on the effect on the groundwater flow system of geochemical reactions resulting from the planned ecological engineering options and implement these effects into the model

In addition, the modelling framework described in this report will serve as a basis for on-going work not presently defined in detail such as the following:

- The detailed tailings area model can be used to predict the effectiveness of additional remedial options that are developed as the result of future field investigations and modelling.
- The detailed tailings area model will be used to investigate the effect of contaminant migration from the tailings on physical changes in porosity and hydraulic conductivity within the tailings and the adjacent soils as a result of biological activities.

Appendix A Hydraulic Conductivity Data

The hydraulic conductivities measured within the tailings impoundment, the Kalin canyon, and some of the surrounding areas are tabulated in Tables A.1 to A.3. The results were grouped according to elevation and the tailings area was divided into four zones and the Kalin canyon into two zones. The geometric mean and median hydraulic conductivities were calculated for each zone.

Generally, for a log normal type distribution which- is typical of many types of field data distributions, a geometric mean is often used in subsequent calculations. In the case of hydraulic conductivities, the geometric mean would be used to describe a certain stratigraphic layer. In the present modelling study, the stratigraphy has not as yet been well defined and thus each zones represent a more heterogeneous mix of soil types and thus it is felt that the geometric mean was not appropriate. Rather the median value, the value at which there are an equal number of values greater and smaller, would be more representative of each zones. Thus, the median value was used in the modelling.

In future modelling, once stratigraphic layers have been defined, the geometric mean for each layer will be calculated and used in the modelling.

Table A.1 Tailings Hydraulic Conductivity Measurements

Piezometer	Elevation (fasl)	Hydraulic conductivity
M-51	1367.5	3.40E-05
H-8	1367.4	1.50E-04
H-1	1367.0	8.90E-05
H-4	1365.9	4.80E-04
H-6	1365.4	3.10E-04
H-3	1365.2	6.80E-06
H-2	1364.8	3.60E-04
H-5	1364.7	1.30E-04
H-7	1364.0	5.40E-03
M-64	1357.7	2.39E-03
M-27S	1357.6	2.10E-05
M-7N	1357.3	3.80E-06
M-41	1356.2	1.20E-06
M-24E	1355.9	7.10E-05
M-4	1355.8	2.20E-03
M-27N	1355.7	8.00E-06
M-30	1355.2	3.70E-04
M-SW	1354.1	5.20E-05
M-40A	1351.8	1.10E-03
M-9	1351.4	1.70E-04
M-25	1351.1	5.80E-05
M-26A	1350.9	3.80E-05
M-40B	1349.7	4.00E-03
M-67	1349.4	1.71E-02
M-47	1347.7	1.30E-03
M-24W	1346.2	7.70E-05
M-45	1343.1	3.60E-04
M-69	1342.8	3.15E-02
M-43	1340.1	6.00E-04
M-32	1338.2	2.10E-04
M-7S	1337.1	7.70E-04
M-46	1337.0	1.30E-02
M-5E	1336.1	4.30E-03
M-24N	1333.6	1.52E-02
M-5N	1323.9	7.83E-03
M-26B	1313.3	7.18E-03
M-75	1310.8	1.40E-02

1365 to 1370 fasl

Median	Geometric Mean
1.40E-04	1.95E-04

1355 to 1365 fasl

Median	Geometric Mean
7.10E-05	1.16E-03

1345 to 1355 fasl

Median	Geometric Mean
1.70E-04	2.66E-03

1310 to 1345 fasl

Median	Geometric Mean
7.18E-03	8.63E-03

Table A.2 Kalin Canyon Hydraulic Conductivity Measurements

Piezometer	Elevation (fasl)	Hydraulic conductivity
M-80	1302.5	2.60E-01
M-81	1309.8	2.22E-01
M-27C	1334.7	2.20E-01
M-79	1311.3	1.42E-01
M-83A	1321.1	9.90E-02
M-60A	1312.0	9.30E-02
M-39A	1321.8	5.00E-02
M-74	1323.6	1.40E-02
M-72A	1336.2	3.34E-03
M-73	1336.5	1.12E-03
M-60B	1337.3	7.00E-04
M-83B	1352.6	3.30E-01
M-86	1359.8	8.46E-02
M-85	1364.9	8.35E-02
M-66A	1342.3	3.30E-02
M-69	1342.8	3.15E-02
M-39	1348.2	2.20E-02
M-34	1347.9	1.60E-02
M-89	1360.1	7.39E-03
M-76	1355.9	7.35E-03
M-72B	1356.8	6.49E-03
M-88	1361.1	3.28E-03
M-87	1367.3	1.89E-03
M-72C	1364.5	7.35E-04

1300 to 1340 fasl

Median	Geometric Mean
9.30E-02	1.00E-01

1340 to 1370 fasl

Median	Geometric Mean
1.60E-02	4.83E-02

Table A.3 Surrounding Hydraulic Conductivity Measurements

Piezometer	Elevation (fasl)	Hydraulic conductivity (cm/sec)	Location
MI	1352.5	6.30E-05	Decant
M61	1353.9	9.00E-03	Decant
M68	1354.2	4.24E-03	Decant
M31	1350.5	1.40E-04	Decant
M33	1362.4	6.30E-05	Decant
M36	1353.4	8.1 OE-05	north Mud
M37	1351.6	2.30E-05	north Mud
M62	1352.2	5.00E-03	beside north Mud Lake
M63	1349.5	9.25E-03	beside north Mud Lake
M71	1350.3	2.07E-03	beside east Mud Lake
M70A	1330.6	4.06E-03	beside east Mud Lake
M70B	1347.1	3.1 OE-06	beside east Mud Lake
M70C	1350.9	2.30E-05	beside east Mud Lake
M50	1330.4	5.1 OE-03	between mine site and Confederation Lake
M52	1351.9	5.20E-03	Boom Lake
M53	1352.5	1.50E-02	Boom Lake
M20B	1333.1	2.20E-05	Mine site
M21	1317.5	1.90E-05	Mine site
M42	1318.7	1.50E-05	Mine site
M71	1350.3	2.07E-03	Mine site
M77A	1346.3	4.30E-02	Mine site
M77B	1353.0	7.80E-03	Mine site
M78A	1309.1	1.04E-01	Mine site
M78B	1334.0	1.42E-02	Mine site
M82	1316.7	9.24E-03	Mine site
M28	1318.2	5.00E-03	between tailings and Confederation Lake