Attachment I

Staff's Fate & Transport Modeling

Introduction

In 2008, Cogema submitted a package of documents (hereinafter "restoration package" or "package") in which their efforts to restore the production aquifers at the Christensen Ranch Mine Units 2 through 6 were described (Cogema, 2008a; ML081060131). The restoration package includes a summary report on procedures common to all mine units, and individual reports summarizing the restoration data for each mine unit. The package was submitted to the U. S. Nuclear Regulatory Commission (NRC) for review and approval.

The restoration package demonstrated that several constituents did not achieve the established restoration goal at the end of the restoration efforts for most mine units. Cogema provided both a qualitative and quantitative impact analyses for those levels on the groundwater quality to the adjacent aquifers (Cogema, 2008). Although the quantitative analysis did not include fate and transport modeling; Cogema did use a "reduction factor" to estimate the fate and transport of those constituent levels. The reduction factor was derived from the model-predicted reductions for the numeric fate and transport model used at Cogema's previously NRC-approved wellfields in the Irigaray project (Cogema, 2005; ML053270030).

Staff reviewed the restoration package and concurs that the licensee used appropriate ALARA methods at several of the mine units, but that the levels of several constituents remained above the primary restoration goals and warrant additional assessment on their fate and transport. Staff did not agree with the licensee that the use of a reduction factor to estimate concentrations at the boundary of the production aquifer was appropriate for the Christensen Ranch wellfields. The hydrogeologic setting at Christensen Ranch differs enough from that at the Irigaray project that the applicability of the reduction factor analysis may be questioned. Therefore, NRC staff constructed a fate and transport model to verify that the remaining constituent concentrations are protective of human health and the environment.

Staff's modeling effort focused on two mine units (Mine Unit 2 (staff divided that wellfield into two wellfields MU-2 North and MU-2 South to be consistent with the baseline data) and Mine Unit 3). The constituents of concern are: calcium, iron, bicarbonate, magnesium, manganese, total dissolved solids (TDS), uranium and radium-226 at MU-2 North; iron, manganese, TDS, uranium and radium-226 at MU-2 South; and manganese and radium-226 at Mine Unit 3. For staff's evaluation, MODFLOW-2000 was used as the numeric groundwater flow model and MT3DMS was used as the numeric fate and transport model. The model designs and various simulation results are documented in this report.

MODFLOW Model Design

The model comprised a rectangular prism of the production and surrounding aquifer. The horizontal dimensions are 2,000 feet in the north-south direction and 6,000 feet in the east-west direction. The model was discretinized into cells with dimensions of 25 feet by 25 feet, resulting in 80 rows and 240 columns. The vertical dimension of the model was discretinized into 3 layers, each of which was assigned a uniform thicknesses. The bottom of the models was assigned an elevation of 0 feet above mean sea level (ft-MSL) and the top elevations for the three layers were assigned an elevation based on the mine unit being modeled. For Mine Unit

2, the top elevation of layer 1, 2 and 3 is 148, 50 and 15 ft-MSL, respectively. For Mine Unit 3, the top elevation of layer 1, 2 and 3 is 162, 50 and 15 ft-MSL, respectively. This information is based on the thickness of the ore body and production aquifer in the restoration report (Cogema, 2008a).

The boundary conditions consist of constant head boundary (CHB) conditions assigned to cells located in the northernmost (Row 1) or southernmost (Row 80) rows in all three layers. The specific heads for the CHBs were set to establish a uniform flow with a hydraulic gradient of 0.01 feet per foot from the south to the north. The specific heads assigned to the various cells for mine units 2 and 3 are listed in Table 1.

A single value for each hydraulic parameter (i.e., horizontal hydraulic conductivity, vertical hydraulic conductivity and specific storage) was assigned to all cells in the flow model. The values are based on average reported value for the specific mine unit based on the restoration report (Cogema, 2008a). The values used in the model are summarized on Table 1.

The model did not contain any inactive cells.

The initial heads were based on model-predicted heads following a steady-state simulation. Because the fate and transport modeling incorporated transient simulations, a transient simulation with the same period was used for the groundwater flow model.

MT3DMS Model Design

Three zones were set up in the MT3DMS model. The zones are shown on Figure 1. Zone 1 represents the area downgradient of the production area, Zone 2 represents the production area and Zone 3 represents the area upgradient of the production area.

The parameters included in the MT3DMS fate and transport model independent of a specific chemical constituent are porosity and dispersivity. The porosity was assigned a value of 0.26 for all simulations based on the financial assurance calculations in the recent license renewal application (Cogema, 2008b; ML081850689). Initially, the longitudinal dispersivity was assigned a value of 25 feet, which is consistent with value in the fate and transport modeling effort for the Irigaray Project (Cogema, 2005). The ratio of longitudinal dispersivity to horizontal transverse dispersivity and the ratio of longitudinal dispersivity to vertical transverse dispersivity were assigned values of 0.1. That value was based on published literature; the value used in the modeling effort for Irigaray was not documented. As discussed below, dispersion is one of the primary factors influencing the constituent concentrations as they migrate from the production area. In subsequent analyses for particular constituents, i.e., uranium and radium-226, the baseline data were evaluated to estimate a site-specific dispersivity. Results of that evaluation yield a longitudinal dispersivity of 11 feet, with a ration of vertical to longitudinal dispersivity of 0.6, and a ratio of traverse to longitudinal dispersivity of 0.1.

The parameters included in the MT3DMS fate and transport model that are constituent dependent are initial concentrations, source term concentrations, distribution coefficient and first-order reaction rate. The initial and source term concentrations are based on data for the respective constituents at the mine units as documented in either the baseline or restoration

reports. For areas outside of the production area and the upgradient source concentrations, the average baseline data are used. For the production area, the initial concentrations are based on the concentrations reported in the restoration reports. The production area is defined as Zone 2 in Layer 3 of the model.

The initial distribution coefficient was assigned a value of 0.5 cubic centimeter per gram (cm^3/g). This value is consistent that used in the Irigaray restoration report (Cogema, 2005); in general, the distribution coefficient was on the lower end of the range resulting in a more-conservative analysis. Site specific distribution coefficients were determined during subsequent analysis of the baseline data and used for selected constituents (i.e., uranium and radium-226) as discussed below. A distribution coefficient of 10 cm^3/g was used for uranium and a distribution coefficient of 30 cm^3/g was used for radium-226.

The first-order reaction rate was only applied to radium-226 and is equal to its decay rate (1.17e-06 day^{-1} or an equivalent half-life of 1620 years).

The concentrations in the production aquifer are expected to decrease with time as groundwater migrates through the production aquifer. Therefore, the model is based on the initial concentrations decay rather than as a continuing source at the elevated levels.

A summary of the input parameters used in the model for all constituents are listed in Table 2.

For the model output, 12 observation points were assigned to the model to record the model-predicted concentrations at those locations during the simulation period. The locations selected were the midpoint of the following cells:

Layers	Row	Column	Distance from Production Area (feet)
1, 2 & 3	31	120	400
1, 2 & 3	35	120	300
1, 2 & 3	39	120	200
1, 2 & 3	43	120	100

A weighted average was determined for the model-predicted concentrations at each location (i.e., all three layers at a specific row and column) based on the relative saturated thickness of each layer.

Results

Mine Unit 2 North

For Mine Unit 2 North, the constituents of concern and mean concentrations in the production aquifer at the end of active restoration are as follows:

Calcium	73.6
Iron	0.43
Bicarbonate	330.3

Magnesium	7.6
Manganese	0.25
TDS	560
Uranium	0.86
Radium-226	350.6 (pCi/L)

For the initial analysis using a distribution coefficient of 0.5 cm^3/g and a longitudinal dispersivity of 25 feet, the model-predicted maximum concentration at 300 feet downgradient of the production areas are as follows:

Calcium	12.3
Iron	0.055
Bicarbonate	103
Magnesium	1.05
Manganese	0.023
TDS	422
Uranium	0.078
Radium-226	42 (pCi/L)

Of the above constituents, only iron, manganese and TDS have a National Secondary Drinking Water Standard. The National Secondary Drinking Water Standard for iron, manganese and TDS is 0.3, 0.05 and 500 mg/L, respectively. The model-predicted levels are below the respective National Secondary Drinking Water Standard. Uranium and radium-226 have National Primary Drinking Water Standards or Maximum Contaminant Levels (MCLs) of 0.030 mg/L and 5 pCi/L, respectively. The model-predicted maximum levels for uranium and radium-226 exceed the respective MCLs.

The model-predicted levels were compared to baseline data. The model predicted levels for calcium, bicarbonate, magnesium, TDS, uranium, and radium-226 were 3.22, 1.3, 2.88, 0.85, 4.43 and 338 standard deviations above the baseline mean value. The baseline data for iron and manganese were generally below the minimum analytical detection limit and thus a standard deviation comparison is not germane for these constituents.

Based on the above conservative analysis, the constituent levels of calcium, bicarbonate, magnesium, manganese, and TDS remaining in the production aquifer does not pose threat to the quality of the aquifer downgradient and outside of the production zone. Based on the above conservative analysis, the maximum model-predicted levels for uranium and radium-226 do pose a measurable impact to the quality of the aquifer and warrants further analysis or restoration.

Because of the conservative nature of the above analysis, staff reviewed the data further. The further review consists of (1) an evaluation of the data distribution, and (2) an evaluation of the assumed values for several parameters in the fate and transport model.

Using the computer software ProUCL (EPA, 2010), the distribution of uranium data within MU-2 North at the end of restoration was determined to not follow a normal distribution; however, the distribution was consistent with a log-normal distribution. The log-normal mean value was 0.33

mg/L. Using a mean value of 0.33 mg/L yielded a model-predicted maximum concentration of 0.044 mg/L at 300 feet downgradient of the production aquifer in the conservative fate and transport model. The value of 0.044 mg/L is above the uranium MCL of 0.03 mg/L and 2 standard deviations above the baseline mean. For radium-226, the distribution of data within MU-2 North at the end of restoration was not a normal distribution but was consistent with a log-normal distribution. The log-normal mean value was 244 pCi/L. Using a mean value of 244 pCi/L yielded a model-predicted maximum concentration of 16.8 pCi/L at 300 feet downgradient of the production aquifer in the conservative fate and transport model. The value of 16.8 pCi/L is above the radium-226 MCL and 15.4 standard deviations above the baseline mean. As the model-predicted levels are above the respective MCLs and above tolerance levels of baseline[1], the analysis using the conservative fate and transport model indicate the constituent levels of uranium and radium-226 do pose a measurable impact to the quality of the aquifer.

The second part of staff's review was an evaluation of the various parameter values used in the fate and transport model. The parameters which had the most impact on the model-predicted levels are the distribution coefficient and dispersivity. The published values for distribution coefficients for uranium at a uranium roll-front setting vary from 0.1 to 20,000 cm^3/g (EPA, 1999; Payne, et al., 2000; Maozhong Min, et al., 2005; Chongxuan Liu, et al., 2004; Phair & Levine, 1952)). Using a value of 500 mg/Kg concentration of uranium in the ore zone (0.05% grade) and 0.041 mg/L in groundwater (during baseline), a calculated in-situ distribution coefficient at MU-2 North is 12,195 cm^3/g. Therefore, one could argue that the distribution coefficient of 0.5 cm^3/g was extremely conservative. However, the model-predicted maximum level was not as sensitive as is argued by some to the value of the distribution coefficient for to a constituent such as uranium. Although in increase in distribution coefficients will greatly increase the time that the maximum level travels a specific distance, the effect on the attenuation of the maximum concentration is limited for the levels used in staff's evaluation. For distribution coefficients above 100, at the setting of the ISR site, the time of migration would be measured in thousands of years but the attenuation is on the order of tenths of mg/L.

The model-predicted maximum levels are most sensitive to dispersivity. Unfortunately, dispersivity is a difficult parameter to measure and the value used in the initial modeling was chosen to be consistent with that used in Cogema's earlier modeling effort (Cogema, 2005). To estimate a better value for dispersivity (as well as an appropriate value for the dispersion coefficient), staff reviewed the baseline data for the mine units in question. An interesting relation was observed if the data for the perimeter wells downgradient of the production aquifer were segregated from the data for the perimeter wells upgradient of the production aquifer. The data for uranium at Mine Units 2 North and South are as follows:

[1] The 2 standard deviations from mean baseline data for uranium are within tolerance levels; however, the statistical data for the baseline data were based on a normal distribution. Had a log-normal distribution been applied to the baseline data as was applied to the restoration data, the tolerance acceptance level would have been exceeded.

Location	Mean Uranium Concentrations in Groundwater (mg/L)	
	MU-2 North	MU-2 South
Upgradient	0.00475	0.00374
Production Aquifer	0.041	0.028
Downgradient	0.02	0.014

The data indicate that uranium concentrations downgradient of the production aquifer are slightly more elevated than the concentrations in the aquifer upgradient. An assumption is that the slightly elevated concentrations are a result of "re-mobilized" uranium concentrations in the production aquifer. Of the parameters that were analyzed for this evaluation, bicarbonate is the other constituent that exhibits a slight increase immediately downgradient of the production aquifer. The concentrations of the other constituents did not exhibit similar spatial variation with respect to upgradient or downgradient of the production aquifer. In the case of radium-226, the data are as follows:

Location	Mean Radium-226 Concentrations in Groundwater (pCi/L)		
	MU-2 North	MU-2 South	MU-3
Upgradient	1.47	2.19	3.126
Production Aquifer	22.7	17.2	81.3
Downgradient	0.47	2.175	3.126

If the assumption is that the increased levels of uranium downgradient of the production aquifer is due to the mobility of a constituent, then the above data for radium suggest that a more limited mobility for these constituents, in particular radium-226, which is consistent with the licensee's qualitative argument.

To evaluate the appropriate dispersivity and distribution coefficient values, the above data for uranium at MU-2 North were incorporated into the fate and transport model. The assumptions for the fate and transport model are that:

(1) the production aquifer is a continuing source of uranium;
(2) the background data for outside of the production zone is equivalent to the upgradient levels; and
(3) the downgradient levels are representative of long-term equilibrium (tens of thousands of years).

Based on the above assumptions, the values for dispersivity and distribution coefficient were adjusted to yield the long-term downgradient levels (Figure 2). The adjusted values for longitudinal dispersivity, ratio of vertical to longitudinal dispersivity, ratio of transverse to longitudinal dispersivity and distribution coefficient are as follow:

Longitudinal dispersivity	11 feet
Ratio of vertical to longitudinal dispersivity	0.6
Ratio of transverse to longitudinal dispersivity	0.1
Distribution coefficient	10 cm^3/g

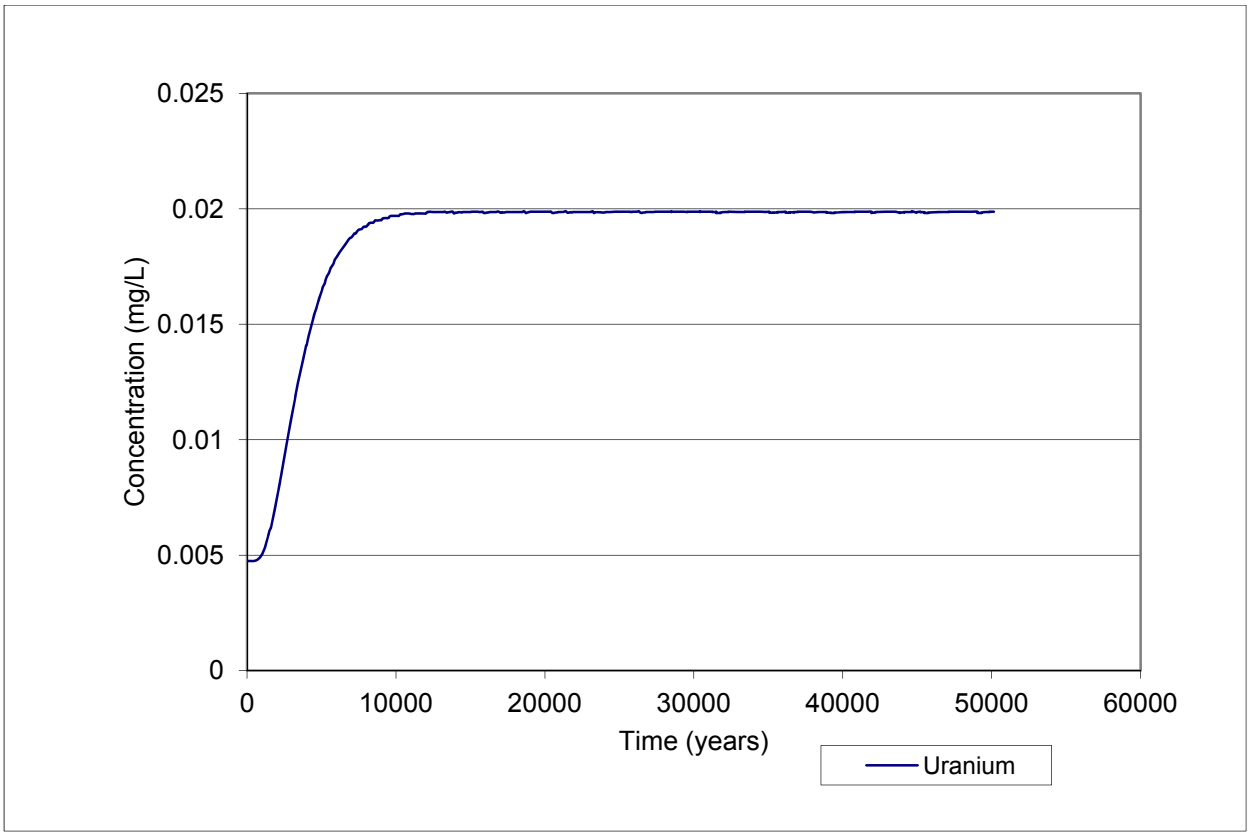

Figure 2: Model simulation results to calibrate to observed uranium levels downgradient of the production zone during baseline conditions. The level downgradient of the production zone is 0.02 mg/L.

The radium data could not be used to estimate dispersivity values. However, the dispersivity values determined for uranium were applied to the simulations for radium-226. Consequently, the unknown parameter for the radium-226 simulation was the distribution coefficient. Using the dispersivity values determined for uranium, the value of the distribution coefficient that yielded the long-term radium-226 levels was 30 cm^3/g (Figure 3). This value is consistent with published distribution coefficients for radium in similar settings as ISR's (Kirby & Salutsky, 1964; Szabo, et al., 2012).

Using the above values for uranium and radium-226, the model-predicted maximum levels for Mine Unit 2 North are 0.027 mg/L and 1.33 pCi/L, respectively. These levels meet the MCLs for uranium and radium-226 and are consistent with the downgradient baseline data.

The model-predicted levels are graphically presented in Appendix A.

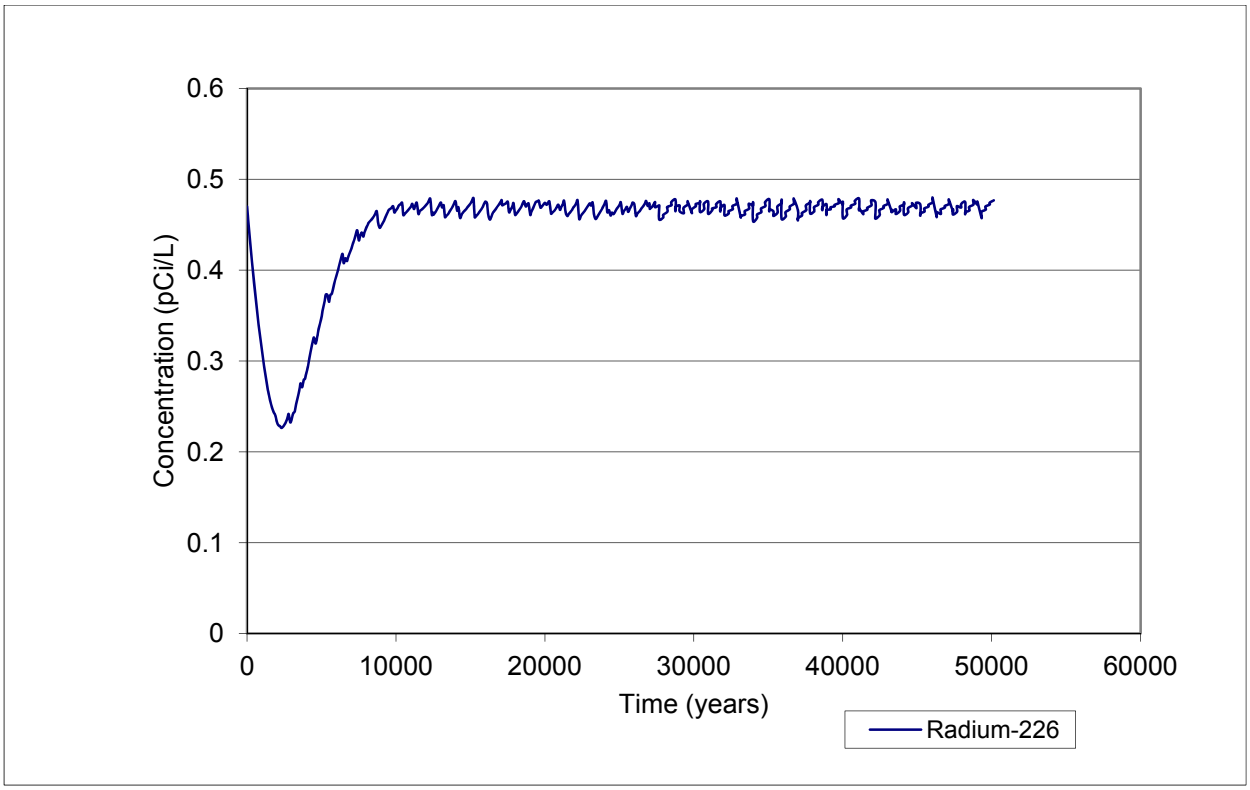

Figure 3: Model simulation results to calibrate to observed radium-226 levels downgradient of the production zone during baseline conditions. The level downgradient of the production zone is 0.047 pCi/L. The model incorporated dispersivity of the uranium simulation.

Mine Unit 2 South

For Mine Unit 2 South, the constituents of concern and their concentrations in the production aquifer at the end of active restoration are as follows:

Calcium	58.4
Magnesium	8.1
Bicarbonate	246
Iron	0.64
Manganese	0.38
TDS	542
Silica	11.8
Uranium	0.13
Radium-226	164.3 (pCi/L)

The levels of calcium, magnesium, bicarbonate, TDS, uranium and radium-226 at Mine Unit 2 South are slightly less than those levels at Mine Unit 2 North. For calcium, magnesium and bicarbonate, the model-predicted maximum levels (based on the analysis for Mine Unit 2 North) would be consistent with the baseline data and thus not represent a measurable impact to the surrounding aquifer. The model-predicted maximum level for silica is 5.24 mg/L, which is

consistent with the baseline data (within 2 standard deviations of the mean) and thus does not represent a measurable impact to the surrounding aquifer. The TDS, iron and manganese levels were subjected to the initial model (distribution coefficient of 0.5 cm3/g and longitudinal dispersivity of 25 feet). The model-predicted maximum levels for TDS, iron and manganese are 438, 0.07 and 0.03 mg/L, respectively. Those levels are below the respective National Secondary Drinking Water Standard and consistent with the baseline data. Consequently, those levels do not present a measurable impact to the surrounding aquifer.

The uranium and radium-266 levels were subjected to the refined models (refined dispersivity and distribution coefficient) as discussed above. The model-predicted maximum levels for radium-226 and uranium are 1.0 pCi/L and 0.012 mg/L, respectively. Those levels are below the respective National Primary Drinking Water Standard and consistent with the baseline data. Consequently, those levels do not pose a measurable impact to the surrounding aquifer.

The model predicted levels are graphically presented in Appendix B.

Mine Unit 3

For Mine Unit 3, the constituents of concern and their concentrations in the production aquifer at the end of active restoration are as follows:

Calcium	43.9
Magnesium	6.25
Bicarbonate	222.6
Iron	0.248
Manganese	0.109
Silica	16.8
Manganese	0.109
Radium-226	185.2 (pCi/L)

The calcium, magnesium, bicarbonate, silica, iron and manganese levels were subjected to the initial model (distribution coefficient of 0.5 cm^3/g and longitudinal dispersivity of 25 feet). The model-predicted maximum levels for calcium, magnesium, bicarbonate and silica are 10.2, 1.38, 118.5 and 8.95 mg/L, respectively. These levels are consistent with the baseline data (3 standard deviations of the baseline mean) and thus do not pose a measurable impact to the surrounding aquifer. The model-predict maximum levels for iron and manganese at a distance of 300 feet downgradient of the production aquifer are 0.042 and 0.013 mg/L, respectively. These levels are below the respective National Secondary Drinking Water Standard and consistent with the baseline data. Consequently, these levels do not present a measurable impact to the surrounding aquifer.

The radium-266 level was subjected to the refined model as discussed above. The model-predicted maximum level for radium-226 does not exhibit a measurable increase in the mean baseline value. As such, this level is below the National Primary Drinking Water Standard and consistent with the baseline data and consequently, does not pose a measurable impact to the surrounding aquifer.

The model predicted levels are graphically presented in Appendix C.

Conclusions

Staff performed fate and transport modeling of constituents identified as exceeding the primary restoration goals in the restoration reports for Christensen Ranch Mine Units 2 and 3. The modeling was performed to verify that the levels remaining in the production aquifer at the end of restoration do not pose a hazard to human health and the environment. The simple model developed for this analysis provides useful information for staff to be reasonably assured that the levels are protective.

Based on the above evaluation, staff concludes that the levels do not pose any measureable impact to the surrounding aquifer.

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Table 1. Parameter Values used in the Numerical Groundwater Flow Models

Parameter	Units	MU-2 North	MU-2 South	MU-3
Layer 1 Top Elevation	ft-MSL	148	148	162
Layer 2 Top Elevation	ft-MSL	50	50	50
Layer 3 Top Elevation	ft-MSL	15	15	15
Layer 3 Bottom Elevation	ft-MSL	0	0	0
Upgradient CHDs	ft-MSL	358	358	465
Dowgradient CHDs	ft-MSL	338	338	445
Horizontal Hydraulic Conductivity	ft/day	0.52	0.52	0.34
Vertical Hydraulic Conductivity	ft/day	0.0052	0.0052	0.0034
Specific Storage	$feet^{-1}$	0.000035	0.000035	0.000035

ft-MSL is feet above mean sea level

ft/day is feet per day

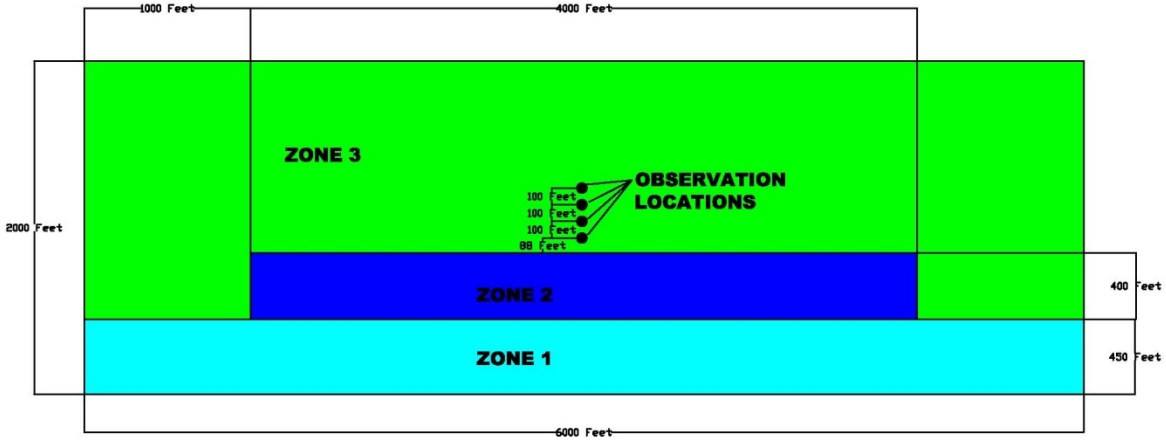
CHD is Constant Head Boundary Conditions (upgradient is row 80; down gradient is Row 1)

Table 2. Parameter Values used in the Numerical Fate and Transport Models

ne U Constituent	Distribution Coefficent	Dispersivity	Reaction Decay Constant	Input Concentration (mg/L)		Model-Predicted Maximum Concentration	Time to Maximum Concentration
				Surrounding Aquifer	Production Zone	(mg/L) (pCi/L for Radium)	(Years)
	cm3/g	feet:[ ]:[ ]	day-1				
MU-2 North							
Calcium	0.5	25:0.1:0.1	N/A	7.47	73.6	12.3	235
Magnesium	0.5	25:0.1:0.1	N/A	0.53	7.6	1.05	235
Bicarbonate	0.5	25:0.1:0.1	N/A	85	330.3	103	235
TDS	0.5	25:0.1:0.1	N/A	411	560	422	235
Iron	0.5	25:0.1:0.1	N/A	0.025	0.43	0.055	235
Manganese	0.5	25:0.1:0.1	N/A	0.005	0.25	0.023	235
Uranium	10	11:0.6:0.1	N/A	0.00475	0.33	0.027	3400
Radium-226	30	11:0.6:0.1	1.16E-06	1.47	350.6	1.3	4300
MU-2 South							
Calcium	0.5	25:0.1:0.1	N/A	7.47	58.4	<MU-2 North	235
Magnesium	0.5	25:0.1:0.1	N/A	0.53	8.1	<MU-2 North	235
Bicarbonate	0.5	25:0.1:0.1	N/A	85	246	<MU-2 North	235
Silica	0.5	25:0.1:0.1	N/A	4.72	11.8	5.23	235
TDS	0.5	25:0.1:0.1	N/A	430	542.9	438.2	235
Iron	0.5	25:0.1:0.1	N/A	0.025	0.64	0.07	235
Manganese	0.5	25:0.1:0.1	N/A	0.005	0.38	0.032	235
Uranium	10	11:0.6:0.1	N/A	0.00374	0.13	0.012	3400
Radium-226	30	11:0.6:0.1	1.16E-06	2.19	164.3	1	4300
MU-3							
Calcium	0.5	25:0.1:0.1	N/A	7.42	43.9	10.2	370
Magnesium	0.5	25:0.1:0.1	N/A	0.98	6.25	1.39	370
Bicarbonate	0.5	25:0.1:0.1	N/A	109.8	222.6	118.5	370
Silica	0.5	25:0.1:0.1	N/A	8.3	16.8	8.96	370
Iron	0.5	25:0.1:0.1	N/A	0.025	0.248	0.042	370
Manganese	0.5	25:0.1:0.1	N/A	0.005	0.109	0.013	370
Radium-226	30	11:0.6:0.1	1.16E-06	3.1	185	baseline	<15000

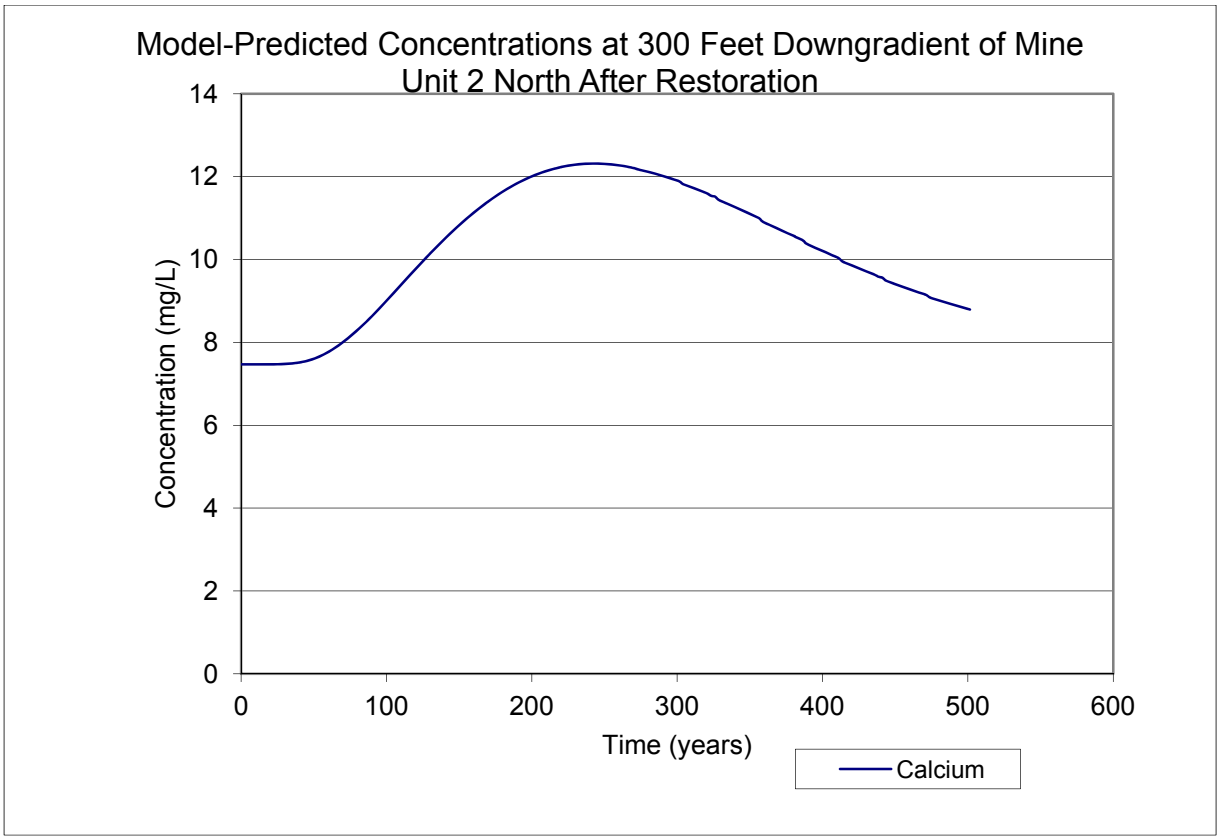
NOTES:
Porosity of 0.26 and bulk density of 1.587 g/cm3 were used for all simulations
Model-predicted maximum concentration at 300 feet downgradient of the production zone.

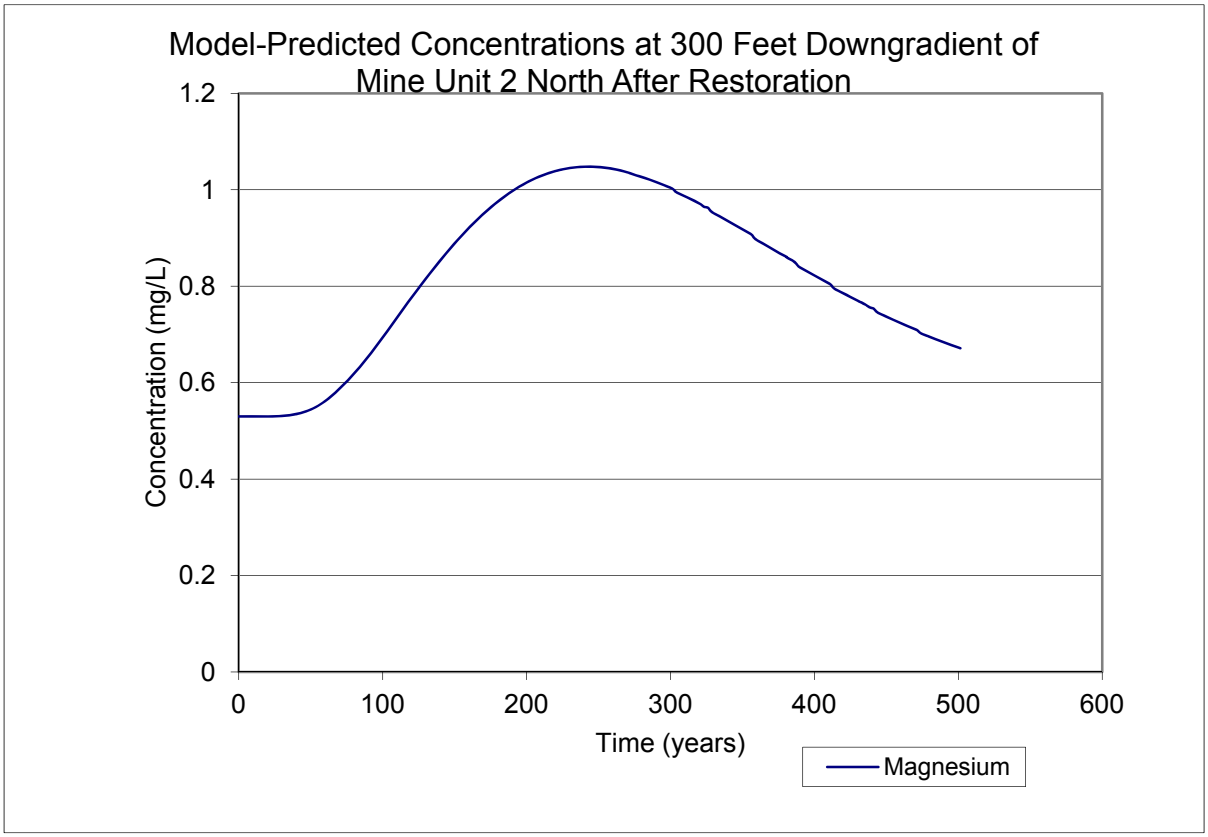
Figure 1. Map View of Model Geometry

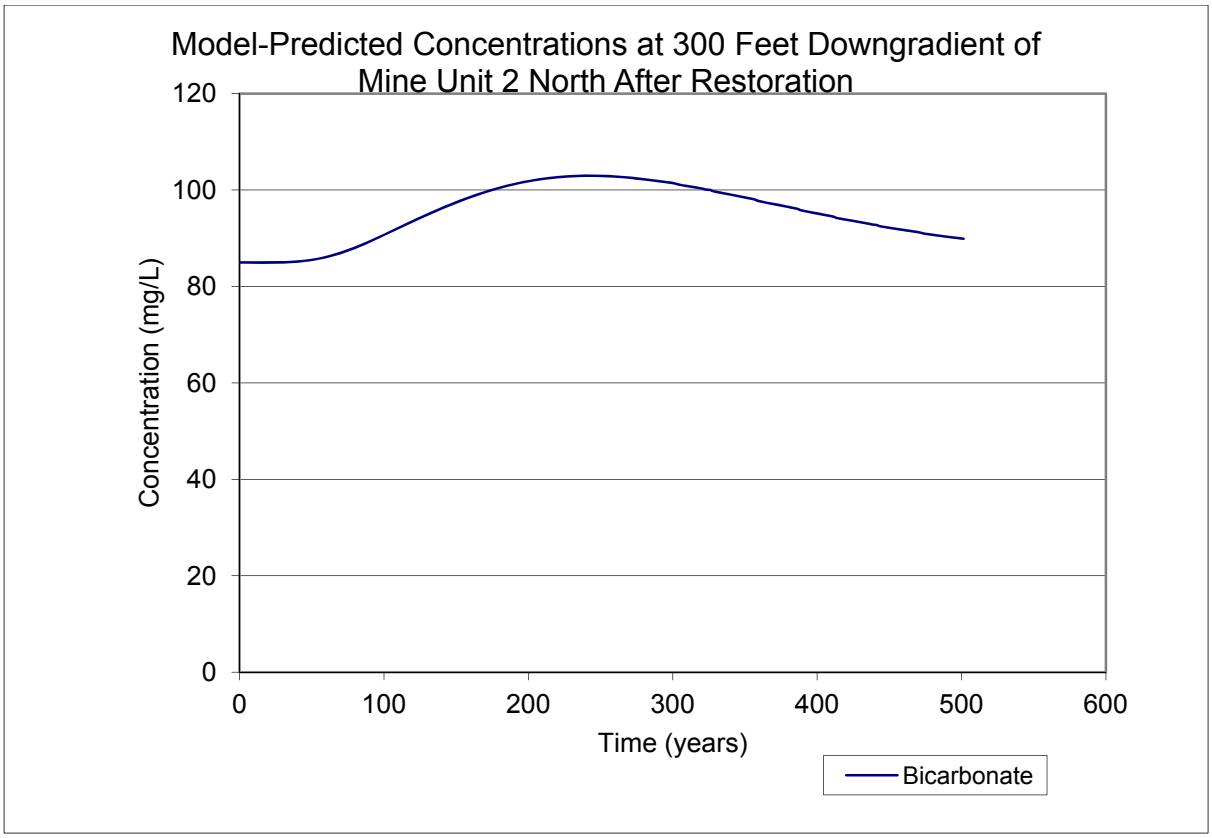


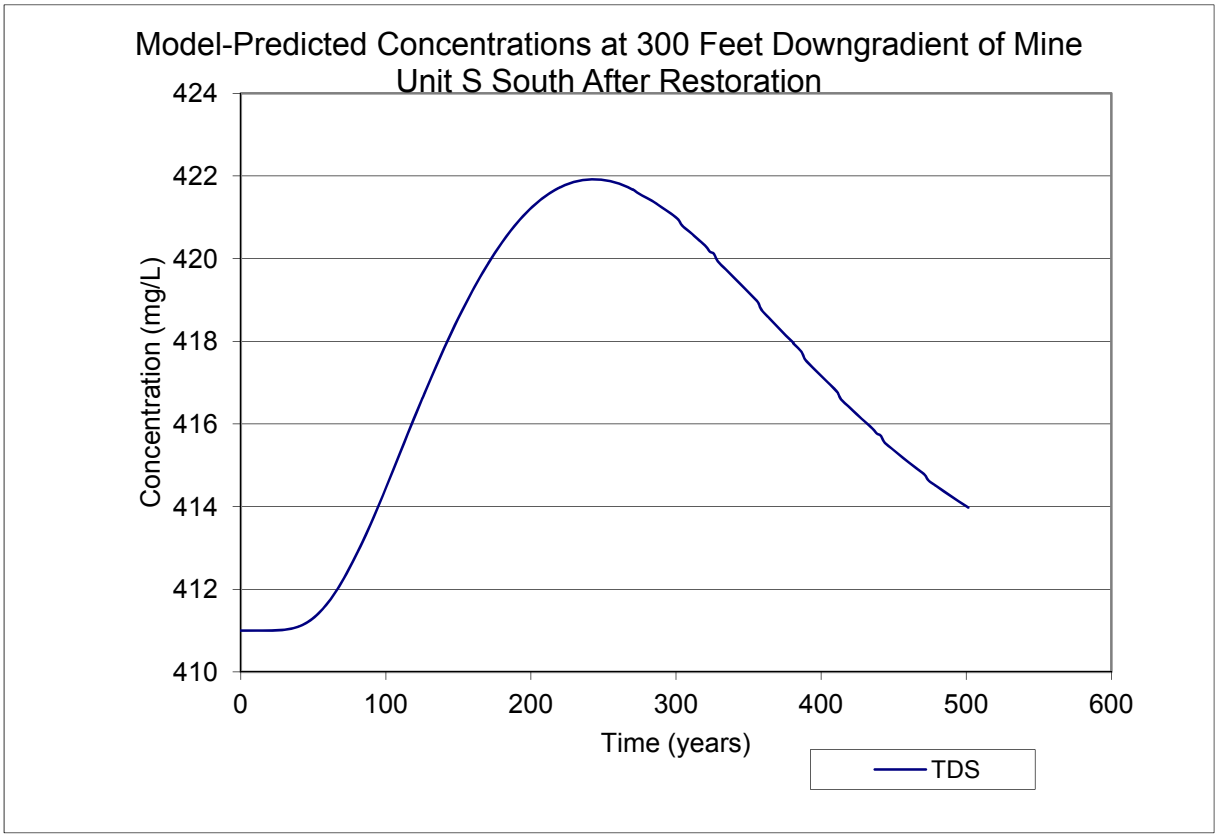
APPENDIX A

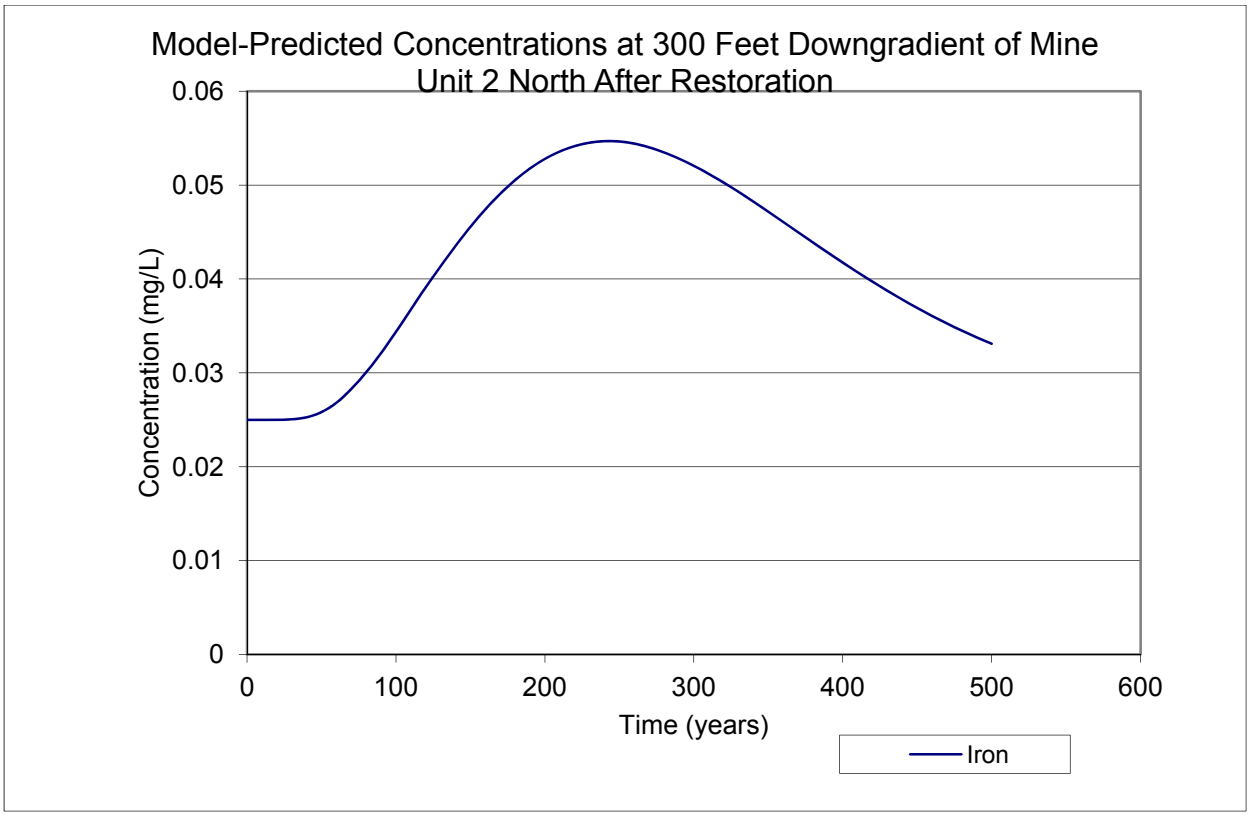
MU-2 North

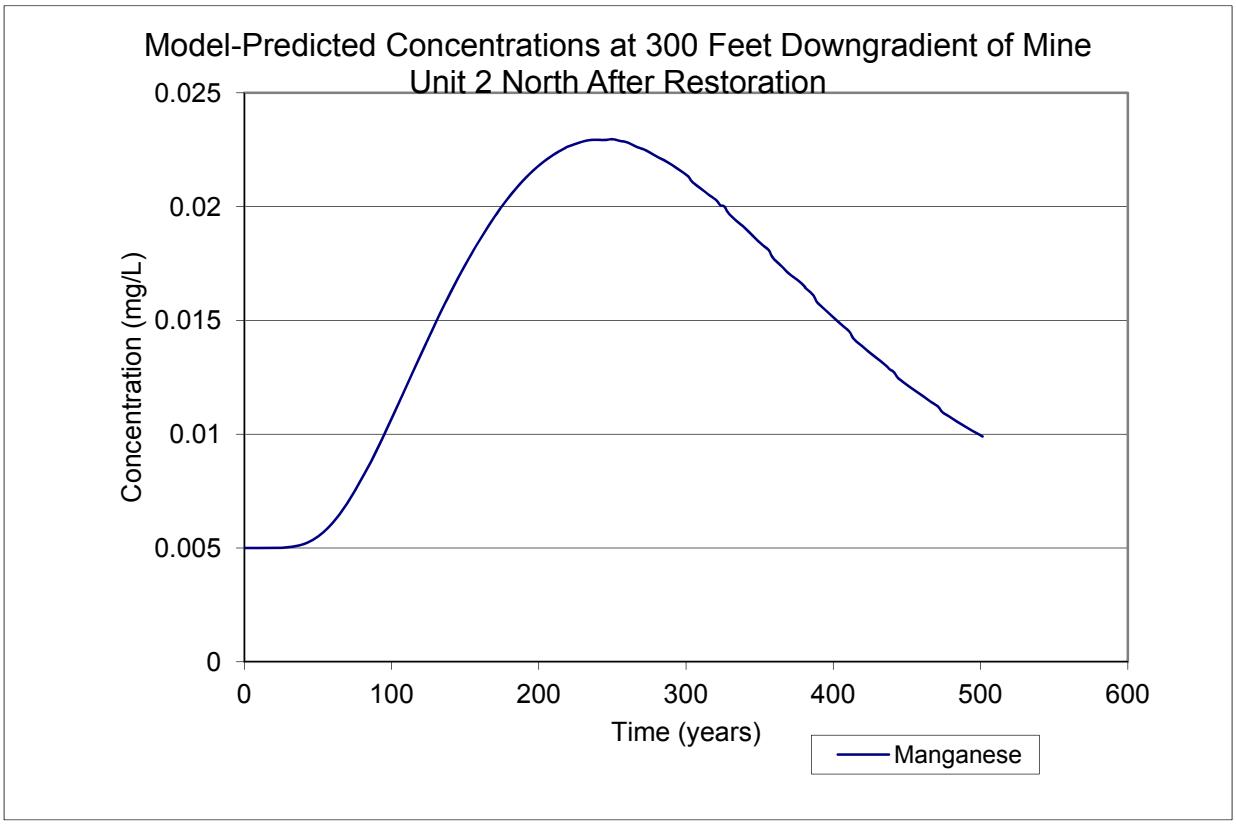

Model-Predicted Concentrations at 300 Feet Downgradient of Mine Unit 2 North After Restoration
Concentration (mg/L)
0
2
4
6
8
10
12
14
0
100
200
300
400
500
600
Time (years)
Calcium

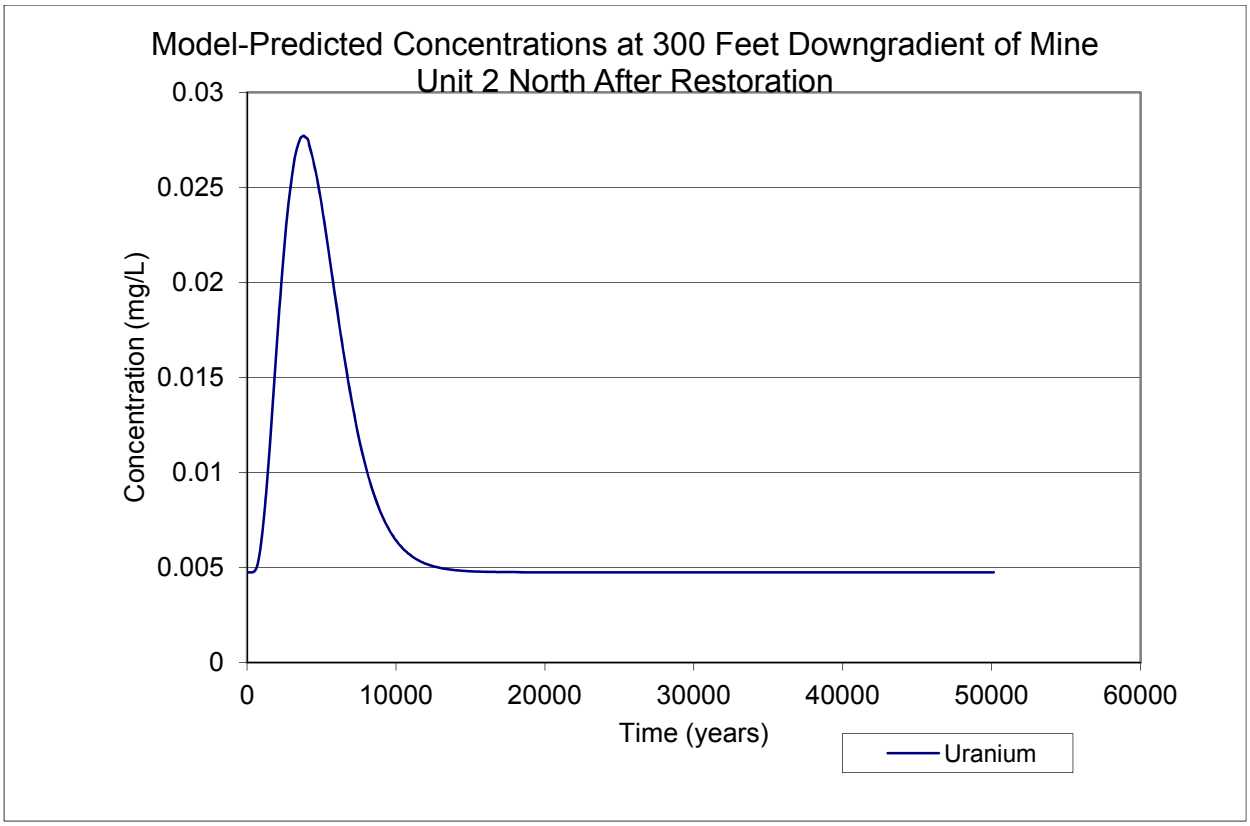

Model-Predicted Concentrations at 300 Feet Downgradient of Mine Unit 2 North After Restoration
Concentration (mg/L)
0
0.2
0.4
0.6
0.8
1
1.2
0
100
200
300
400
500
600
Time (years)
Magnesium

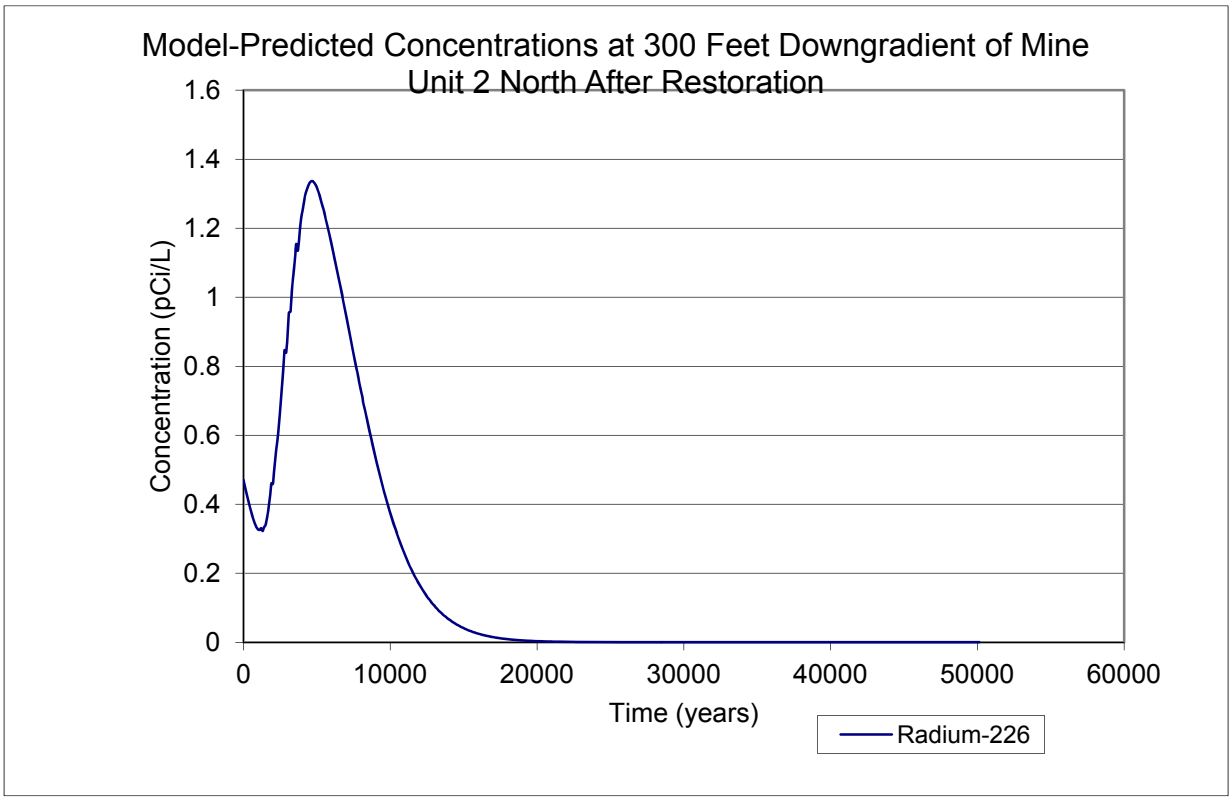

Model-Predicted Concentrations at 300 Feet Downgradient of Mine Unit 2 North After Restoration
120
100
80
60
40
20
0
Concentration (mg/L)
0
100
200
300
400
500
600
Time (years)
Bicarbonate


Model-Predicted Concentrations at 300 Feet Downgradient of Mine Unit S South After Restoration
424
422
420
418
416
414
412
410
Concentration (mg/L)
0
100
200
300
400
500
600
Time (years)
TDS


Model-Predicted Concentrations at 300 Feet Downgradient of Mine Unit 2 North After Restoration
0.06
0.05
0.04
0.03
0.02
0.01
0
Concentration (mg/L)
0
100
200
300
400
500
600
Time (years)
Iron

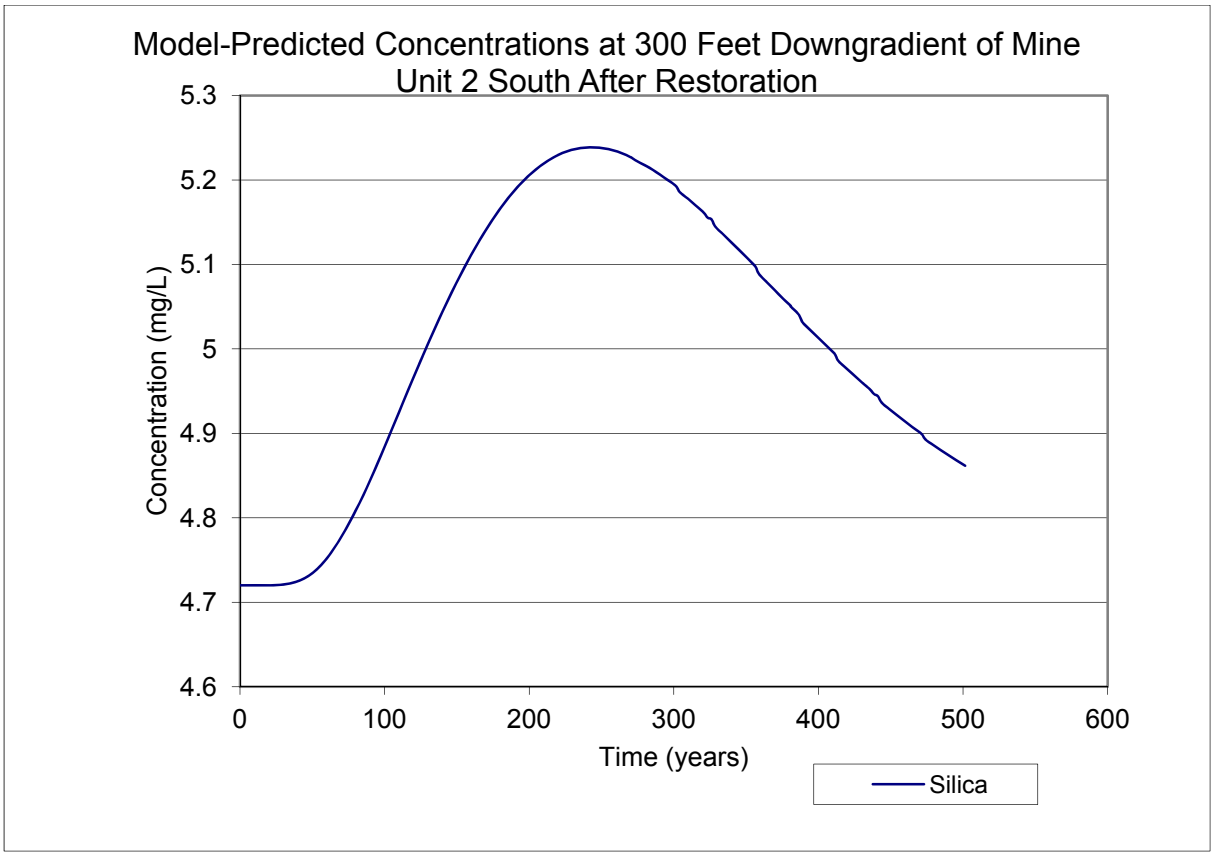

Model-Predicted Concentrations at 300 Feet Downgradient of Mine Unit 2 North After Restoration
0.025
0.02
0.015
0.01
0.005
0
Concentration (mg/L)
0
100
200
300
400
500
600
Time (years)
Manganese

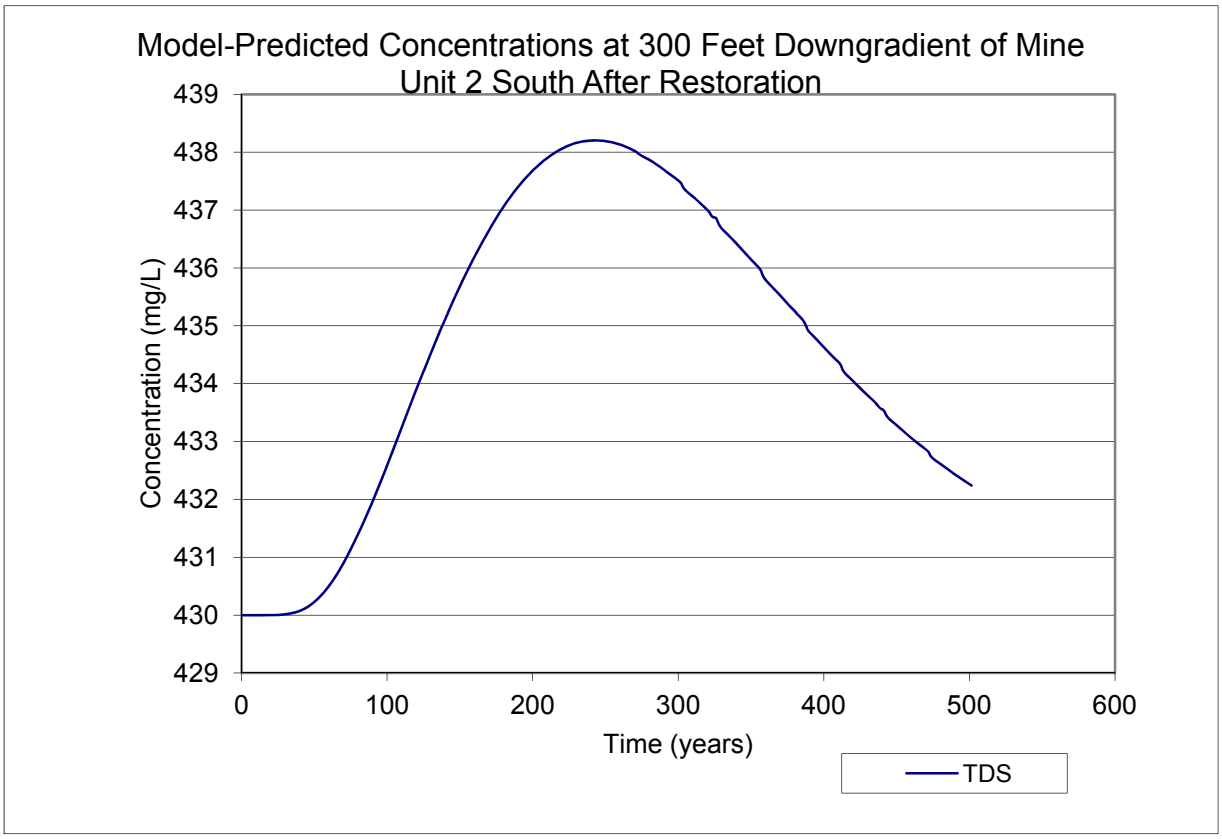

Model-Predicted Concentrations at 300 Feet Downgradient of Mine Unit 2 North After Restoration
Concentration (mg/L)
0.03
0.025
0.02
0.015
0.01
0.005
0
0
10000
20000
30000
40000
50000
60000
Time (years)
Uranium

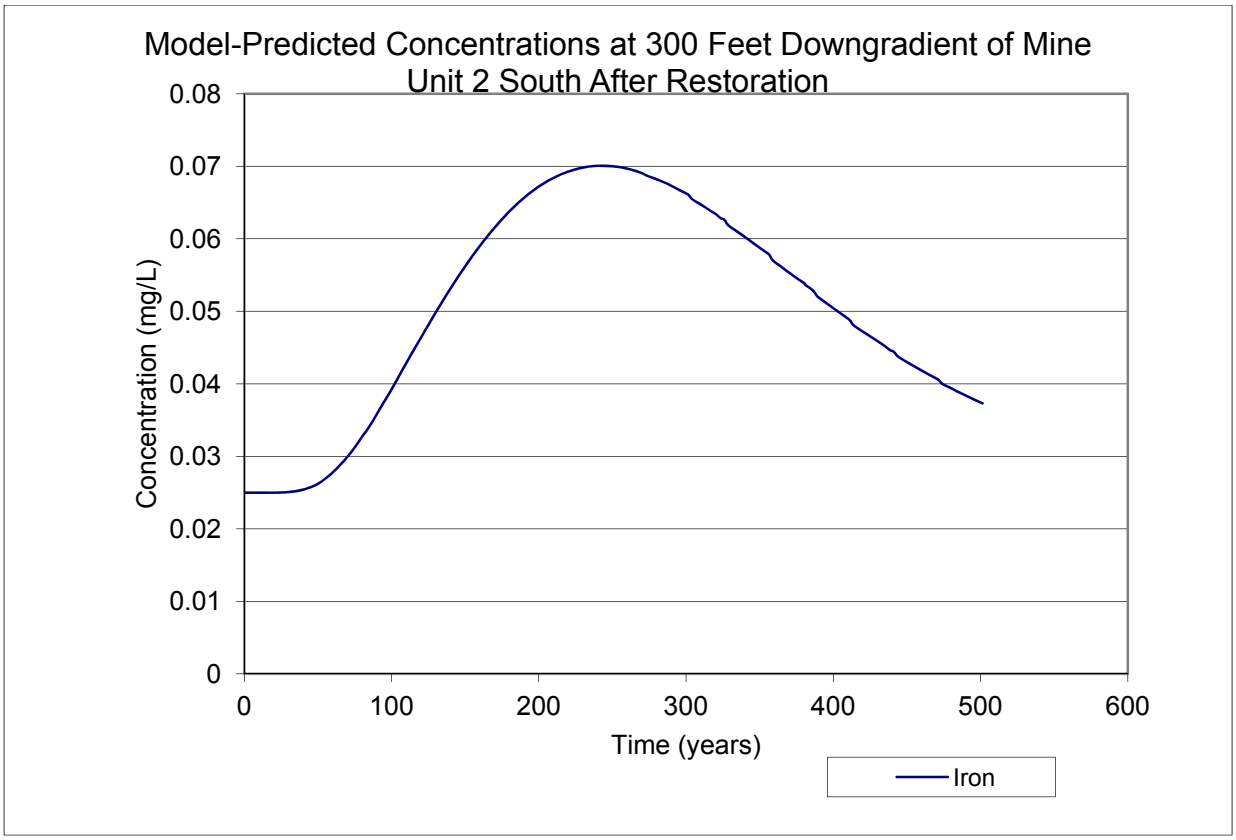

Model-Predicted Concentrations at 300 Feet Downgradient of Mine Unit 2 North After Restoration
Concentration (pCi/L)
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0
10000
20000
30000
40000
50000
60000
Time (years)
Radium-226

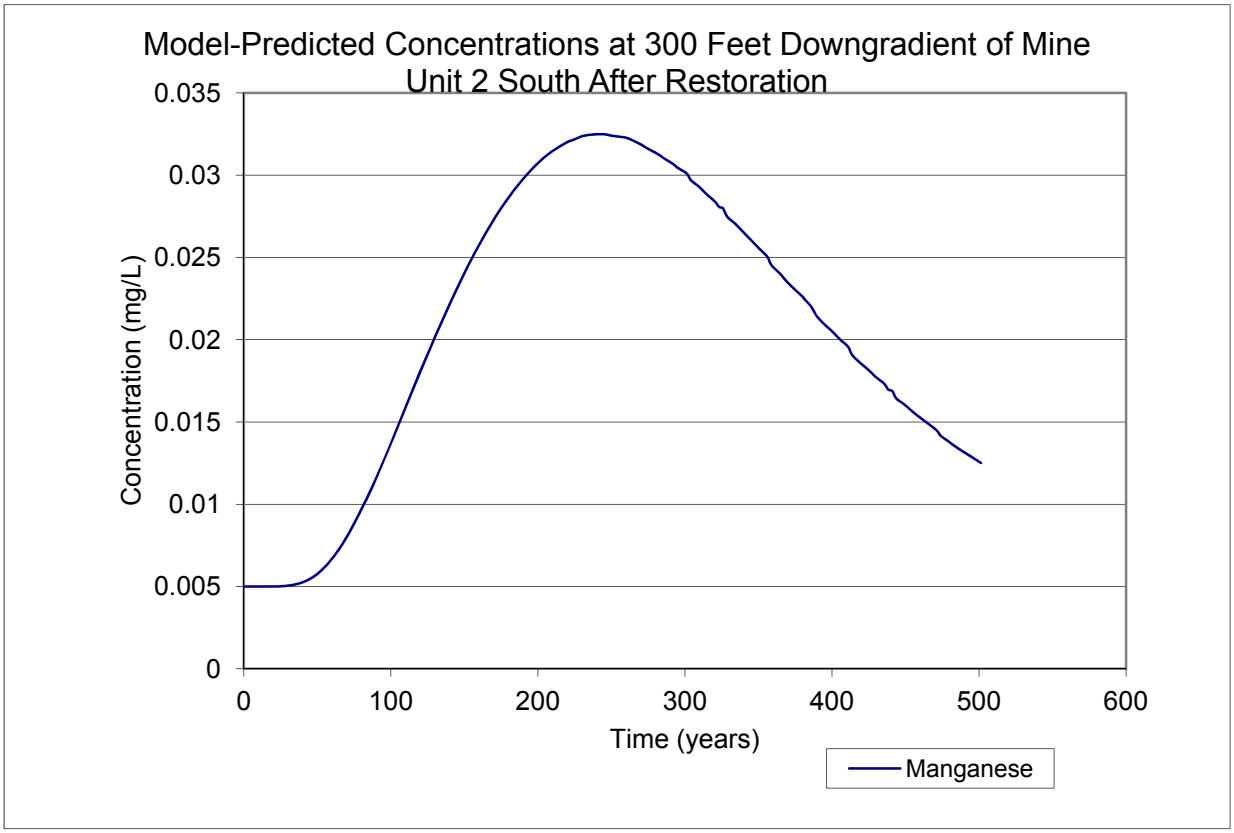
APPENDIX B

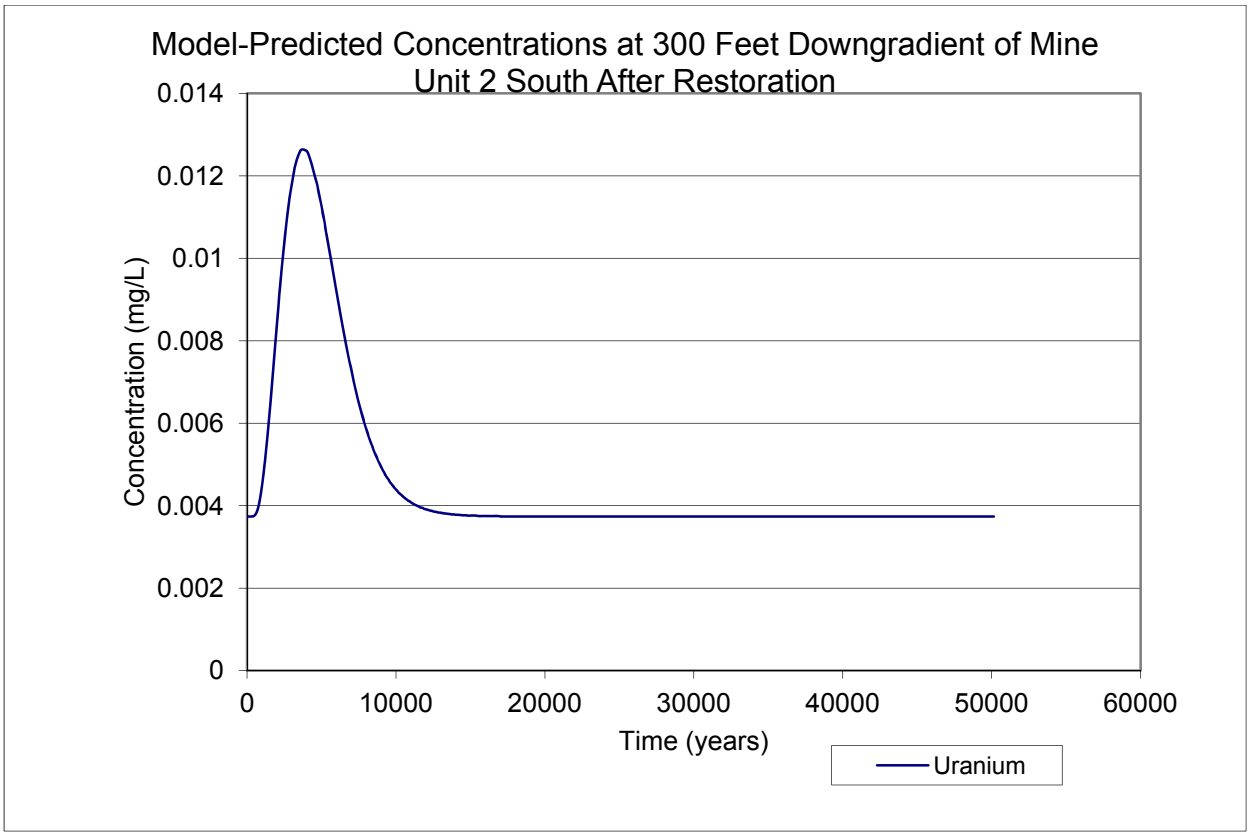
MU-2 South

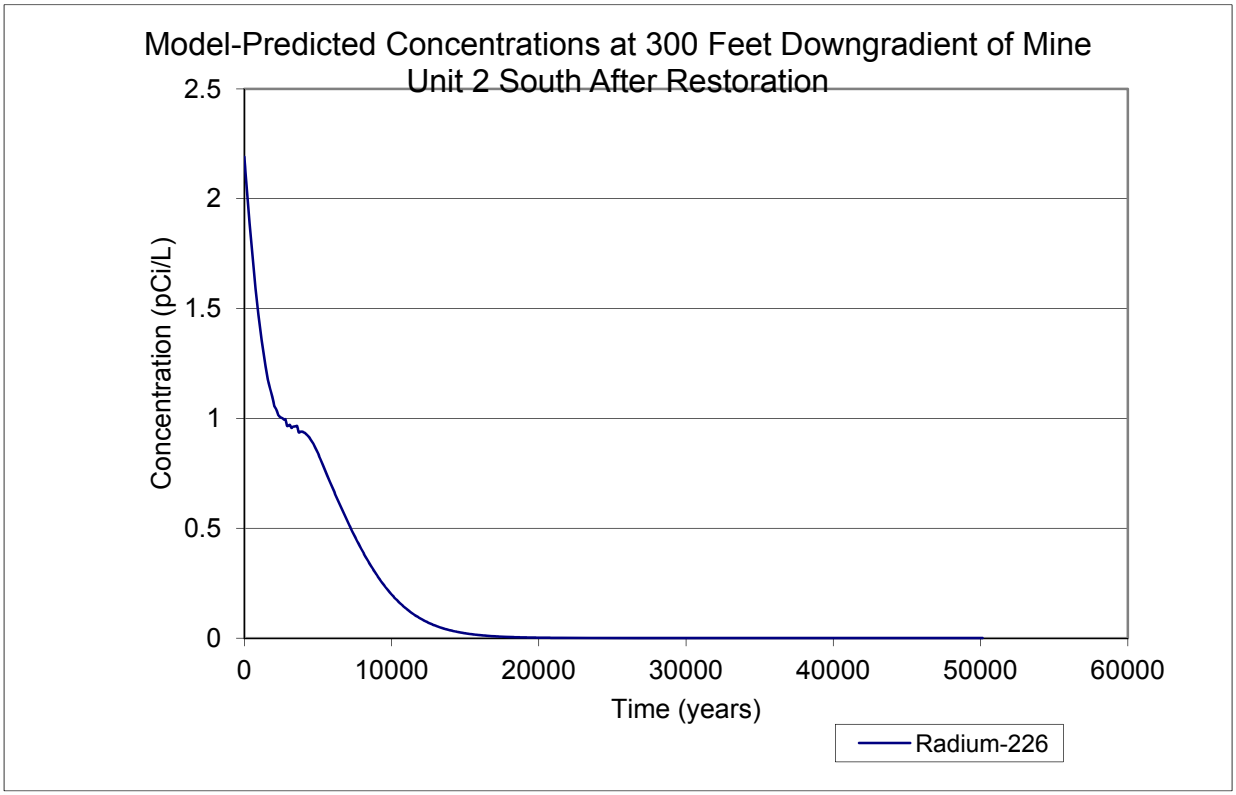

Model-Predicted Concentrations at 300 Feet Downgradient of Mine Unit 2 South After Restoration
Concentration (mg/L)
5.3
5.2
5.1
5
4.9
4.8
4.7
4.6
0
100
200
300
400
500
600
Time (years)
Silica


Model-Predicted Concentrations at 300 Feet Downgradient of Mine Unit 2 South After Restoration
Concentration (mg/L)
439
438
437
436
435
434
433
432
431
430
429
0
100
200
300
400
500
600
Time (years)
TDS


Model-Predicted Concentrations at 300 Feet Downgradient of Mine Unit 2 South After Restoration
Concentration (mg/L)
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
0
100
200
300
400
500
600
Time (years)
Iron

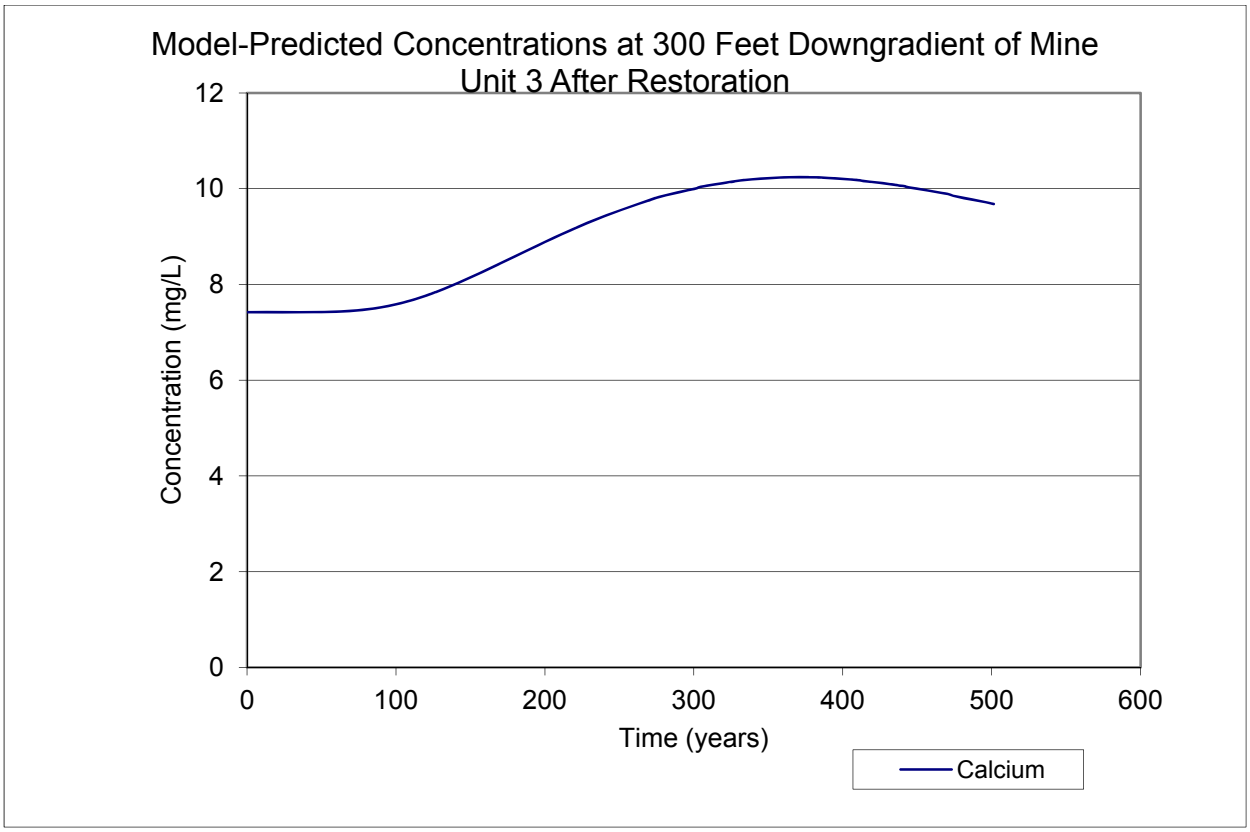

Model-Predicted Concentrations at 300 Feet Downgradient of Mine Unit 2 South After Restoration
Concentration (mg/L)
0.035
0.03
0.025
0.02
0.015
0.01
0.005
0
0
100
200
300
400
500
600
Time (years)
Manganese

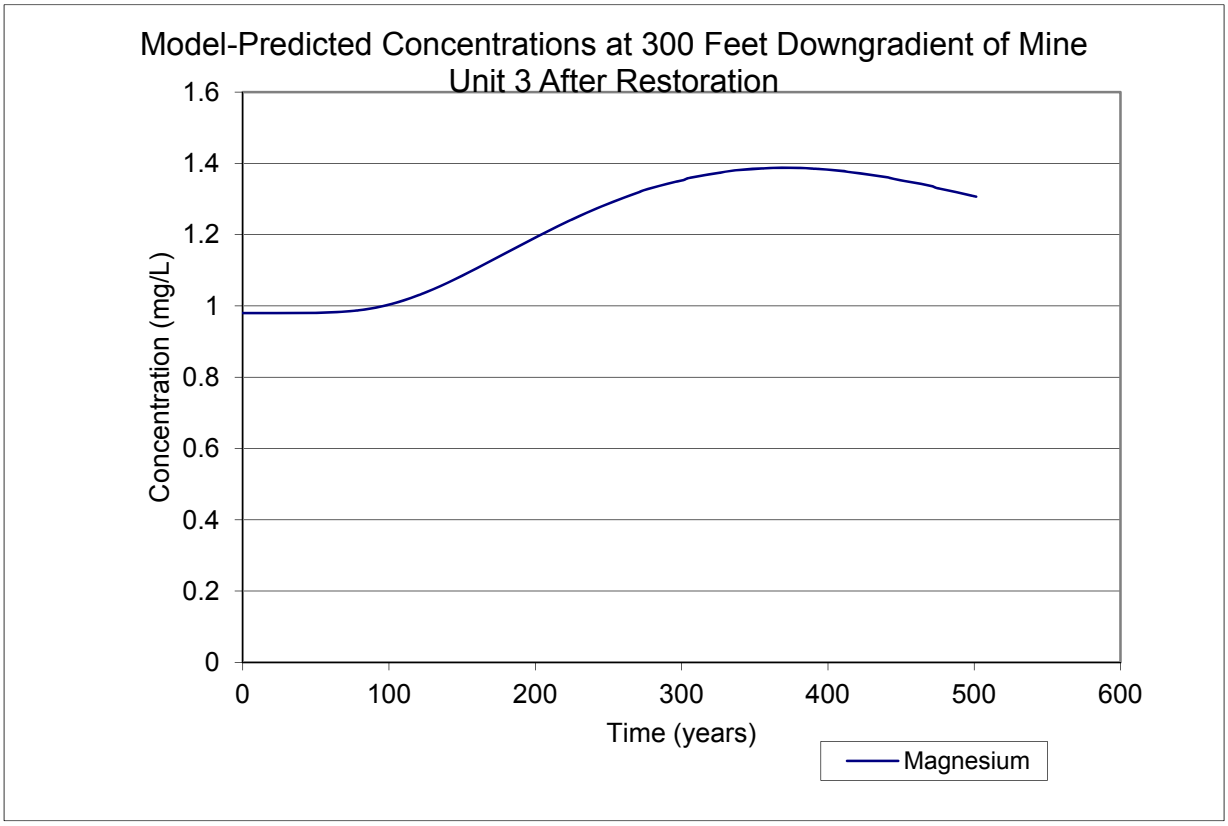

Model-Predicted Concentrations at 300 Feet Downgradient of Mine Unit 2 South After Restoration
Concentration (mg/L)
0.014
0.012
0.01
0.008
0.006
0.004
0.002
0
0
10000
20000
30000
40000
50000
60000
Time (years)
Uranium

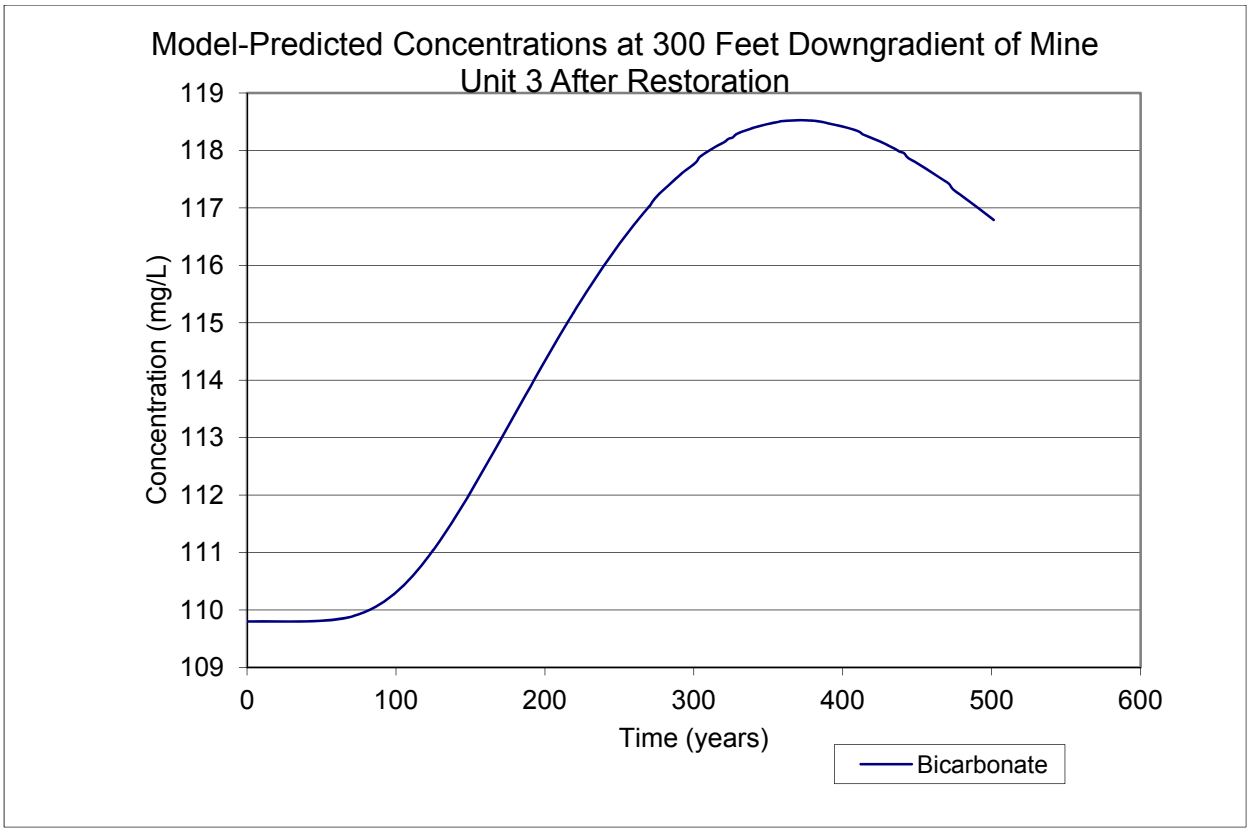

Model-Predicted Concentrations at 300 Feet Downgradient of Mine Unit 2 South After Restoration
Concentration (pCi/L)
2.5
2
1.5
1
0.5
0
0
10000
20000
30000
40000
50000
60000
Time (years)
Radium-226

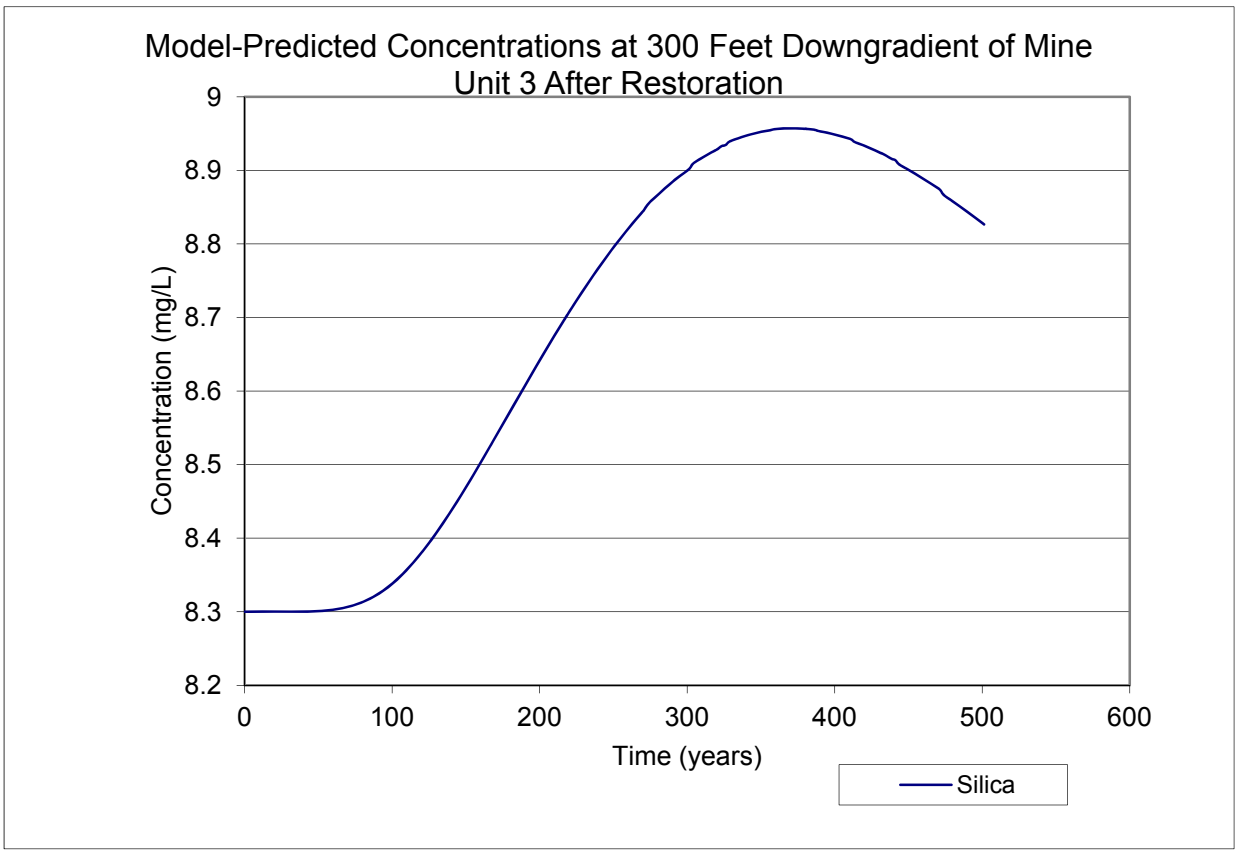
APPENDIX C

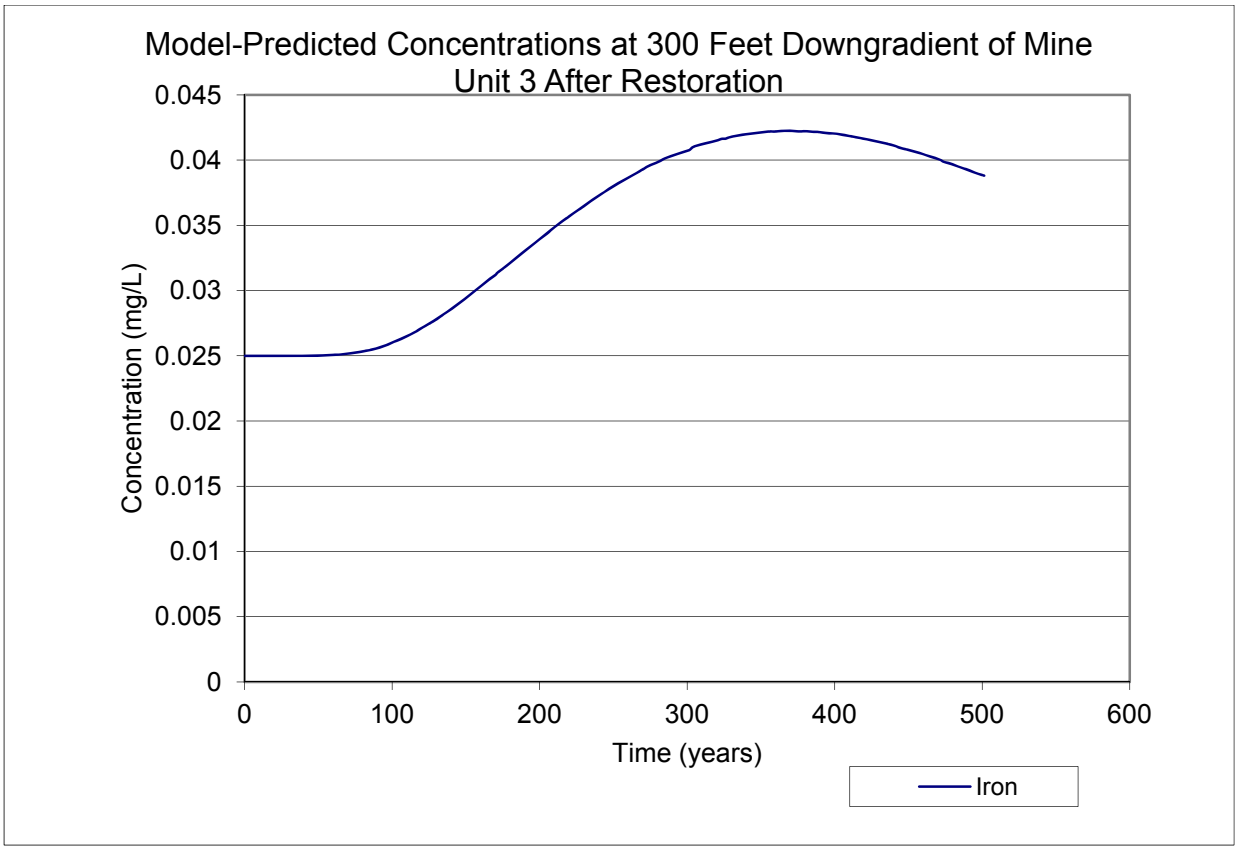
MU-3

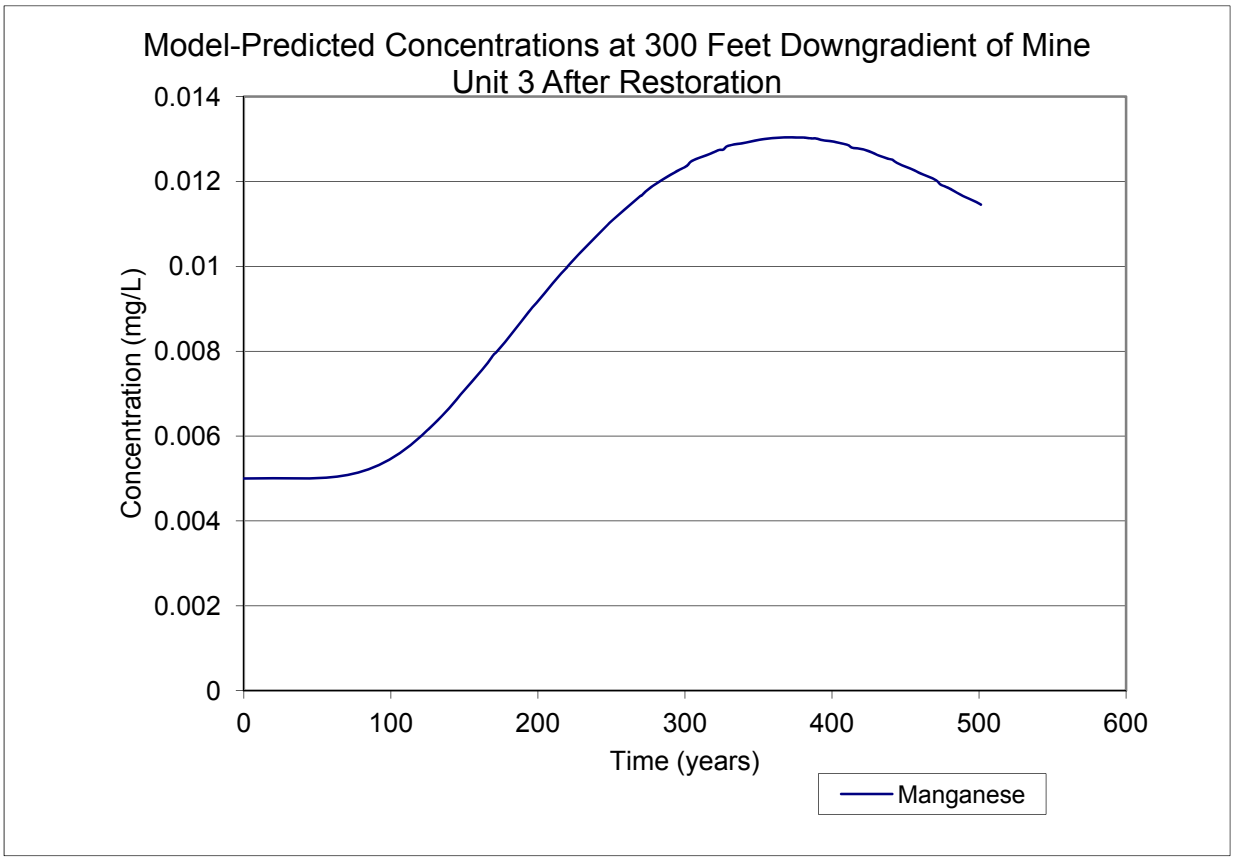

Model-Predicted Concentrations at 300 Feet Downgradient of Mine Unit 3 After Restoration
Concentration (mg/L)
0
2
4
6
8
10
12
0
100
200
300
400
500
600
Time (years)
Calcium

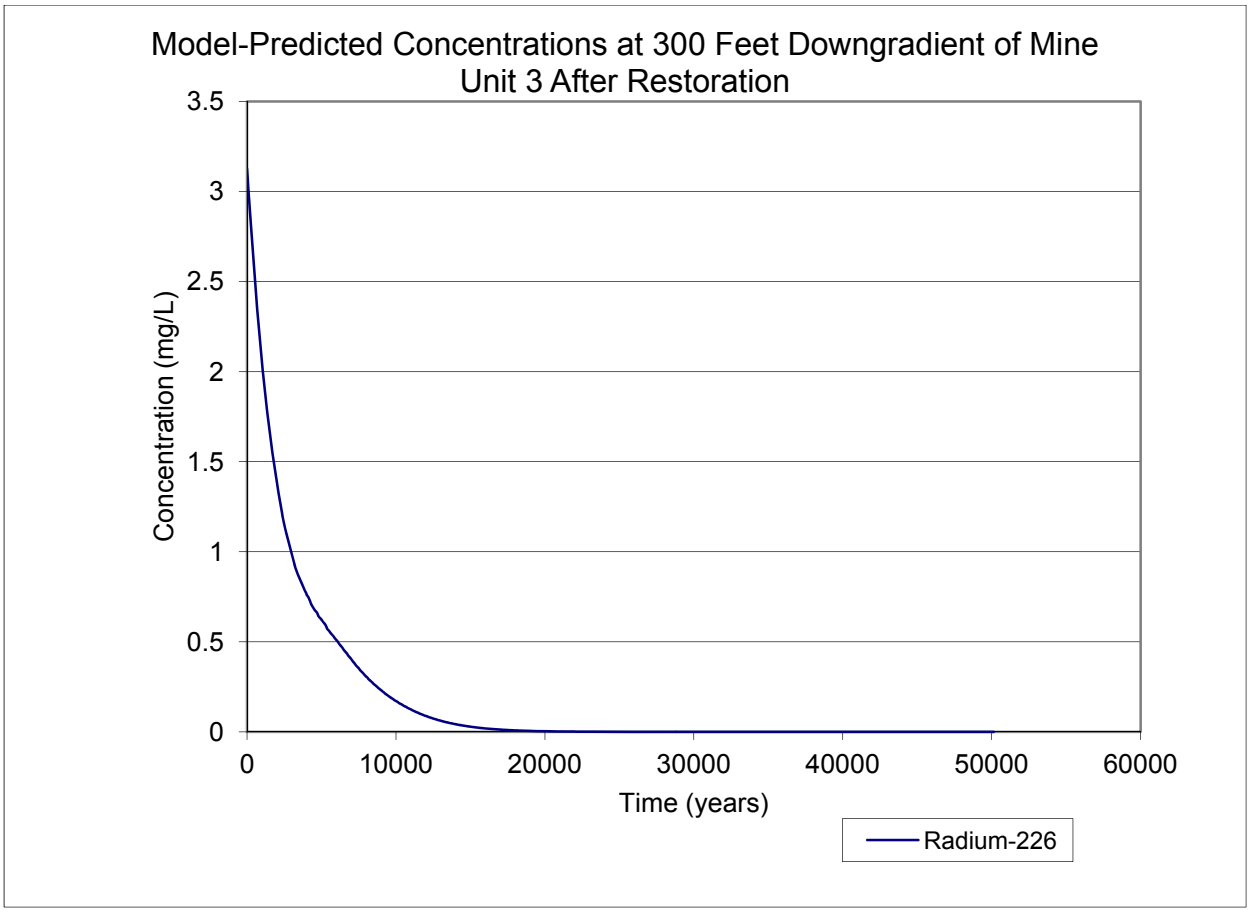

Model-Predicted Concentrations at 300 Feet Downgradient of Mine Unit 3 After Restoration
Concentration (mg/L)
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
0
100
200
300
400
500
600
Time (years)
Magnesium


Model-Predicted Concentrations at 300 Feet Downgradient of Mine Unit 3 After Restoration
Concentration (mg/L)
119
118
117
116
115
114
113
112
111
110
109
0
100
200
300
400
500
600
Time (years)
Bicarbonate


Model-Predicted Concentrations at 300 Feet Downgradient of Mine Unit 3 After Restoration
Concentration (mg/L)
9
8.9
8.8
8.7
8.6
8.5
8.4
8.3
8.2
0
100
200
300
400
500
600
Time (years)
Silica


Model-Predicted Concentrations at 300 Feet Downgradient of Mine Unit 3 After Restoration
0.045
0.04
0.035
0.03
0.025
0.02
0.015
0.01
0.005
0
Concentration (mg/L)
0
100
200
300
400
500
600
Time (years)
Iron


Model-Predicted Concentrations at 300 Feet Downgradient of Mine Unit 3 After Restoration
0.014
0.012
0.01
0.008
0.006
0.004
0.002
0
Concentration (mg/L)
0
100
200
300
400
500
600
Time (years)
Manganese


Model-Predicted Concentrations at 300 Feet Downgradient of Mine Unit 3 After Restoration
Concentration (mg/L)
3.5
3
2.5
2
1.5
1
0.5
0
0
10000
20000
30000
40000
50000
60000
Time (years)
Radium-226