TECHNICAL MEMORANDUM

August 24, 2018

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Prepared for: Turner Ranch Properties and New Mexico Environmental Law Center

Subject: Contaminant Transport through Groundwater at the Proposed Copper Flat Mine

INTRODUCTION

New Mexico Copper Corporation (NMCC) proposes to construct the Copper Flat Copper Mine near Hillsboro NM. NMCC has applied to the New Mexico Environment Department (NMED) for Discharge Permit 1840 which would permit discharges to the groundwater from various mine facilities. DP 1840 also provides for groundwater monitoring of those facilities. This memorandum reviews how contaminant dispersion affects the layout of monitoring wells in the groundwater monitoring plan. Specifically, this memorandum documents the development of a interpretative groundwater model to discuss potential dispersion at the mine site.

NMCC presented calculations of predicted groundwater contaminant concentrations assume that the liners will operate as designed, essentially meaning the liner beneath the tailings storage facility (TSF) has no leaks, no manufacturer defects or construction caused imperfections and the andesite beneath the waste rock dumps (WRDs) is impermeable. These assumptions are unrealistic as addressed elsewhere. The purpose of this analysis is to estimate whether the proposed monitoring network is sufficient to detect the movement offsite of contaminants leaching from the TSF or WRD. Specifically, the purpose is to assess the effect that dispersion has on the movement of contaminants from the site and through the monitoring well system. A second purpose is to assess whether the hydrogeologic conditions at the site would allow contaminants from a substantial leak beneath either facility would reach offsite resources, specifically groundwater on the Ladder Ranch.

Based on the analysis presented herein, the proposed monitoring is not sufficient to adequately detect contaminants leaving either WRDs or TSF. Also, contamination would be sufficient to leave the mine site and reach groundwater at the Ladder Ranch.

The method employed here is to complete transport calculations for a simulated leak into a hypothetical aquifer that is representative of the aquifer that underlies the TSF, the Santa Fe Group (SFG). By hypothetical, the aquifer has a domain with size and properties similar to those of the SFG. This includes consideration of the fault, which can serve as an impediment to downgradient flow but which could also have a fracture zone that allows flow of groundwater and transport of contaminants north-south parallel to the fault.

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As noted, the aquifer considered for transport is the SFG which dominates the hydrogeology from the mine site to the Caballo Reservoir (Reservoir). This analysis uses hydrogeology and parameters as determined by NMCC studies, including Jones et al (2014) and Jones and Finch (2018). This means for purposes of this analysis I have accepted the parameter values as calibrated by Jones et al (2014), although I consider some sensitivity analysis of these parameters to assess how dependent the results are on the parameters. A generic fault was also included.

As noted by Anderson et al (2015, p 11) for generic models, the "model" is not calibrated to any observed data with one minor exception. The exception here was that the conductance for the fault was set so that during steady state model runs, there was a head drop of approximately 30 feet through the fault, to emulate the drop generally reported in NMCC studies.

For simplicity, the figures presented herein are either snapshots of figures or tables from relevant reports or a screen captures from the GUI.

SIMULATED DOMAIN AND AQUIFER

The project area is within the foothills of the Black Range near Hillsboro NM and about ten miles west of the Reservoir on the Rio Grande (Figure 1). Las Animas Creek flows from north of the project site southeast to the reservoir directly east of the project site. Percha Creek flows mostly west to east from about two miles south of the project to the reservoir. Both streams are perennial in reaches and intermittent elsewhere. The proposed project's pumping wells, shown on Figure 1, are four to six miles east of the mine site.

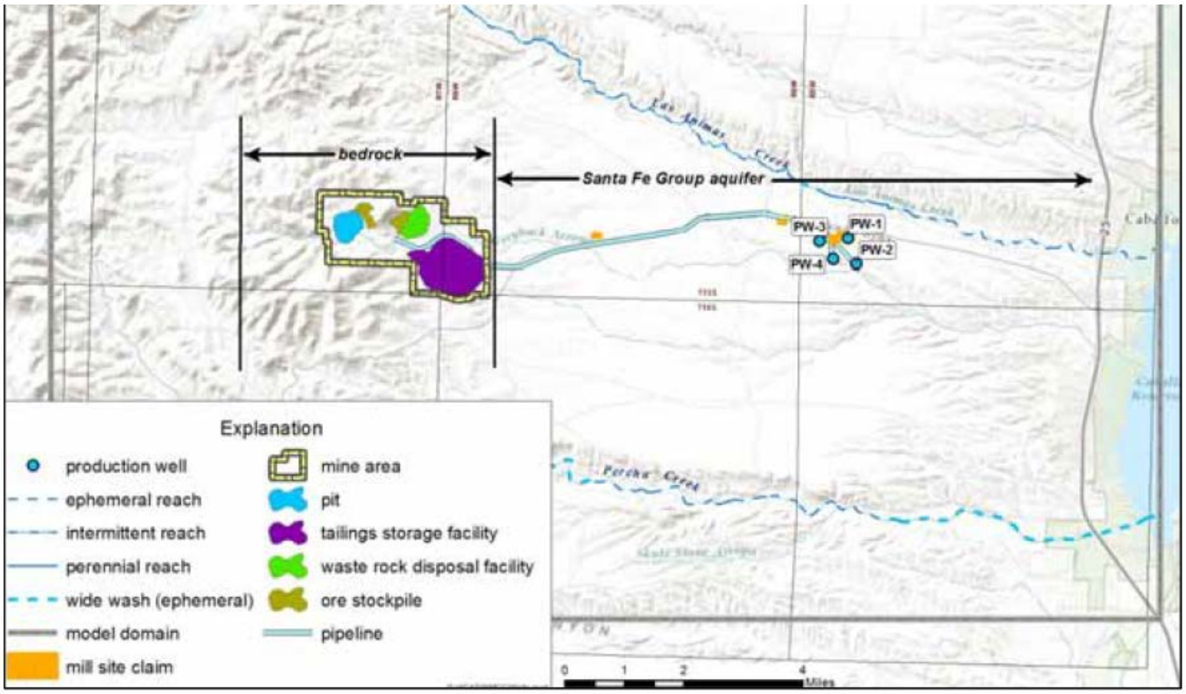

Figure 1.1. Map showing New Mexico Copper Corporation proposed mine facilities, mine area, and the affected area evaluated, Sierra County, New Mexico.

Figure 1: Figure 1.1 from Jones and Fink (2018)

The Santa Fe group is the primary formation for transport from the tailing and waste rock to downstream wells or the river (Figures 2 and 3). The mine site lies in a band of bedrock, known as the Animas Uplift. East of the site, the SFG spans the Palomas Basin to the reservoir. The SFG is about 1000 feet thick (Figure 3). The SFG underlies the east portion of the mine site, specifically the tailings impoundment. The mine pit is within andesite bedrock; mine dewatering causes a deep drawdown cone, but the TSF and two largest WRDs are east of the drawdown cone centered on the pit.

Jones et al (2014) developed a groundwater model for the regional aquifer from west of the project to the Reservoir. Their model was not intended as a transport model. The three model formation figures (showing model layers 2, 3 and 4) and table (Figures 4 through 7) show the general layout of that model and calibrated conductivity for the site. Jones et al represented he SFG in the model by numerous formation zones, as may be seen by closely looking at the legend for each model figure and comparing to the table, which provides their calibrated parameters.

Conductivity (K) in the SFG varies from 0.2 to 20 ft/d, with K in the uplift and in layer 2 generally less than 1 ft/d and below the fault in the Palomas Basin ranging from 4 to 20 ft/d. Most transport would occur in layer 2, which has saturated thickness ranging from 200 to 1000 feet. The 200-ft thick portions (as labeled in the tables (Figure 7)) are the SFG within Animas Creek.

Vertical anisotropy, the ratio of horizontal to vertical conductivity, is generally 0.01. Most transport would occur through Jones et al layer 2 which is 1000 feet thick with Kh=1.0 ft/d and Kv=0.01 ft/d, although west of the fault near the mine, K would be 0.4 ft/d.

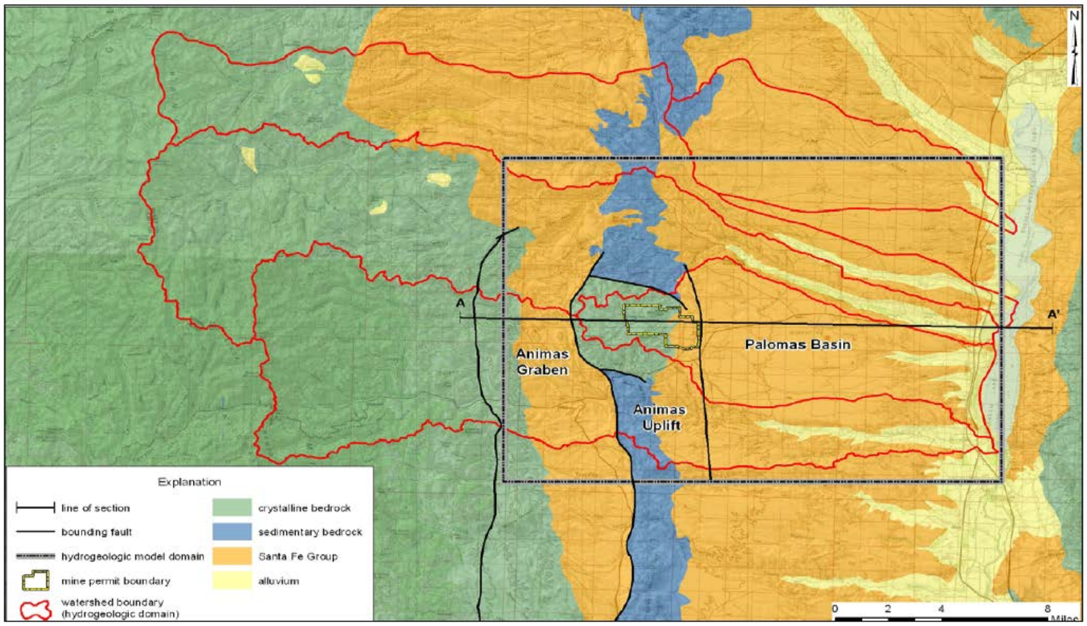

Figure 4.1. Hydrogeologic zones.

Figure 2: Figure 4.1 from Jones et al (2014)

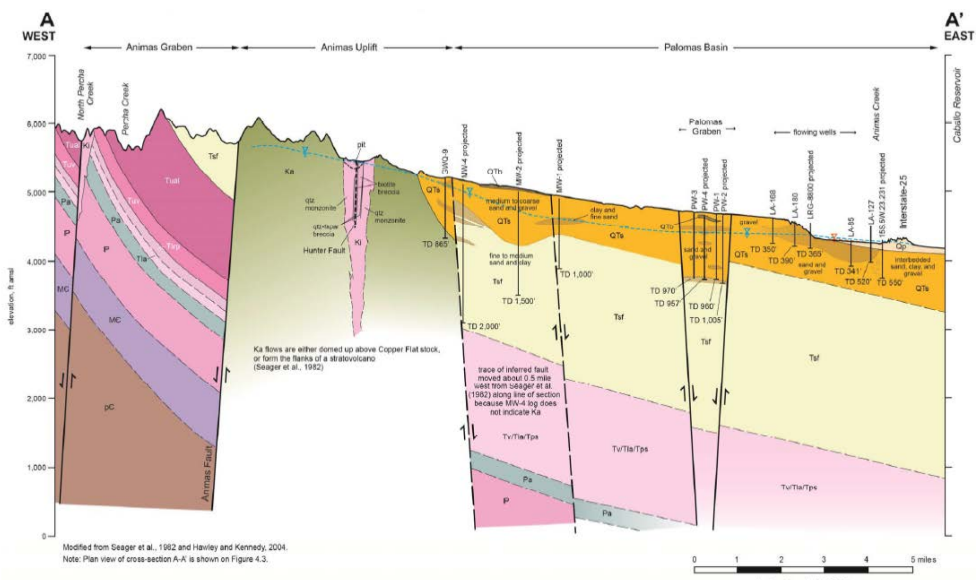

Figure 4.2. Hydrogeologic zones, west-to-east cross-section.

Figure 3: Figure 4.2 from Jones et al (2014) showing the cross-section in Figure 2.

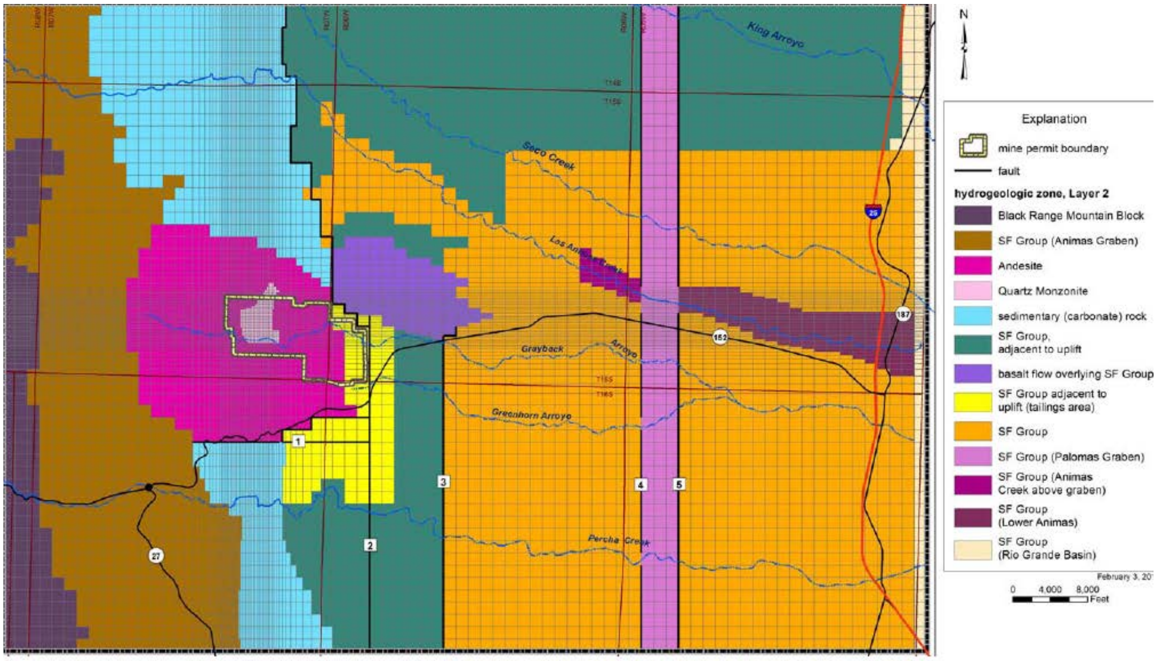

Figure 6.3. Layer 2 hydrogeologic zones.

Figure 4: Figure 6.3 from Jones et al (2014)

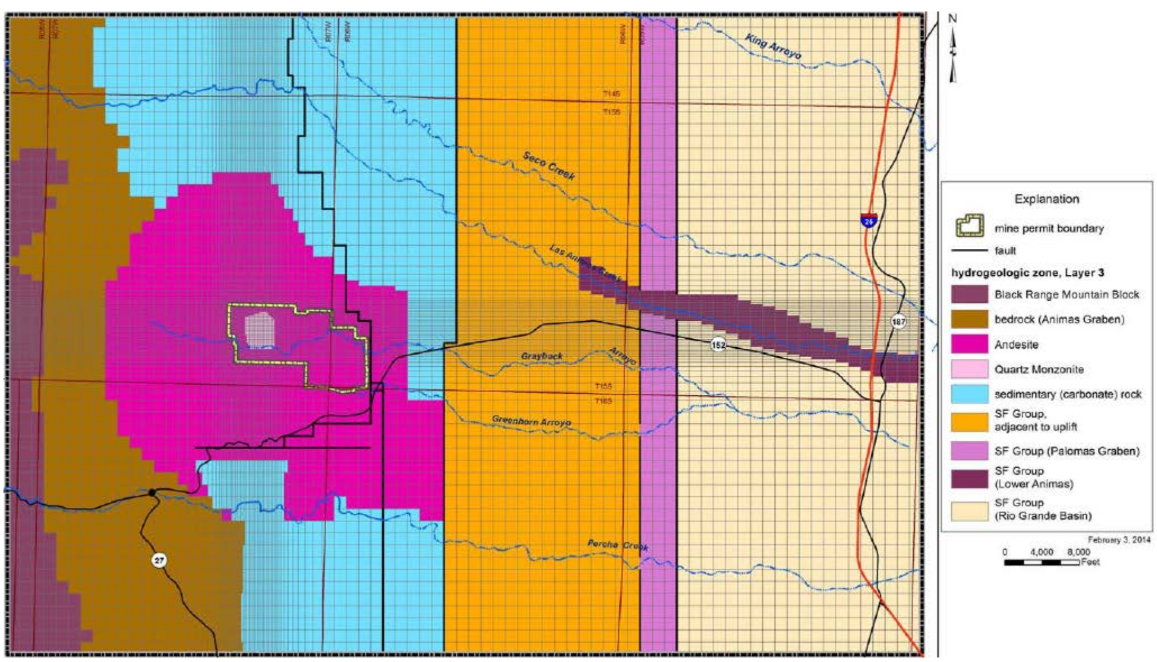

Figure 6.4. Layer 3 hydrogeologic zones.

Figure 5: Figure 6.4 from Jones et al (2014)

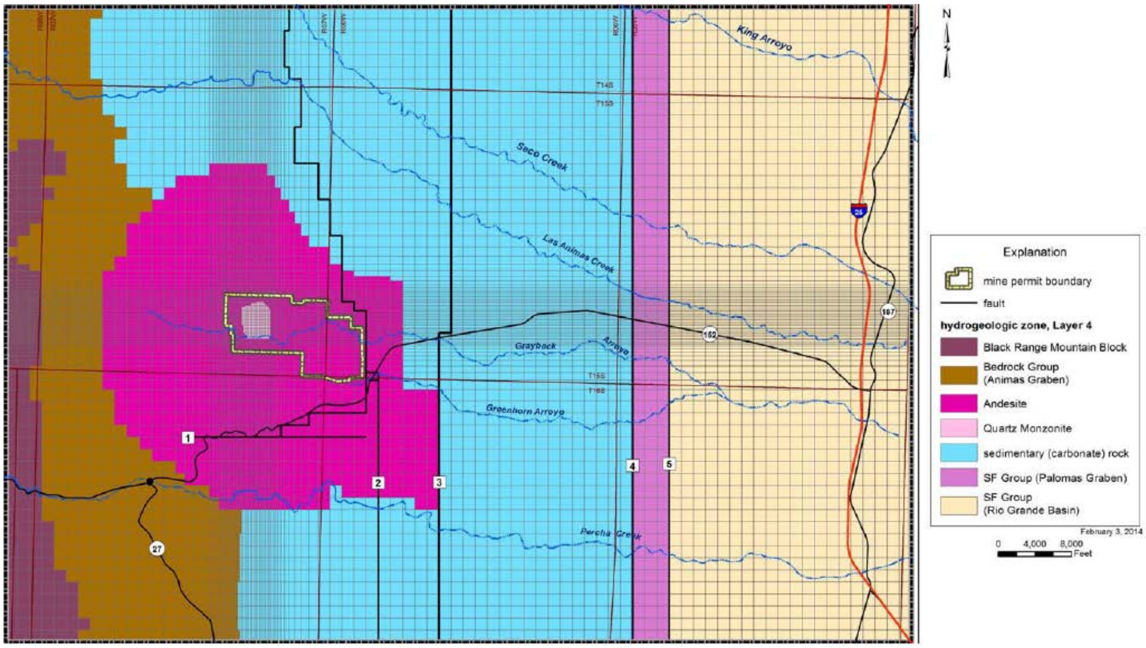

Figure 6.5. Layer 4 hydrogeologic zones.

Figure 6: Figure 6.5 from Jones et al (2014)

Table 6.1. Modeled aquifer parameters

Hydrogeologic Unit	Transmissivity (ft^2/dy)	Saturated Thickness (ft)	Hydraulic Conductivity (ft/dy)	Vertical Anisotropy (ratio)	Specific Yield (%)	Storage Coefficient (%)
Layer 1						
Alluvium / SF Group	2,400	50	48.0	1.25E-04	10%	
Alluvium / SF Group (Lower Animas and Rio Grande Basin)	10,000	200	50.0	1.60E-04	10%	
Layer 2						
Black Range Mountain Block	2	1,000	0.002	0.01	0.1%	0.1%
SF Group (Animas Graben)	500	500	1.000	0.01	10%	10%
Andesite	2	1,000	0.002	0.01	0.1%	0.1%
Quartz Monzonite	2	1,000	0.002	0.01	0.1%	0.1%
Sedimentary (carbonate) rock	80	1,000	0.080	0.01	0.5%	0.5%
SF Group adjacent to uplift, edge of basin	200	1,000	0.200	1.0	5%	5%
SF Group adjacent to uplift (Upper Animas)	40	200	0.200	0.01	5%	5%
Basalt flow overlying SF Group	0.2	200	0.001	0.01	1%	1%
SF Group	900	1,000	0.900	0.01	10%	0.1%
SF Group (Palomas Graben)	1000	1000	10.000	1.0	10%	0.2%
SF Group (Animas Creek above graben)	2000	200	10.000	0.0001	10%	0.1%
SF Group (Lower Animas)	20000	1,000	20.000	0.01	10%	0.1%
SF Group (Rio Grande Basin)	20000	1000	20.000	1.0	10%	0.1%
Layer 3						
Black Range Mountain Block	2	2,000	0.001	0.01		0.01%
Bedrock (Graben)	700	1,000	0.700	0.01		0.01%
Andesite	2	2,000	0.001	0.01		0.01%
Quartz Monzonite	2	2,000	0.001	0.01		0.01%
Sedimentary (carbonate) rock	100	2,000	0.050	0.01		0.01%
SF Group, adjacent to uplift	400	2,000	0.200	0.01		0.4%
SF Group (Palomas Graben))	8,000	2,000	4.000	1.0		0.4%
SF Group, lower Animas	10,000	1,000	10.000	0.01		0.1%
SF Group (Rio Grande Basin)	800	2,000	0.400	0.01		0.4%
Layer 4						
Black Range Mountain Block	3	3,000	0.001	0.01		0.01%
Bedrock (Graben)	100	2,000	0.050	0.01		0.01%
Andesite	3	3,000	0.001	0.01		0.01%
Quartz Monzonite	3	3,000	0.001	0.01		0.01%
Sedimentary (carbonate) rock	150	3,000	0.050	0.01		0.01%
SF Group (Palomas Graben)	2,000	3,000	0.667	0.01		1%
SF Group (Rio Grande Basin)	2,000	3,000	0.667	0.01		0.6%

Figure 7: Table 6.1 from Jones et al (2014)

Regional groundwater contours based on well observations show a west to east slope through the existing mine site (Figure 8), on which drawdown to the existing pit lake is superimposed (Figure 9). The groundwater "slope" is wider north-south than the mine site, so the general flow direction through the mine site is west to east to the Reservoir (Figure 8). Jones et al's steady state simulation results are similar (Figure 6.11 in Jones et al (2014)). The gradient is substantially steeper near the proposed mine site and flattens further east (Figure 8), indicating a steeper gradient through the mine site than directly to the east of the mine site and to the Reservoir.

One of the waste rock dumps and the TSF lie east of the divide created by dewatering the pit and formation of the pit lake (Figure 9). The flow vectors shown on Figure 9 show a component of flow toward the northeast from the WRD and to the southeast from the TSF. The flow component to the northeast would direct transport toward Ladder Ranch.

The next section develops an interpretative groundwater model with parameters similar to those expected for the SFG beneath the TSF and for the andesite beneath the WRDs.

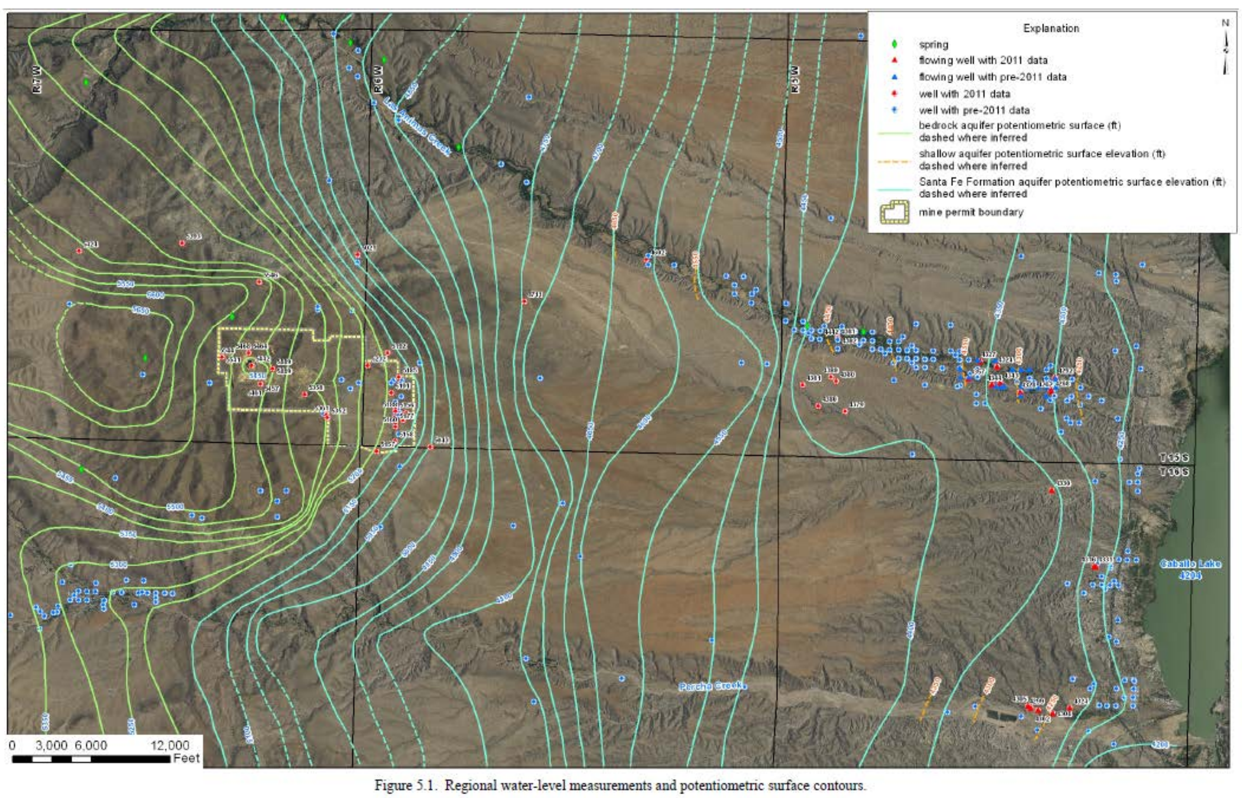

Figure 5.1. Regional water-level measurements and potentiometric surface contours.

Figure 8: Figure 5.1 from Jones et al (2014)

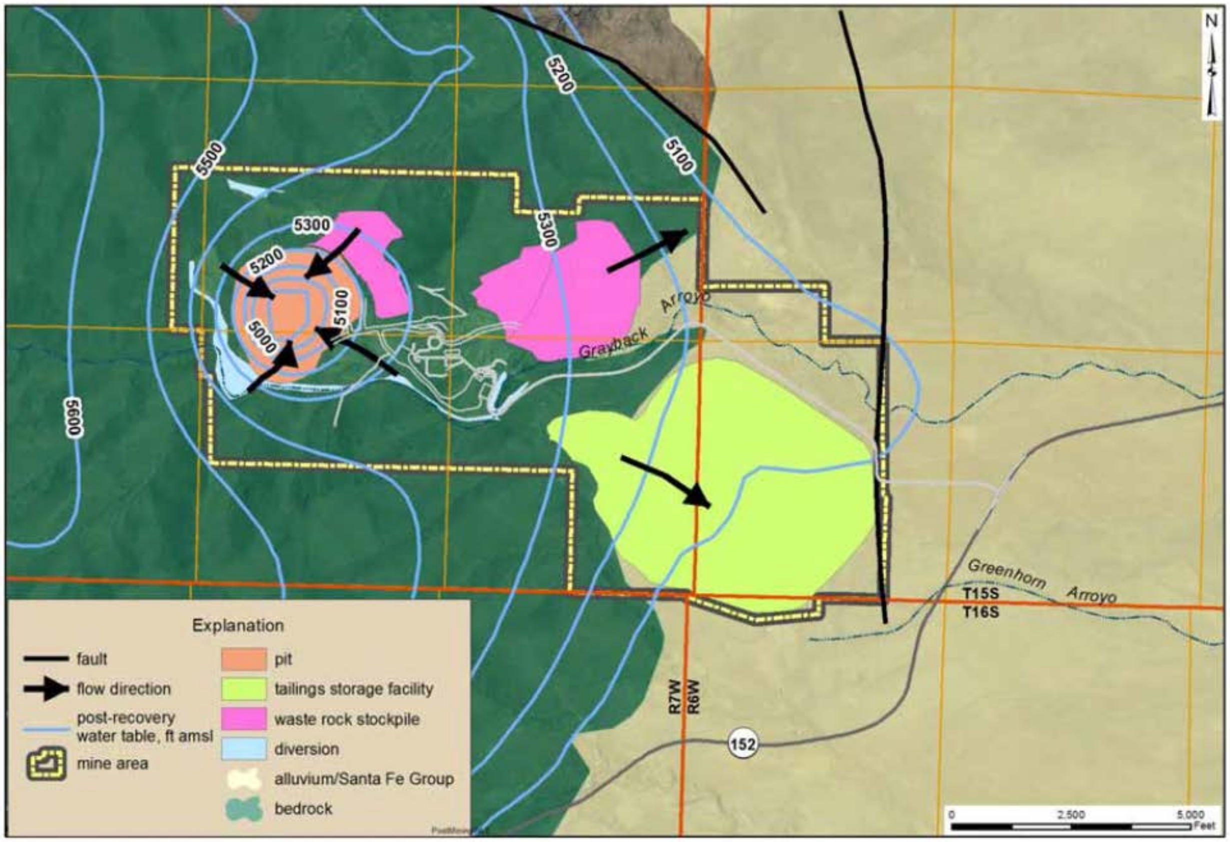

Figure 3.17. Proposed mine facilities and projected post-mining groundwater elevation.

Figure 9: Figure 3.17 from Jones and Finch (2018).

INTERPRETATIVE MODEL DEVELOPMENT

The purpose of the calculations was to estimate the rate a plume released at the mine site would travel to the east and how much it would disperse. Calculations are performed using the MODFLOW-2000 groundwater flow and the MT3DMS transport model code, as implemented with the Groundwater Vista graphical unit interface (GUI). The analysis is in the form of an interpretative model, which according to the definition of Anderson et al (2015, p 11) is both a screening model and a generic model. A screening model can “help the modeler develop an initial understanding of a groundwater system [or] test hypotheses about the system” (Id.). The hypotheses tested include the rate of transport and the potential dispersion for the development of a plume. A generic model can “explore processes in generic hydrogeologic setting” (Id.). A generic model helps the modeler understand processes without considering uncertain complexities of the aquifer. The complexities should not be so substantial as to be expected to significant change the calculated results. Understanding these processes help to establish appropriate monitoring well spacing and to determine the extent that contaminants could affect nearby property.

Two model domains were considered due to the different materials that underlie the WRD and the TSF. The WRD would leak into andesite bedrock and the TSF would leak into the SFG. The objective was to assess the width of plume with respect to monitoring well layout and with respect to exceedances at monitoring wells. The discharge through the domain for each scenario was assumed to be directly west to east, as described above, rather than including nuances of flow northeast from under the WRD or southeast from under the TSF, as shown in Figure 9.

Simulation of the TSF and the Santa Fe Group

This domain was from the TSF to the Reservoir. The distance from the east portion of the mine to the Reservoir is 62,000 feet. There is about 6600 feet between the lip of the pit lake dewatering cone and the east end of the mine site. The mine width is a little less than two miles, so the domain width was set at approximately 21,000 feet with the mine centered north-south of the expected west to east flow path. The north and south boundaries are parallel to the flow direction and therefore are no-flow boundaries. The width is sufficient for the calculation of a plume without the plume being constrained by the no-flow boundaries, although this was tested during simulations. The calculation domain was 68,000 feet east to west and 21,000 feet north-south. The west end coincides with the groundwater divide formed by the pit lake and future mine dewatering.

The ground surface at the west end is at 5400 ft amsl. It drops 200 feet to 5200 ft amsl within 5300 feet to the east, for a surface gradient equal to 0.037736. East of that, the gradient is 1000/(68,000 - 5300) or 0.015949 as the surface drops to 4200 feet at the Reservoir. These gradients are similar to those discussed above with respect to Figure 8.

The model domain then was 68,000 feet by 21,000 feet, with cell size 100 by 100, and 50 by 50 feet near the mine site (Figure 10). The slope change occurs at a fault, simulated with a horizontal flow barrier (HFB) boundary (visible in the cross-section portion of Figure 10). One row and one column were set at 75 feet to transition from the 50- to 100-foot square cell size. Four 250-foot thick layers were established vertical flow and dispersion calculations. The uppermost layer was unconfined and the others were set as confined. The depth to water simulated by Jones et al (2014) was never more than 250 feet so layer 1 herein should not become unsaturated.

Constant head (CH) boundaries through all layers on the west and east side of the domain provides the flow through the model domain. A CH boundary holds the head constant by providing water to the model domain based on the gradient and conductivity of the parameter zones[1]. Head was set at 5300 ft amsl on the west, or 100 feet below ground surface (bgs) and

[1] A groundwater divide formed by pit dewatering would be a no flow boundary. The constant head boundary was used to provide flow which could result from recharge or groundwater flowing south of the pit drawdown as shown in Figure 9.

at 4190 on the east, or 10 feet below the reservoir level and simulated top of layer 1. There was no simulated recharge except for the simulated leak.

Hydraulic conductivity (K) for the formations in Figure 11 was set using steady model runs and choosing K values that would provide a flow through the system similar to NMCC model flow to the reservoir and that would not flood or desaturate layer 1. This was done using a steady state sensitivity analysis in which K for parameter zones 1 and 2 are adjusted over a range from 0.04 to 5 ft/d (Figure 12). Flow through the system ranged from about 36,000 to 655,000 ft^3/d during the varying of K1 and from less than 100,000 to almost 350,000 ft^3/d while varying K2. For the lower K1 values, layer 1 desaturated which was not appropriate for this modeling because it is getting near the lower range of K values expected at this site. For the higher K2 values, layer 1 became flooded (the simulated water table exceeded the ground surface).

Additionally, to test whether the fault could enhance north-south flow, a one-column thick zone 3 with K=50 ft/d was added. The conductance at the HFB was based on a 20-foot thick wall and the K value set to establish an approximate 30-foot head drop. With K1=1.0 ft/d, K2=0.4 ft/d, and K3=50 ft/d, and K for the fault equal to 0.01 ft/d, the flow through the system was 275,000 ft^3/d (2300 acre-feet per year). This is about 20% of the discharge estimated from the Palomas Basin into the Reservoir (Jones et al 2014).

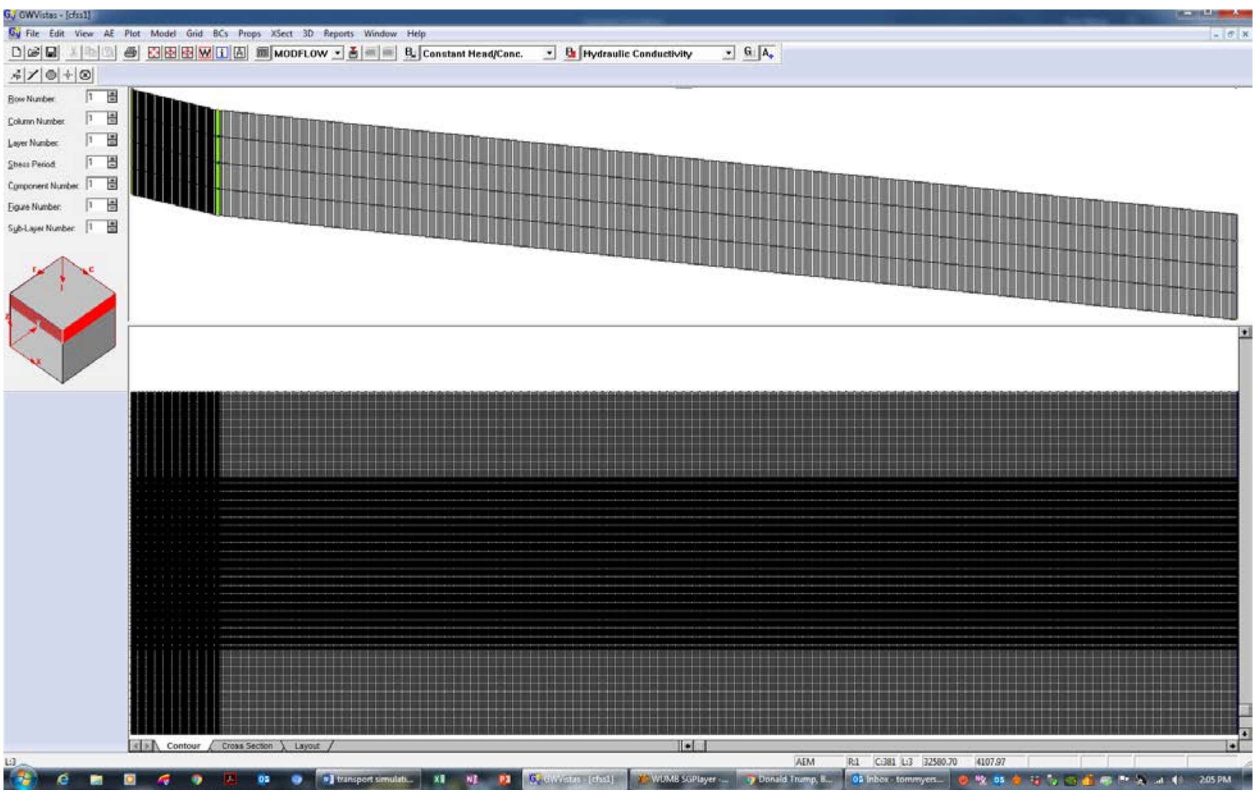

Figure 10: Screen capture of the model grid for the domain between the mine site and Caballo Reservoir (on the east).

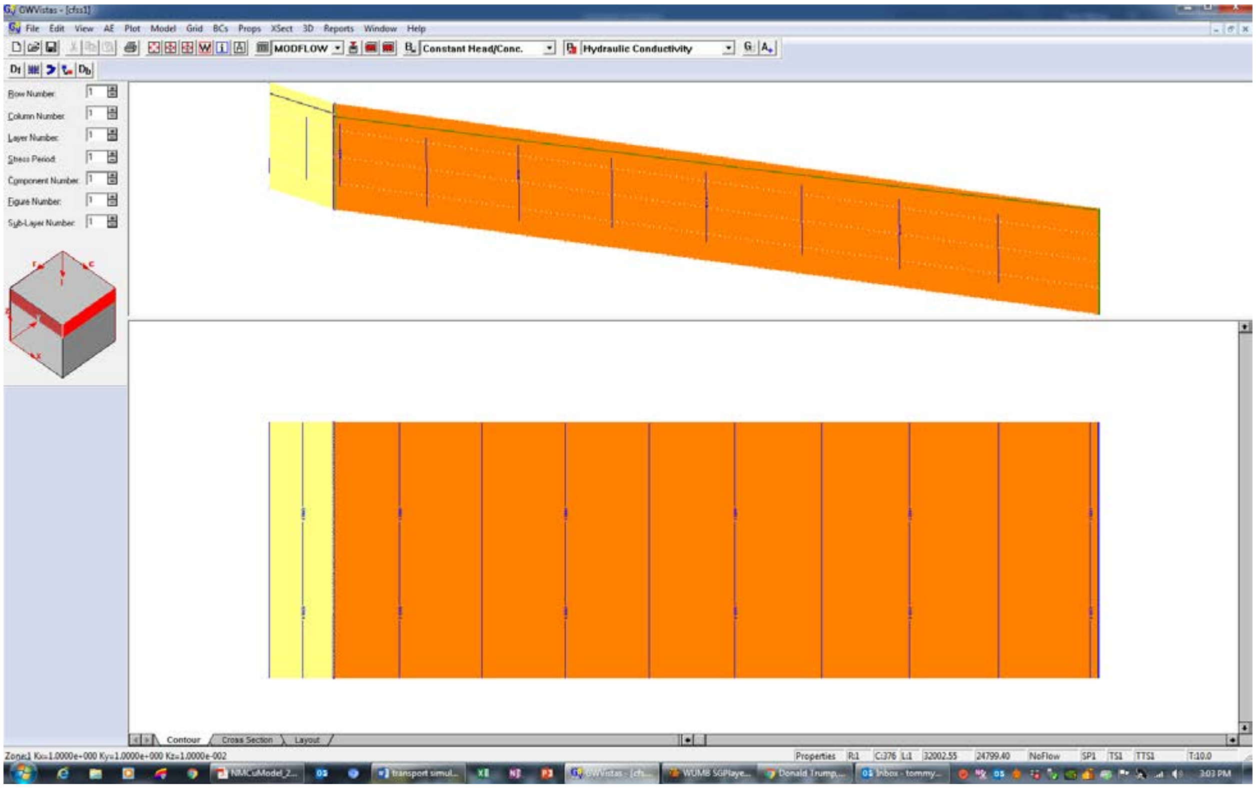

Figure 11: Parameter zones for the model domain. The orange is zone 1, the yellow zone 2, and the red (one column near the HFG).

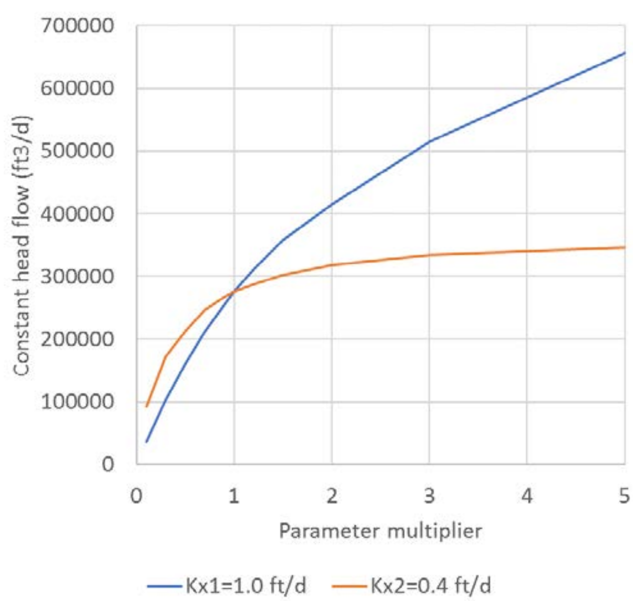

Figure 12: Variation of constant head flux with conductivity being varied for Kx1=1.0 and Kx2=0.4 ft/d.

Andesite

Simulation of a leak from the WRDs into and through the andesite required a different domain than was used for the TSF. Dispersion was expected to be less than for the TSF through the SFG so a much smaller domain was chosen. The domain was decreased to 25,000 feet by 12,000 feet, with the parameter zones remaining the same. The domain shown in Figure 11 represents the domain used for andesite except for the smaller dimensions. The HFB was removed from the simulation because its K was about the same as for the andesite. The fault fracture zone was also removed. The slope changes at the formation transition. The model cells are as described above, with the cells in the andesite being 50 by 50 feet and in the SFG being 100 by 100 feet, with a transition occurring at the formation transition.

The final K was selected as for the SFG, with a sensitivity analysis performed for each formation. Flux varied from about 400 to 6000 ft^3/d, but both higher K1 (SFG zone) and lower K2 (andesite) caused substantial portions of layer 1 to become desaturated. The chosen values were K1=0.05 and K2=0.01 ft/d, respectively.

Steady state model runs set initial heads for all leakage simulations for both aquifer types and contaminant sources.

SIMULATION OF LEAKAGE

The discharge permit documents assume there will be no leaks from the TSF liner and the andesite beneath the WRD is effectively an impermeable liner. Jones and Finch (2018) estimate leakage from the TSF due to manufacturers imperfections would be 0.5 gpm, or about 720 gpd, or about 100 ft^3/d spread over the TSF area. Distributed as assumed by Jones and Finch, seepage would not travel far from the source.

The type of leak that would threaten groundwater would be a concentrated source, due to a tear or other liner imperfection. For this analysis, two leakage scenarios were considered for the TSF and one for the WRD. For the TSF, a leak equivalent to 0.3 ft/d over a 50-foot square model cell would occur at some point on the mine site. This is 700 ft^3/d (4 gpm), or seven times the overall leakage estimated by Jones and Finch (2018). A second leak was to consider a significantly larger leak over the same area, or 1.54 ft/d (20 gpm). The WRD leak was set as for the smaller leak on the TSF, at 0.3 mg/l over a 50-foot square model cell. A higher rate was not used because it would be much higher than the andesite would accept and such a leak would manifest at the base of WRD rather than entering the ground.

The concentration was set at 1000 mg/l. It is considered simply a conservative tracer that would allow dispersion and travel time from the source to be tracked. Because the contaminant is considered conservative, the contours can be scaled to consider a different concentration. In other words, if the concentration is 100 mg/l, the 100 mg/l contour can be considered to be the 10 mg/l.

Each simulation was run by simulating transient flow using MODFLOW-2000 followed by transport using MT3DMS. Dispersion coefficients are 25, 5, and 2.5 feet based on the flow path length through the model cells, following Xu and Eckstein (1995).

The baseline transport scenario is a discharge at 0.3 ft/d and 1000 mg/l for 100 years to fully develop the plume through the domain. This scenario allowed various transport properties of the formations to be explored. After 100 years, the leak formed a 9-foot mound[2]. The 0.01 contour reaches the reservoir at about 100 years (Figure 13). Dispersion caused the 0.01 mg/l contour to expand 6000 feet to the north at about 50,000 feet east of the discharge point. Flow through from CH boundaries is about 275,000 ft^3/d.

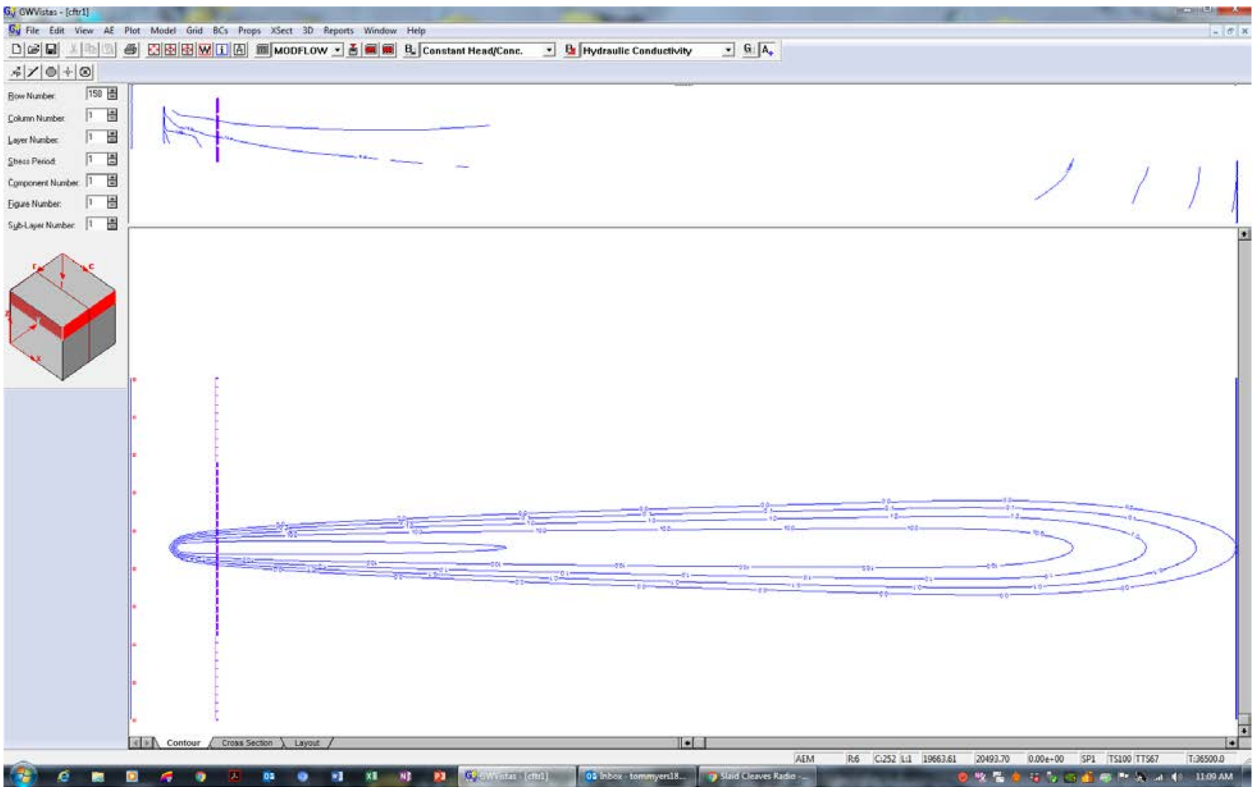

Figure 13: Concentration contours at 100 years for the baseline scenario of 0.3 ft/d for a 50-ft square model cell, concentration equal to 1000 mg/l. (K1=1, K2=0.4, K3=50, Khfb=0.01)

Test of the Fault

The first test of the model was to determine the effect of the HFB using the 100-year leak scenario. The fault K was decreased to 0.001 ft/d to assess the sensitivity of the simulation to fault conductance. This caused massive mounding including a flooded ground surface above the fault (Figure 13). The HFB effectively dammed the flow causing a large outflow from

[2] Throughout this memorandum, the mounds are shown using maps of drawdown. A mound is "negative", so the contours showing a mound are negative.

storage. The contaminant plume was about 90% of the size of the plume for baseline (Figure 14). Decreasing fault conductance slows the transport, but not substantially.

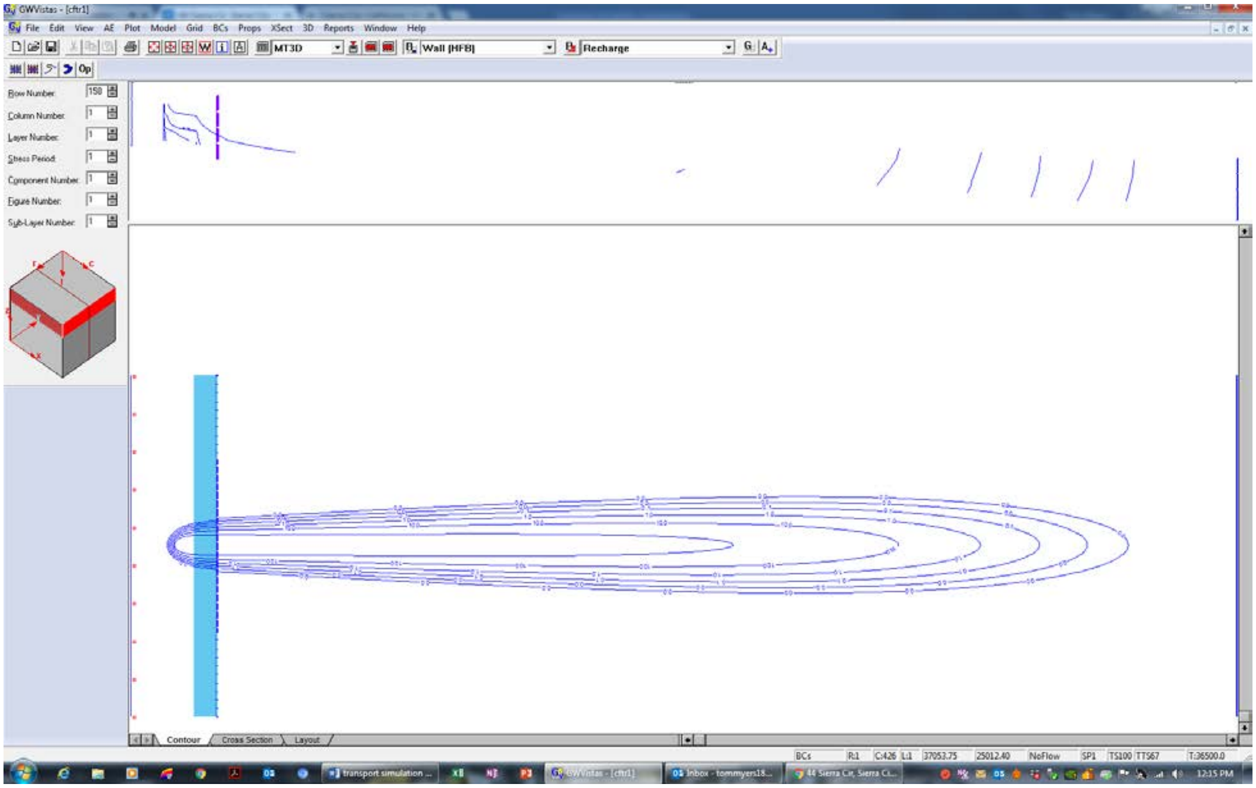

Figure 14: Concentration contours at 100 years for changing the baseline scenario to Khfb to 0.001 ft/d.

The fracture zone does not apparently affect transport (Figures 13 and 14), but that could be due to there being no impetus or gradient parallel to the fault. If a geologic anomaly caused a gradient vector along the fault, transport could occur along the fault fracture zone.

To test whether the fault would cause flow and transport away from the flow centerline if there were heterogeneities, I removed the fracture zone south of the midpoint of the domain (Row 158) so that K=0.4 ft/d rather than 50 ft/d in that area. Flow modeling caused about 4 feet of mounding south along the fault, which caused a gradient northward along the fault. The plume expanded further, with the 0.01 mg/l contour beyond the east end of the model (Figure 15). Examined closer, near the fault the contours shift northward about one row (100 feet) which allows more groundwater and contaminants to flow through the fault. There does not appear to be a significant difference in overall contaminant transport due to the fracture zone and additional 4 feet of head caused by the low K south of the contaminant source.

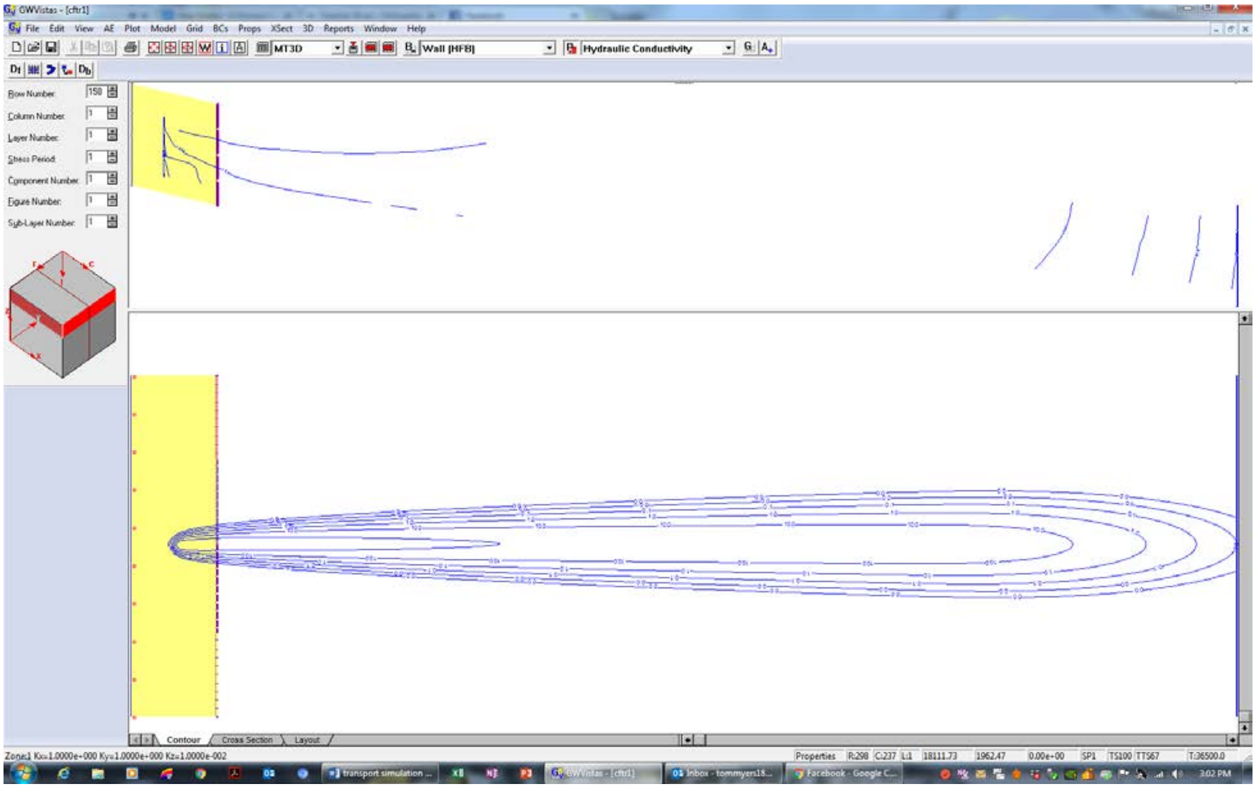

Figure 15: Concentration contours at 100 years for decreasing the fracture zone to half of the model width. All parameters the same as in the baseline.

Comparative Simulation of Leaks

The mine life is about 12 years after which the WRD and TSF would be reclaimed and flow into them decreased. Leaks would eventually decrease even if not detected and repaired. Once reclamation commences, flow would continue through the WRD and draindown would continue through the TSF. The longest likely leak therefore is about 15 years, which reflects the time the TSF is operating and the WRD has significant unreclaimed areas. The transient simulation is broken into a 15-year period for the leak and a 100-year period without the leak.

Comparisons are made among the three scenarios by considering concentration contours after 1, 2, 15, and 115 years from the beginning of the leak, and by considering various concentration hydrographs. The contour maps also show the relative location of the simulated monitoring wells. The concentration hydrographs are for a series of monitoring wells spaced east to west along the primary flow path and for a series of monitoring wells spaced perpendicular to the primary flow path. The east to west monitoring wells are labeled based on their distance right (east) of the source and model layer. For example, MW1000L2 is a monitoring well 1000 feet east of the source and in model layer 2. The simulated monitoring wells spaced north of the flow path at 100 feet, are labeled as MW***N, with *** being feet north of MW1 at the flow path (Figure 16).

Simulated as recharge reaching the water table, leaks form mounds on the water table that reflect their rate of leakage and the hydrologic properties of the surrounding aquifer. After 15 years, the 4 gpm and 20 gpm leaks at the TSF would form 8- and 40-foot mounds, respectively (Figures 16 and 17). The mound has spread several thousand feet, especially for the 20 gpm leak. A 40-foot mound is not unusual for a leak that does not flood the ground surface. The fault east of the leak bounds the drawdown cone making it elliptical rather than circular. The leak in the andesite forms a mound over 150 feet high that has not spread more than 500 feet (Figure 18), obviously due to the low K used to simulate the formation (0.01 ft/d). The high point of the mound occurs in just the one cell beneath the leak. Reality would have the leak flowing from the source through fractures which the model does not discretely simulate.

The 1.0 mg/l contour has not reached the fault, about a mile downgradient, within a year for either TSF leak scenario, but has dispersed laterally between model rows 149 to 166, or about 1700 feet centered on the primary flow path (Figures 19 and 20). The plume is much less dispersed after one year for the WRD leak, for which the concentration contours form a steep gradient between the 100 and 0.01 mg/l contours (Figure 21). The area within the 100 mg/l contour has values close to 1000 mg/l, due to much slower dispersion through the andesite due to slower groundwater flow.

After two years, the 0.1 mg/l contour has reached the fault for the 4 gpm TSF leak and the 1.0 mg/l contour has reached the fault for the 20 gpm TSF leak, respectively (Figures 22 and 23). Considering that the shapes are very similar with the higher flow rate being spread just a little further, the primary difference is the mass of contaminant within the plume, which would be more than five times as great for the 20 gpm leak. The plume in the andesite has not expanded significantly beyond its one-year area (not shown).

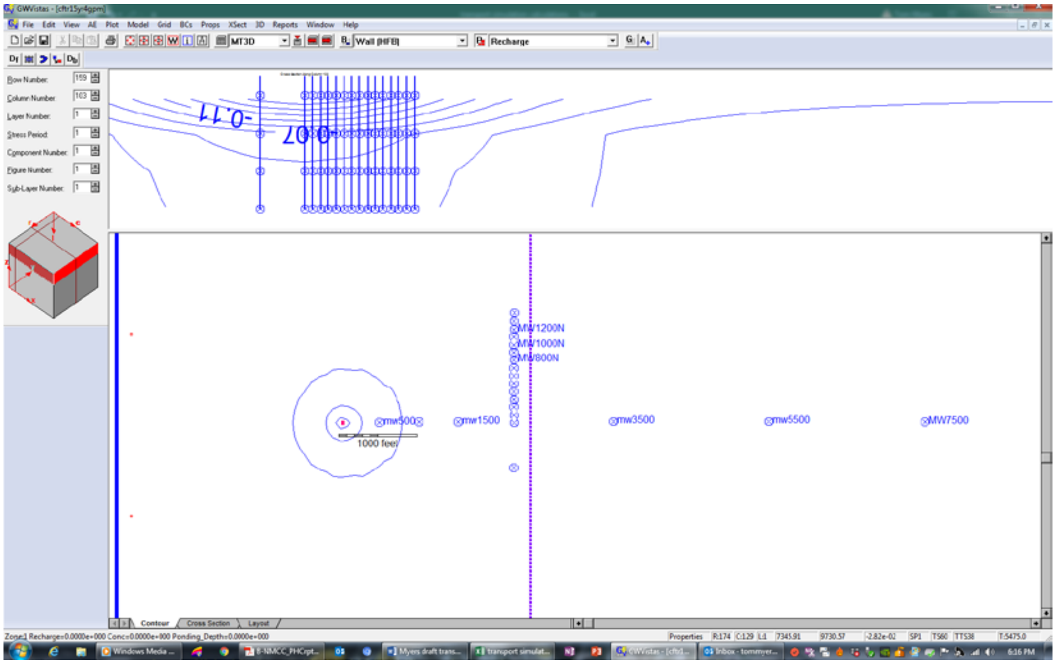

Figure 16: Drawdown contours showing the mound that develops with 15 years of a 20 gpm leak. Two-foot contours

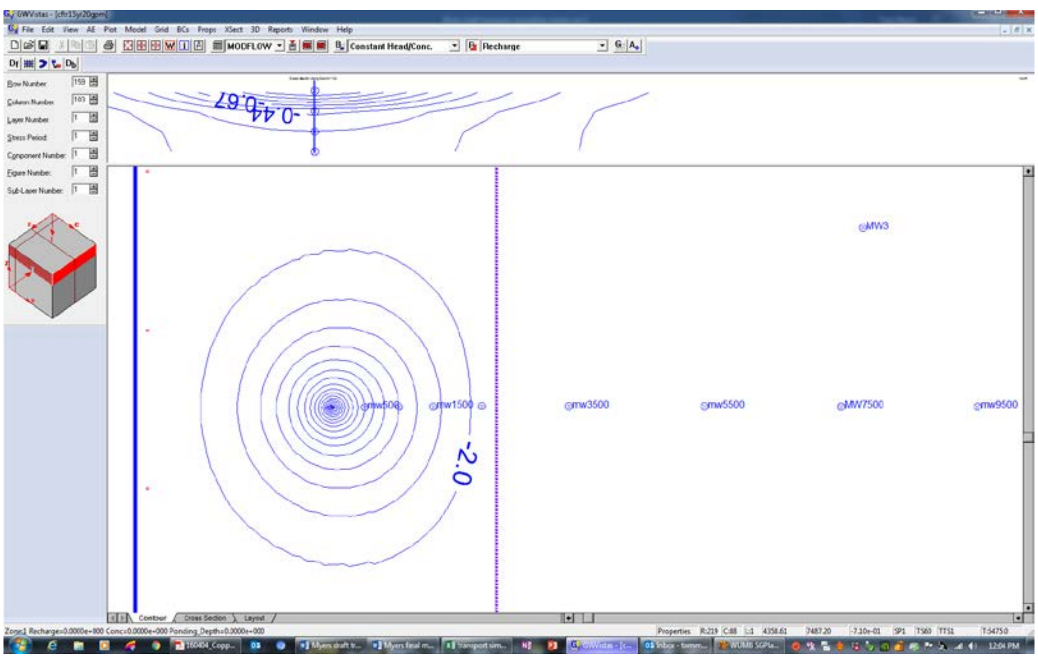

Figure 17: Drawdown contours showing the mound that develops with 15 years of a 20 gpm leak. Two-foot contours.

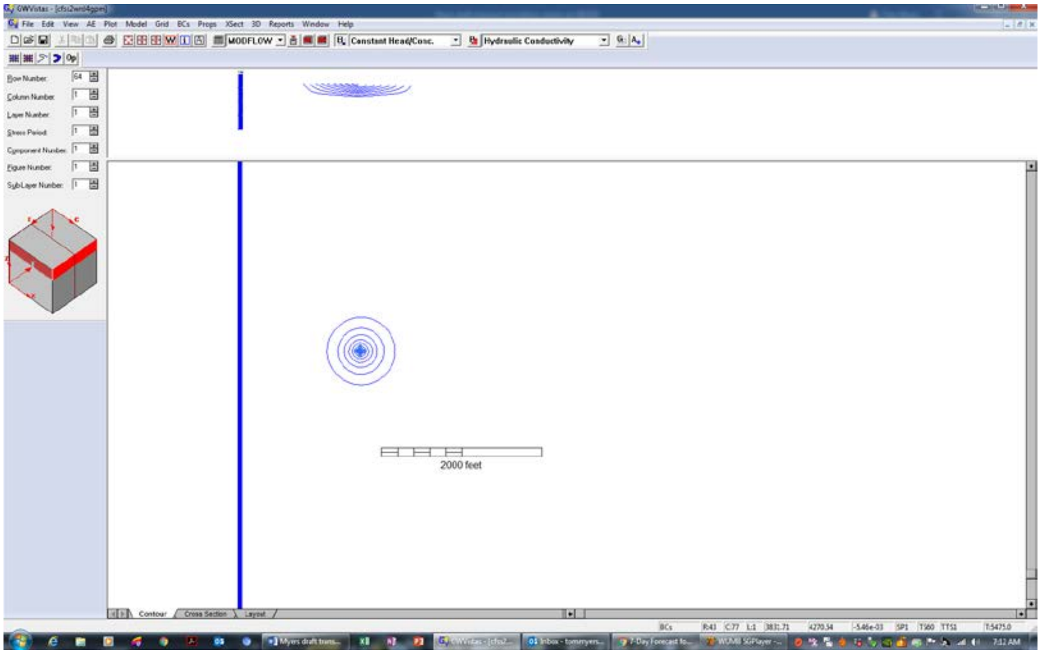

Figure 18: Drawdown contours showing the mound that develops in the andesite under the WRD with a 4 gpm leak for 15 years.

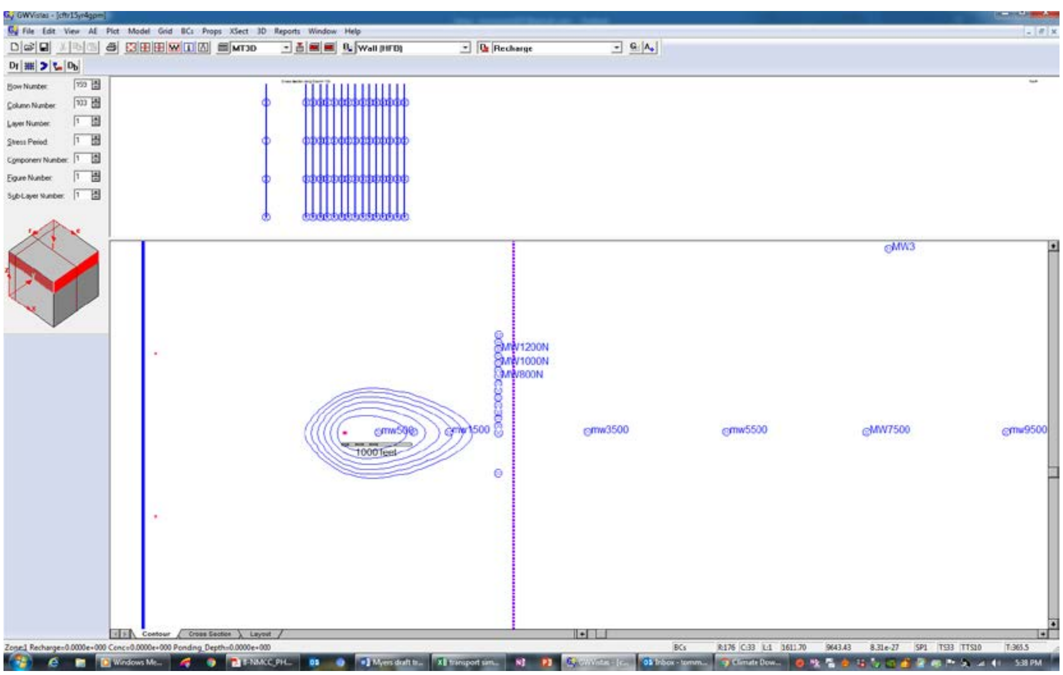

Figure 19: Concentration contours after 1 year of a 15-year leak at 4 gpm for the TSF

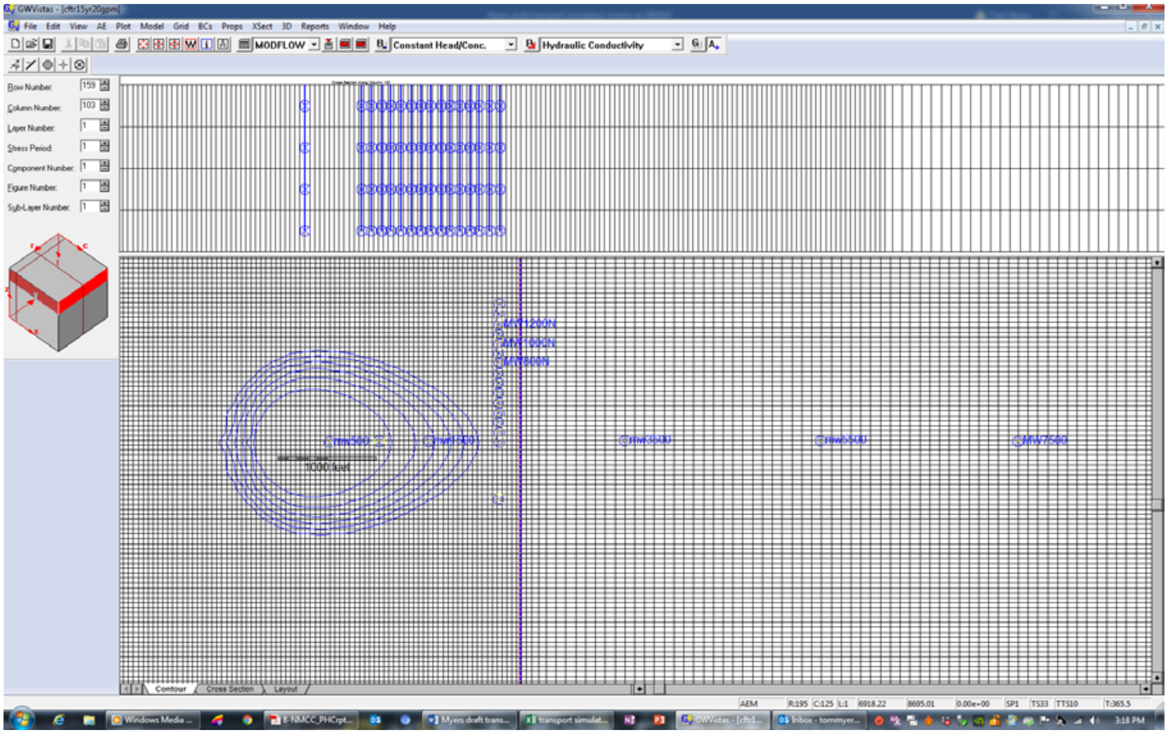

Figure 20: Concentration contours after 1 year of a 15-year leak at 20 gpm for the TSF.

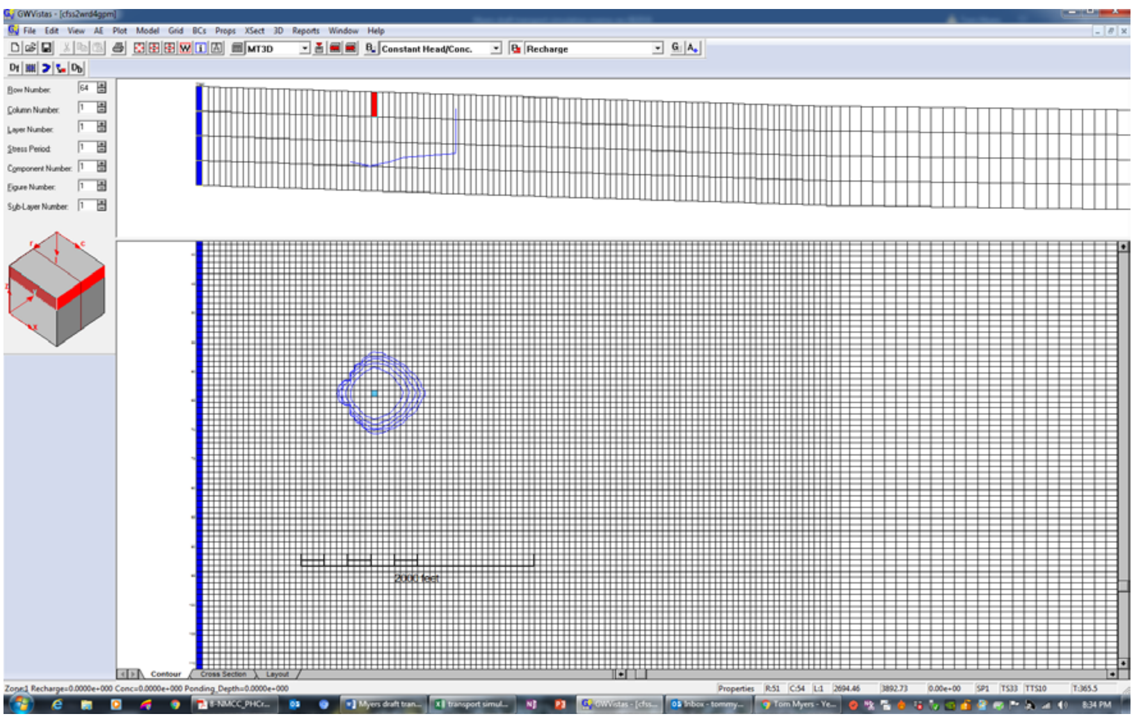

Figure 21: Concentration contours after 1 year of a 4 gpm leak on the andesite. The inner contour is 100 mg/l.

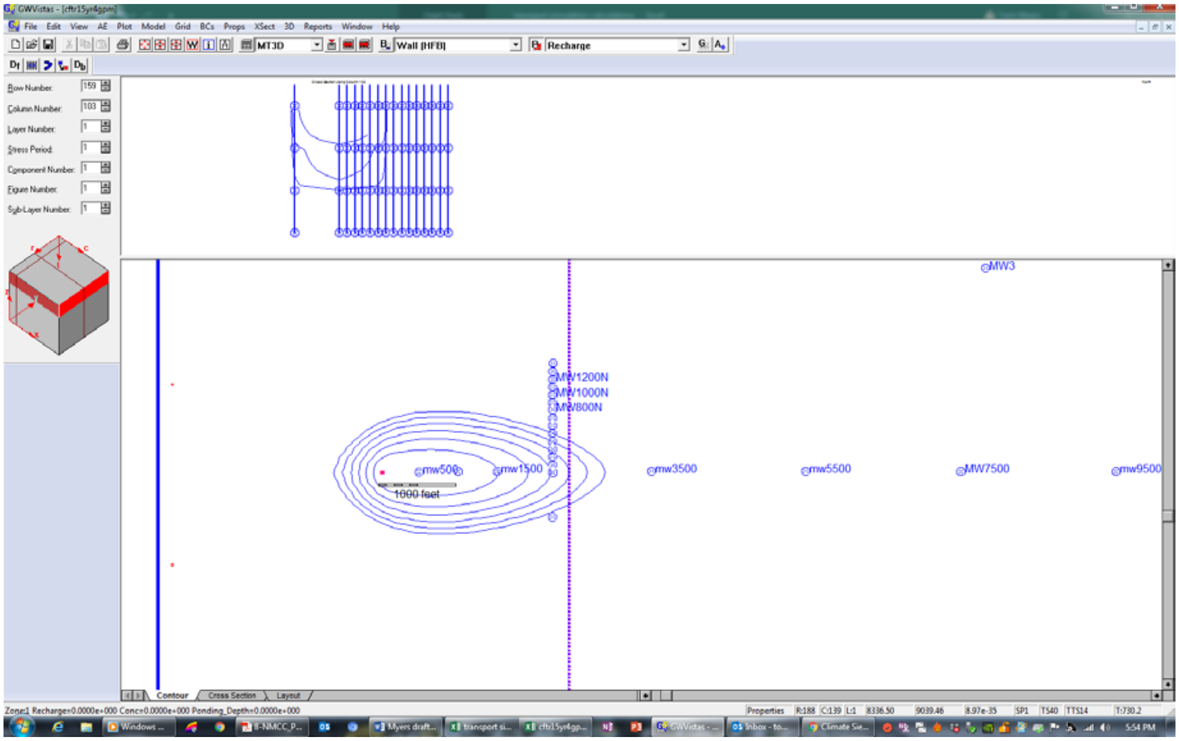

Figure 22: Concentration contours after 2 years of a 15-year leak at 4 gpm for the TSF.

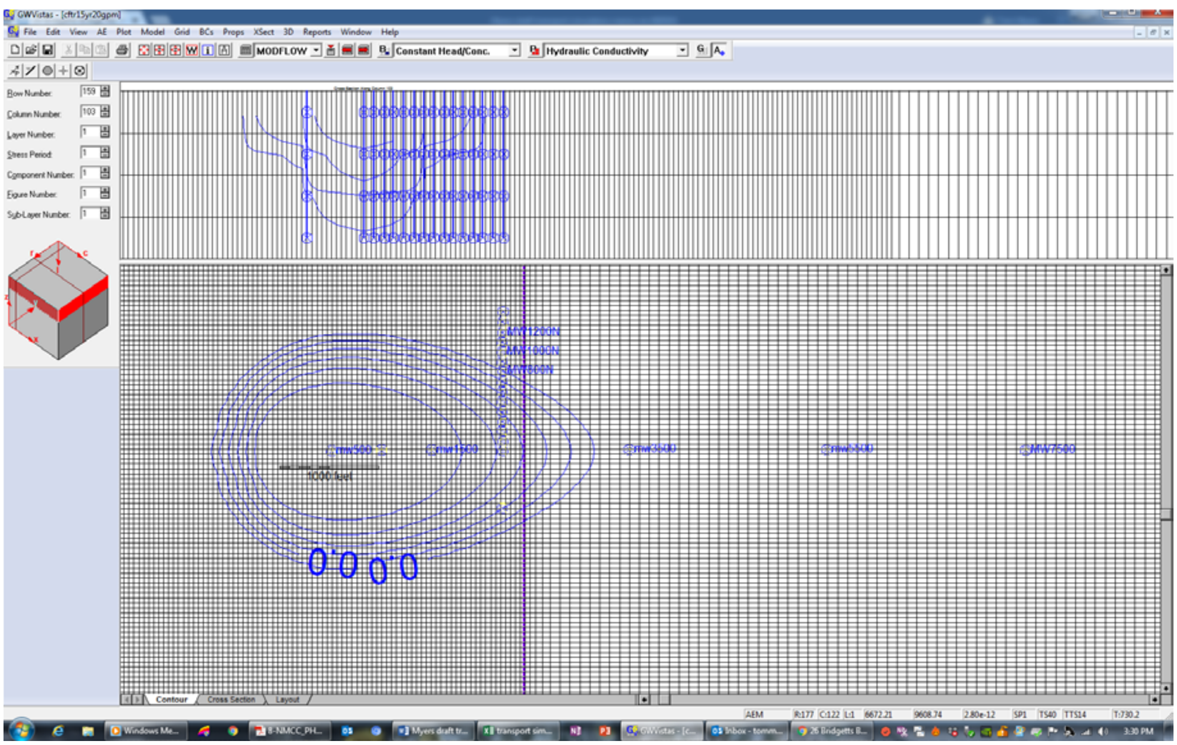

Figure 23: Concentration contours after 2 years of a 15-year leak at 20 gpm for the TSF.

The leak ends after 15 years, so the total mass to leak into the domain will be there and the plume could be considered to be fully developed. The 10 mg/l contour for the 4-gpm leak extended about two miles downgradient from the source and the 100 mg/l contour encloses an area more than a mile and half long (Figure 24).

Dispersivity sensitivity was tested using this scenario. Doubling lateral and vertical dispersity expanded the plume a couple hundred feet (Figure 25). The 100 mg/l contour is noticeably wider but also about 100 feet shorter. Based on a comparison between Figure 25 and Figure 24, the size of the plume is not substantially sensitive to the lateral and vertical dispersivity.

At 20 gpm, the contours after 15 years are spread substantially further north to south, but the distance it expanded downgradient is not substantially different (Figure 26). Lateral dispersivity depends partly on concentration gradients, so the additional mass near the flow path likely pushed more contaminant away from the flow path.

The 15-year leak in the andesite forms a substantially different plume, being about 2000 to 2500 feet in all directions, after 15 years (Figure 27). The concentration in the area near the source is substantially higher than in the other leak scenarios which reflects the slower and decreased flow through the andesite; there is less groundwater flowing through the andesite to dilute it.

After 100 years, the plumes from the 4- and 20-gpm leaks in the TSF have reached the Reservoir (Figures 28 and 29). The primary difference is the mass, with the 4-gpm leak having a 10 mg/l contour in the center while the 20-gpm leak has a 100 mg/l contour. The distance travelled is substantially the same because it is controlled by advection, while dispersion controls the shape.

The contaminant travels much less distance in the andesite, with plume being much less spread (Figure 30). The presence of fractures would change this by extending the reach of contaminant transport in any direction from the source. The concentration contours do not expand substantially in a lateral direction which allows the concentration to remain high along the flow path.

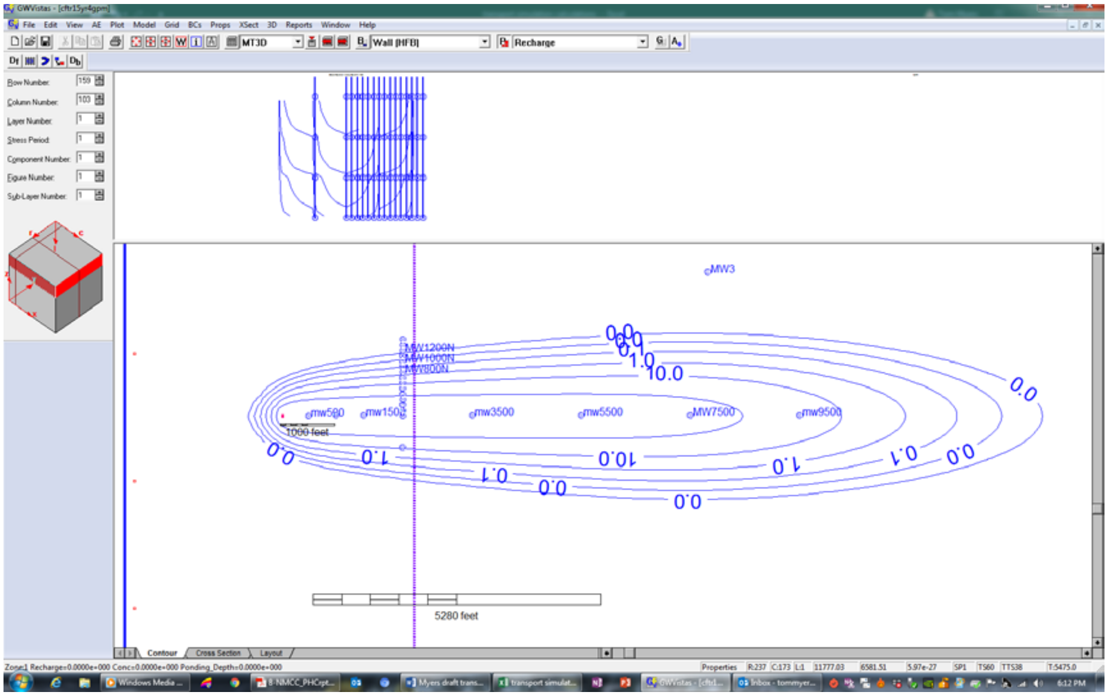

Figure 24: Concentration contours after 15 years of a 15-year leak at 4 gpm for the TSF.

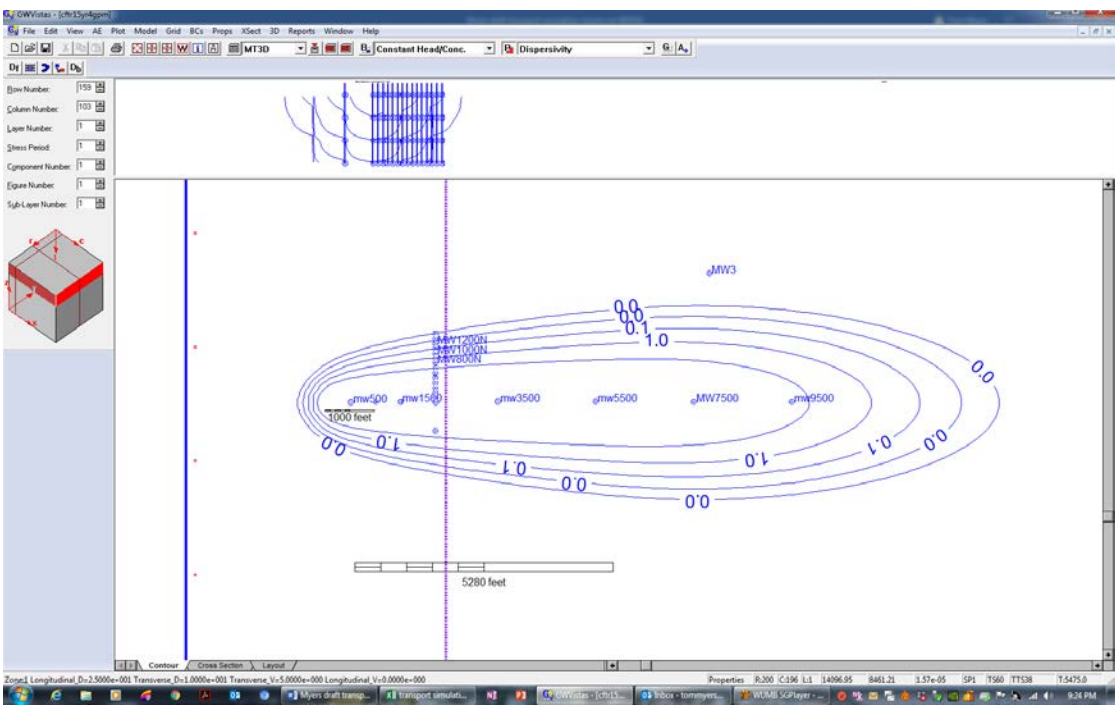

Figure 25: Concentration contours after 15 years of a 15-year leak at 4 gpm for the TSF, with lateral and vertical dispersivity equal to 10 and 5 ft.

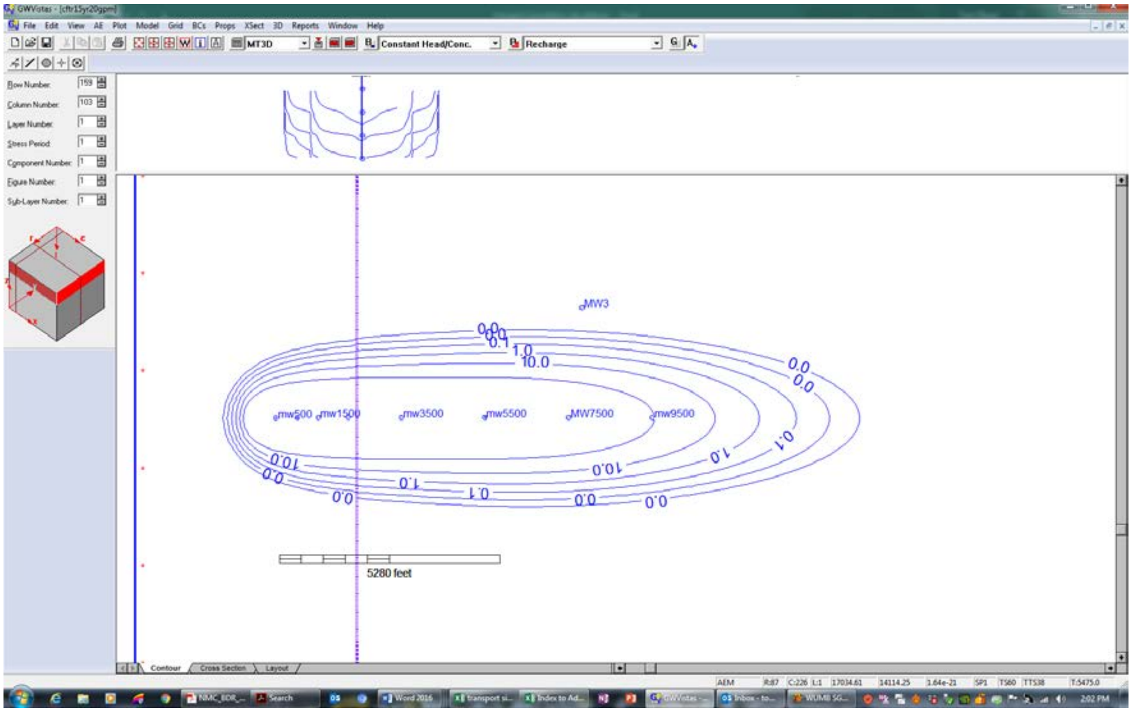

Figure 26: Concentration contours after 15 years of a 15-year leak at 20 gpm.

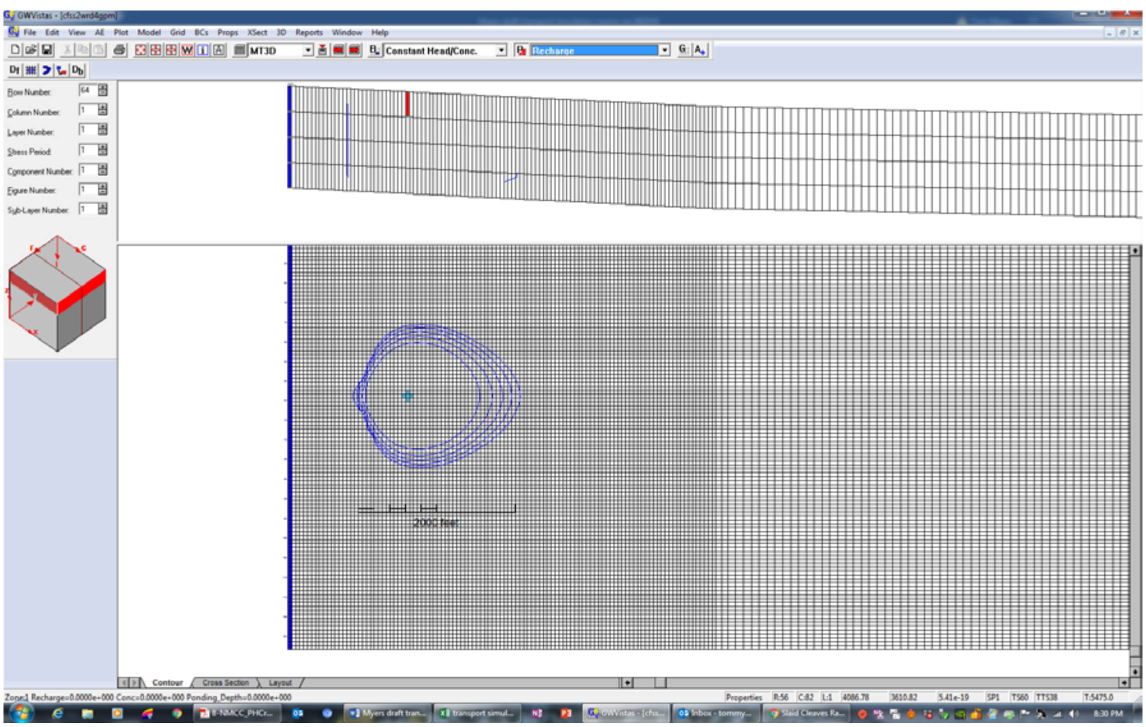

Figure 27: Concentration contours after 15 years of a 4 gpm leak on the andesite.

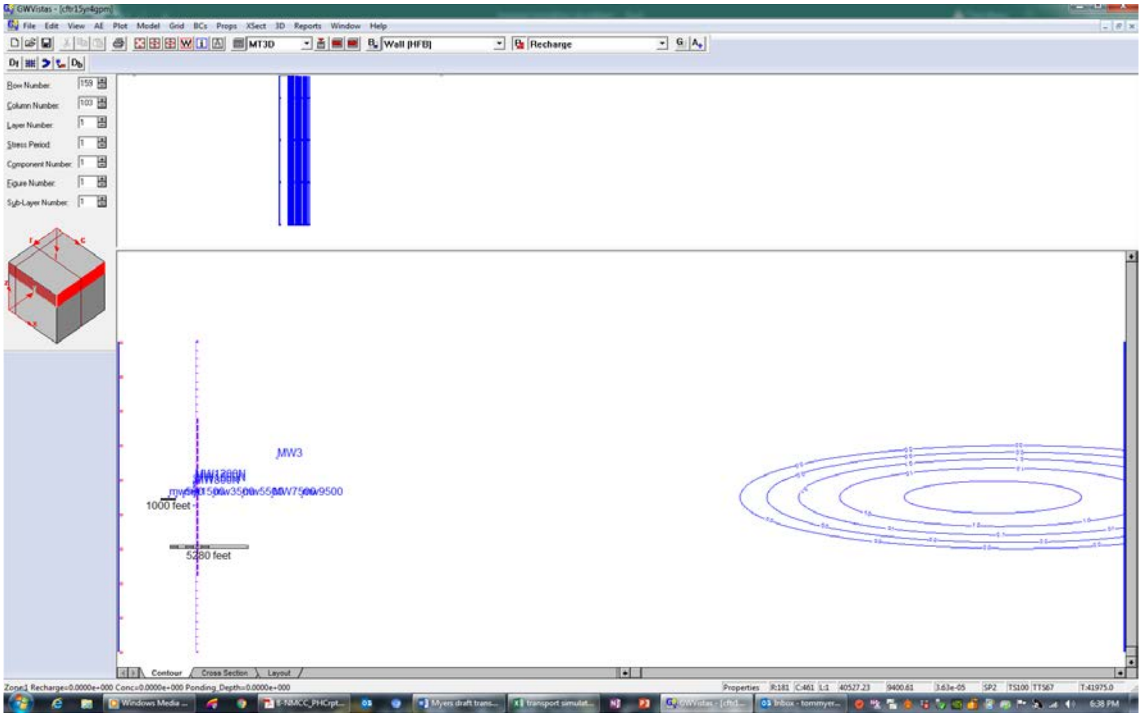

Figure 28: Concentration contours 100 years after the end of a 15-year leak at 4 gpm at the TSF.

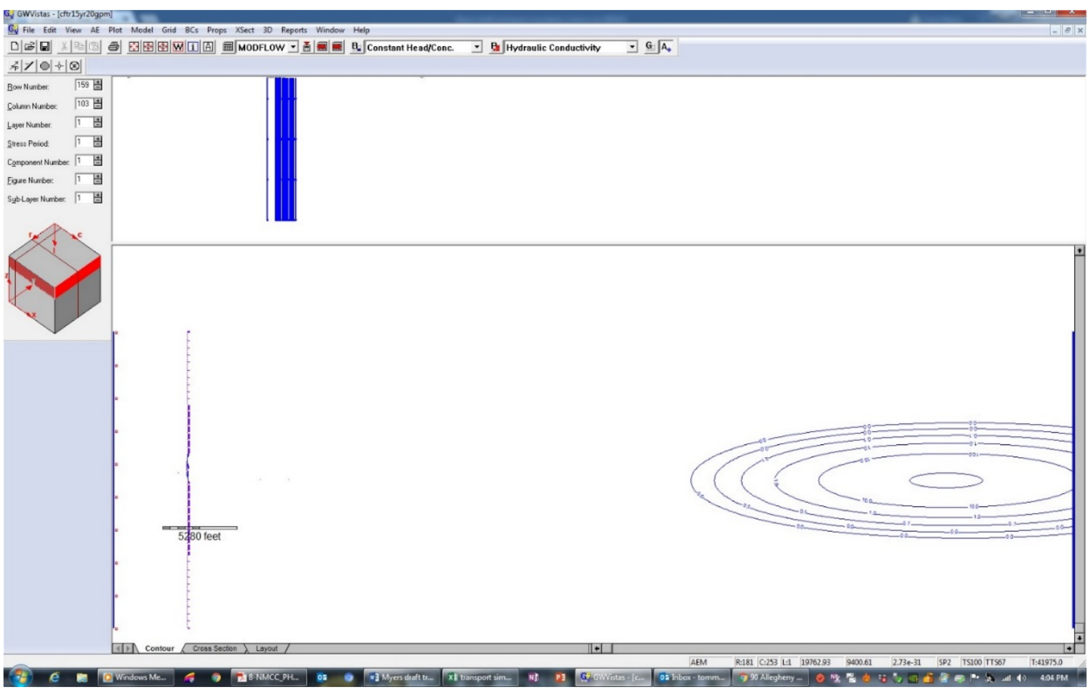

Figure 29: Concentration contours 100 years after the end of a 15-year leak at 20 gpm at the TSF.

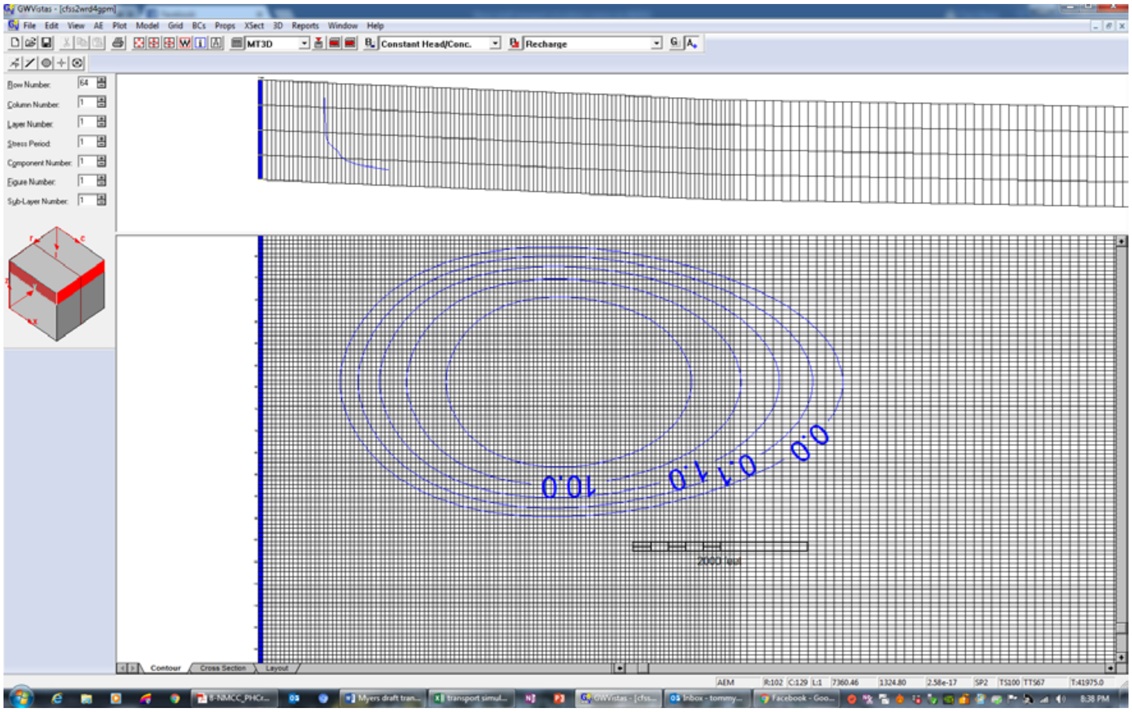

Figure 30: Concentration contours 100 years after a 15 year 4 gpm leak on the andesite.

Concentration with Distance along the Flow Path

Concentration hydrographs show that the peak is almost 800 mg/l for at least 500 feet downgradient and almost 700 mg/l for 1000 feet from the 4-gpm leak (Figure 31). The peaks drop stepwise to 9500 feet, and presumably further from the leak. Contaminants initially appear at the monitoring wells within 1500 feet within a year, but at 3500, 5500, 7500, and 9500 feet, initial detection occurs at about 4, 7, 9, and 11 years, respectively (Figure 31). At depth within layer 2, close to the source, within 1500 feet, the peaks are less than 50 mg/, but increase to almost 100 mg/l from 3500 to 9500 feet from the source (Figure 32). Concentration is much lower in layer 3 and reaches its peak even further from the source (not shown).

For the 20-gpm leak, the concentration exceeds 900 mg/l up to 1500 feet from the source for a substantial portion of the 15-year leak period (Figure 33). At 3500 feet the concentration peaks at 800 mg/l and at 9500 feet, the concentration peaks at over 500 mg/l. A substantial long-term leak would create a large plume in which the concentration of a conservative tracer will eventually be a large proportion of its leak concentration. With distance from the source and time, a substantial mass of contaminant reaches deeper into the aquifer (Figures 34 and 35). The monitoring wells from 3500 feet in layer 2 from the source reach to about 300 mg/l after ten years (Figure 34). At 7500 feet, the concentration approached 100 mg/l in layer 3 after 20 years (Figure 35).

That the hydrographs become horizontal demonstrates that transport becomes steady state with the flow; shorter leaks would not cause the concentration to reach its full potential, which is of course why it is important to detect and remediate them sooner. The concentration drops quickly after the peak passes.

The concentration hydrographs for the 4-gpm leak from the WRD on andesite does not plateau but reaches peaks much later than for the TSF (Figures 36 and 37). The general shape of the graphs reflects the difference in K between the formations. Groundwater flows much slower through the andesite which allows a much longer period for dispersion. Yet, at short distances such as 500 and 1000 feet, the peak is higher than for the TSF because there is also less dilution due to less groundwater in the andesite. The slow passage of contaminants manifests in them not even being detectable at 3500 feet until after 90 years and not detectable at all until after the simulated monitoring period (115 years) ended at 5500 feet; contrast this to the transport from the TSF in a formation just two orders of magnitude more conductive in which the plume has completely passed 9500 feet in 115 years.

Concentrations exceeded 500 mg/l in layer 2 at least up to 1500 and possibly to 2500 feet, although at much longer periods from the commencement of the leak (Figure 37). This reflects a substantial mixing at depth. That the concentration at depth peaks long after it does at the surface indicates that the contaminant mass that caused the peaks in layer 1 may also transport more deeply to cause the peaks in layer 2 further downgradient. Contaminants do not extend into layer 3 for the times plotted, but it is possible that much additional downward dispersion could cause a substantial mass at depth far in the future (longer period than analyzed here).

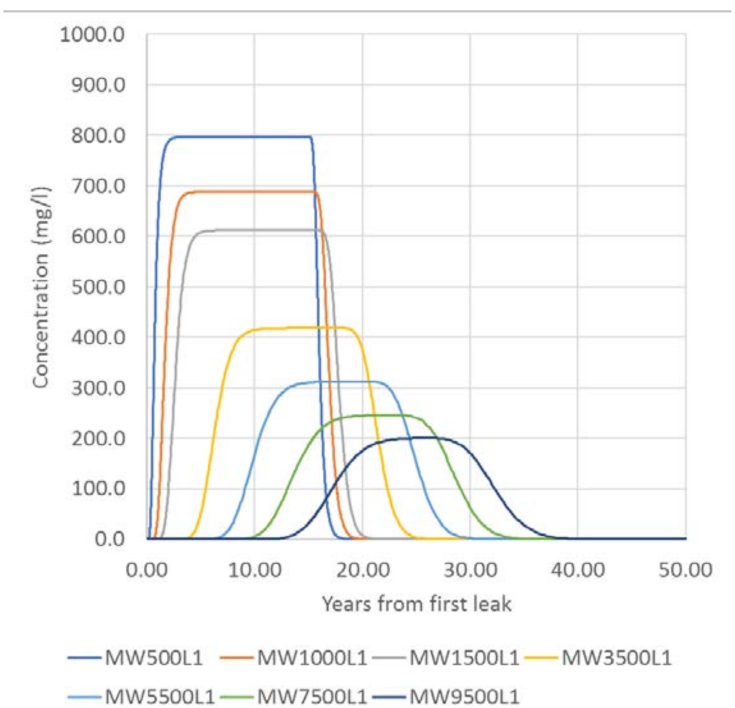

Figure 31: Concentration hydrographs for monitoring wells in layer 1 downgradient from the 4-gpm source at the TSF. Monitoring well names indicate the distance from the source and the layer.

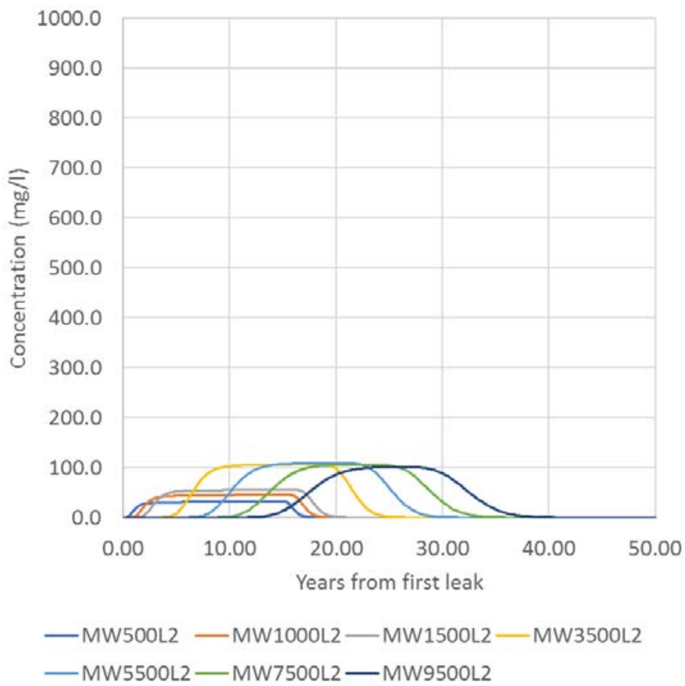

Figure 32: Concentration hydrographs for monitoring wells in layer 2 downgradient from the 4-gpm source at the TSF Monitoring well names indicate the distance from the source and the layer.

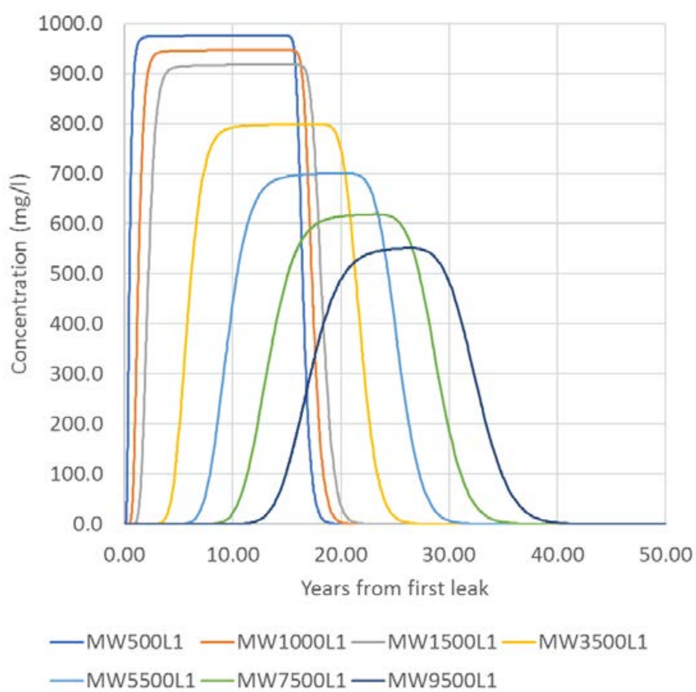

Figure 33: Concentration hydrographs for simulated monitoring wells in layer 1 for the 20 gpm leak scenario. Monitoring well names indicate the distance from the source and the layer

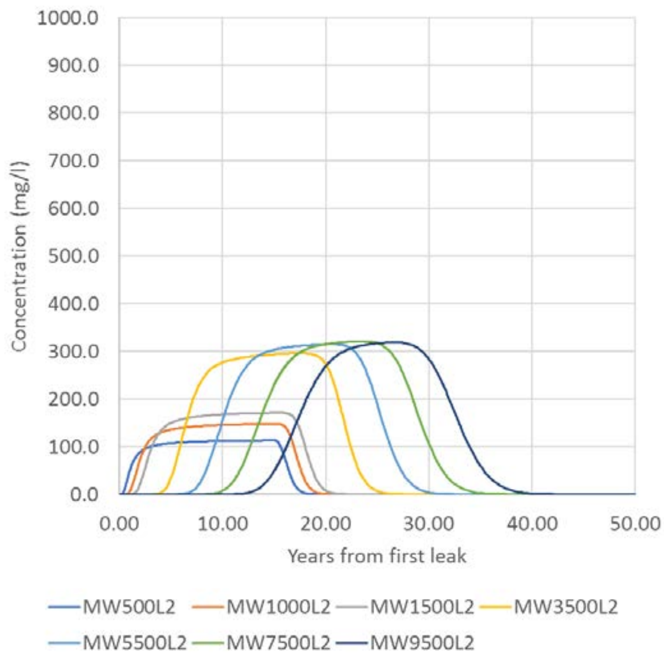

Figure 34: Concentration hydrographs for simulated monitoring in layer 2 for the 20 gpm scenario. Monitoring well names indicate the distance from the source and the layer

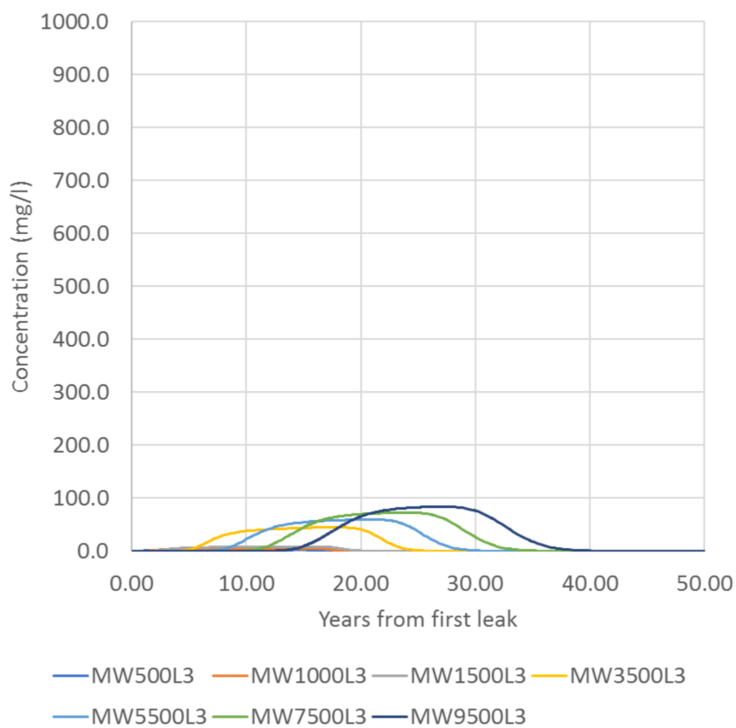

Figure 35: Concentration hydrographs for simulated monitoring wells in layer 3 for the 20 gpm leak scenario. Monitoring well names indicate the distance from the source and the layer

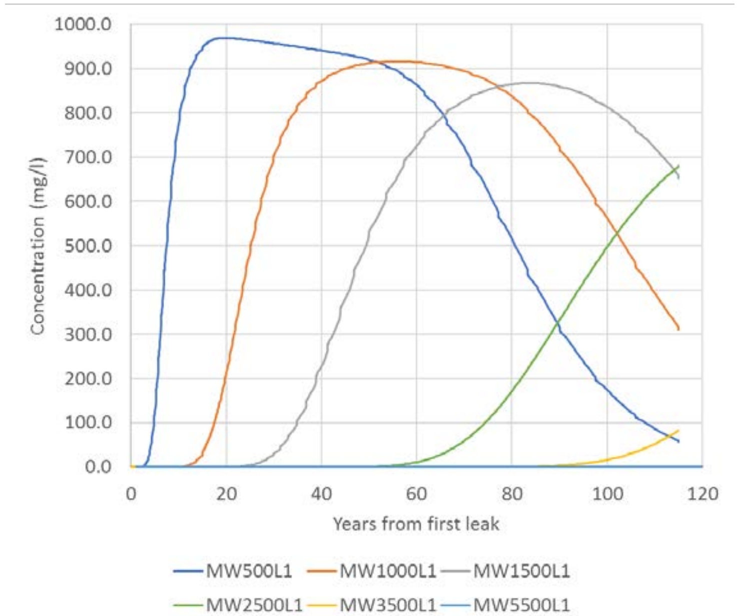

Figure 36: Concentration hydrographs for simulated monitoring wells in layer 1 for the 4-gpm leak at the WRD on andesite. Monitoring well names indicate the distance from the source and the layer

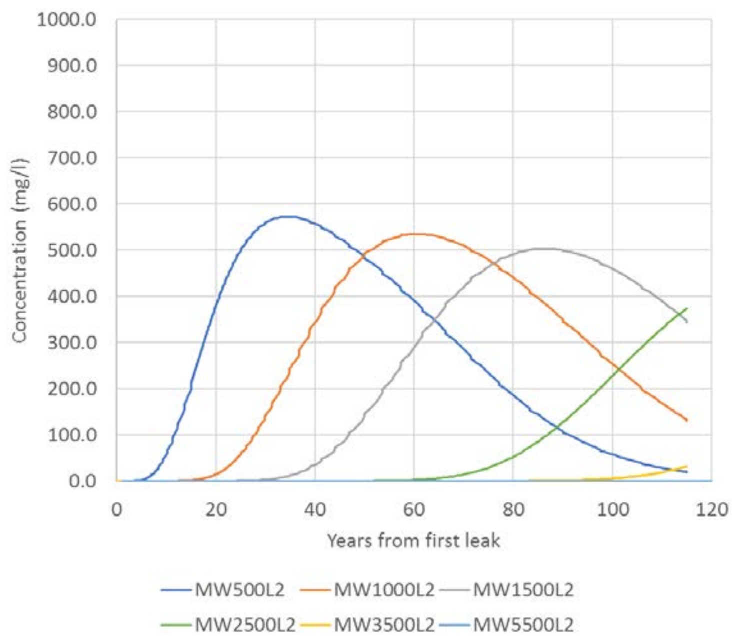

Figure 37: Concentration hydrographs for simulated monitoring wells in layer 2 for the 4-gpm leak at the WRD on the andesite. Monitoring well names indicate the distance from the source and the layer

Concentration Transverse to the Flow Path

The previous section considered the evolution of concentration along the flow path from the source for 9500 feet. It is very unlikely that monitoring wells would lie perfectly on a line from the source and far more likely that that monitoring wells would be developed in the plume away from the primary flow path. This section considers a transect 2000 feet from the source (for the TSF) of monitoring wells developed at 100-foot spacing out to 1200 feet away from the flow path, as shown on several concentration contour plots above, including Figure 16. As noted previously, the monitoring nomenclature describes the location. Herein, MW***NL* refers to *** feet north of the flow path and * refers to the layer number.

The 4-gpm leak would first reach a monitoring well at 2000 feet in layer 1 at about two years and reach several percent of the leak concentration after about three years (Figure 38). It takes five years for the concentration to exceed 500 mg/l near the plateau (Figure 38). MW100NL1 lags about 50 mg/l, at most, but MW200L1 is more than 200 mg/l lower. Further from the flow path, the concentration drops to less than 100 mg/l at 400 feet. At depth in layer 2, none of the concentrations substantially ever exceed 70 mg/l (7% of the leak concentration) (Figure 39).

The 20-gpm leak causes concentration to exceed 500 mg/l in layer 1 as far as 500 at 800 mg/l as far as 200 feet from the flow path, respectively, where it plateaus at just less than 900 mg/l (Figure 40). The times to detection are similar as for the 4-gpm leak. In layer 2, the concentrations remain below 200 mg/l (Figure 41), similar to the observation above that the highest concentrations at depth occur a substantial distance from the source.

Contaminants from the 4-gpm leak at the WRD would not reach the monitoring well at 2000 feet until about 40 years after the mine commenced operations, therefore closer monitoring is essential. Leaks that occur at the far-upgradient side of the WRD are about 2000 feet from the downgradient side, where monitoring wells would be placed (Figure 9 and Figure 47, below). For this analysis, I considered a transect of monitoring wells that crosses the flow path at 500 and 1000 feet from the source (Figure 42).

Detectable concentrations (assumed here to be greater than 1% of the leak concentration) occur about 4 years after mining commences 500 feet downgradient of the source (Figure 43). Out to about 400 feet from the flow path, the concentrations are just slightly less than at the flow path. The peaks occurred about 16 years after mining commences, but concentrations remain very high to about 60 years. Out to 800 feet they are over 300 mg/l, although a detectable concentration did not initially occur for 15 years. In layer 2, peaks up to 100 feet from the flow path exceeded 500 mg/l but not for more than 30 years, although detection would have been possible after about 10 years (Figure 44). If monitoring continued for 40 years, detection of a substantial plume would occur out to about 400 feet.

At 1000 feet from the source, no contaminants are detectable for at least 15 years from the beginning of mining, or near the time closure would commence (Figure 45). All the way to 600 feet from the flow path, concentrations rise to over 800 mg/l after about 40 years and high concentrations, within about 10% of the peak, for over 50 years. Peaks are not as long lasting in layer 2, but exceed 300 mg/l at some point out to 500 feet from the flow path (Figure 46). The vertical dispersion into layer 2 assures that contaminants would eventually reach groundwater significantly below the ground surface.

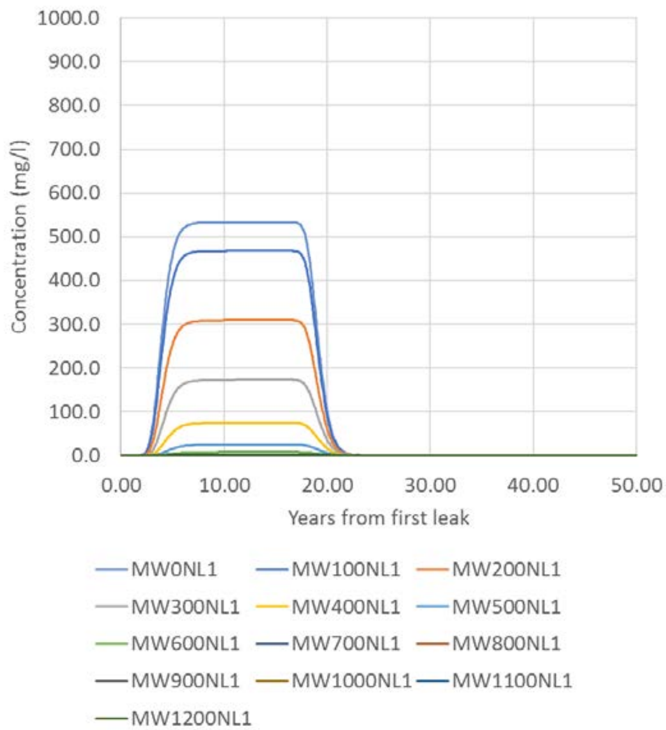

*Figure 38: Concentration hydrographs for monitoring wells along a transect north of the flow path 2000 feet from the source in layer 1 for the 4-gpm leak at the TSF. MW***NL* refers to *** feet north of the flow path and * refers to the layer number.*

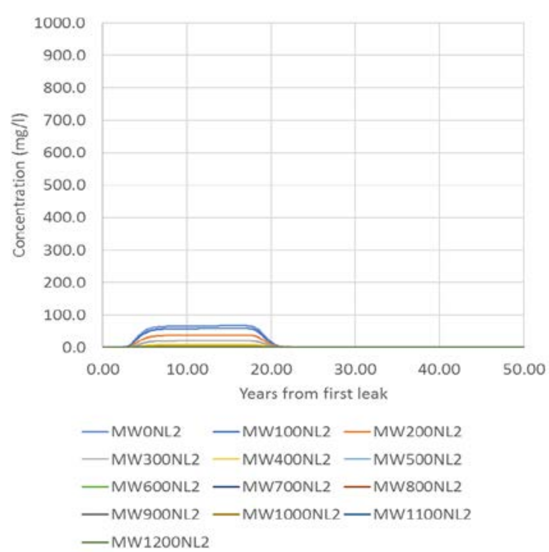

*Figure 39: Concentration hydrographs for monitoring wells along a transect north of the flow path 2000 feet from the source in layer 1 for the 4-gpm leak at the TSF. MW***NL* refers to *** feet north of the flow path and * refers to the layer number.*

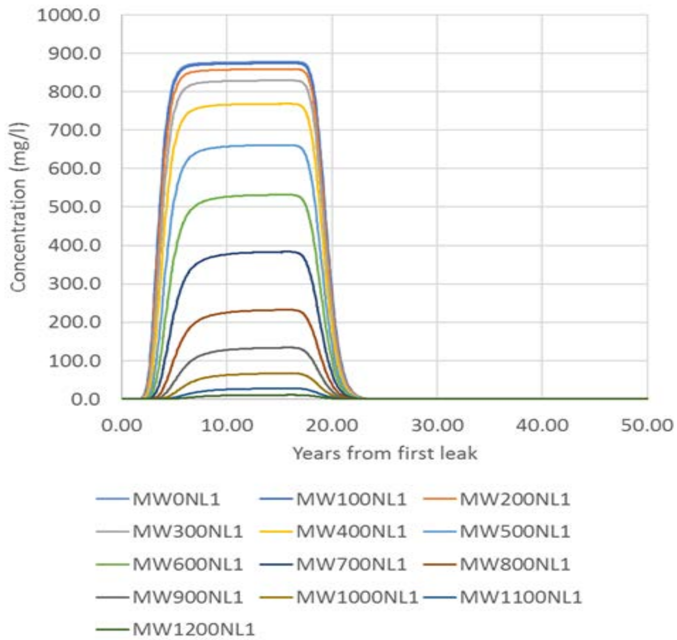

*Figure 40: Concentration hydrographs for monitoring wells along a transect north of the flow path 2000 feet from the source in layer 1 for the 20-gpm leak at the TSF. MW***NL* refers to *** feet north of the flow path and * refers to the layer number.*

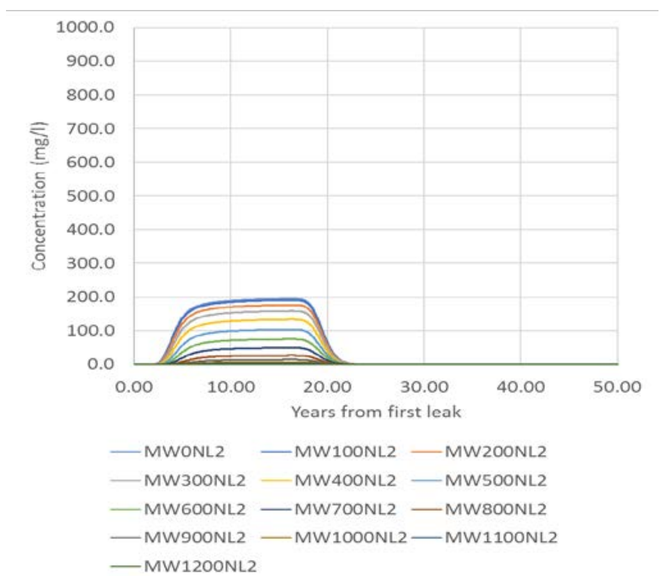

*Figure 41: Concentration hydrographs for monitoring wells along a transect north of the flow path 2000 feet from the source in layer 2 for the 20-gpm leak at the TSF. MW***NL* refers to *** feet north of the flow path and * refers to the layer number.*

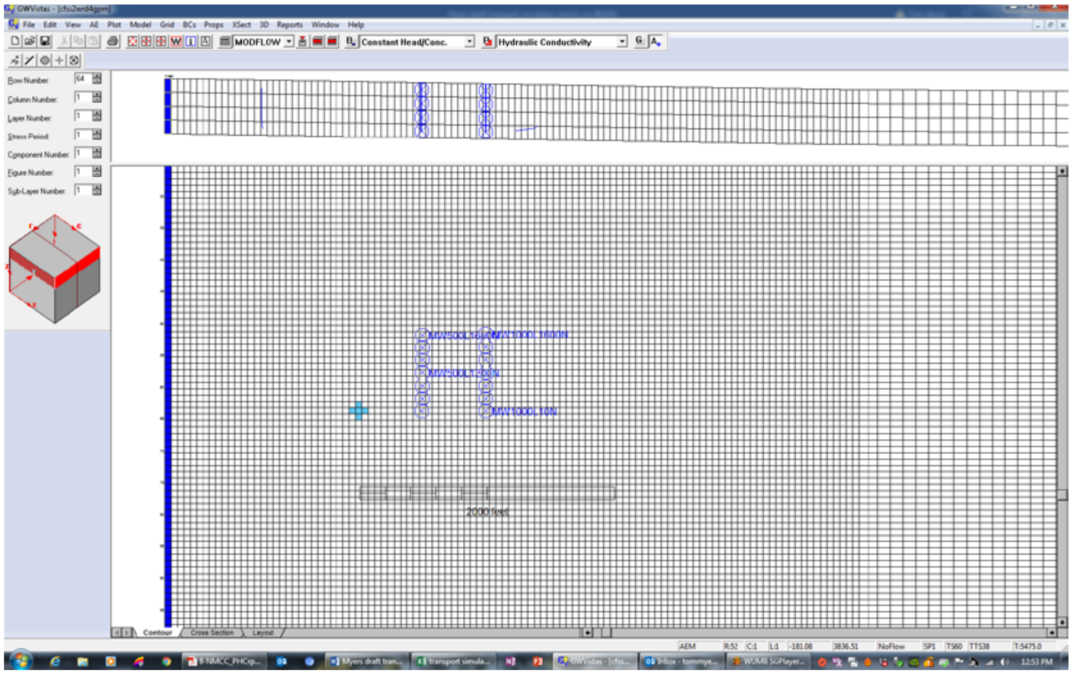

Figure 42: Simulated monitoring wells downgradient from the WRD source in andesite

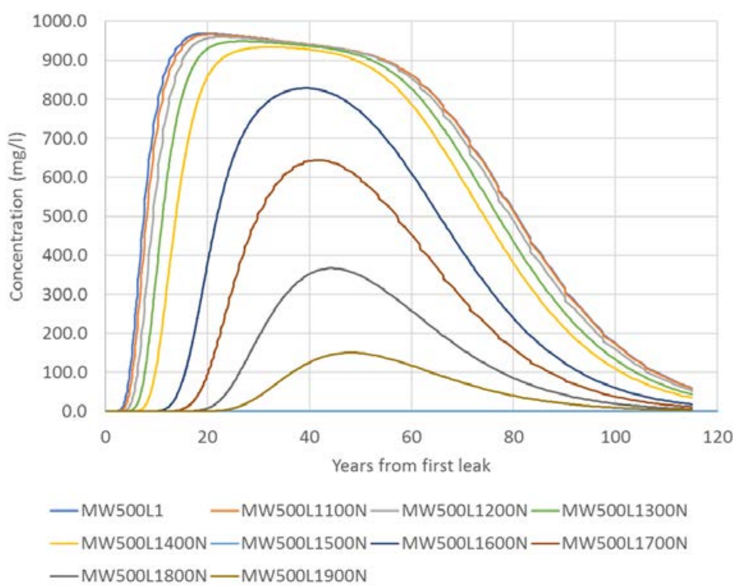

*Figure 43: Concentration hydrographs for monitoring wells along a transect north of the flow path 500 feet from the source in layer 1 for the 4-gpm leak at the WRD. MW***NL* refers to *** feet north of the flow path and * refers to the layer number.*

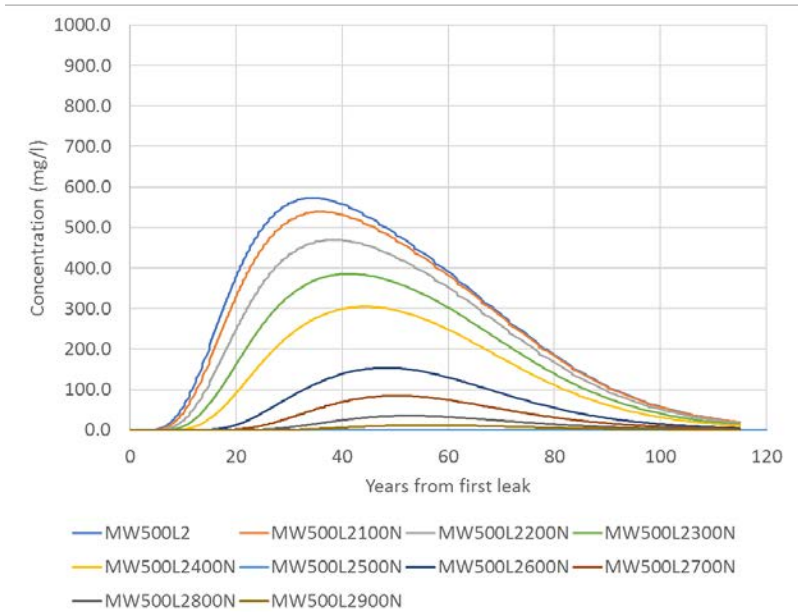

*Figure 44: Concentration hydrographs for monitoring wells along a transect north of the flow path 500 feet from the source in layer 2 for the 4-gpm leak at the WRD. MW***NL* refers to *** feet north of the flow path and * refers to the layer number.*

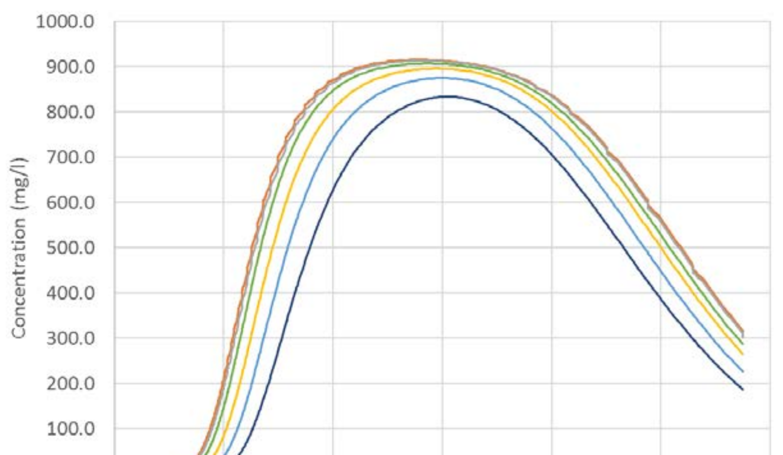

*Figure 45: Concentration hydrographs for monitoring wells along a transect north of the flow path 1000 feet from the source in layer 1 for the 4-gpm leak at the WRD. MW***NL* refers to *** feet north of the flow path and * refers to the layer number.*

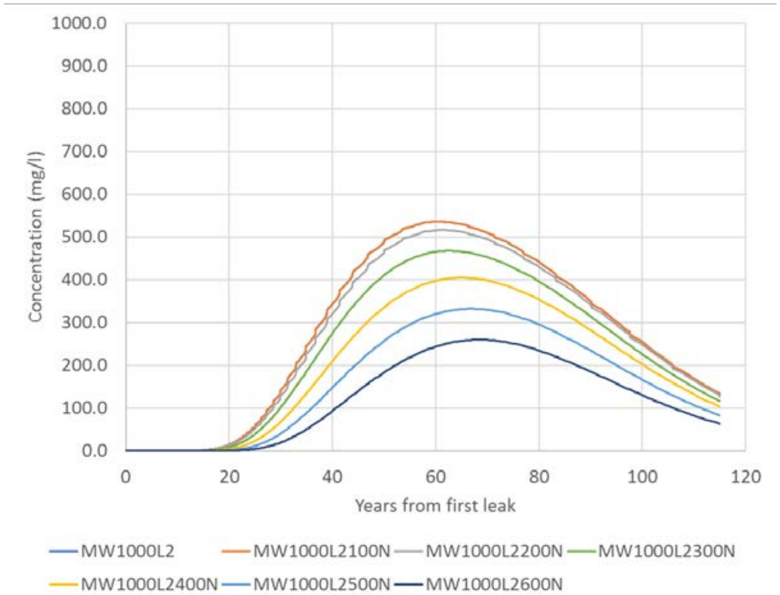

*Figure 46: Concentration hydrographs for monitoring wells along a transect north of the flow path 1000 feet from the source in layer 2 for the 4-gpm leak at the WRD. MW***NL* refers to *** feet north of the flow path and * refers to the layer number.*

Summary of Contaminant Transport of a Leak at the Proposed Copper Flat Mine

This section compared three scenarios, consisting of 15-year leaks from the TSF or WRD into either SFG or andesite. The first two were at the TSF, with the leak equaling either 4 or 20 gpm spread over a 50-foot square model cell. The SFG K equaled 0.4 ft/d above the fault at the leak and 1 ft/d below the fault. The K values had been chosen based on a sensitivity analysis of K value to select values that would create flow conditions similar to that modeled by Jones et al (2014). The third scenario was a 4 gpm leak over a similar area under the WRD into andesite bedrock; the K for the andesite was set at 0.01 ft/d, as specified by Jones et al (2014). The SFG K was set at 0.05 ft/d, also within the range presented by Jones et al (2014). Dispersion was considered according to standard textbook values.

The various scenarios of the transport of a contaminant from a leak in a WRD or a TSF show that the peak concentration occurs only on the flow path from the source. The concentration decreases with distance and depth from the flow path.

Significant differences between transport from the leaks into the SFG from the TSF and into the andesite from the WRD included the shape and movement of the plume downgradient. The plume from the TSF was elongated with high concentrations primarily near the flow path. The gradient in the concentration contours was substantial so that within 700 feet the concentration would be less than 40% of that at the flow path for the 20 gpm leak. At most, the concentration was just 1% of that at the leak within 1700 feet from the flow path. After a few decades, the contaminant was beyond 9500 feet from the source and had primarily discharged to the Reservoir by the end of the model run.

The plume emanating from the TSF was long and narrow for both leak rates. However, the plume shape was not highly sensitive to dispersion coefficient, meaning that the plume width would not vary significantly based on the chosen lateral dispersion parameters.

Higher conductivity increases the groundwater flow rate and the rate the plume moves downgradient away from the source, but does not have a substantial effect on dispersion. However, additional flow would dilute the concentration.

Contaminant transport from a leak in the WRD was substantially different from a leak in the TSF. The contaminant moves only slowly in any direction. Its advective flow along the flow path is slow due to the low groundwater flow rate. It barely reaches 1000 feet downgradient within 15 years. The plume is almost circular, and the concentration is within 10% of the leak concentration for a substantial area around the source. It has not reached the 9500-foot point within 115 years, whereas the TSF leak has passed that point within 40 years. The shape is due to lateral dispersion occurring at rates similar to advective transport due to the very low groundwater flow rate.

It may be difficult to detect the plume if it is too far from the flow path due to dispersion. If wells are spaced greater than the plume width, an entire plume can move between wells without detection. Detection also depends on the trigger level, meaning what concentration should be used to establish that a plume is passing. The following section discusses dispersion with respect to monitor wells.

DISPERSION FROM A LEAK

Contaminant dispersion raises three issues with respect to groundwater monitoring. First, if wells are spaced too widely, contaminant plumes will pass through undetected. This is a function of what change in concentration at a monitoring well would be considered a detection. Second, concentration drops with distance from the primary flow path, so it is probable that monitoring wells will be monitoring lower than the full contamination. Third, contaminants will continue to flow downgradient even after the leak is stopped. The following discussion considers these three points.

A leak from a mine site will flow through the groundwater to resources downgradient. The leak will advect along the primary flow path. Dispersion will cause the front of the plume to reach downgradient points faster than expected by advective flow velocities. Dispersion will also cause some of the contaminant to move much slower than the advective flow velocity. In the case of low K, such as in the andesite, a substantial plume may not be detected within 500 to 1000 feet from the source until mining has ceased.

Dispersion also occurs laterally and vertically. Maximum concentration occurs along the flow path, and it decreases with distance from the source. At no point does the concentration ever equal or exceed the source concentration because dispersion begins immediately up release into the groundwater.

The calculations herein are based on hydrologic properties representative of the Santa Fe Group aquifer or the andesite bedrock and standard dispersion coefficients and should be representative of dispersion expected for leaks from the proposed Copper Flat project. Even a monitoring well on the flow path will detect concentrations less than that of the source leak. Transverse to the flow path, the concentration decreases rapidly within the SFG. A plume could slip through monitoring wells that are spaced too widely. In the andesite, the plume moves slowly but disperses large masses north and south so that the plume is effectively as wide as it is long.

A concentration level that would trigger further monitoring or remediation must be based on the understanding that the observed concentration is likely less than the maximum concentration that would be observed on the flow path. Dispersion must be considered therefore when placing monitoring wells and when setting the trigger level. Monitoring wells should be placed no further apart than the plumes calculated herein. Trigger level should be based on a percent change from background. Remedial actions should be triggered by a given change in concentration. The following section addresses the specific monitoring plan proposed at Copper Flat.

RECOMMENDATIONS FOR MONITORING THE PROPOSED COPPER FLAT MINE

The TSF covers an area that would be about 6000 feet across along the primary flow path (Figure 47). Leaks could occur up to 6000 feet from the monitoring wells near the downgradient perimeter. At the furthest distance from the monitoring wells, the plume is widest, but the concentrations are lowest, meaning that to detect the leak the trigger points must be low. Leaks near the downgradient perimeter will not have dispersed laterally near as far and could pass the monitoring wells undetected if not spaced closely enough.

After one year, the simulated peak from a 4 gpm leak from the TSF 500 feet upgradient from the perimeter was 617 mg/l at the flow path, eventually reaching about 800 mg/l after three years. Dispersion placed the 100 mg/l contour at most 250 feet from the flow path (Figure 19). It expands only slightly by the time two years is reached (Figure 22). Although 100 mg/l is only one tenth the concentration of the leak, it is appropriate to use this contour because larger leaks would have a higher concentration, as may be seen for the 20 gpm leak (Figures 20 and 23).

The longest distance a leak would travel would be from the west edge of the TSF, or about 6000 feet (Figure 48). At 5500 feet considered at MW5500L1, the concentration on the flow path was 300 and 700 mg/l for the 4-gpm and 20-gpm leak, respectively. Concentration was more than 60% less within 400 feet of the flow path for the 4-gpm leak and about 50% within 700 feet for the 20-gpm leak at 2000 feet. The plume shape did not change substantially with distance, so these horizontal reductions in concentration should apply at more distant locations.

Detecting the leak at 500 feet requires closer spacing than detecting a leak at longer distance. Assuming the trigger concentration can be appropriately set, doubling the 250-foot distance observed for the smaller leak to 500 feet would be the spacing necessary to detect this leak. This would also satisfy the requirement that much closer spacing is necessary to detect short-term leaks. This analysis does not consider toxicity of the contaminant, so a short-term leak could be deleterious if it is a very toxic substance. A 500-foot spacing would be an adequate trade-off between certainty of detection and risk at the TSF, if NMED sets a trigger concentration low enough to detect the movement of a plume through the perimeter.

The original draft DP 1840 indicates 16 monitoring wells for the TSF and two additional wells that monitor either a drain pond (PGWQ-17) or waste rock (PGWQ-13). Finch and McCoy (2016) list one as upgradient and Figure 5 in Finch and McCoy (reproduced here as Figure 48) show that seven of the wells listed in the draft permit (GWQ-10, NP-1, NP-2, GWQ94-14, GWQ94-15, GWQ94-21, GWQ94-21B) will be plugged and abandoned (yellow on Figure 48), as they will be under the TSF. On August 10, 2018, NMED issued an amended DP 1840 that requires an additional TSF monitoring well on the southwest toe of the TSF. Including the joint monitoring wells, there are 11 monitoring wells between GWQ-12, on the south side of the TSF, to PGWQ-13 on the north. The perimeter is about 8500 feet. Spaced at 500 feet over 8500 feet, there should be 18 monitoring wells, so DP 1840 must have seven additional monitoring wells along the eastern half of the TSF to adequately monitor potential leaks from the facility. There should be eight monitoring wells between the existing GWQ-12 and GWQ13-28 and seven monitoring wells between GWQ13-28 and PGWQ-13, including the existing GWQ-8. The spacing should be approximately 500 feet.

WRD-2 and -3 cover an area that would be up to 3000 feet across along the primary flow path (Figure 48). Leaks could occur up to 3000 feet from the monitoring wells near the downgradient perimeter. A leak forming at the upgradient side would flow and disperse until it reaches a monitoring well network along the downgradient end on the east, or along the north and south sides. However, calculations herein indicate the contaminants move slowly enough they may not reach the downgradient side until after the mine has closed. Dispersion would cause almost as much transport as advection, monitoring wells away from the advective flow paths will detect concentrations that are a substantial proportion of that on the flow path. This is substantially different from transport from the TSF.

Assuming a leak 500 feet upgradient from the downgradient WRD edge, the contaminant plume would be detected up to 400 feet from the advective flow path (Figure 43). This is based on the concentration hydrographs for up to 400 feet from the flow path being detectable at about the same time and peaking at close to the same concentration (Figure 43); concentration hydrographs further from the flow path also peaked at relatively high levels but years after the leak commenced. Considering 400 feet on either side of the flow path, spacing should therefore be no more than 800 feet to detect a leak within a reasonable period.

The perimeter of WRD-3 is about 5000 feet from the northernmost point between PGWQ-3 and PGWQ-4 (Figure 48) and the Impacted Stormwater Impoundment A. There are three proposed monitoring wells along its eastern perimeter – PGWQ-4, -7, and -8; one other, PGWQ-6 is downgradient from a stormwater pond and should not be considered as monitoring the waste rock. The recently amended DP 1840 added well PGWQ-24 to the northeast corner of WRD#3. Existing well GWQ-3 on Figure 47 is not listed in draft DP 1840. Well PGWQ-5 is listed as monitoring waste rock, but based on travel times estimated herein, it is not a useful monitoring well. Instead of four proposed monitoring wells, there should be seven, including one on each end of the perimeter line to account for substantial expected dispersion to the north and south. The current proposed monitoring plan should be amended to include monitoring wells at each end of the line as described and five spaced evenly in between.

The andesite under the WRD is not a homogeneous medium, although the analysis herein treats it as one. DP1840 should additionally be amended to require that NMCC attempt to locate fractures within the rock that could transport contaminants from the sources. Additional monitoring wells should be installed in any fracture zones located in the andesite. Monitoring a fracture would not replace one of the other monitoring wells because the fracture would constrain the contaminant preventing dispersion that the proposed spacing accounts for.

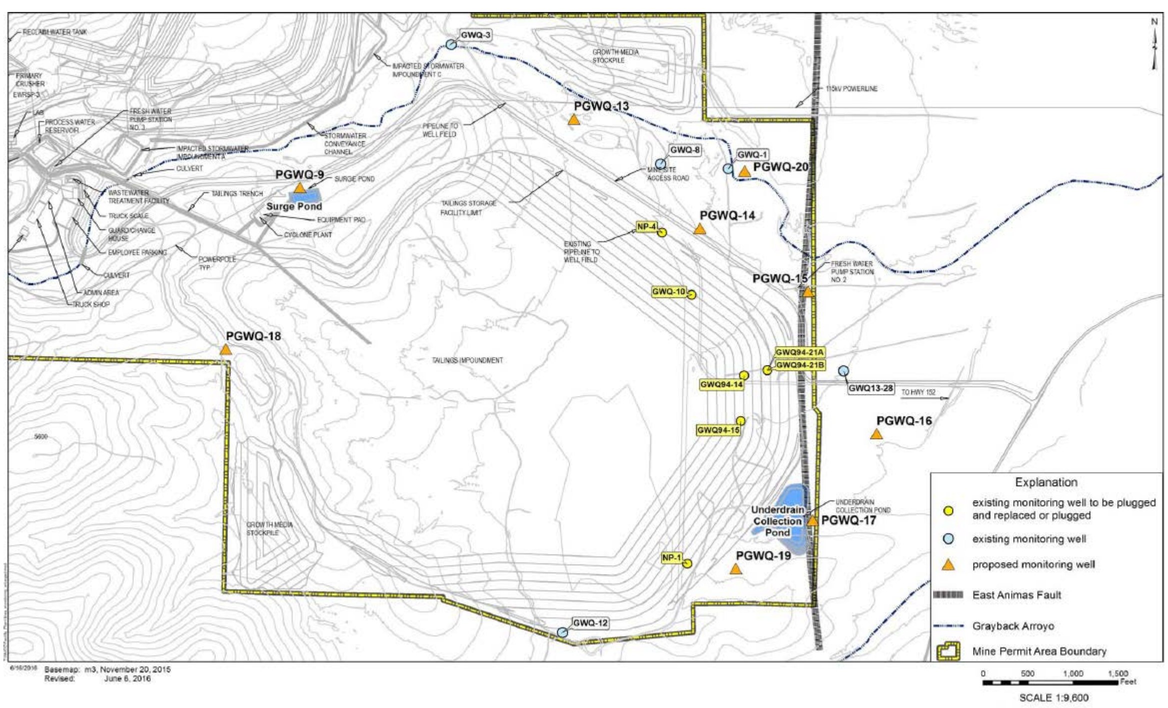

Figure 5. Monitoring wells location detail for Tailings Storage Facility, Underdrain Collection Pond, and Surge Pond.

Figure 47: Figure 5 from Finch and McCoy (2016)

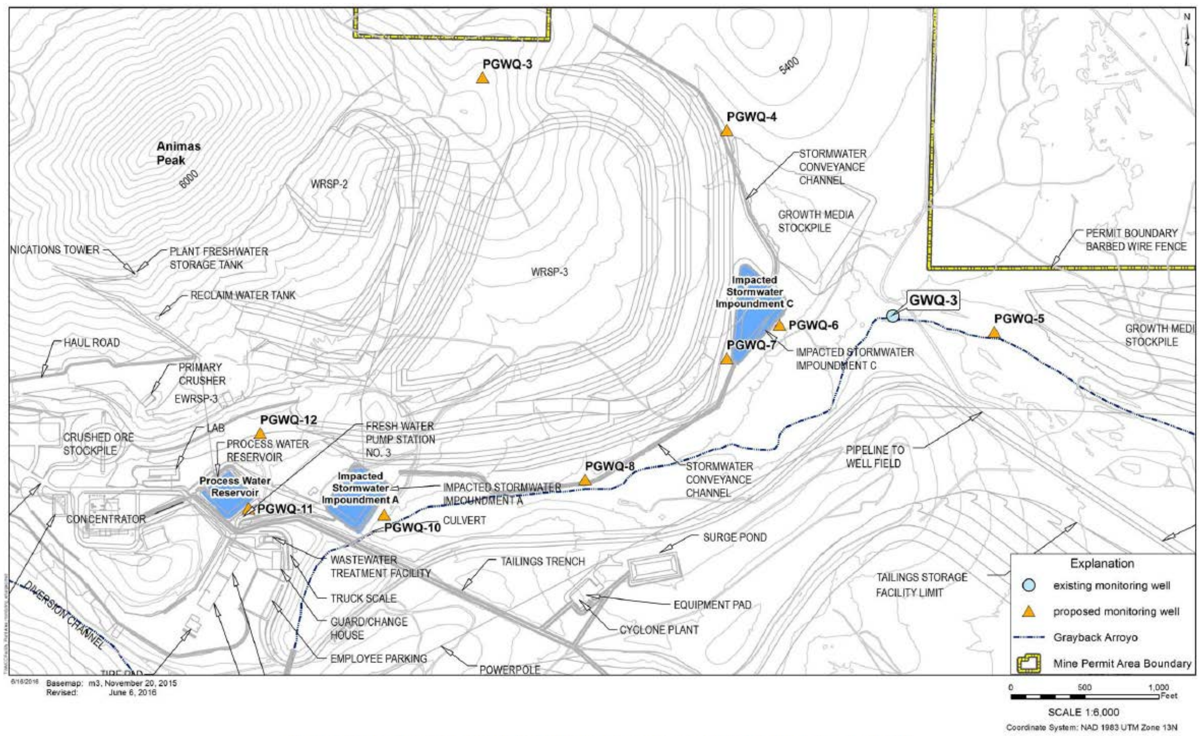

Figure 4. Monitoring wells location detail for WRSP-2 and -3, and Impact Stormwater Impoundments A and C.

Figure 48: Figure 4 from Finch and McCoy (2016).

REFERENCES

Finch ST, McCoy AM (2016) Water-quality monitoring plan for the Copper Flat Mine discharge permit pursuant to 20.6.7.11.R and 20.6.7.28 NMAC. Prepared for New Mexico Copper Corporation, Albuquerque NM. June 2016

Jones MA, Finch ST (2018) Probable hydrologic consequences of the Copper Flat Project, Sierra County, New Mexico, Revision 1.0. Prepared for New Mexico Copper Corporation. John Shomaker and Associates, Albuquerque, NM. Revised May 22, 2018.

Jones MA, Shomaker JW, Finch ST (2014) Model of groundwater flow in the Animas Uplift and Palomas Basin, Copper Flat Project, Sierra County, New Mexico. Prepared for New Mexico Copper Corporation, Albuquerque NM. August 15, 2014.

Velasquez Environmental Services (Velasquez) (2017) Copper Flat Mine Discharge Permit Application Pursuant to 20.6.7 NMAC. Prepared for New Mexico Environment Department and New Mexico Copper Corporation. Revision 1, August 2017

Xu M, Eckstein Y (1995) Use of weighted lest-squares method in evaluation of the relationship between dispersivity and field scale. Ground Water 33(6):905-908.