Contents

Figures

Tables

1.0 Introduction

1.1 General Setting

The Slick Rock Uranium Mill Tailings Remedial Action (UMTRA) Project sites are located on the banks of the Dolores River, San Miguel County, Colorado. The North Continent (NC) site lies approximately 1 mile downstream from the intersection of the Dolores River and Highway 141, and the Union Carbide (UC) site is approximately 1 mile downstream from the NC site (Figure 1). Both sites lie at an elevation of approximately 5,450 feet (ft) above mean sea level (MSL). Surface remediation of tailings and mill related contamination was completed in December 1996, with the contaminated material placed in the Burro Canyon disposal cell located 5 miles east of the Slick Rock processing sites.

1.2 Study Objective

As part of the final compliance strategy for the cleanup of contaminated ground water at the Slick Rock UMTRA Project sites it is necessary to develop a computer ground water model. This model, which consists of ground water flow and contaminant transport components, is designed to assist in forecasting whether natural flushing of various contaminants is a viable remediation alternative.

This document presents the development of steady state deterministic and steady state stochastic hydrologic flow and contaminant transport models to predict future contaminant concentrations. The various flow and transport parameters that affect the hydraulic head and contaminant distribution for the models are described. Contaminants that are modeled include nitrate, manganese, molybdenum, selenium, and uranium.

The steps used for obtaining a calibrated flow and transport model for the site follow the ASTM Standard Guides D5447–93 and D5718–95. The specific steps are to: (1) evaluate the hydrogeologic setting and develop a conceptual model, (2) select the code to be used in the analysis, (3) establish the relationship between the conceptual and numerical models, (4) perform flow model calibration and sensitivity analysis on transport parameters, and (5) predictive simulations.

Stochastic simulations for the steady state model were performed, varying both flow and transport parameters, to evaluate the uncertainty in the predicted concentrations. These stochastic simulations were used to calculate mean concentrations and the probability of contamination remaining above acceptable levels across the site at specific times.

2.0 Conceptual Model

2.1 Aquifer System Framework

The Slick Rock site rests on floodplain and terrace deposits (alluvium) associated with the Dolores River. This alluvium is composed of unconsolidated clayey sands, sandy gravels, and

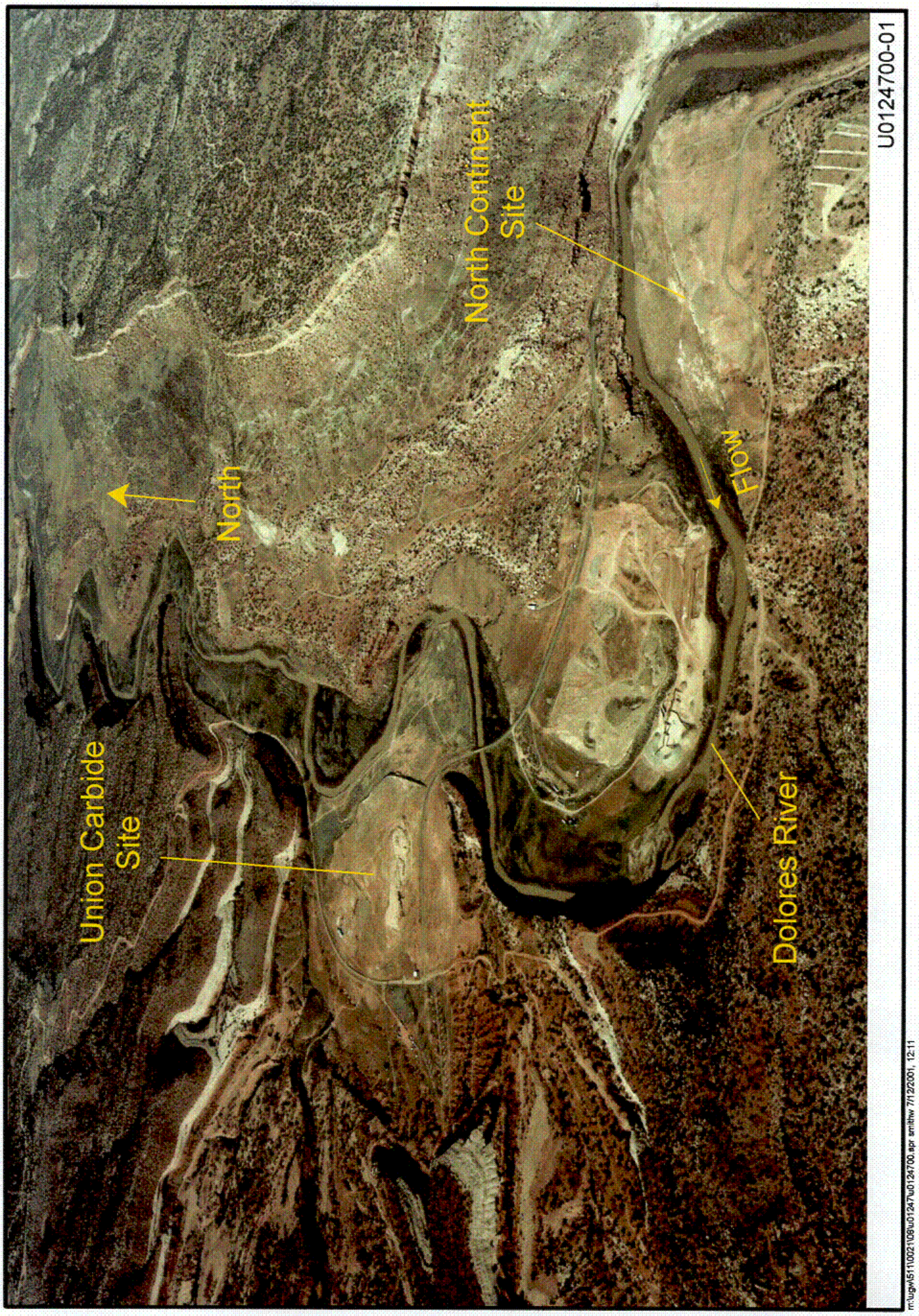

Figure 1. Location of the Slick Rock Site

C01

cobbles, and ranges in thickness from 10 to 21 ft. The UC site alluvium is underlain by approximately 50 ft of the Entrada Sandstone, which is underlain by the Navajo Sandstone. The NC site alluvium is underlain by the Morrison and Summerville Formations, which consist of interbedded clay, shale, mudstone, siltstone, and sandstone layers.

The alluvial aquifer in the vicinity of both sites is unconfined, while the Entrada Sandstone aquifer appears to be unconfined near the top of the unit and may be semi-confined near the bottom of the unit. The Morrison aquifer, based on the lithologic description of borehole 0275 and information found in the literature, appears to be semi-confined to confined, while the Summerville aquifer is assumed also to range from semi-confined to confined. The Navajo Sandstone aquifer is confined in the vicinity of the two sites.

2.2 Ground Water Flow System

Water level elevations measured in the wells screened in the alluvial aquifer in March 2001 are displayed in Figure 2. This map shows that the alluvial ground water flow trends to the north-northwest, and follows the canyon walls of the Dolores River valley. The alluvial aquifer receives recharge from upgradient subsurface flow, precipitation and snowmelt, and from the Dolores River during spring runoff. The Entrada Sandstone receives recharge from similar sources as the alluvial aquifer with the exception of the Dolores River.

Data collected indicate the alluvial aquifer discharges to the Dolores River during low flow. Discharge from the Entrada, Morrison, and Summerville is primarily a function of leakage from locations where these units crop out.

From this point on, only the alluvial aquifer and a "bedrock" aquifer will be discussed since they are the two aquifers included in the model. As previously mentioned, the Entrada underlies the alluvial aquifer at the UC site, while both the Morrison and Summerville formations underly the alluvial aquifer at the NC site. The hydraulic parameters of the Summerville Formation were not measured in the field due to lack of ground water encountered during the drilling of borehole 0275.

2.3 Hydrologic Boundaries

This model is divided into four layers. A detailed discussion of the layers is provided in Section 4.1. In layer 1 of the model, which represents the alluvium, the hydrologic boundaries are well defined by the Dolores River Canyon walls. In the vicinity of the UC site and the area between the sites the extent of the alluvium is controlled by the outcrops of the Entrada Sandstone along the western portions of the river valley, and by the Morrison Formation to the east. Morrison Formation outcrops along both sides of the Dolores River limit the extent of the alluvium in the vicinity of the NC site. The area beyond the limit of the alluvium is represented by inactive cells.

The northern and southern boundaries are not as well defined by hydrologic or geologic boundaries. The model extends approximately 3,000 ft to the south of the NC site, and approximately 3,000 ft north of the UC site.

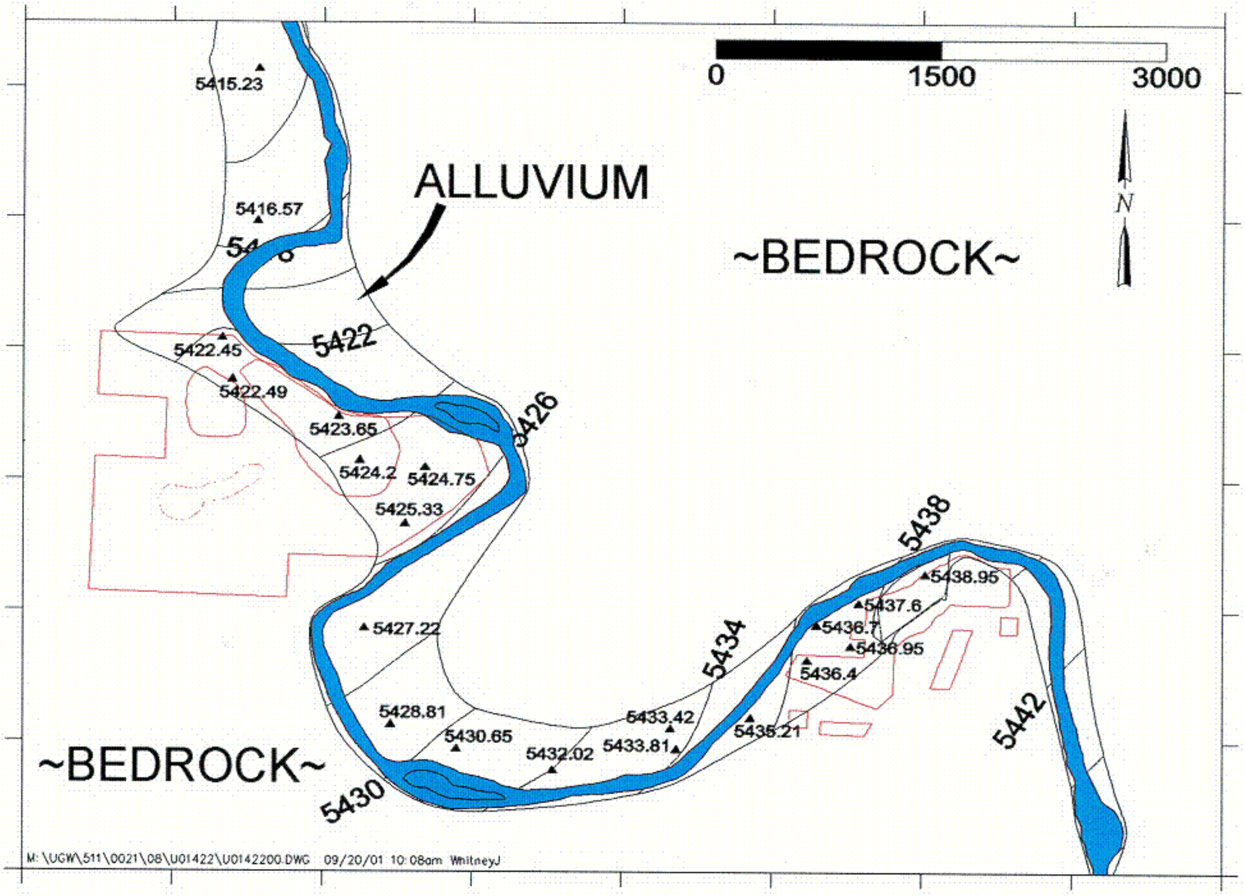

Figure 2. Alluvial Aquifer Ground Water Surface Contour Map, March 2001

Layers 2, 3, and 4 boundaries are not well defined. The extent of these layers is not limited by hydrologic or geologic boundaries, but model boundaries can be established far enough from the former sites to have minimal effect on the model results.

2.4 Hydraulic Properties

The flow model hydraulic properties of interest that influence the aquifer system are the horizontal and vertical hydraulic conductivity of the alluvial aquifer, areal recharge due to precipitation and snowmelt, and recharge from and discharge to the Dolores River.

2.5 Contaminant Transport Properties

The contaminant transport properties of interest are the initial contaminant concentration distribution, effective porosity, aquifer bulk density, distribution coefficient (K_d), and dispersivity.

2.6 Sources and Sinks

The Dolores River is a main source of recharge to the alluvial aquifer. Recharge over the area is an annual source of water to the site. The Dolores River is considered to be both a sink and a source (i.e., the aquifer discharges water to the river along some reaches, and the river recharges the alluvial aquifer along other reaches). These discharges and recharges are seasonal in nature.

2.6.1 Sources

Multiple sources of recharge to the alluvial aquifer have been identified. These include recharge from precipitation and snowmelt, from the upgradient alluvium of the Dolores River valley, and from the Dolores River.

Historical meteorological data from the Uravan, Colorado, weather station (station number 058560) was used as a source of precipitation data for the Slick Rock site. Data collected from this station are the most representative since this station is the closest to the site (approximately 26 miles northeast) and lies at approximately the same elevation. Data collected from 1960 through 2000 indicate there is on average 12.8 inches (0.0029 feet per day [ft/day]) of annual precipitation in the Slick Rock area, with July through October being the wettest months.

The Thronthwaite Method (Thronthwaite 1957) was used to calculate the recharge potential for the alluvial aquifer. This method takes into account the mean monthly air temperature, annual precipitation, potential evaporation, and potential runoff to estimate the amount of precipitation available for recharge to the aquifer. Of the 12.8 in/yr of precipitation, an estimated 1.99 to 2.79 in/yr is available for aquifer recharge. This translates into a net recharge flux of 0.00046 to 0.00064 ft/day.

2.6.2 Sinks

Two main sources of discharge from the alluvial aquifer have been identified. These include evapotranspiration and ground water discharge from the alluvial aquifer into the Dolores River. Evapotranspiration is accounted for by the use of a net recharge estimate (which includes the loss due to evapotranspiration).

2.7 Conceptual Water Budget

A conceptual water budget was developed for the Slick Rock site to compare to the ground water modeling results. This budget was designed for the alluvial aquifer only (layer 1 of the model), which dictates over 90 percent of the ground water flow within the model.

There are four main components to the water budget for the Slick Rock site, two of which act as sources (supplying water to the alluvial aquifer), and two that act as sinks (removing water from the alluvium). The source components include alluvial aquifer recharge from precipitation and the Dolores River. Sink components include ground water discharge from the alluvium into the Dolores River, and ground water flow through the general head boundary established along the northern extent of the model. The extent of the alluvium is very limited near the southern edge of the modeled area, and therefore is not considered to be a main source of flow into the model. Each component is summarized in Table 1 and is discussed separately.

Table 1. Conceptual Water Budget for the Slick Rock Ground Water Model

Description	Flow Component	Flux Range (ft/day) Min	Flux Range (ft/day) Max	Area (ft^2)	Inflow Range (ft^3/day) Min	Inflow Range (ft^3/day) Max	Outflow Range (ft^3/day) Min	Outflow Range (ft^3/day) Max
Recharge from Precipitation	Inflow	0.00045	0.00064	7,758,750	3,491	4,966	0	0
Recharge from River	Inflow	0.34	0.77	275,100	93,534	211,827	0	0
Discharge from River	Outflow	0.34	0.77	275,100	0	0	93,534	211,827
Northern Boundary	Outflow	0.34	0.77	6,600	0	0	2,244	5,108
Total					97,025	216,793	95,778	216,935

2.7.1 Recharge from Precipitation

As presented in Section 2.6.1 of this Appendix, based on the Thronthwaite Method there is between 1.99 and 2.79 in/yr of precipitation available for recharging the alluvium. This estimate represents a net precipitation, with evapotranspiration taken into account. This range translates into a flux of 0.00045 to 0.00064 ft/day. Applying this flux to the area of active cells within layer 1 (7,758,750 ft^2), the amount of recharge is estimated to range from 3,491 to 4,966 ft^3/day.

2.7.2 Recharge to the Alluvium from the Dolores River

The influx of water entering the alluvium from the Dolores River was estimated using the Darcy equation of Q=KIA, where Q is the total flow (ft^3/day), K is the hydraulic conductivity (ft/day), I is the hydraulic gradient (unitless), and A is the area perpendicular to the flow (ft^2).

For the purposes of this water budget, a hydraulic conductivity range of 80 to 180 ft/day was assumed. Using the average alluvial aquifer gradient of 0.0043, the flux ranges from 0.34 to 0.77 ft/day.

Throughout the Dolores River valley, the river acts as both a source and a sink for the alluvial aquifer. A total of 2,752 cells are contained in the river package. The recharge and discharge is associated only with the cells that are adjacent to the alluvium. It is assumed that one-third of these river cells do not influence the flow into and out of the river. As a result, of the total 2,752 cells it is assumed that 917 cells control recharge to the river and the remaining 917 cells control the discharge. Applying an average saturated thickness of 12 ft to these cells, along with a cell width of 25 ft, the cross-sectional area becomes 275,100 ft^2.

Applying the flux range to the area of cells associated with water movement from the river into the aquifer, the total amount of recharge ranges from 93,534 to 211,827 ft^3/day.

2.7.3 Discharge from the Alluvium to the Dolores River

A similar approach was taken to estimate this flow component as described above. The same assumptions and input values were used, and there is an estimated 93,534 to 211,827 ft^3/day that flows from the alluvium into the Dolores River.

2.7.4 Groundwater Flow through the Model Northern Boundary

Again applying the Darcy equation to the northern boundary, the volume of water leaving the system downgradient of the modeled area can be estimated. Assuming the same hydraulic conductivity range of 80 to 180 ft/day, and applying the same groundwater gradient, the flux ranges from 0.34 to 0.77 ft/day. Along the northern boundary there are 22 cells, with a width of 25 ft and an average saturated thickness of 12 ft. Applying this flux range to a cross-sectional area of 6,660 ft^2, the total flow leaving the modeled area ranges from 2,244 to 5,108 ft^3/day.

As shown in Table 1, based on these assumptions and parameter estimations the total amount of flow into the alluvial aquifer system is expected to range between 97, 025 and 216,793 ft^3/day. The total flow leaving the alluvial aquifer system is expected to range from 95,778 and 216,935 ft^3/day.

3.0 Computer Code

3.1 Code Selection

MODFLOW (McDonald and Harbaugh 1988), a modular three-dimensional finite-difference ground water flow model published by the U.S. Geological Survey (USGS) was selected as the flow code for this project. MT3DMS (Zheng and Wang 1999), a modular three-dimensional transport model for simulation of advection, dispersion, and chemical reaction of contaminants in ground water systems was selected as the transport code for this project. Each of these codes is divided into a main program and a group of independent subroutines called *modules*. Each module is made up of *packages* that deal with a single aspect of the simulation. The user of either MODFLOW or MT3DMS need only use those modules that simulate the stresses placed upon the flow and transport systems. This version of MT3DMS contains a new transport solver that is very efficient and makes multiple long simulation runs feasible.

GWVistas (Environmental Simulations, Inc. 1997), a Windows-driven, graphical, pre- and post-processor for MODFLOW and MT3DMS is used in conjunction with the site model to facilitate data entry, data-file modification, program execution, and analysis of modeling results.

3.2 Code Description

These codes are fully described in the references cited. They have been verified, benchmarked, and approved for use by most government and regulatory agencies.

4.0 Steady State Flow Model

4.1 Model Grid and Model Boundary Conditions

Because the Dolores River changes its course through the portion of the river valley containing the sites, the model grid was not rotated. The x-axis of the model is oriented in the east/west direction. A 25 ft by 25 ft orthogonal grid, consisting of 260 rows and 320 columns, was designed to encompass the sites and an extensive area surrounding the sites. The western and eastern boundaries of the model were arbitrarily set such that this boundary does not influence the modeling results.

The northern boundary is set approximately 3,000 ft north of the UC site. Setting the boundary at this location accomplished two things: (1) the boundary is far enough away from the UC site such that any condition assigned to this boundary would not impact the area of the UC site, and (2) the boundary is only approximately 1,300 ft north of well 0685, therefore, some data are available from a nearby source to assist with calibrating the model. For the southern boundary, which is set 3,000 ft south of the NC site, the same is true. The boundary was set far enough away from the site to not influence the modeling results, and is located between the two background wells and the NC site. (Figure 3 shows the model extent of layer 1 [the gray area represents inactive cells]. Layers 2, 3, and 4 cover the same area as layer 1, with all cells within the area active).

Figure 3. Extent of Ground Water Model

C03

This model is divided into four layers, with layer 1 representing the alluvial material and layers 2, 3, and 4 representing the bedrock unit underlying the alluvium. In the model layer 1 ranges from 10 to 21 ft thick. As previously discussed, the Morrison and Summerville Formations underlie the NC alluvium, while the Entrada Sandstone underlies the UC alluvium. Each of these bedrock units dip approximately 6° to the northeast.

In the vicinity of the UC Site, the Entrada Sandstone is approximately 50 ft thick. The model was set up to have Layers 2 and 3 each set to a thickness of 12.5 ft, while Layer 4 was set to 25 ft thick, for a total of 50 ft. Due to the dip of the beds, the thickness of these 3 layers increases towards the east; however, the model was established to have a total bedrock thickness of 50 ft in the vicinity of the UC Site, as was measured during the field investigation.

For modeling purposes, the model contains a single bedrock unit underlying both the NC and UC sites that was assigned the hydraulic properties of the Entrada Sandstone. This is considered to be a conservative approach, since the Entrada Sandstone is typically more conductive than the other two formations.

The bedrock unit is split into three layers for contaminant transport modeling purposes, with contaminant initial concentrations assigned to layer 2 and layers 3 and 4 assigned background concentrations. As a result only the upper-most zone of the bedrock contains contamination, which is consistent with the actual field conditions. If the bedrock unit was not spilt into these different layers, then the model would have assigned the contaminant initial concentrations to the entire bedrock thickness.

The Dolores River, flowing generally north and located adjacent to the two sites, is represented in the model using the river package. River stage elevations for the steady state deterministic and steady state stochastic models are based on data collected from USGS Gaging Station #09168730, located along the Dolores River just upstream of the UC site (Figure 4). During the field investigation seven river elevation measuring points (0342 through 0348) were established along the Dolores between the Highway 141 bridge and just downstream of the UC site (Figure 4). River elevations were measured at various times during the year, and compared to the rating curve created for the USGS gaging station.

Table 2 provides the data collected from locations 0342 through 0348 during various times of the year, and the associated gradient established between each location. The statistical model river flow from September 1999 to June 2001 (which represents the most complete data set) is 50 cubic feet per second (cfs). On October 20, 2000, river elevations were measured at the seven locations at which time the Dolores River flow was at 48 cfs. As a result, the model cells containing the river were assigned stage elevations equivalent to those measured on October 20, 2000, since the flow at this time is closest to that which is most commonly encountered.

The River Package also requires input for river bottom elevation, thickness of the riverbed, and conductivity of the riverbed material. Based on field observations, the Dolores River adjacent to the UC and NC sites is on average 1 to 2 ft deep. As a result, the river bottom elevation is set 1.6 ft below the stage elevation for each river cell. The riverbed material was assumed to be 1 ft thick, and is assigned a conductivity of 12.1 ft/day, which is comparable to the assumed vertical hydraulic conductivity of the alluvial material.

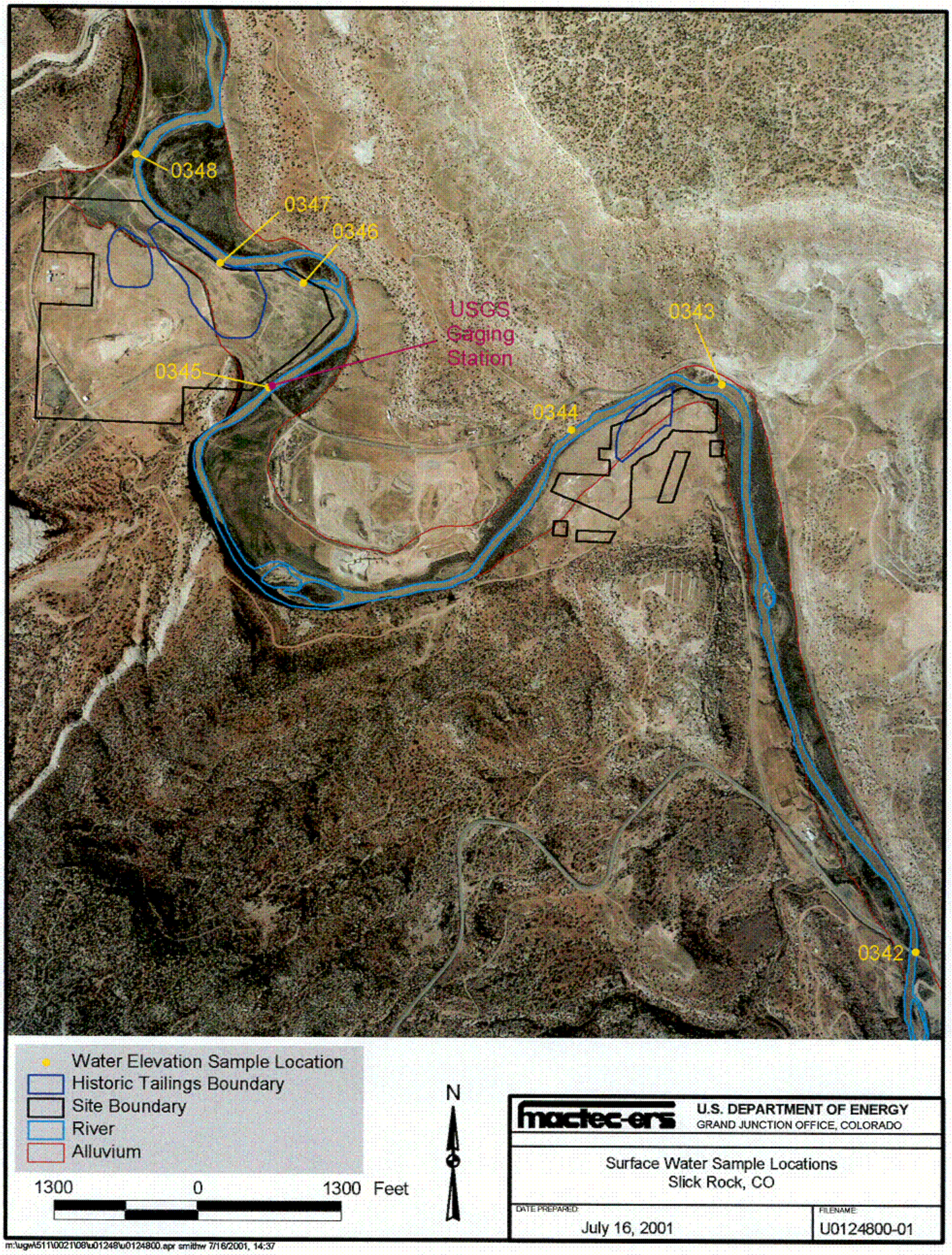

Figure 4. River Elevation Measuring Point Location Map

C04

Table 2. Dolores River Stage Elevation Data

	Dolores River Stage Elevation (ft MSL)			
Date	**9/13/00**	**10/20/00**	**3/27/01**	**4/10/01**
Location				
0342	5,454.05	5,454.06	5,454.90	5,454.71
0343	dry	dry	5,441.70	5,441.65
0344	5,436.78	5,436.76	5,437.26	5,437.12
0345	5,427.45	5,427.47	5,427.85	5,427.76
0346	5,424.87	5,424.89	5,425.59	5,425.49
0347	5,423.12	5,423.11	5,423.78	5,423.67
0348	5,421.14	5,421.40	NA	NA
flow (cfs)	40	48	141	109
stage (ft)	4.12	4.16	4.54	4.43

		Dolores River Hydraulic Gradient				
FROM	**TO**	**9/13/00**	**10/20/00**	**3/27/01**	**4/10/01**	**avg**
0342	0343	na	na	0.0024	0.0024	0.0024
0343	0344	na	na	0.0032	0.0032	0.0032
0344	0345	0.0016	0.0016	0.0017	0.0016	0.0016
0345	0346	0.0013	0.0013	0.0012	0.0012	0.0012
0346	0347	0.0023	0.0024	0.0024	0.0024	0.0024
0347	0348	0.0019	0.0016	na	na	0.0018

4.2 Hydraulic Parameters

Aquifer tests were completed at three different locations (one location on the NC site, another location on the UC site, and a third downgradient of the UC site) to determine the hydraulic parameters of the alluvial aquifer. Tests were performed in September 2000 and February 2001. Analysis of these data indicated that the horizontal hydraulic conductivity (K_x) ranged from 13 to over 300 ft/day, with a geometric mean of 121 ft/day. A sensitivity analysis showed that a conductivity of 121 ft/day provided the best fit for the model (Section 4.6). As a result, 121 ft/day was used for the steady state calibrated model, with the horizontal conductivity equal to the transverse conductivity (K_y). The vertical conductivity (K_z) was set at 12.1 ft/day, or 10% of the horizontal conductivity.

4.3 Boundary Conditions

In layer 1 of the model, no-flow cells are assigned to areas beyond the extent of the alluvium (Figure 3). At the northern (downgradient) end of the active cells, a general head boundary (GHB) is present. This type of boundary is set at this location in order to reduce the impact of the extent of the model grid on the modeling results. A ground water elevation is assigned to the GHB which represents the elevation that would be encountered 1,500 ft north of the grid. This elevation is based on the ground water gradient measured north of the UC site, in the area between wells 0684 and 0685.

Layer 1 also includes the river package cells in areas where the river flows through the top layer (Figure 3 and Section 4.1).

4.4 Calibration Objectives and Results

Prior to beginning model calibration, it is important to decide upon the acceptance criteria for the calibration process. The acceptance criteria chosen for this project are:

1) The model must be able to simulate the general flow directions observed at the site. Simulated steady state ground water elevations are presented in Figure 5. The ground water flow direction based on these elevations is similar to that which is based on Figure 2.

Figure 5. Simulated Alluvial Aquifer Ground Water Surface Contour Map

2) The numerical model should not have any inherent bias. In other words, because the model will either over or under predict the measured hydraulic heads, the arithmetic mean of the residuals should be as close to 0.0 as possible and fairly evenly distributed above and below 0.0. Figure 6 displays the observed hydraulic heads versus residuals for the steady state model. The plot shows there is a negative bias, in other words, the model overestimates the water levels compared to the measured water levels.

3) Twenty-one calibration targets are located in layer 1 (Figure 7) and two targets in layer 2 (Figure 8) of the steady state model. The target values are based on historical average water level data. Wells 0508 and 0510 (installed in 1982), and wells 0684 and 0685 (installed in 1986) were installed prior to the 2000 field investigation, and as a result the average water level for these locations was based on a larger database. The remaining targets, all part of the 300 series of wells, were installed in August or September 2000 and the average water level was based on the available data since installation. Several flow model calibration objectives were set prior to calibrating the model. The objectives and the calibrated model results for the steady state are shown in Table 3. Although some of the criteria are not met (residual mean, sum of squares, and minimum residual), they are not

C05

exceeded by a significant amount. The target residual values are shown on Figures 9 and 10 for the layer 1 and layer 2 targets, respectively. A negative residual value indicates the simulated head is greater than the observed head.

4) The mass balance error must be less than 1 percent. The mass balance error for the steady state model is 0.022 percent.

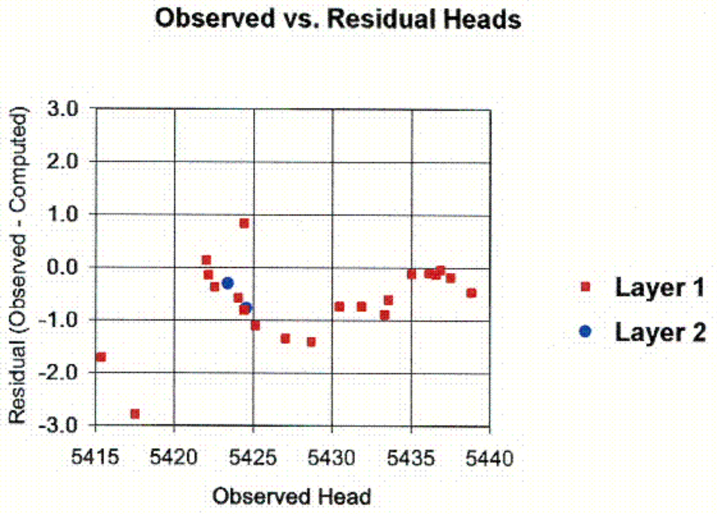

Figure 6. Comparison of Residual versus Observed Head

Figure 7. Layer 1 Targets

C06

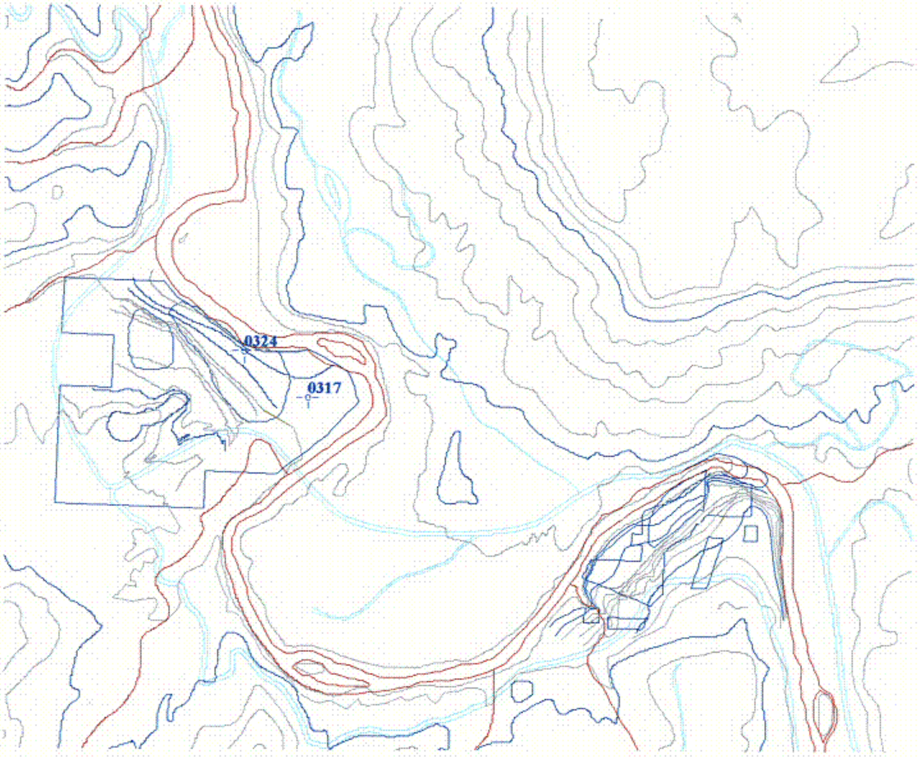

Figure 8. Layer 2 Targets

Table 3. Calibration Objectives and Results

	Residual Mean (ft)	Absolute Residual Mean (ft)	Sum of Squares (ft^2)	Minimum Residual (ft)	Maximum Residual (ft)	Standard Deviation/Range (%)
Objective	0	< 1.	< 20.	> -2.0	< 2.0	< 5.0
Actual	-0.625	0.709	20.81	-2.786	0.839	3.063

C07

Figure 9. Layer 1 Target Residual Values

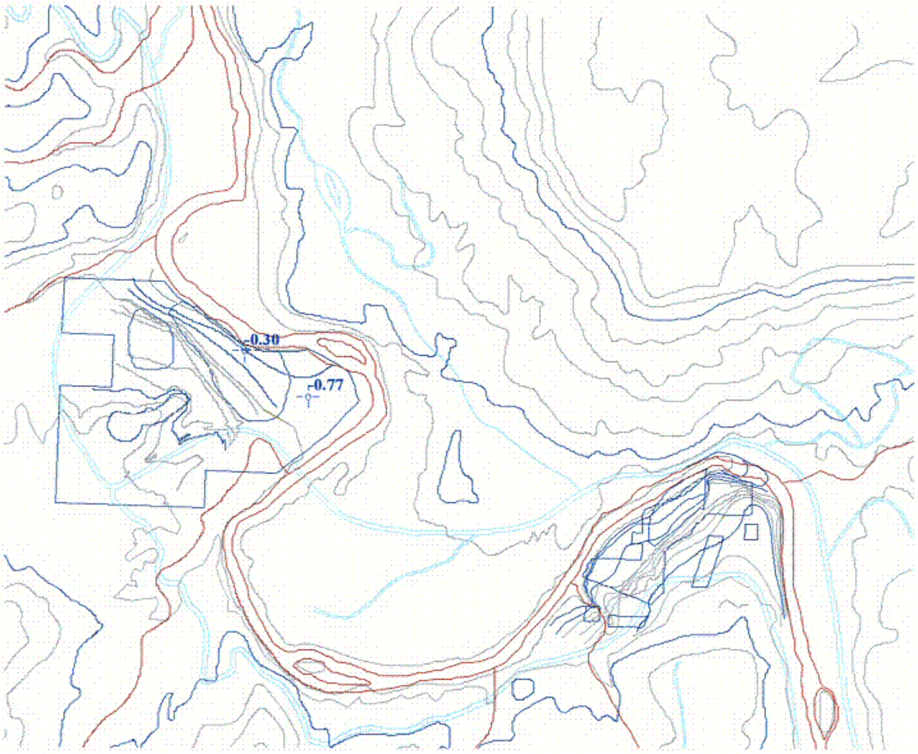

Figure 10. Layer 2 Target Residual Values

C08

4.5 Calibration and Residual Analysis

The steady state calibrated model results and the residual at each target are shown in Table 4. A plot of predicted (computed) hydraulic head versus observed hydraulic head would fall on a straight line for a calibrated model. Figure 11 demonstrates that the model accurately predicts field measurements.

Table 4. Calibration Target Residuals

Well	Model Layer	Observed Head (ft MSL)	Computed Head (ft MSL)	Residual (ft)
0317	2	5,424.54	5,425.31	-0.77
0324	2	5,423.37	5,423.67	-0.30
0313	1	5,425.14	5,426.24	-1.10
0315	1	5,424.39	5,425.20	-0.81
0318	1	5,424.03	5,424.60	-0.57
0319	1	5,422.14	5,422.28	-0.14
0320	1	5,422.01	5,421.87	0.14
0508	1	5,424.41	5,423.57	0.84
0510	1	5,422.55	5,422.92	-0.37
0684	1	5,417.53	5,420.32	-2.79
0685	1	5,415.38	5,417.09	-1.71
0310	1	5,433.56	5,434.17	-0.61
0312	1	5,433.32	5,434.21	-0.89
0328	1	5,431.85	5,432.59	-0.74
0329	1	5,430.45	5,431.19	-0.74
0330	1	5,428.67	5,430.07	-1.40
0331	1	5,427.05	5,428.40	-1.35
0302	1	5,438.8	5,439.27	-0.47
0303	1	5,437.48	5,437.67	-0.19
0304	1	5,436.54	5,436.66	-0.12
0305	1	5,436.84	5,436.89	-0.05
0309	1	5,435.03	5,435.15	-0.12
0327	1	5,436.13	5,436.23	-0.10

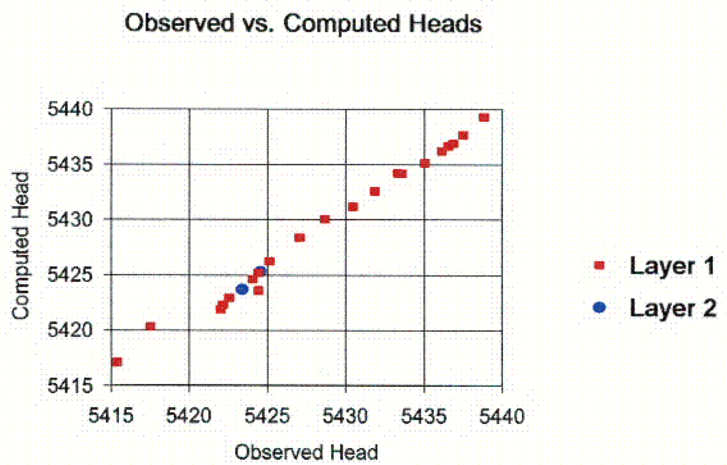

Figure 11. Comparison of Computed Head versus Observed Head

C09

4.6 Flow Model Sensitivity Analysis

A sensitivity analysis is useful to evaluate the effects that variations in flow and transport parameters have on the final predicted results. Highly sensitive parameters can be treated as uncertain for stochastic simulations. GWVistas contains an auto sensitivity package which allows the user to run the flow model using up to eight different values for the one parameter to be tested, and compares the residual sum of squares result from each run. Generally only five of the maximum eight variations of the parameter are necessary in order to determine if the parameter is sensitive. The flow parameters selected for the sensitivity analysis are horizontal hydraulic conductivity of layers 1 and 2, vertical hydraulic conductivity of layers 1 and 2, recharge, river conductance, GHB conductance, and river stage. Table 5 presents the values assigned to each flow parameter for the sensitivity analysis.

Table 5. Values Used for the Flow Model Sensitivity Analysis

Parameter (units)	Flow Parameter Values				
Kx, Layer 1 (ft/d)	60.5	90.8	121	151.3	181.5
Kz, Layer 1 (ft/d)	6.05	9.08	12.1	15.1	18.1
Kx, Layer 2 (ft/d)	0.5	0.75	1.0	1.25	1.5
Kz, Layer 2 (ft/d)	0.05	0.075	0.1	0.125	0.15
Recharge (ft/d)	0.00028	0.000041	0.00055	0.00069	0.00083
River Conductance (ft^2/d)	6.1	9.1	12.1	15.1	18.2
GHB Conductance (ft^2/d)	60.5	90.8	121	151.3	181.5
Change in River Stage (ft)	-0.6	-0.3	0	0.3	0.6

The criterion used for the sensitivity analysis for these flow parameters is the residual sum of squares, (i.e., the difference between the computed head and observed head at the 23 target wells). The results of the sensitivity analysis for these eight parameters are shown in Figures 12 through 19. Visually, this qualitative (subjective) analysis indicates that the model is only sensitive to changes in the river stage.

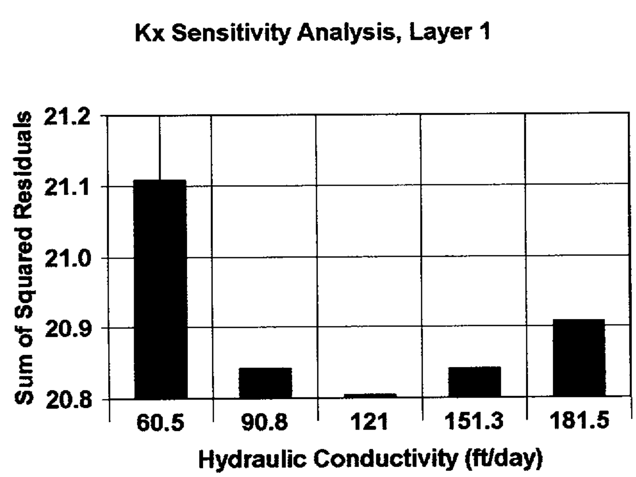

Figure 12. Layer 1 Horizontal Hydraulic Conductivity Sensitivity Analysis Results

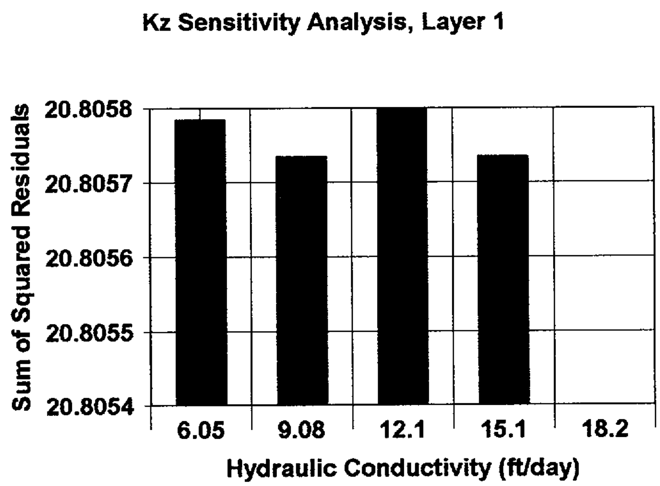

Figure 13. Layer 1 Vertical Hydraulic Conductivity Sensitivity Analysis Results

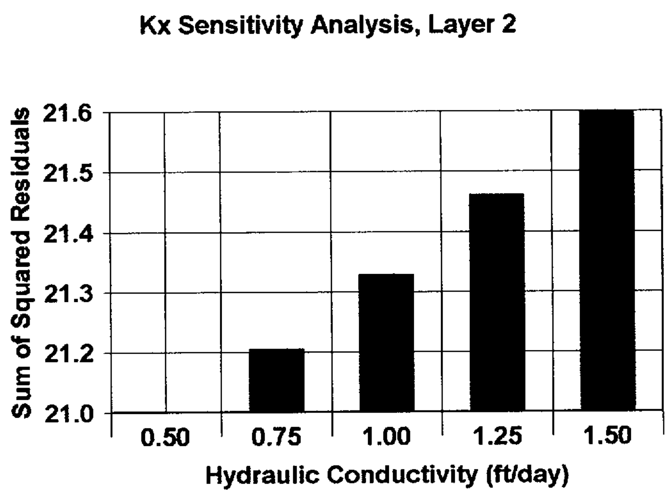

Figure 14. Layer 2 Horizontal Hydraulic Conductivity Sensitivity Analysis Results

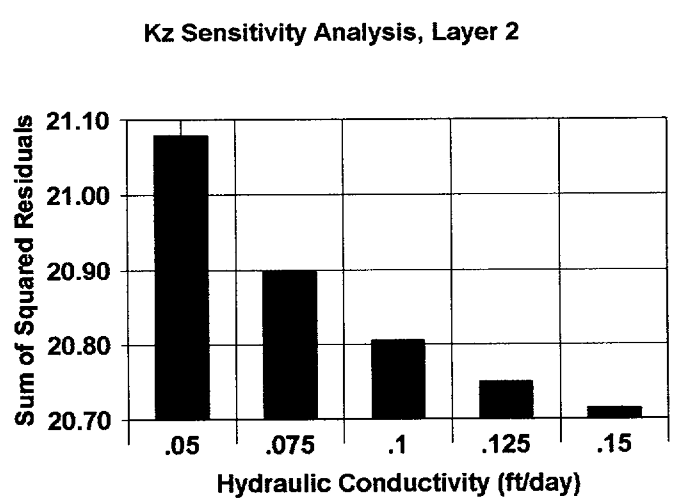

Figure 15. Layer 2 Vertical Hydraulic Conductivity Sensitivity Analysis Results

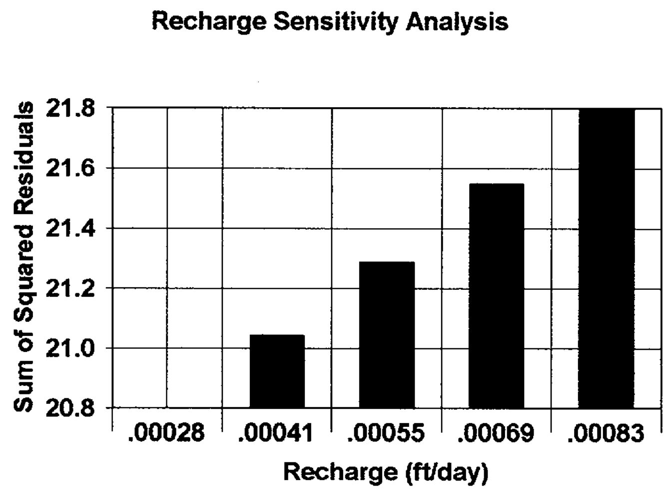

Figure 16. Recharge Sensitivity Analysis Results

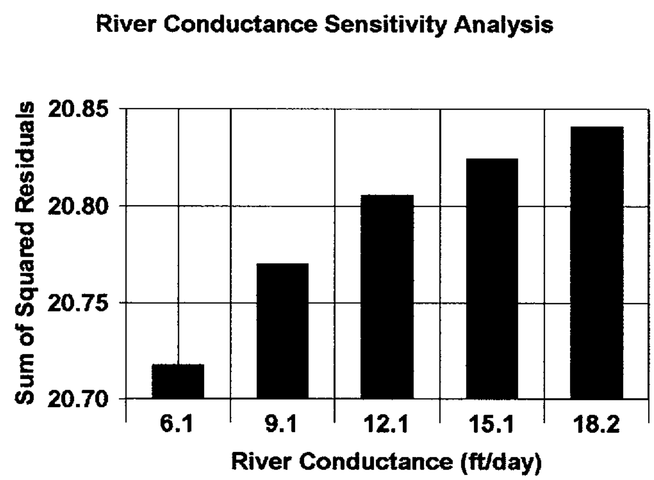

Figure 17. River Conductance Sensitivity Analysis Results

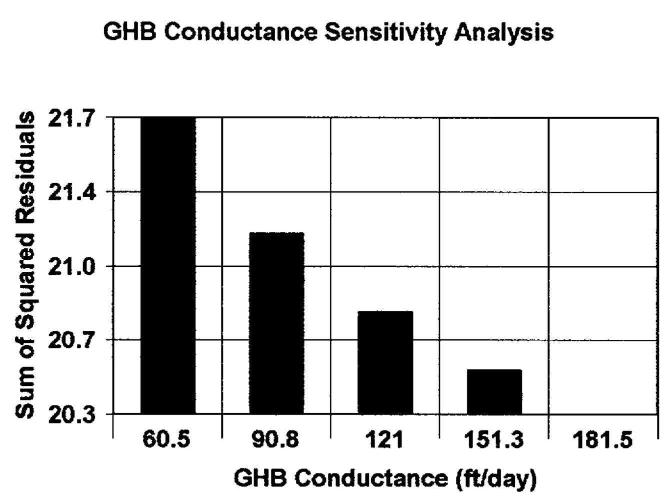

Figure 18. General Head Boundary Conductance Sensitivity Analysis Results

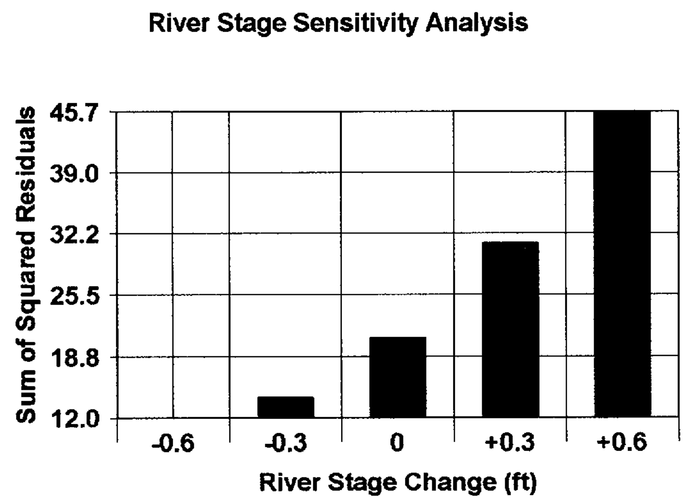

Figure 19. River Stage Sensitivity Analysis Results

As an additional quantitative (objective) check, the coefficient of variation (CV) of the residual sum of squares was calculated for each of these parameters. The CV is defined as the standard deviation (σ) divided by the mean ($\bar{x}$). Parameters resulting in a CV greater than 1 percent between the predicted residual sum of squares for each parameter value are considered sensitive. The CV has been calculated using an unbiased estimate of the standard deviation (σ) adjusted for sample size (Dixon and Massey 1957). The results of the CV analysis are shown in Table 6. Based on these criteria, the model is sensitive to horizontal conductivity of layer 2, recharge, GHB conductance, and the Dolores River stage.

Table 6. Flow Parameter Coefficient of Variation Analysis

Flow Parameter	Mean	Standard Deviation	Adjusted Standard Deviation	Coefficient of Variation
Horizontal Hydraulic Conductivity, Layer 1	20.90	0.1219	0.1294	0.0062
Vertical Hydraulic Conductivity, Layer 1	20.81	0	0	0
Horizontal Hydraulic Conductivity, Layer 2	21.32	0.2305	0.2446	0.0115
Vertical Hydraulic Conductivity, Layer 2	20.85	0.1448	0.1536	0.0074
Recharge	21.3	0.3953	0.4194	0.0197
River Stage	24.84	13.83	14.67	0.591
GHB Conductance	20.91	0.5357	0.5684	0.0272
River Conductance	20.79	0.0476	0.0506	0.0024

In addition to running a sensitivity analysis for the river conductance, small-scale sensitivity analyses were completed for the width of the river cells, and river bottom thickness. As discussed in Section 4.1, the grid for the model is set at 25 ft by 25 ft. Applying the base map which contained the location of the Dolores River to locate the river over the grid, it was apparent that in many instances the river did not fill the entire cell (i.e., the cell only contained a portion of the river). For cells in which the river occupied greater than 50 percent of the cell, the entire cell was designated as part of the river package. Likewise, cells where the river occupied less than 50 percent of the cell were not assigned river package parameters. In order to determine if the cell width for these cells needed to be adjusted, a sensitivity analysis was performed where the cell width was reduced by 50 percent. The model was re-run with the adjustment, and the results did not significantly vary from the unaltered model, suggesting the model is not sensitive to this parameter.

The same was true for the riverbed thickness. Different values were input for this parameter, and the results indicate the parameter is not sensitive.

Despite the fact that the sensitivity analysis indicates the model would be better calibrated with a the Dolores River stage reduced by at least 0.6 ft, this change was not made to the model. Field observations noted the river was 1 to 2 ft deep, and making this change based on the model calibration results would produce a less representative conceptual model. As a result, the river depth remained at 1.6 ft.

5.0 Steady State Contaminant Transport Model

5.1 Transport Parameters

The contaminant transport parameters of interest are the initial contaminant concentration distribution, longitudinal, transverse, and vertical dispersivity, effective porosity, bulk density, and the distribution coefficient (K_d).

Initial contaminant concentration plumes were developed in **Surfer®** for the alluvial zone (layer 1) and the top upper-most bedrock zone (layer 2) using February/March 2001 data. Layers 3 and 4 are assumed to have not been impacted by the site activity; therefore, only background concentrations are assigned to these layers.

Each set of data were kriged in **Surfer®** and interpolated to approximately a 12.5 ft grid spacing, or one-half of the model grid size. This surface was then interpolated to all active model grid cell centers and imported as the initial concentration plume into the appropriate layer. The plots presented in Figures 20 through 29 show the initial concentration plumes for model layers 1 and 2 for nitrate, manganese, molybdenum, selenium, and uranium, respectively.

The literature on dispersivity as it relates to large-scale models is vague and often contradictory, with longitudinal values ranging from 2 percent to 30 percent of the length of the plume or maximum flow path length. In addition, dispersivity is almost impossible to measure in the field for large sites. The primary (or longitudinal) flow direction for this site is to the north, with a slight trend to the northwest. The flow direction generated from the MODFLOW model dictate the longitudinal and transverse dispersivity directions. Values of 100, 10, and 1 ft have been assigned to longitudinal, transverse, and vertical dispersivity for layer 1 of the model, respectively. Values of 20, 2, and 0.2 have been assigned to longitudinal, transverse, and vertical dispersivity for layers 2, 3, and 4, respectively. Commonly a value of 10 percent of the length of the plume path is used for longitudinal dispersivity. With a maximum flow path length of approximately 1,500 ft, this dispersivity value is ~7 percent of the length and considered a conservative estimate.

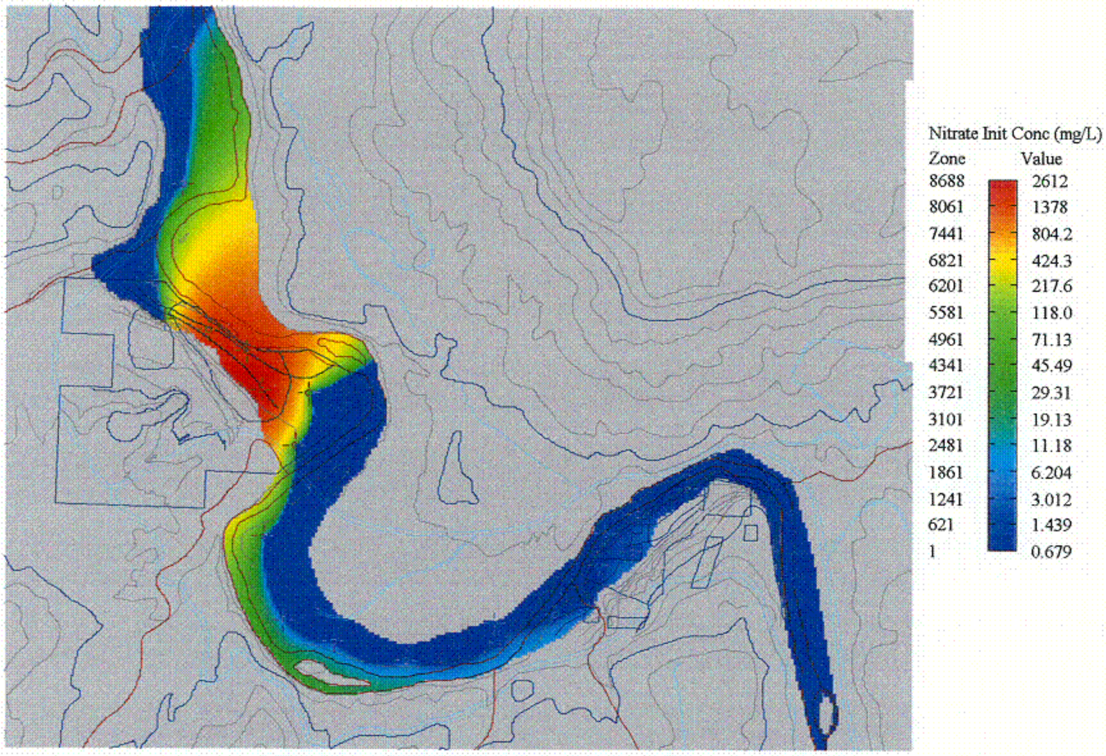

Figure 20. Layer 1 Nitrate Initial Concentration

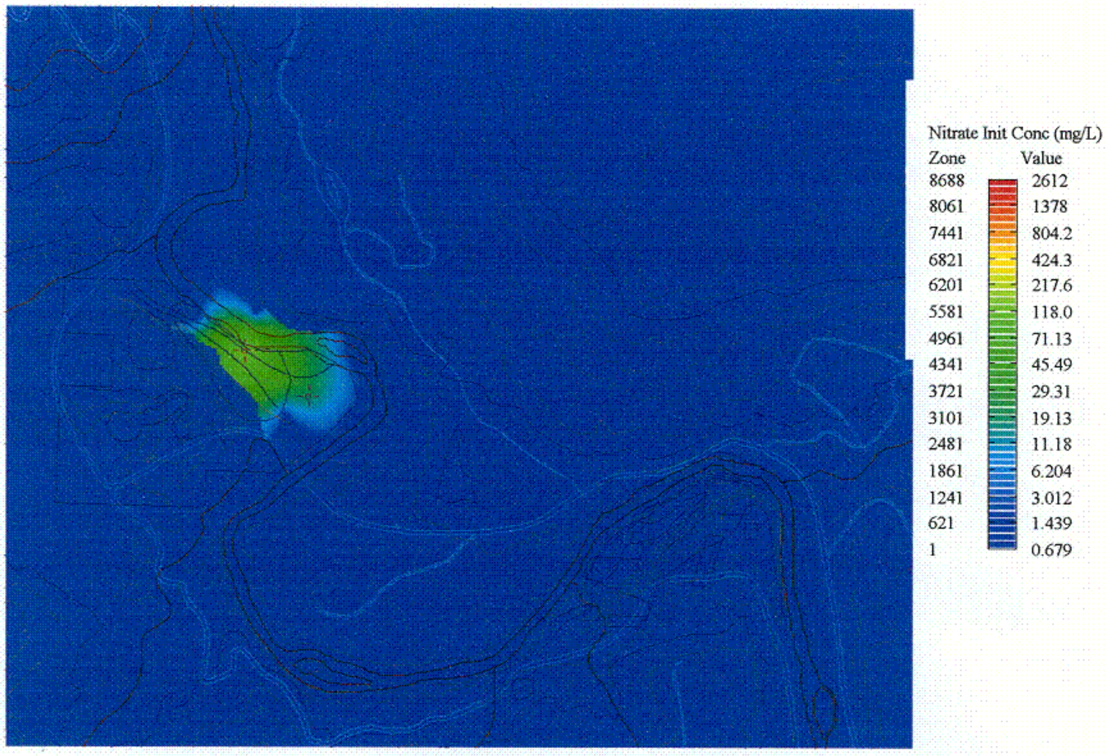

Figure 21. Layer 2 Nitrate Initial Concentration

C10

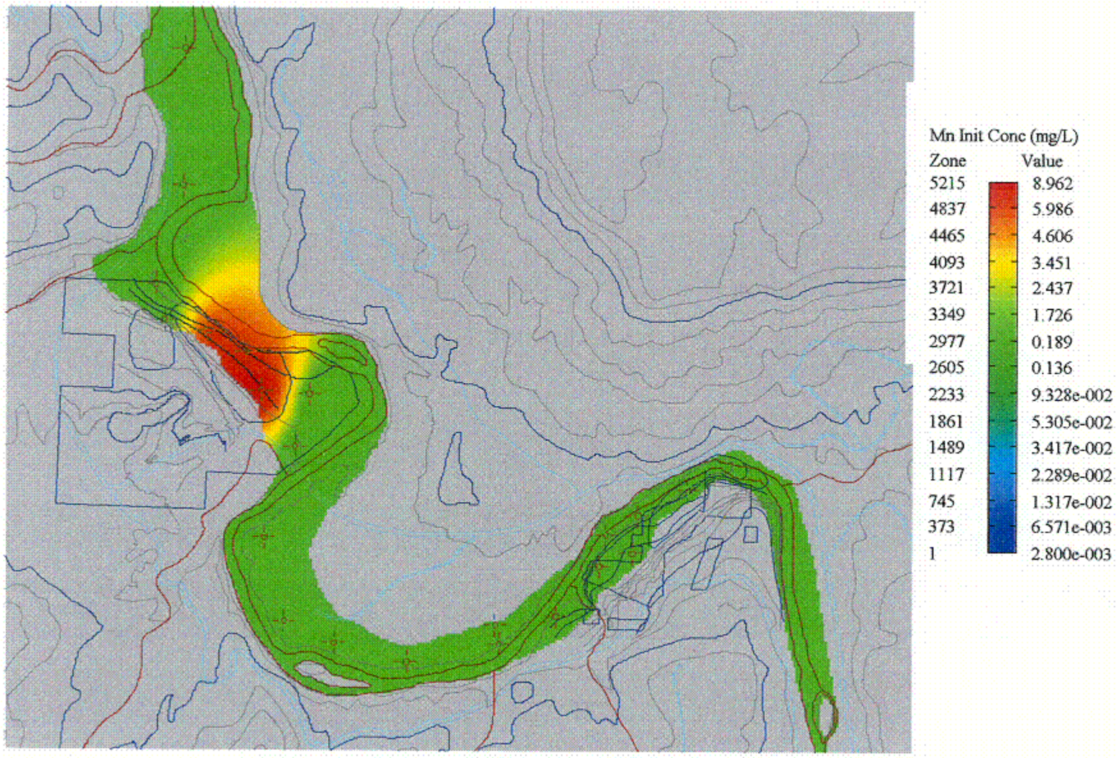

Figure 22. Layer 1 Manganese Initial Concentration

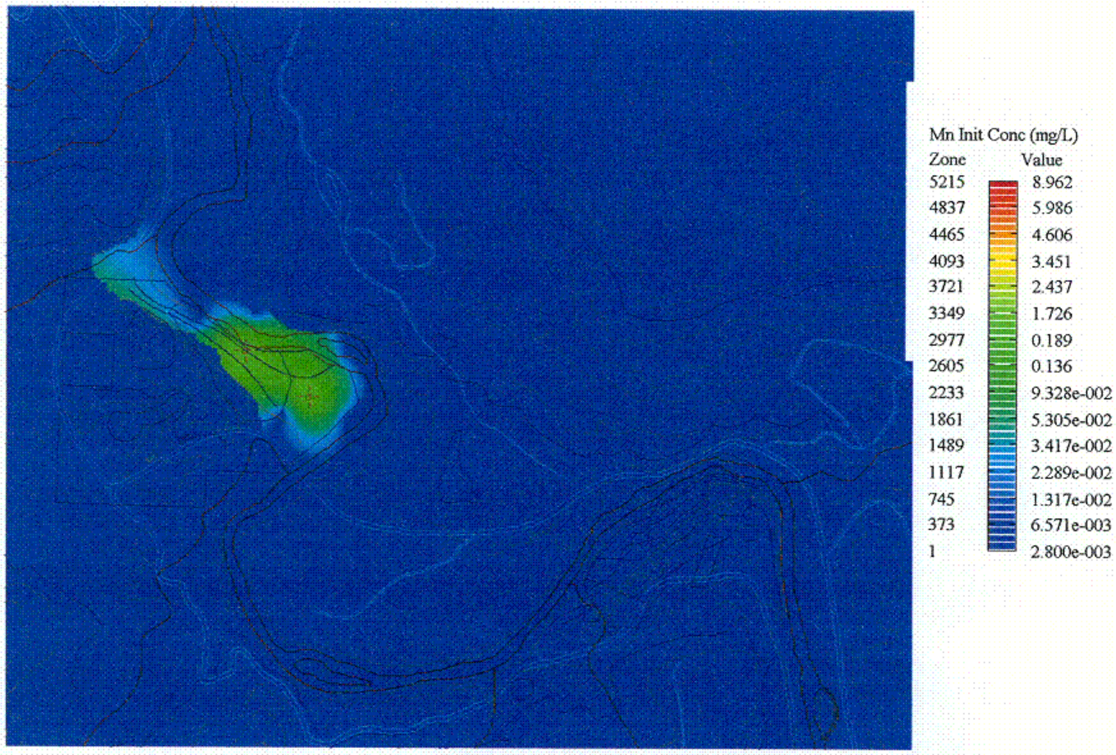

Figure 23. Layer 2 Manganese Initial Concentration

C11

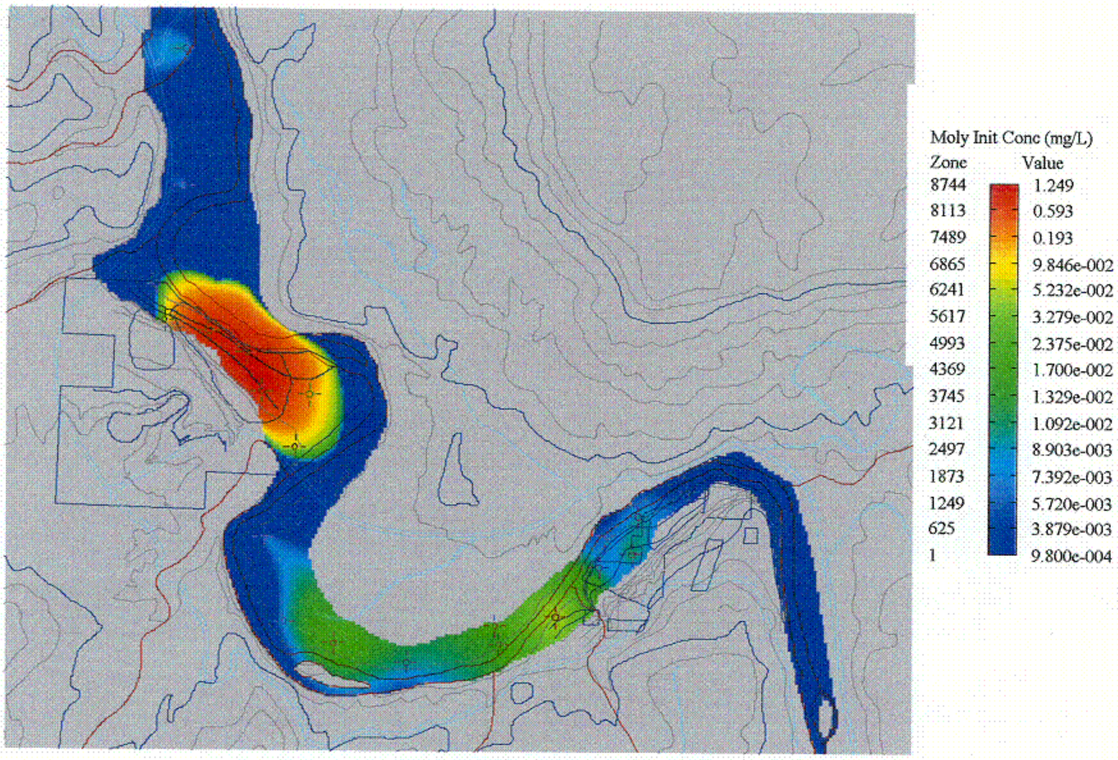

Figure 24. Layer 1 Molybdenum Initial Concentration

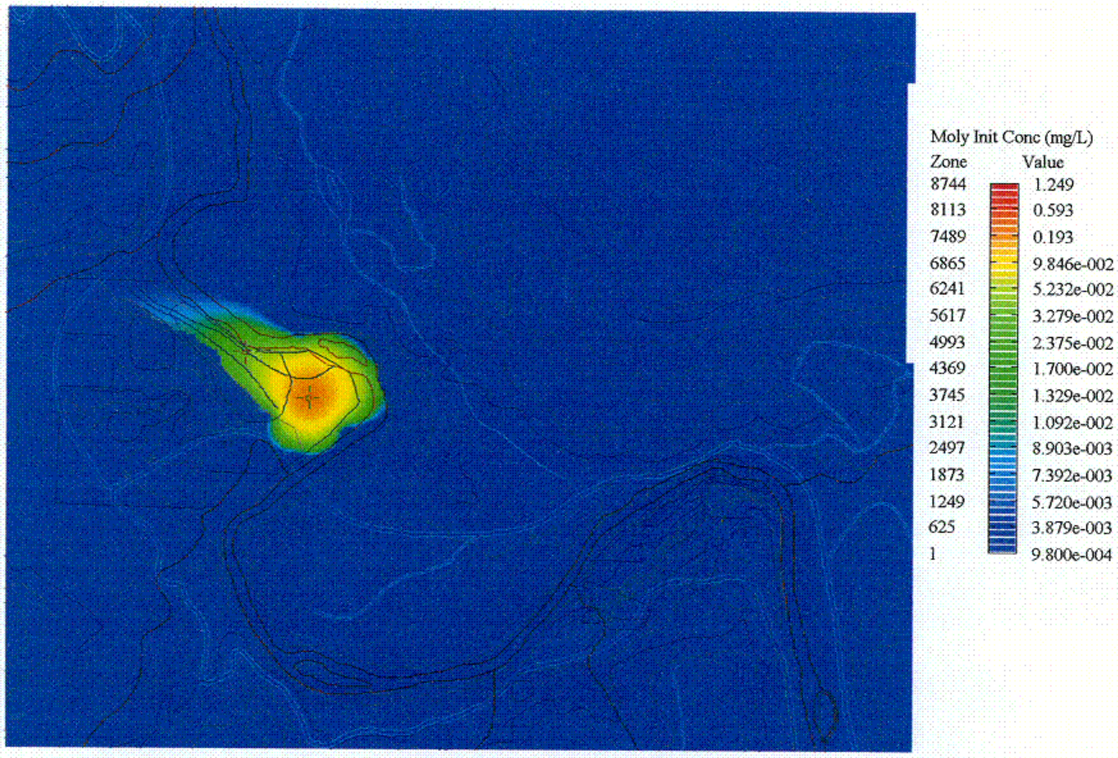

Figure 25. Layer 2 Molybdenum Initial Concentration

C12

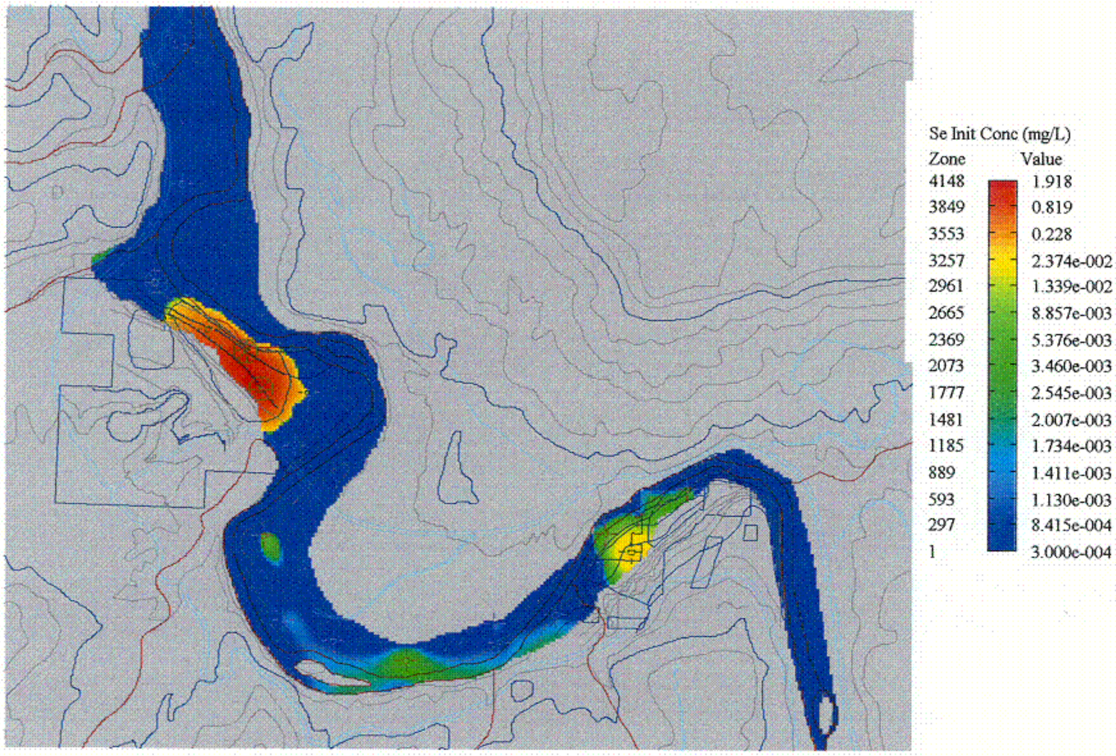

Figure 26. Layer 1 Selenium Initial Concentration

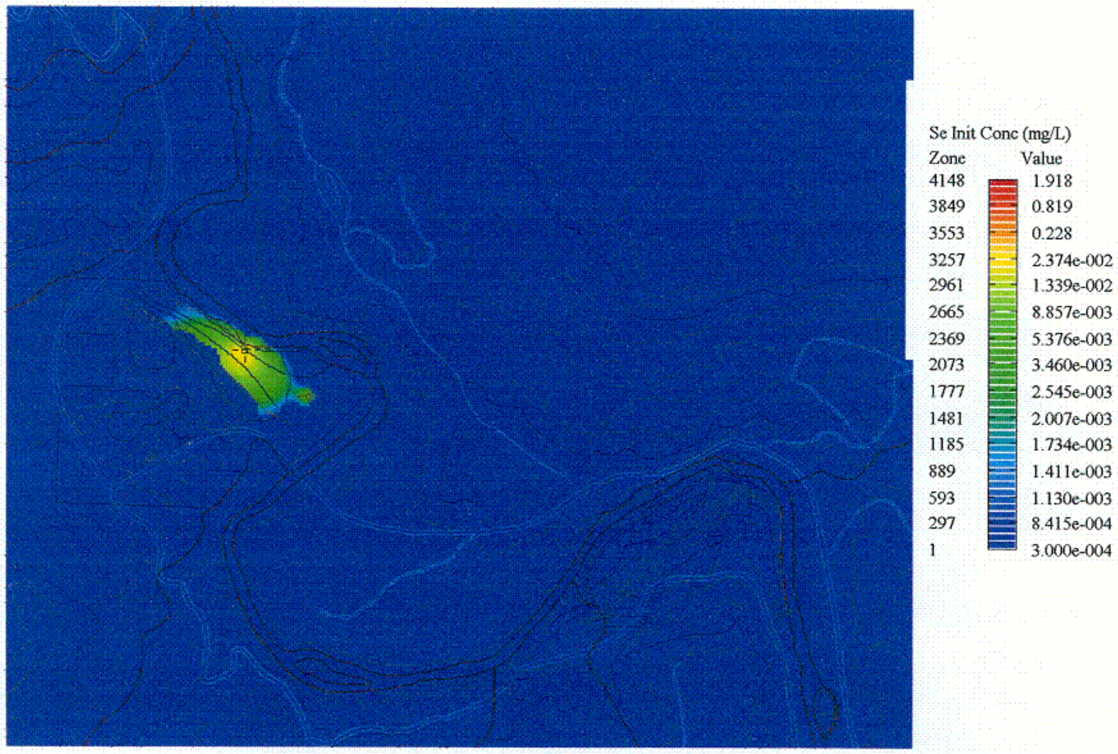

Figure 27. Layer 2 Selenium Initial Concentration

C13

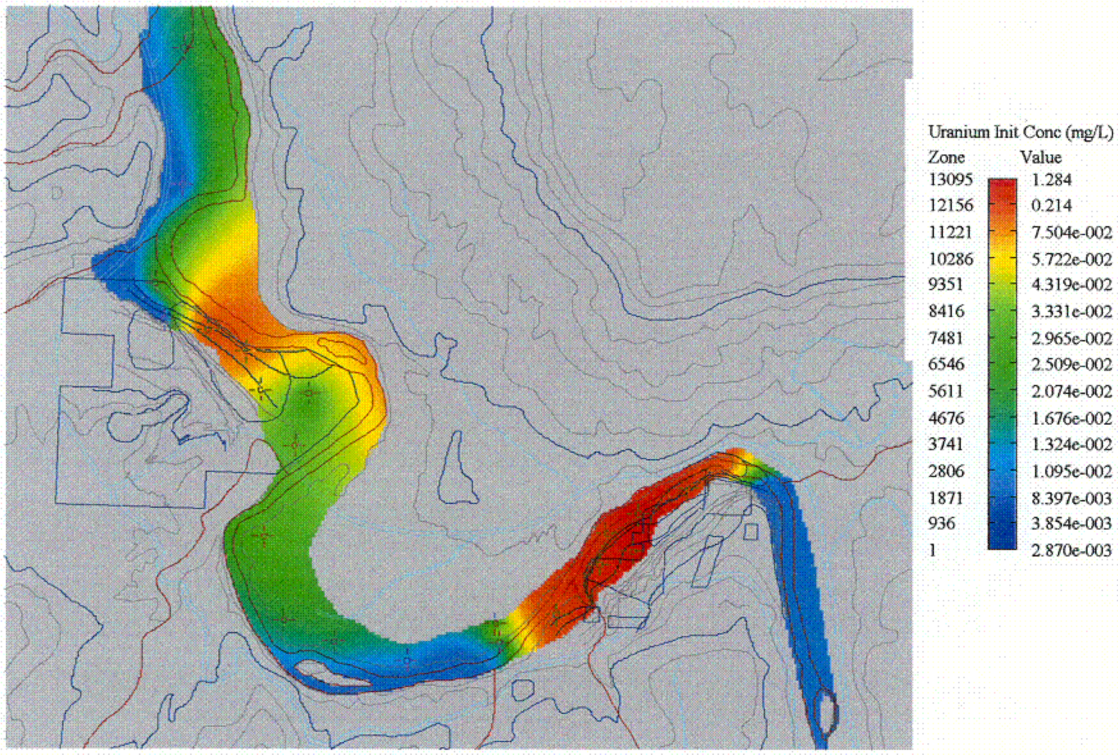

Figure 28. Layer 1 Uranium Initial Concentration

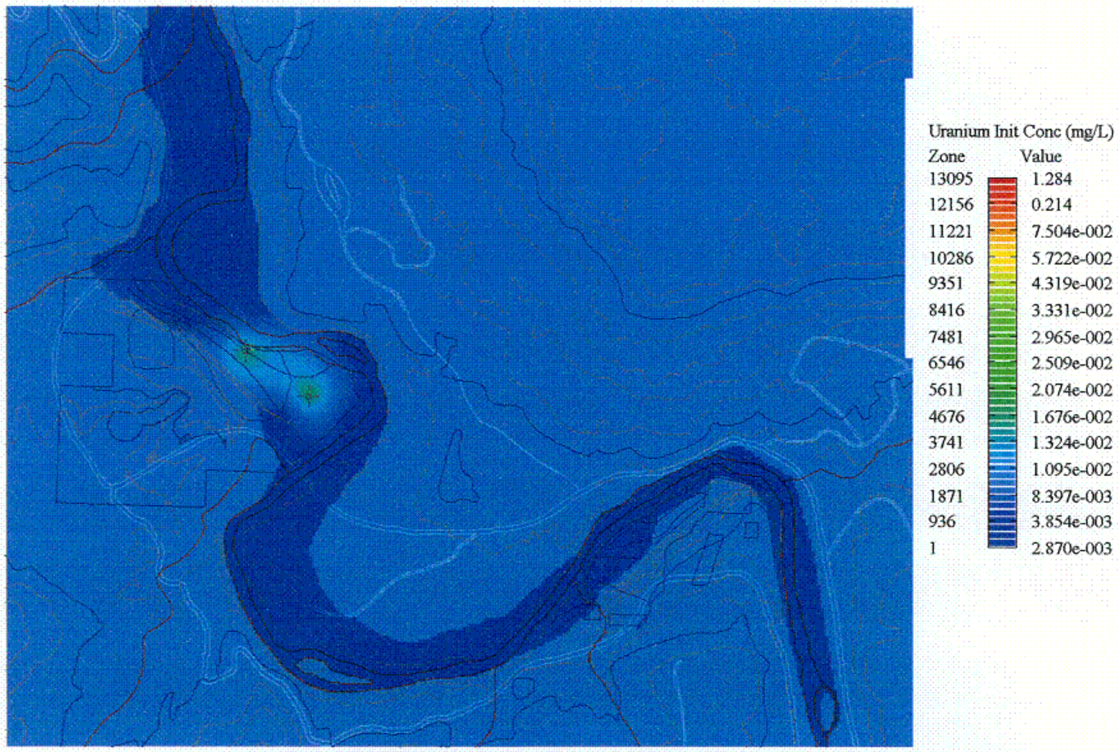

Figure 29. Layer 2 Uranium Initial Concentration

C14

The effective porosity was set to 25 percent for the alluvium, and 15 percent for the bedrock layers. Bulk density was set at 1.55 grams per cubic centimeter (g/cc) for all layers of the model.

The K_d will have the greatest impact on the amount of time required for natural flushing to reduce the contamination level below the required standard. K_d values were not directly measured for the bedrock material underlying the alluvium. Based on the lithology of these bedrock units, the K_d values will be less than the values measured in the alluvium. In order to take a conservative approach, K_d values assigned to the alluvium were also assigned to the upper most bedrock unit (layer 2) in the model. The average K_d value and range for each of the contaminants are shown in Table 7.

Table 7. Contaminant K_d Values

Contaminant	K_d (Average value / Range)	Source
Nitrate	0 / NA	Baes and Sharp 1983
Manganese	5 / 0.2 to 10,000	Baes and Sharp 1983
Molybdenum	0.26 / 0.08 to 0.38	ESL Report (DOE 2001)
Selenium	7.0 / 3.5 to 8.1	ESL Report (DOE 2001)
Uranium	0.5 / 0.16 to 0.87	ESL Report (DOE 2001)

5.2 Transport Calibration and Parameter Sensitivity Analysis

The calibration of the transport model and sensitivity analysis of the transport parameters is not as straight forward as for the flow model and flow parameters. The calibration and sensitivity analysis for the flow model is based on the residual sum of squares of observed head minus computed head. Similarly, the calibration and sensitivity analysis for the transport model could be based on the residual sum of squares of observed concentration minus computed concentration.

Preliminary modeling results indicated selenium was the contaminant that took the longest time to flush from the alluvial aquifer. As a result, the sensitivity analysis for the transport modeling parameters was completed using selenium as the contaminant. The transport parameters selected for sensitivity analysis are porosity, bulk density, K_d, longitudinal dispersivity, transverse dispersivity, and vertical dispersivity. These parameters are associated with layer 1 only since the high contaminant concentrations are contained within this layer. For the sensitivity analysis, the transport parameters were simulated at three different values that correspond to the lowest expected value, the most likely value, and the highest expected value. When completing the sensitivity analysis for longitudinal dispersivity, the transverse and vertical dispersivity values were also changed the same percentage. However, when the analyses were completed for the transverse dispersivity and vertical dispersivity, only those values were changed while the remaining parameters retained their original value. In this manner, the sensitivity of the individual parameter could be evaluated.

Parameter values for the sensitivity analyses are contained in Table 8.

Table 8. Sensitivity Parameter Values

Parameter	Lowest Expected	Most Likely	Highest Expected
Porosity	0.15	0.25	0.35
Bulk Density (g/cc)	1.24	1.55	1.86
K_d (mL/g)	3.5	7	8.7
Long. Disp. (ft) (long / transv / vert)[a]	50 / 5 / 0.5	100 / 10 / 1	200 / 20 / 2
Trans. Disp. (ft) (long / transv / vert)[a]	100 / 5 / 1	100 / 10 / 1	100 / 20 / 1
Vert. Disp. (ft) (long / transv / vert)[a]	100 / 10 / 0.5	100 / 10 / 1	100 / 10 / 2

[a]long / transv / vert represents longitudinal, transverse, and vertical dispersivity estimates, respectively

A quantitative procedure similar to the one described for flow model parameters (Section 4.6) was also used to determine if the parameter tested is sensitive. As a result, the coefficient of variation (CV) of the difference in predicted selenium concentration at each selected time interval (5, 25, 50, 70, 100 years) was calculated. Any parameter resulting in a CV greater than 15 percent between the predicted selenium concentration at any time interval is considered sensitive and will be treated as stochastic.

The results (Table 9) indicate that the transport model is not sensitive to porosity, bulk density, transverse dispersivity, or vertical dispersivity. However, the transport model is highly sensitive to the K_d and longitudinal dispersivity.

Table 9. Transport Parameter Coefficient of Variation Analysis

Porosity

YEAR	MEAN	STDEV	ADJ STDEV	CV
5	1.3485	0.0003	0.00034	0.00025
25	1.2478	0.0021	0.00237	0.0019
50	1.04087	0.00205	0.00231	0.00222
70	0.94082	0.00197	0.00222	0.00236
100	0.84112	0.00341	0.00385	0.00457

Bulk Density

YEAR	MEAN	STDEV	ADJ STDEV	CV
5	1.34467	0.00871	0.00982	0.0073
25	1.23487	0.04832	0.0545	0.04413
50	1.03127	0.04621	0.05212	0.05054
70	0.94241	0.05682	0.06409	0.06801
100	0.83152	0.07139	0.08053	0.09684

Table 9 (continued). Transport Parameter Coefficient of Variation Analysis

K_d

YEAR	MEAN	STDEV	'ADJ STDEV	CV
5	1.34353	0.01623	0.01831	0.01363
25	1.1904	0.12685	0.14308	0.1202
50	0.98883	0.12204	0.13766	0.13921
70	0.88815	0.15507	0.17492	0.19694
100	0.76325	0.19476	0.21969	0.28783

Longitudinal Dispersivity

YEAR	MEAN	STDEV	ADJ STDEV	CV
5	1.35667	0.12505	0.14106	0.10397
25	1.25643	0.28055	0.31646	0.25187
50	1.08733	0.34004	0.38356	0.35275
70	0.95505	0.32648	0.36827	0.38561
100	0.82375	0.34268	0.38654	0.46925

Transverse Dispersivity

YEAR	MEAN	STDEV	ADJ STDEV	CV
5	1.3462	0.01172	0.01322	0.00982
25	1.24287	0.02477	0.02794	0.02248
50	1.03793	0.01655	0.01867	0.01799
70	0.94118	0.01375	0.01551	0.01648
100	0.83838	0.01638	0.01847	0.02203

Vertical Dispersivity

YEAR	MEAN	STDEV	ADJ STDEV	CV
5	1.34553	0.09319	0.10511	0.07812
25	1.23577	0.13804	0.15571	0.12601
50	1.03887	0.07187	0.08107	0.07804
70	0.95361	0.06308	0.07115	0.07461
100	0.84268	0.04687	0.05287	0.06274

5.3 Predictive Results for Contaminants

A contaminant transport model using MT3DMS, based on the calibrated steady state flow model, was used for predictive simulations. Simulation results throughout this report are listed for layer 1 because the highest contaminant concentrations are contained within this layer. Simulation results were extracted for selected times up to 100 years into the future. These results are included in Table 10 for the five modeled contaminants. Each is discussed separately.

Table 10. Predicted Steady State Maximum Concentrations for Nitrate, Manganese, Molybdenum, Selenium, and Uranium (mg/L)

	Modeled Contaminant				
	Nitrate	**Manganese**	**Molybdenum**	**Selenium**	**Uranium**
Standard (mg/L)	44	3.5	0.1	0.18	0.044
Source	UMTRA	Background	UMTRA	Risk-Based	UMTRA
Max Conc @ 5 yrs	832.8	5.82	0.750	1.22	0.435
Max Conc @ 10 yrs	412.3	5.50	0.526	0.909	0.171
Max Conc @ 15 yrs	244.9	5.47	0.369	0.715	0.126
Max Conc @ 25 yrs	151.6	5.11	0.207	0.505	0.065
Max Conc @ 50 yrs	67.8	3.60	0.097	0.274	0.035
Max Conc @ 60 yrs	42.5	3.03	na	0.225	na
Max Conc @ 70 yrs	na	na	na	0.211	na
Max Conc @ 80 yrs	na	na	na	0.197	na
Max Conc @ 90 yrs	na	na	na	0.181	na
Max Conc @ 100 yrs	na	na	na	0.166	na

5.3.1 Nitrate

Figures 30, 31, and 32 present the nitrate concentration distribution after 5, 15, and 25 years. As indicated by Table 10, the nitrate maximum concentration falls below the UMTRA Project standard of 44 mg/L between 50 and 60 years. Figure 32 shows that very limited cells containing nitrate concentrations above the standard remain after 25 years.

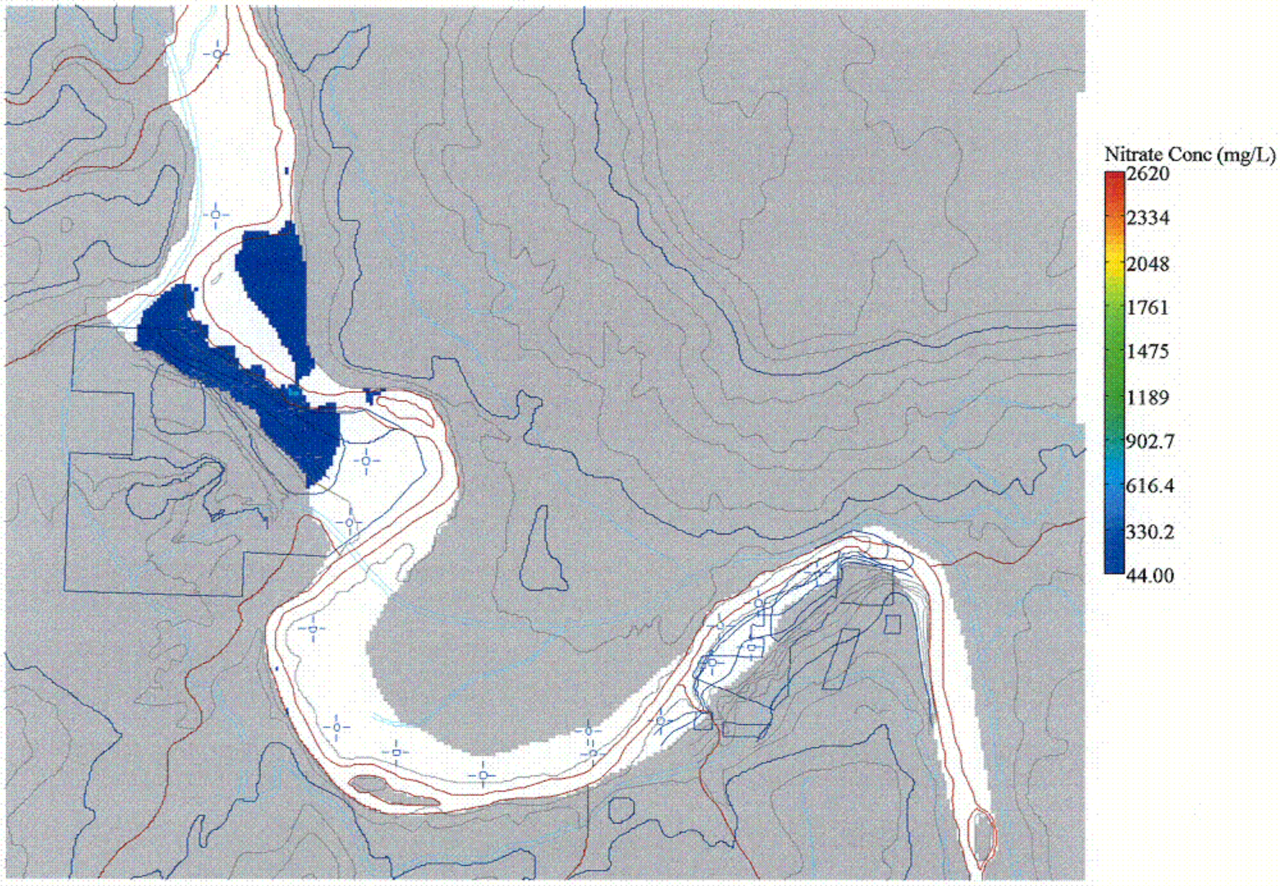

Figure 30. Predicted Steady State Nitrate Concentration at 5 Years

C15

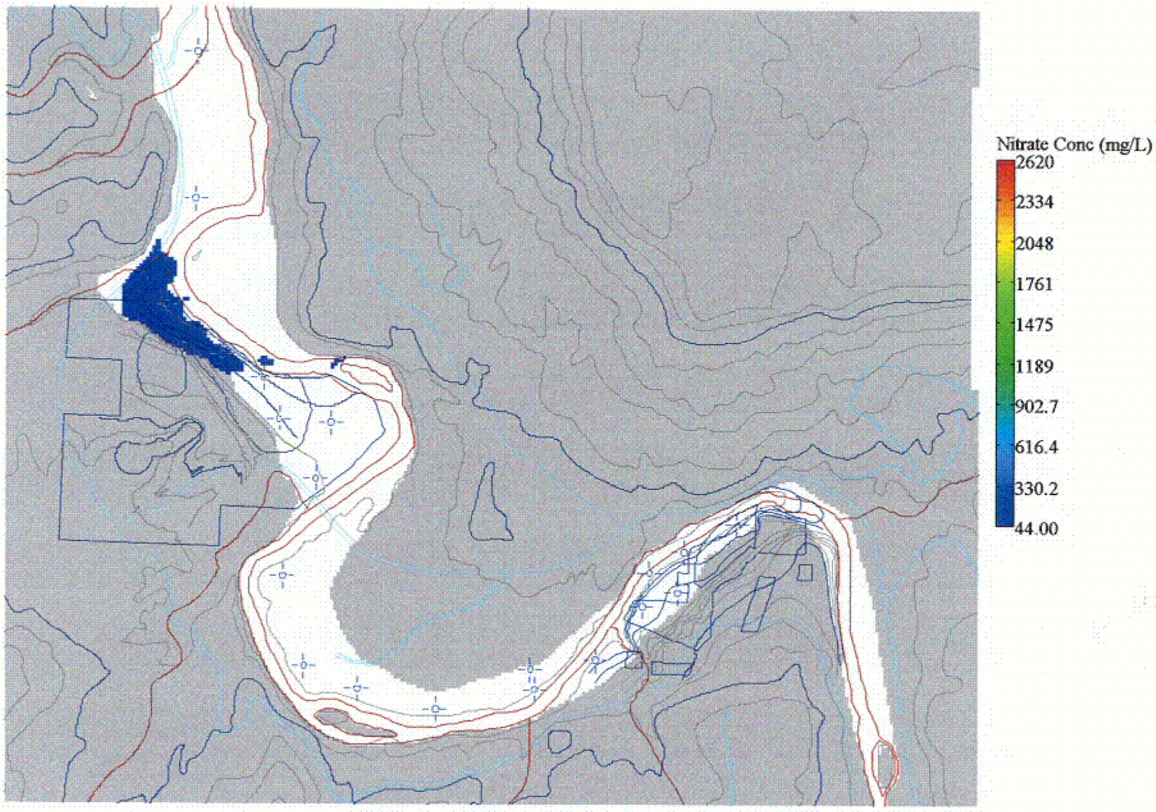

Figure 31. Predicted Steady State Nitrate Concentration at 15 Years

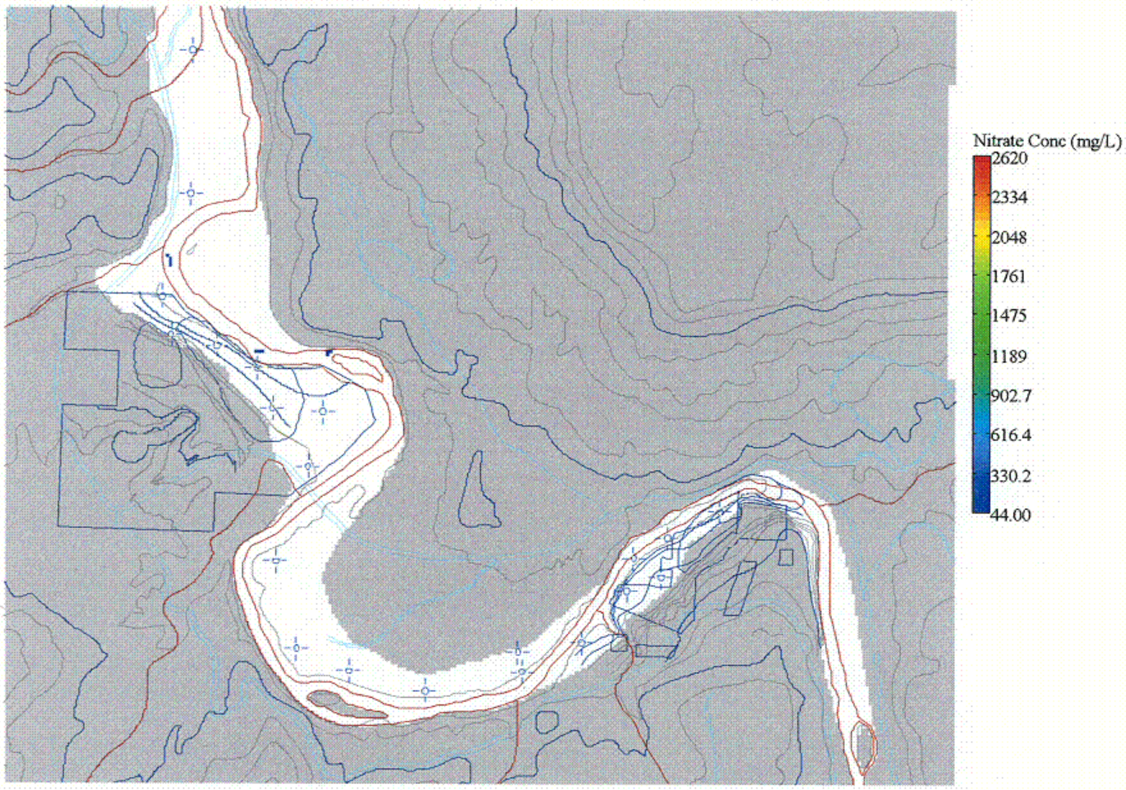

Figure 32. Predicted Steady State Nitrate Concentration at 25 Years

C16

5.3.2 Manganese

As shown in Table 10, the maximum manganese concentration falls below the maximum observed background concentration of 3.5 mg/L after 50 years. Figures 33 and 34 present the manganese distribution after 5 and 15 years, respectively.

Figure 33. Predicted Steady State Manganese Concentration at 5 Years

C17

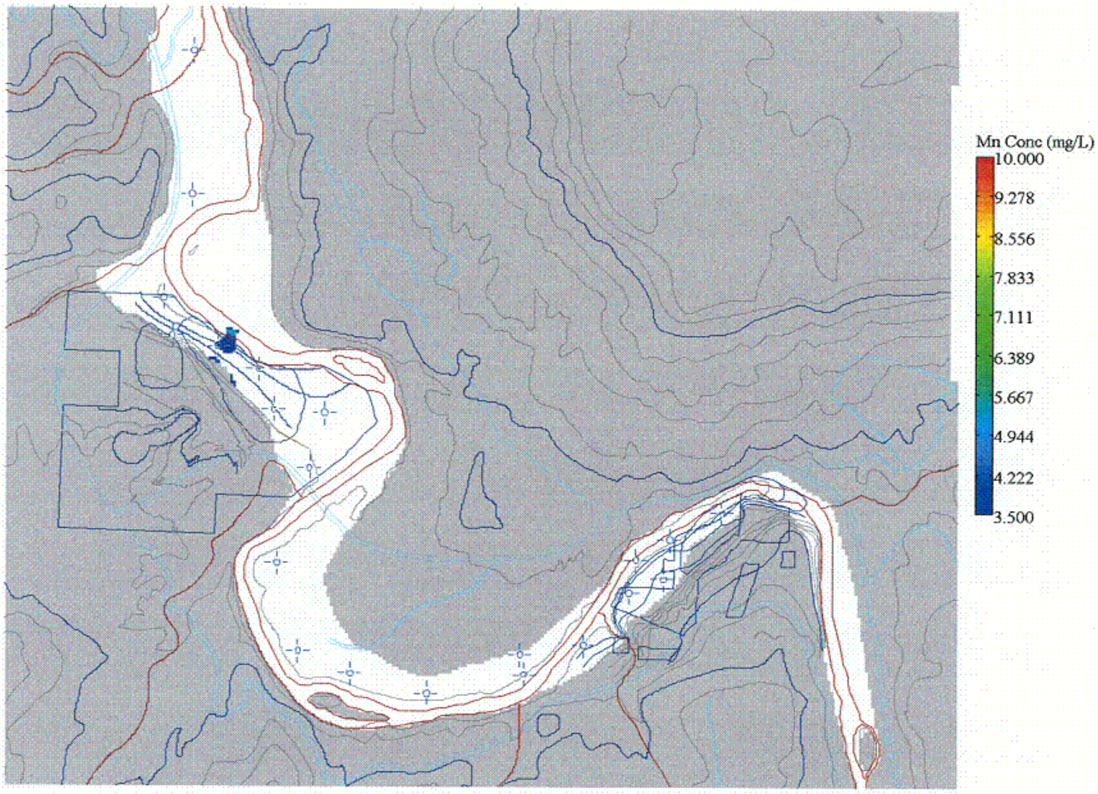

Figure 34. Predicted Steady State Manganese Concentration at 15 Years

C18

5.3.3 Molybdenum

The results presented in Table 10 indicate the molybdenum concentration falls below the UMTRA Project standard of 0.1 mg/L prior to 50 years of natural flushing. Figures 35, 36, and 37 present the molybdenum distribution after 5, 10 and 15 years, respectively.

Figure 35. Predicted Steady State Molybdenum Concentration at 5 Years

C19

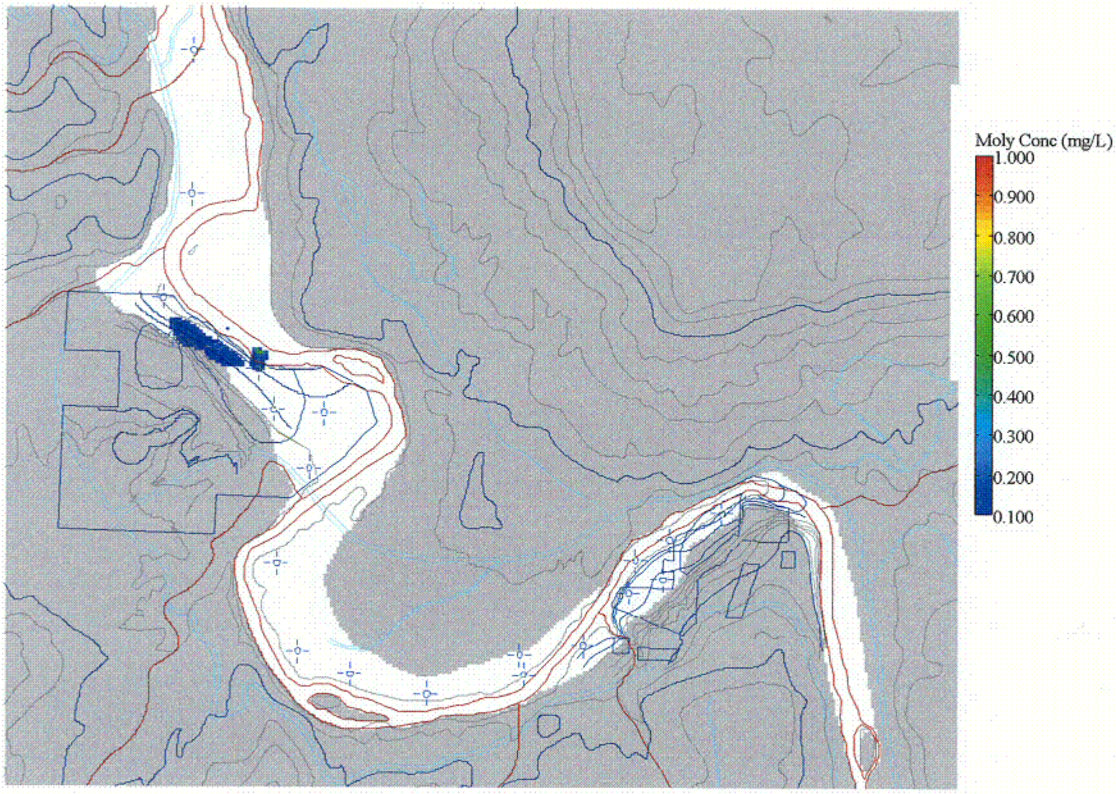

Figure 36. Predicted Steady State Molybdenum Concentration at 10 Years

Figure 37. Predicted Steady State Molybdenum Concentration at 15 Years

C20

5.3.4 Selenium

Figures 38, 39, and 40 present the selenium concentration distribution after 5, 50, and 70 years. After 100 years, the model predicts the maximum concentration will be 0.166 mg/L.

While these plots give a general aerial view of the remaining contamination area, they do not provide a clear picture of the contaminant decrease with time. The plots in Figures 41 through 43 show the decrease in concentration versus time for monitor well locations 0318, 0508, and 0320, respectively. As Figure 43 shows, well 0320, which is located just downgradient from the ground water plume, is not adversely impacted.

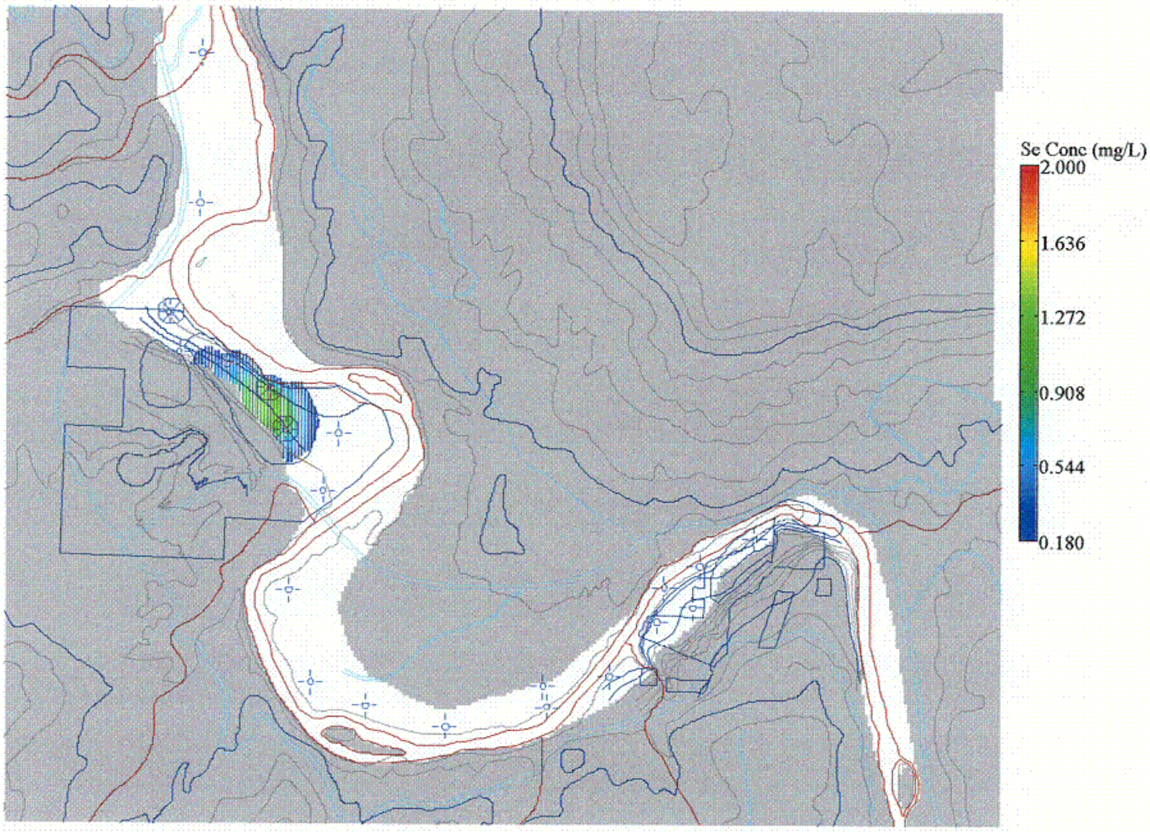

Figure 38. Predicted Steady State Selenium Concentration at 5 Years

C21

Figure 39. Predicted Steady State Selenium Concentration at 50 Years

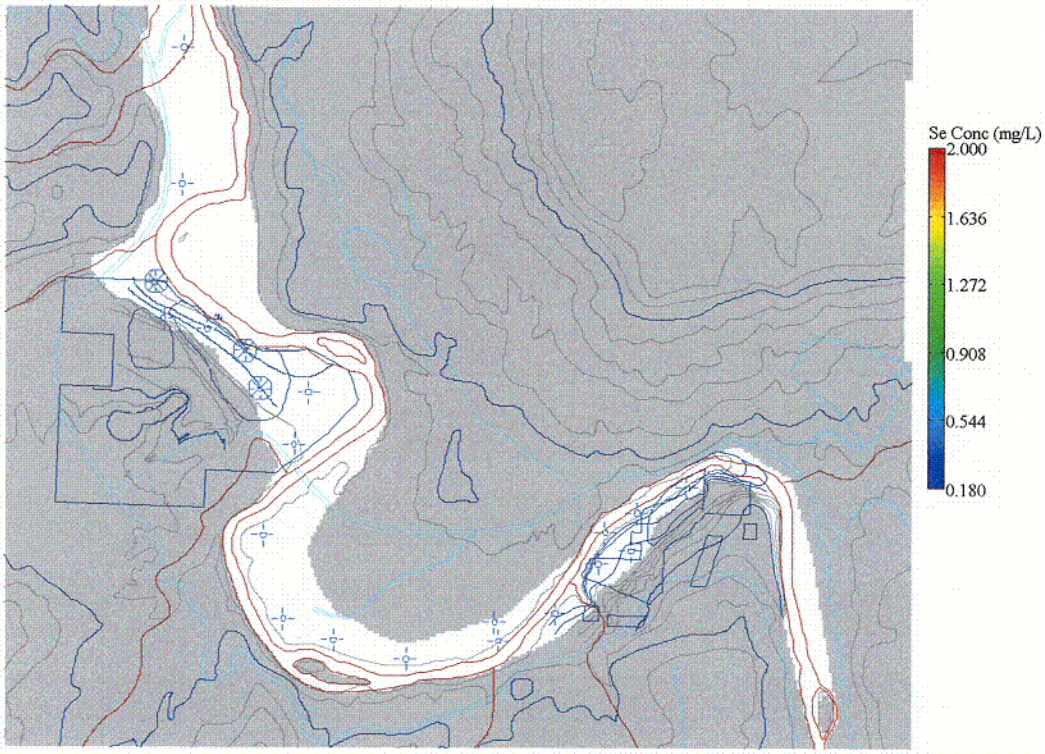

Figure 40. Predicted Steady State Selenium Concentration at 70 Years

C22

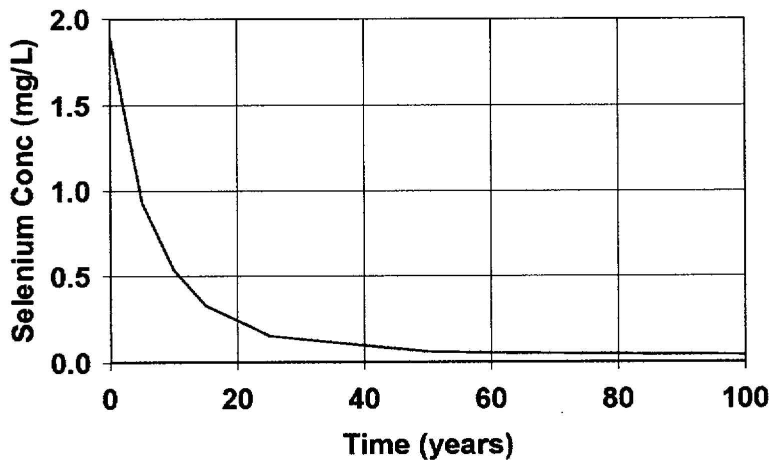

Figure 41. Selenium Concentration versus Time for Well 0318

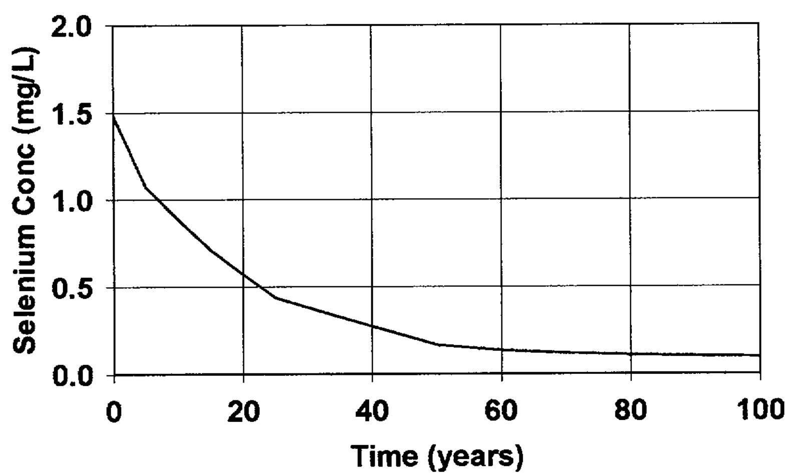

Figure 42. Selenium Concentration versus Time for Well 0508

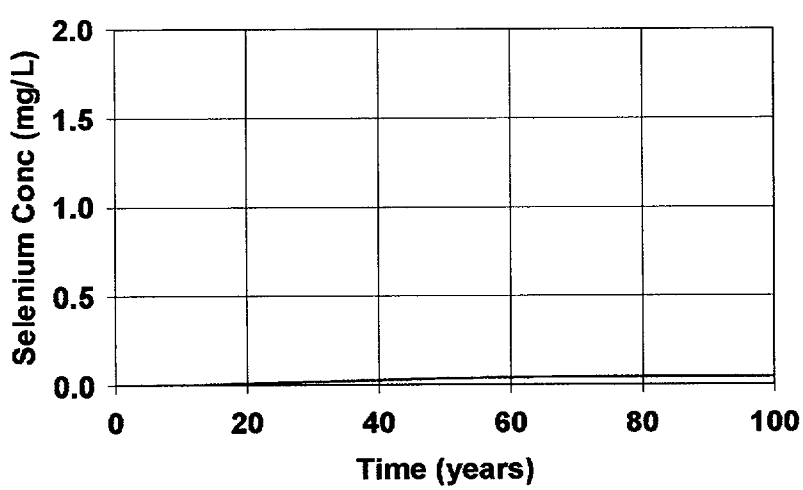

Figure 43. Selenium Concentration versus Time for Well 0320

5.3.5 Uranium

Predicted uranium concentrations above the UMTRA Project standard of 0.044 mg/L at 5 and 15 years into the future are presented in Figures 44 and 45, respectively. After 25 years, the maximum concentration is just above the standard at 0.065 mg/L, and is limited to only three cells. This model predicts that prior to 50 years, the maximum uranium concentration present will be below the 0.044 mg/L standard.

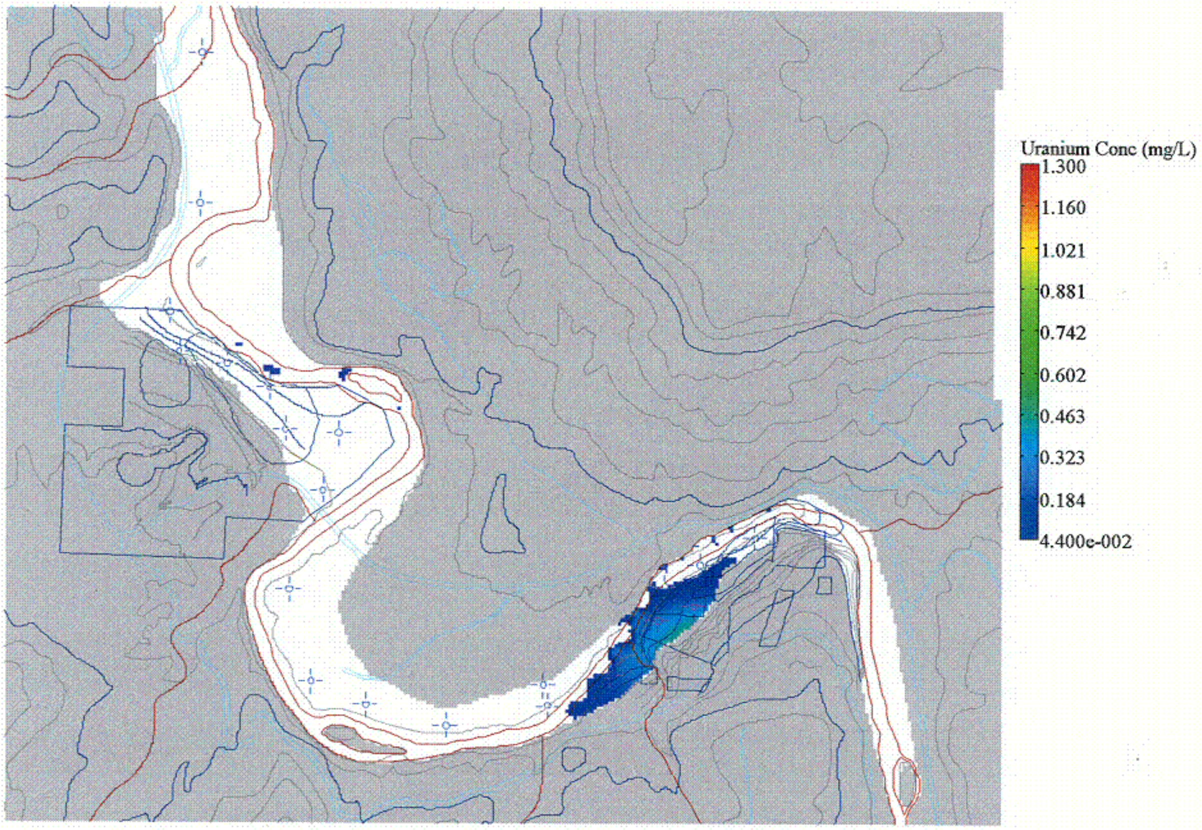

Figure 44. Predicted Steady State Uranium Concentration at 5 Years

C23

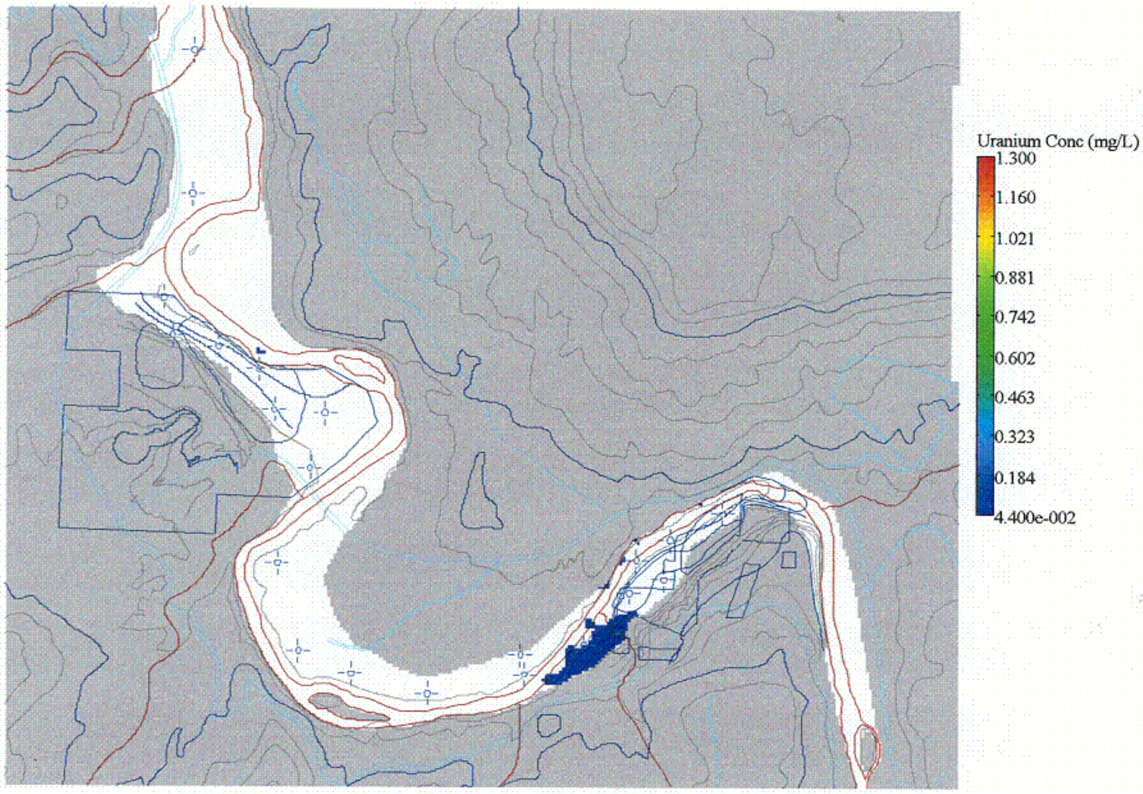

Figure 45. Predicted Steady State Uranium Concentration at 15 Years

6.0 Stochastic Simulations

6.1 Stochastic Parameters

The flow and transport parameters that are treated as uncertain parameters are shown in Table 11. The distribution type and distribution parameters assigned to each of the stochastic parameters are specified. Even though the flow model is not sensitive to horizontal hydraulic conductivity (Section 4.6), it was treated as stochastic because the estimated geometric mean of the hydraulic conductivity was obtained from a data set having a wide range of data. Likewise, even though the transport model is not sensitive to porosity, it was treated as stochastic because the value used for the model input was obtained from the literature.

Table 11. Stochastic Flow and Transport Parameters

Parameter	Distribution		
	Type	Minimum	Maximum
Kx, Layer 1	Uniform	16	200
Kx, Layer 2	Uniform	0.2	2
Longitudinal Dispersivity, Layer 1	Uniform	50	200
Longitudinal Dispersivity, Layer 2	Uniform	10	40
K_d for Selenium (mL/g)	Triangular	3.5	8.7
Recharge (ft/day)	Triangular	0.00046	0.00064
Porosity, Layer 1	Uniform	0.15	0.35
Porosity, Layer 2	Uniform	0.1	0.3

C24

Stochastic MT3DMS links the longitudinal, transverse, and vertical dispersivity parameters by reducing all three by a single factor while completing the simulations. As a result, because the longitudinal dispersivity is one of the stochastic parameters, the transverse and vertical dispersivity will also be treated as stochastic.

Non-stochastic flow and transport parameters are shown in Table 12.

Table 12. Non-Stochastic Flow and Transport Parameters

Parameter	Value
Ky / Kz, Layer 1 (ft/day)	121 / 12.1
Ky / Kz, Layer 2 (ft/day)	1.0 / 0.1
GHB Conductance (ft^2/day)	121
Riverbed Conductance (ft^2/day)	12.1
Bulk Density (g/mL)	1.55
Initial Se Concentration (mg/L)	Feb/Mar 2001 data

One of the problems associated with stochastic simulations is to determine how many realizations (individual simulations) are sufficient. From a strict mathematical standpoint, hundreds or even thousands of realizations may be necessary to truly represent the uncertainty when random samples are drawn from distributions for a number of parameters. A qualitative or subjective justification to determine if enough realizations were simulated can be obtained by looking at a plot of cumulative average residual sum of squares versus realization number. If there is limited change in the cumulative average as the number of realizations increases, then it can be safely concluded that enough simulations have been run. The plot in Figure 46 indicates that the cumulative average residual sum of squares becomes relatively stable at approximately 21.3 ft^2 after 50 realizations. Therefore, 100 realizations should be adequate to account for the uncertainty in the stochastic parameters.

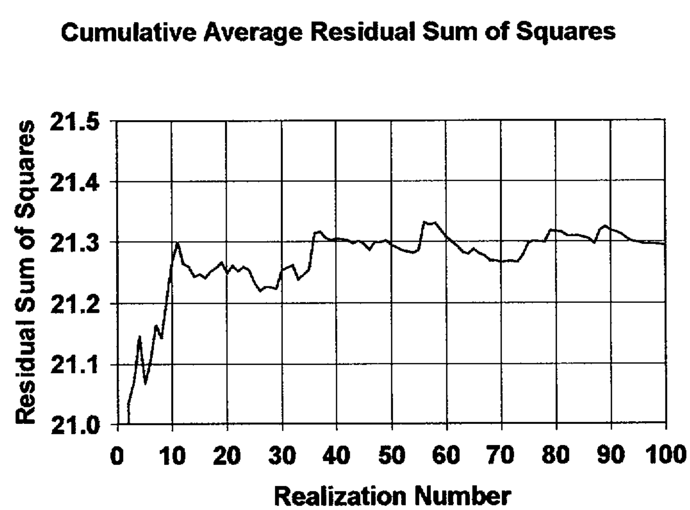

Figure 46. Cumulative Average Residual Sum of Squares versus Realization Number

Another useful evaluation tool is to look at how the individual realizations compare to the calibrated flow model results. The plot in Figure 47 shows the residual sum of squares for each of the 100 realizations. About 12 percent of the realizations are below the calibrated model residual sum of squares value of 20.8 ft^2, which is plotted on the figure.

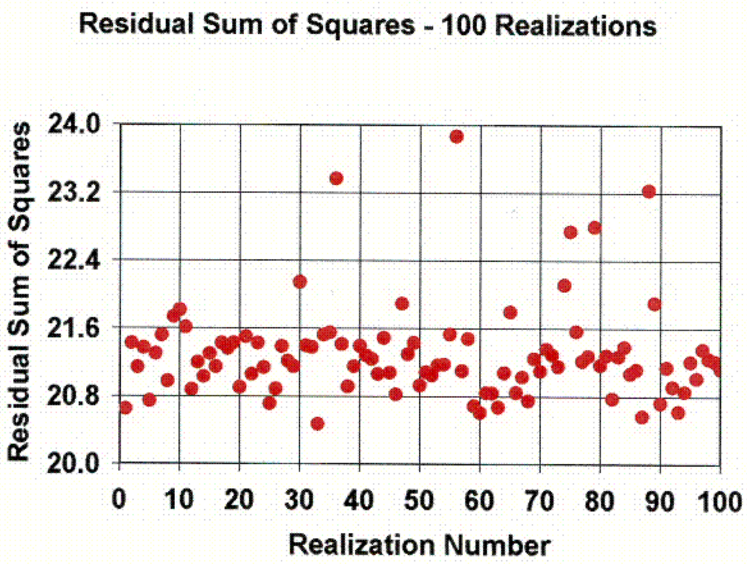

Figure 47. Residual Sum of Squares versus Realization Number

Figure 48 is a plot of the average or mean head field of the 100 realizations. A visual comparison of Figure 48 with the steady state single realization results in Figure 5 shows that they are almost identical.

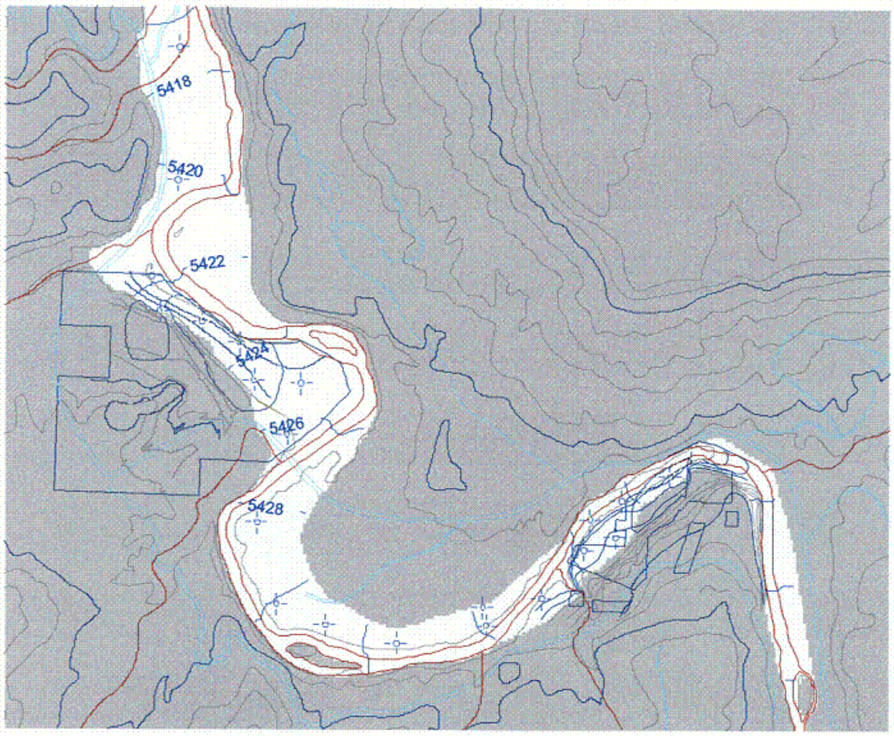

Figure 48. Average Simulated Steady State Stochastic Ground Water Elevations

6.2 Predictive Results for Selenium

Contaminant transport simulation results for selenium were extracted for selected times up to 100 years into the future. Average concentrations and the associated uncertainty at each time period of interest are based on 100 computer simulations. Figures 26 and 27 show the initial concentration plumes for the model layers 1 and 2, respectively. The initial concentration for layers 3 and 4 was set to the background value of 0.0003 mg/L. Predicted selenium distribution in the alluvial aquifer above the risk-based 0.18 mg/L ground water standard at 5, 10, 25, and 50 years into the future are presented in Figures 49 through 52, respectively. The maximum average remaining concentration at 5, 10, 25, and 50 years is 0.937, 0.621, 0.326, and 0.194 mg/L, respectively. At 60 years, the concentration is predicted to be below the 0.18 mg/L human health risk-based standard.

Comparing these concentrations to those generated from the deterministic model, the average remaining concentration from the stochastic model results are lower. The reason for this discrepancy is shown in Table 13, which provides the values used for the stochastic parameters in the deterministic model and the mid-point stochastic values. As previously mentioned, these parameters have a uniform distribution with the exception of K_d and recharge, which have a triangular distribution (Table 11). For the triangular distributed parameters, the mid-point stochastic value will produce a faster clean-up time (i.e., a lower maximum concentration). Of the uniform distributed parameters, the horizontal hydraulic conductivity of layer 2, recharge, and dispersivity of layers 1 and 2 will result in a faster clean-up time. The horizontal hydraulic conductivity of layer 1 and porosity of layer 2 will tend to generate a slower clean-up time.

Table 13. Comparison of Deterministic versus Mid-point Stochastic Parameter Values

Parameter (units)	Deterministic Value	Mid-point Stochastic Value
Horizontal Hydraulic Conductivity (ft/day), Layer 1	121	108.2
Horizontal Hydraulic Conductivity (ft/day), Layer 2	1.0	1.1
Recharge (ft/day)	0.00046	0.000512
Dispersivity (long/trans/vert), Layer 1 (ft)	100 / 10 / 1	125 / 12.5 / 1.25
Dispersivity (long/trans/vert), Layer 2 (ft)	20 / 2 / 0.2	25 / 2.5 / 0.25
Selenium K_d (mL/g)	7.0	6.52
Porosity, Layer 1	0.25	0.25
Porosity, Layer 2	0.15	0.2

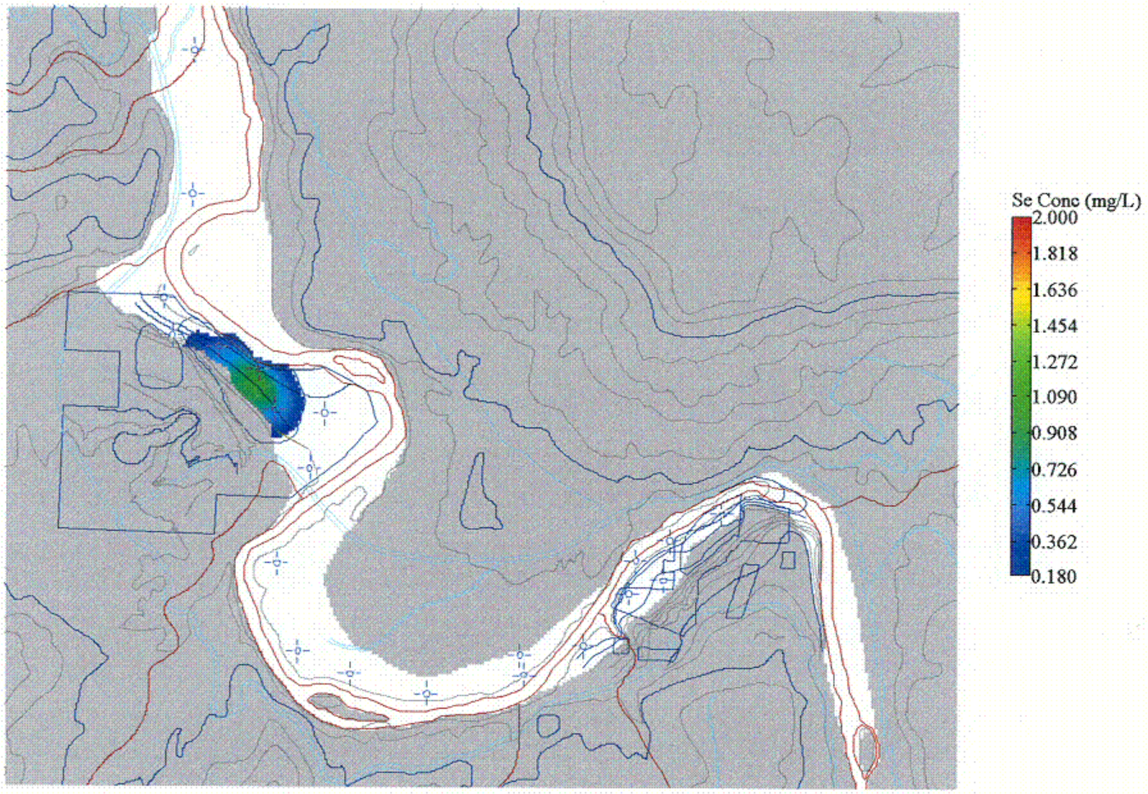

Figure 49. Predicted Stochastic Selenium Concentration at 5 Years

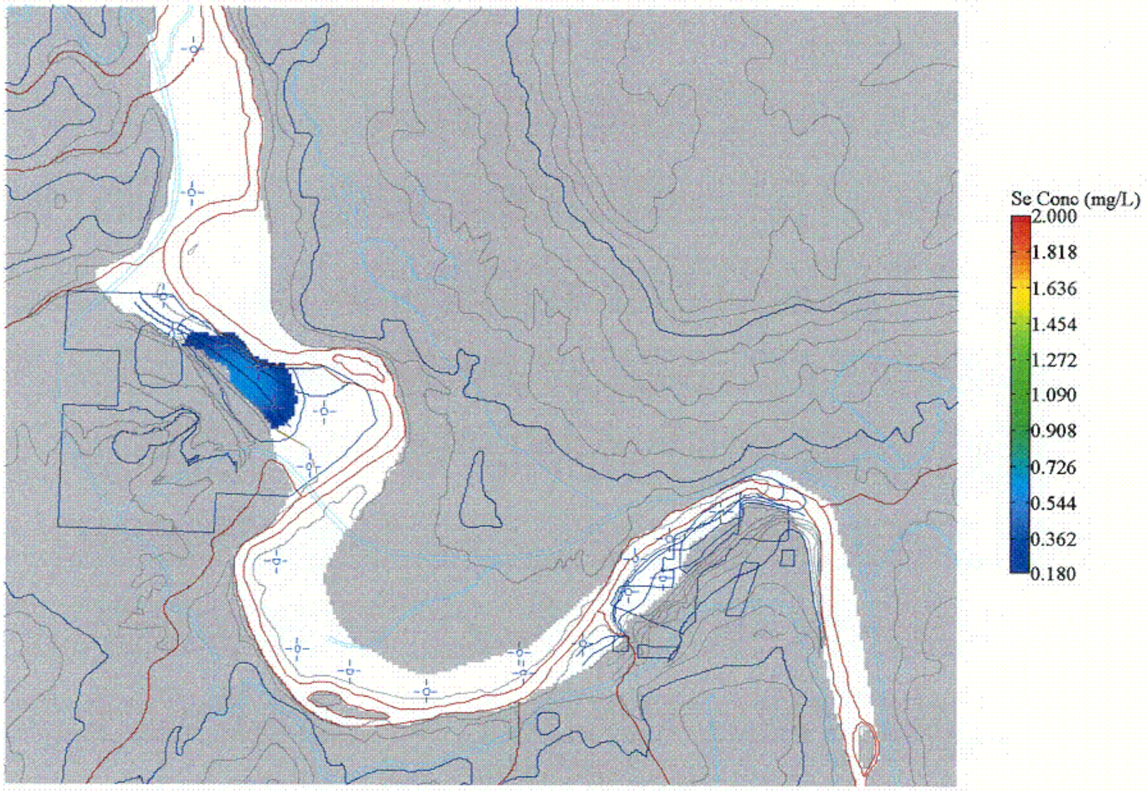

Figure 50. Predicted Stochastic Selenium Concentration at 10 Years

C26

Figure 51. Predicted Stochastic Selenium Concentration at 25 Years

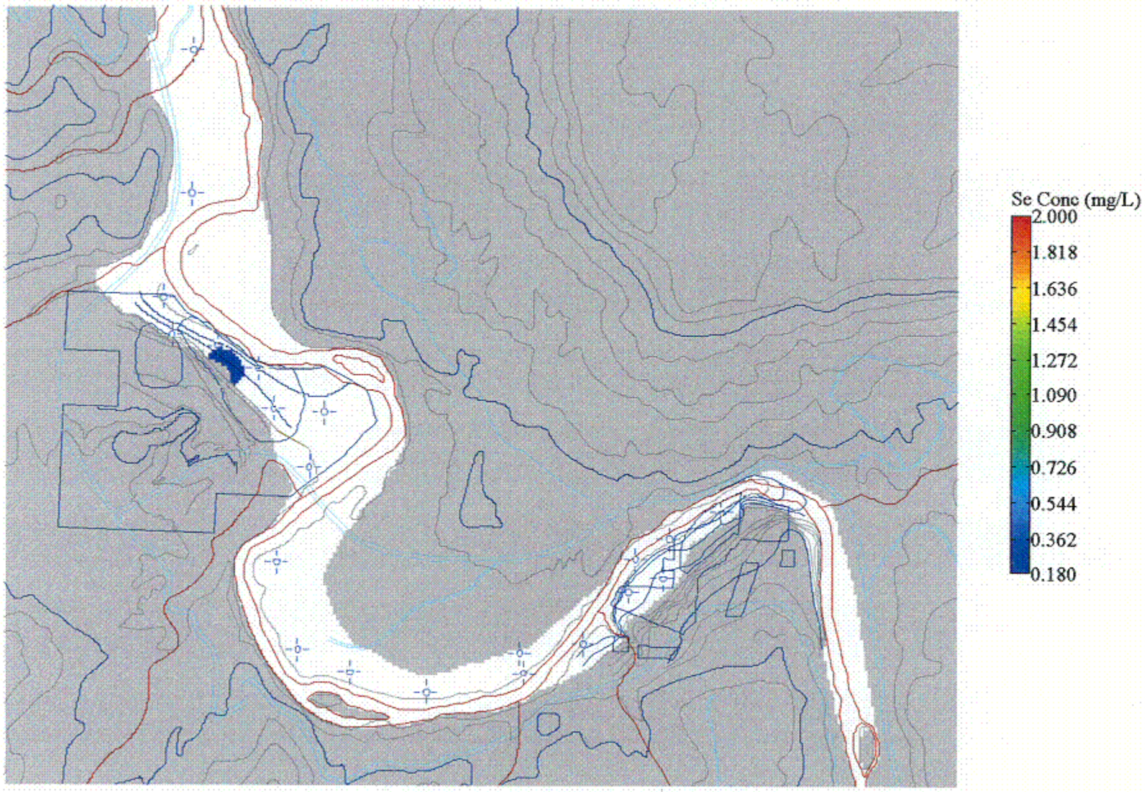

Figure 52. Predicted Stochastic Selenium Concentration at 50 Years

C27

By varying the value of the uncertain or stochastic parameters during each of the 100 simulations, the variance associated with the mean predicted concentration was used to calculate the probability that the mean selenium concentration will exceed the selenium standard. Probability contour maps showing areas within the alluvial aquifer that exceed the selenium ground water standard at 5, 10, 25, and 50 years into the future are illustrated in Figures 53 through 56, respectively. At 5 and 10 years there is 100 percent probability that the standard will be exceeded over a sizeable area on and northeast of the UC site. At 50 years there is a 35 percent probability that the standard will be exceeded over a small area of the alluvial aquifer, and at 100 years there is a 14 percent probability the selenium concentration will exceed 0.18 mg/L.

Figure 53. Probability of Selenium Concentration Exceeding the Standard at 5 Years

C28

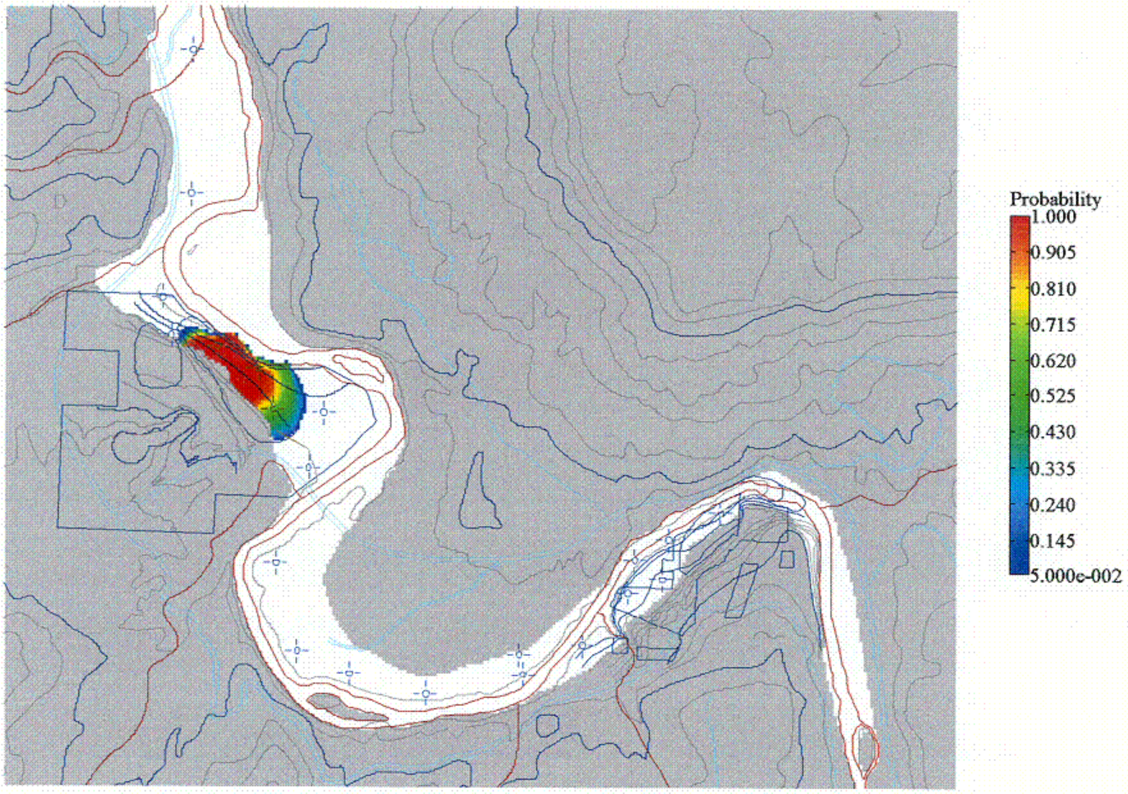

Figure 54. Probability of Selenium Concentration Exceeding the Standard at 10 Years

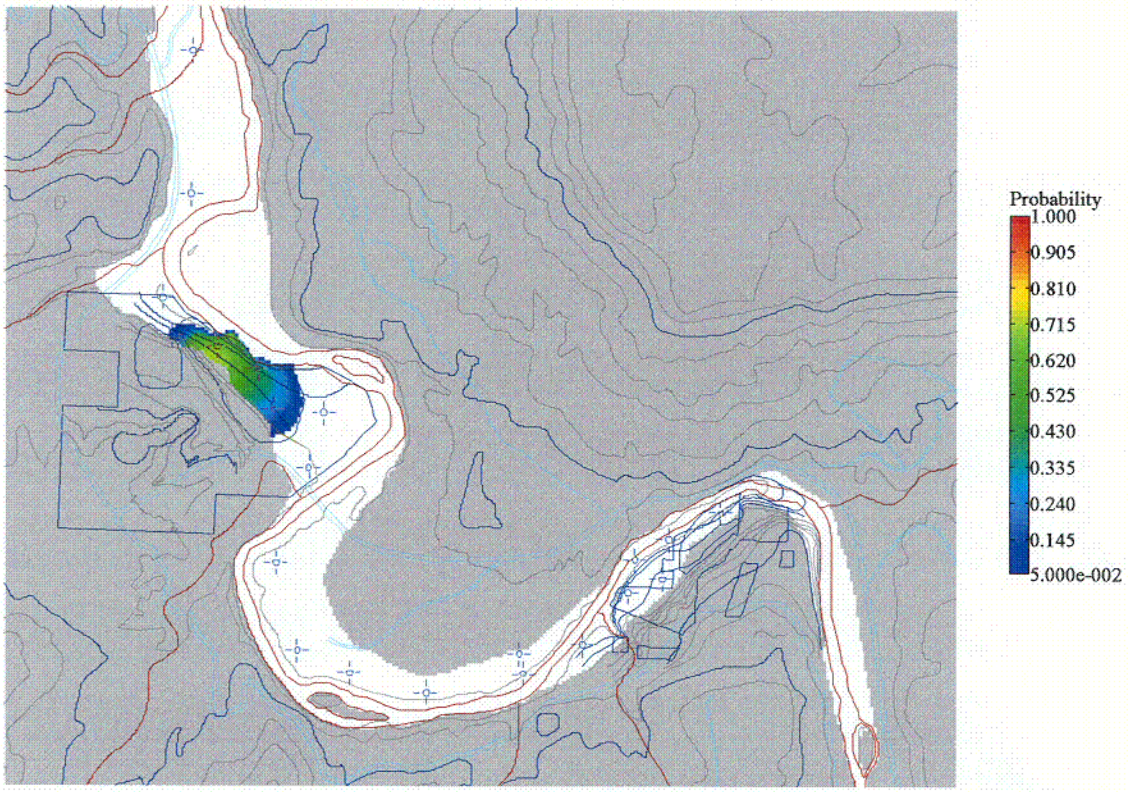

Figure 55. Probability of Selenium Concentration Exceeding the Standard at 25 Years

C29

Figure 56. Probability of Selenium Concentration Exceeding the Standard at 50 Years

7.0 Summary and Conclusions

A ground water flow and transport model was developed to evaluate if natural processes will reduce site-related contaminant concentrations to regulatory levels in the alluvial aquifer within 100 years. Contaminants modeled during this investigation include nitrate, manganese, molybdenum, selenium, and uranium. Two different versions of the model were developed and employed to address conditions in the vicinity of the site. A steady state deterministic flow and transport model was used as the basis for the stochastic model. A steady state stochastic flow and transport model was used to quantify the uncertainty in flow and transport parameters. Based on modeling results, natural flushing appears to be an acceptable compliance strategy which results in contaminant concentrations below applicable standards, risk-based standards, or background concentrations after the 100 year time frame for nitrate, manganese, molybdenum, selenium, and uranium.

7.1 Qualitative Analysis

Ground water flow patterns predicted by the steady state deterministic flow model (Figure 5) and the steady state stochastic flow model (Figure 48) closely resemble the ground water gradient measured in March 2001 (Figure 2). This visual analysis suggests that the calibrated flow model adequately and accurately predicts the observed water level elevations.

C30

7.2 Quantitative Analysis

Data presented in Table 3 and Figures 6 and 11 indicate that the calibrated steady state flow model satisfies the acceptance criteria and calibration objectives established prior to the modeling process. Calibration results presented in Figure 6 demonstrate that the flow model has a slight bias of overestimating water levels across the site. However, this bias is not large enough to influence the modeling results, as shown by a mean residual of –0.625 ft and an absolute mean residual of 0.709 ft. Results presented in Figure 11 demonstrate that the predicted hydraulic heads versus the observed heads fall on a straight line, as expected. According to the flow model results, the total inflow and outflow for the alluvial aquifer (layer 1) of the model is 151,226 ft^3/day and 151,194 ft^3/day, respectively. These values fall within the range established by the conceptual water budget.

7.3 Model Predictions

Results of the steady state MT3DMS predictive simulations indicate:

- On average the maximum nitrate concentration in the ground water beneath the Slick Rock site will decrease to below the UMTRA Project standard for nitrate of 44 mg/L within 60 years (Table 9).
- After 60 years, the maximum predicted manganese concentration is 3.03 mg/L, which is below the maximum observed background concentration of 3.5 mg/L.
- Molybdenum concentrations drop below the 0.1 mg/L UMTRA Project standard between 25 and 50 years.
- The maximum predicted selenium concentration after 100 years is 0.166 mg/L, which is below the risk-based benchmark of 0.18 mg/L.
- Uranium concentrations drop below the UMTRA Project standard of 0.044 mg/L prior to 50 years of natural flushing (Table 10).

The steady state stochastic MT3DMS simulations were completed for selenium only, and indicate the maximum selenium concentration after 100 years will be 0.131 mg/L, with the concentration dropping to below the 0.18 mg/L risk-based standard within 60 years. The reason this maximum concentration is not the same as the maximum concentration predicted by the deterministic model is discussed in Section 6.2. Average concentrations and the associated uncertainty at each time period of interest are based on 100 computer simulations.

8.0 References

ASTM, 1993. *Standard Guide for Application of a Ground-Water Flow Model to a Site-Specific Problem*, ASTM D 5447-93, American Society for Testing and Materials.

ASTM, 1995. *Standard Guide for Documenting a Ground-Water Flow Model Application*, ASTM D 5718-95, American Society for Testing and Materials.

Baes, C.F., and R.D. Sharp, 1983. "A Proposal for Estimation of Soil Leaching and Leaching Constants for Use in Assessment Models," *Journal of Environmental Quality*, 12:1

Dixon, W.J., and F.J. Massey, Jr., 1957. *Introduction to Statistical Analyses*, Second Edition, McGraw-Hill Book Company, Inc., New York.

Environmental Simulations, Inc., 1997. *Guide to Using Ground Water Vistas, Advanced Model Design and Analysis*, Herndon, Virginia.

McDonald, M.G., and A.W. Harbaugh, 1988. *Techniques of Water-Resources Investigations of the United States Geological Survey,* Chapter A1: A Modular Three-Dimensional Finite-Difference Ground-Water Flow Model, Book 6, Modeling Techniques, U.S. Geological Survey Open-File Report.

Thronthwaite, C. W., and J.R. Mather, 1957. Instructions and Tables for Computing Potential Evaporation and the Water Balance. *Climatology*, 10 (3).

U.S. Department of Energy, 2001. *Determination of Distribution Ratios, UMTRA Ground Water Project, Slick Rock, Colorado, Site,* ESL-RPT-2001-02, prepared by MACTEC Environmental Restoration Services, LLC, for the U.S. Department of Energy, Grand Junction Office, Grand Junction, Colorado.

Zheng, C. and P. Wang, 1999. *MT3DMS: A Modular Three-Dimensional Multispecies Transport Model for Simulation of Advection, Dispersion, and Chemical Reactions of Contaminants in Ground Water Systems*, Documentation and User's Guide, Department of Geological Sciences, University of Alabama, Tuscaloosa, Alabama.

Appendix I

Ecological Risk Assessment
for the
Slick Rock, Colorado, UMTRA Site

Ecological Risk Assessment

1.1 Problem Formulation

The problem formulation phase in this risk assessment is represented in part by the information presented in the baseline risk assessment (BLRA) (DOE 1995). The BLRA was based on analytical data collected at the Slick Rock site prior to 1995. These data were reviewed to determine if concentrations of analytes in ground water, surface water, and sediment may pose a potential ecological risk. Information on the geologic setting, ground water hydrology, geochemistry, and habitats of the two sites were incorporated in the BLRA evaluation. Principal results of the BLRA included an initial screening of chemical analytes as ecological contaminants of potential concern (E-COPCs) and an assessment of potential risk to biota, including livestock and irrigated crops. The assessment of potential risk, however, was primarily qualitative.

Since the completion of the BLRA, additional ground water and surface water samples have been collected at the Slick Rock site and at upgradient reference areas. These new analytical data, which include the 2000–2001 sampling efforts, have been included in this update.

1.1.1 Potentially Affected Habitats and Populations

The Slick Rock site is dominated by disturbed grassland, desert shrubland, and riparian communities along the Dolores River. Surrounding habitats are generally characterized as semi-arid, influenced by the low to moderate annual precipitation. Flora and fauna of the sites and surrounding areas were investigated between 1986 and 1994. Detailed information is provided in *The Environmental Assessment of Remedial Action at the Slick Rock Uranium Mill Tailings Sites Slick Rock, Colorado* (DOE 1994) which documents the results of the investigations and lists the potential ecological receptors, including threatened or endangered species. Ecological characterization and surveys targeted terrestrial ecological receptors, with an emphasis on riparian plant communities and associated wildlife along the Dolores River. Mammalian wildlife such as gray fox, coyote, striped skunk, raccoon, deer, and rodents, including beaver and muskrat, likely use the riparian habitats for foraging, resting, denning, and other activities. In addition, 66 species of birds were recorded during these surveys, including both resident and migratory species. The Dolores River provides a source of drinking water in the area, adding to its attractiveness to wildlife. Most of the area (including riparian areas) is currently used for grazing livestock (primarily cattle), which may also use the river for drinking. The river supports an aquatic community, which includes plants, invertebrates, and vertebrate species. Twelve species of fish, both native and nonnative, have been documented in river near the Slick Rock site, including two species of native sucker, roundtail chub, channel catfish, and black bullhead. The wetland and aquatic habitats of the Dolores River are also used by waterfowl (e.g., mallards), wetland birds, (e.g., great blue herons), and shorebirds (e.g., spotted sandpipers).

The Biological Assessment for the sites, which is included as part of the environmental assessment (EA) for the remedial action on the sites (DOE 1994), identified 11 threatened or endangered species that may occur in the vicinity of the sites. For the four fish species included on this list (the bonytail chub, humpback chub, razorback sucker, and Colorado pikeminnow), only the Colorado pikeminnow is known to have historically occurred in the Dolores River, and since 1960, is only known to occur near its confluence with the Colorado River, approximately 120 miles down stream of the Slick Rock site. Of the remaining seven species, only the bald eagle and southwestern river otter are known to occur in the vicinity of the Slick Rock site and are still listed as threatened or endangered. Wintering bald eagles are occasionally observed along the river, but are not known to nest along the Dolores. The southwestern river otter occurs there as a result of a reintroduction program that started in 1988. Finally, suitable habitat for the recently listed (endangered) southwestern willow flycatcher occurs along the Dolores River; however, surveys for this species that were conducted at the Slick Rock site in 1990 and 1991 failed to confirm its presence.

1.1.2 Summary of the 1995 Ecological Risk Assessment Results

In the 1995 BLRA (DOE 1995), all ground water constituents were used as a starting point for identifying E-COPCs in that medium because no upgradient (i.e., background) data were available. E-COPCs were identified as those constituents that were detected in at least two ground water samples, or if detected in only one sample, showed a detection that was sufficiently above the detection limit as to indicate a nonspurious result. In addition, constituents with low predicted toxicity to ecological receptors (calcium, magnesium, phosphate, potassium, silica, and sodium) were also not considered as potential constituents of ecological concern. Analytical data from surface water and sediment samples from the Dolores River were also evaluated for E-COPCs. Analytes for these samples were limited to cadmium, calcium, copper, magnesium, molybdenum, nitrate, selenium, uranium, vanadium, and zinc (calcium, magnesium, and nitrate not being included as analytes in the sediment samples). For these samples, upstream location SRK-01-0696 was used to identify background conditions. An analyte in surface water or sediment was identified as E-COPCs if it was detected at a downstream location at a concentration exceeding the maximum background concentration. Calcium and magnesium were excluded as being essential nutrients. As shown in Table 1, the BLRA initially identified 26 ground water-based constituents as E-COPCs for further evaluation. In addition, three E-COPCs (cadmium, uranium, and zinc) were identified for surface water and seven (cadmium, copper, molybdenum, selenium, uranium, vanadium, and zinc) for sediment.

Based on this information, a screening-level assessment of ecological risks at the site evaluated potential pathways, receptors, and potential adverse effects related to these constituents and media. No other contaminated media and subsequent pathways or effects were addressed in the BLRA. Concentrations of E-COPCs in ground water, surface water, and sediments were then compared to toxicity standards and guidelines (if available) for various ecological receptors.

Although limited phytotoxicity information was found, the results of the BLRA indicated that the concentration of molybdenum in the ground water at the Union Carbide (UC) site could pose a potential risk to deep-rooted plants that may contact it. No risk to deep-rooted plants was found for the North Continent (NC) site. However, the ground water concentrations at the NC site were found to exceed water quality standards for freshwater aquatic life for aluminum, chloride, and iron. At the UC site, these exceedences included aluminum, cadmium, chloride, iron, manganese, molybdenum, and selenium. In addition, sulfate concentrations in ground water at the NC site and nitrate, selenium, sulfate, and vanadium concentrations in ground water at the UC site exceeded drinking water standards for livestock. From these results, it was concluded that the ground water quality was unacceptable for use as surface water ponds. Further, the ground water concentrations of manganese and molybdenum at the NC and those for cadmium, iron, manganese, molybdenum, selenium, and vanadium at the UC site exceeded water quality standards for irrigation, limiting its use for this purpose as well.

Table 1. Summary of Ecological Contaminants of Potential Concern in Ground Water, Surface Water, and Sediments from the Baseline Risk Assessment (DOE 1995)

Contaminant Analyzed in Ground Water[a]	Constituents Detected in Ground Water at the NC Site[b]	Constituents Detected in Ground Water at the UC Site[b]	Constituents Detected Above Background in the Dolores River[c]
Aluminum	X	X	
Ammonium	X	X	
Antimony	X		
Arsenic			
Barium		X	
Beryllium			
Boron	X	X	
Bromide	X	X	
Cadmium		X	SW[d], SD[e]
Chloride	X	X	
Chromium		X	
Cobalt			
Copper			SD
Cyanide			
Fluoride	X	X	
Iron	X	X	
Lead			
Manganese	X	X	
Mercury			
Molybdenum	X	X	SD
Nickel		X	
Nitrate	X	X	
Selenium		X	SD
Silver			
Strontium	X	X	
Sulfate	X	X	
Sulfide	X	X	
Thallium			
Tin			
Uranium	X	X	SW, SD
Vanadium		X	SD
Zinc		X	SW, SD
Radionuclides			
Lead – 210	X	X	
Polonium – 210	X	X	
Radium – 226	X	X	
Thorium – 230	X	X	

[a]Includes all analytes except calcium, magnesium, phosphate, potassium, silica, and sodium, which were considered to be of low potential toxicity in the BLRA (DOE 1995).
[b]Ground water constituents that exceeded the method detection limit in more than one sample.
[c]Detected constituents that exceeded the maximum upstream (background) concentration. Note that only cadmium, copper, molybdenum, nitrate (surface water only), selenium, uranium, vanadium, and zinc were included as analytes in these media.
[d]SW = surface water
[e]SD = sediment

Of the three E-COPCs identified in surface water samples from the Dolores River (cadmium, uranium, and zinc), none exceeded its corresponding water quality standard for the protection of aquatic life. Further, the BLRA predicted no ecological risk to aquatic organisms from exposure to E-COPCs in sediment based on comparison to National Oceanographic and Atmospheric Administration (NOAA) sediment quality values and U.S. Geological Survey (USGS) background ranges. Therefore, the BLRA did not predict potential ecological risks associated with E-COPCs in the Dolores River based on the information available. In the cases of both surface water and sediments, however, the BLRA acknowledges that these conclusions are based on limited database.

1.1.3 Update of the 1995 Ecological COPCs

For the current risk assessment, additional data collected and information received subsequent to the issuance of the BLRA are used to reevaluate the list of E-COPCs that are further assessed for potential ecological risk. The recent ground water data includes additional radiological parameters, including gross alpha and gross beta activity, radium-228, uranium-234, and uranium-238. Also, analyses for volatile organic compounds (VOCs) resulted in detections of the four "BTEX" compounds (benzene, toluene, ethylbenzene, and xylenes). Ten of the original nonradiological ground water analytes that were not detected in the previous sampling rounds were discontinued.

Nine analytes that were identified as E-COPCs in the BLRA were also discontinued as ground water analytes. These are aluminum, antimony, boron, fluoride, and sulfide at the NC site, and aluminum, barium, boron, chromium, fluoride, nickel, sulfide, and zinc at the UC site. It should be remembered, however, that because no upgradient well data were available, the identification of E-COPCs for ground water in the BLRA was based on the analytes' detection in two or more samples, not on detected concentrations greater than background. Therefore, it is uncertain whether the concentrations of these analytes are site-related or are within background range. However, of these nine analytes, only aluminum was found to be at concentrations that indicated potential risk to ecological receptors. For both sites, this potential risk was based on the its comparison to water quality standards for the protection of aquatic life, and thus, would only indicate a risk if the ground water was pumped to the surface. For these reasons, these nine constituents are not further evaluated in this assessment.

Thus, of the 26 nonradiological and radiological analytes for ground water that were identified as E-COPCs in the BLRA (excluding essential nutrients, phosphate, and silica), 17 have been continued in recent ground water sampling at these sites, along with five additional radiological analytes and four organic analytes. "Recent" data was considered to be data from samples collected in 2000 and 2001. The reevaluation of the ground water constituents as E-COPCs (as based on the recent data) is presented in Table 2. Associated with the recent site characterization data, upgradient data are being collected, and these data are used to screen the site data for concentrations above background.

Constituents that are considered to be essential nutrients, and are therefore excluded as E-COPCs are calcium, magnesium, potassium, and sodium. Among the other constituents that were excluded from consideration as E-COPCs in the BLRA because of their low potential toxicities, phosphorus (as phosphate) is still excluded. Sulfate and chloride are also anions of relatively low potential toxicity in biota. High sulfate in water is known to cause diarrhea in humans and livestock; however, some evidence indicates that this effect is temporary and the individual will

Table 2. Summary of Preliminary Ecological Contaminants of Potential Concern in Ground Water at the Slick Rock Site Based on Sampling Data from September 2000 through March 2001

Constituent	Maximum Concentration in Ground Water					Ecological COPC? (Site)	Reason
	Back-ground	NC On-Site	NC Down-gradient	UC On-Site	UC Down-gradient		
Nonradiological Inorganic Analytes (mg/L)							
Ammonium	1.0	0.33	0.0823	**118**	**2.04**	UC	Exceeds background range
Bromide	3.68	1.52	0.293	**14.7**	0.231	UC	Exceeds background range
Cadmium	0.00037	<0.0003	<0.0003	**0.0097**	<0.0003	UC	Exceeds background range
Calcium	587	193	111	**1,060**	133	No	Essential nutrient
Chloride	858	**890**	67.4	**5,470**	58.9	NC, UC	Exceeds background range
Iron	19.6	4.07	0.641	**32**	0.43	UC	Exceeds background range
Magnesium	517	229	73.1	349	60.5	No	Essential nutrient
Manganese	3.53	0.739	1.44	**12.8**	0.547	UC	Exceeds background range
Molybdenum	0.0046	**0.0546**	**0.0439**	**1.83**	**0.0211**	NC, UC	Exceeds background range
Nitrate	0.756	**1.09**	**2.45**	**3,510**	**5.7**	NC, UC	Exceeds background range
Phosphorus (as PO_4)	0.0545	0.0545	**0.0590**	**0.499**	**0.0924**	No	Low toxicity
Potassium	14.7	**34.9**	**16**	**30.1**	10.1	No	Essential nutrient
Selenium	0.0012	**0.0367**	**0.008**	**2.52**	0.00035	NC, UC	Exceeds background range
Sodium	1,560	**1,769**	273	**2,210**	104	No	Essential nutrient
Strontium	8.84	5.50	1.57	**11.8**	1.59	UC	Exceeds background range
Sulfate	4,590	3,270	934	**1,160**	389	UC	Exceeds background range
Uranium	0.0139	**1.31**	**0.0406**	**0.1**	**0.0175**	NC, UC	Exceeds background range
Vanadium	<0.0015	<0.0015	<0.0015	**0.556**	<0.0015	UC	Exceeds background range
Radiological Analytes (pCi/L)							
Gross Alpha	<78.9	**1,386**	28.8	61.6	7.04	NC	Exceeds background range
Gross Beta	<78.3	**355**	20.6	37.1	14.8	NC	Exceeds background range
Lead-210	<1.32	<1.49	<1.3	<1.39	<1.36	No	Not detected
Polonium-210	<0.09	<0.09	<0.29	<0.43	<0.32	No	Not detected
Radium-226	0.19	**0.27**	0.18	**3.22**	0.14	NC, UC	Exceeds background range
Radium-228	<1.03	**1.27**	<1.08	**4.04**	<0.99	NC, UC	Exceeds background range
Thorium-230	<1.7	<1.7	<1.7	<1.8	<1.7	No	Not detected
Uranium-234	7.5	**445**	**14.8**	**35.4**	**10.8**	NC, UC	Exceeds background range
Uranium-238	5.6	**459**	**15.8**	**40**	**6.3**	NC, UC	Exceeds background range
Volatile Organic Analytes (mg/L)							
Benzene	--	--	--	17.4	--	UC	Detected at high levels
Ethylbenzene	--	--	--	0.584	--	UC	Detected at high levels
Toluene	--	--	--	13.6	--	UC	Detected at high levels
Total Xylenes	--	--	--	6.54	--	UC	Detected at high levels

NC = North Continent; UC = Union Carbide.
Text in shaded cells indicates value exceeds the maximum NC site upstream concentration, which is considered to be background.

acclimate to the high sulfate ingestion without long-term adverse effect (EPA 1999a). Sulfate- and chloride-based salts are commonly used to test the toxicity of cationic elements, indicating a general lack of toxic potential of the anions, which would otherwise interfere with the test results. However, because both sulfate and chloride have State of Colorado water quality standards for the lower Dolores River, they have not been excluded from consideration as E-COPCs. Despite the relatively low toxicities of these anions and cations, it is recognized that at high concentrations in water, they can contribute to adverse ecological effects due to high osmotic potentials, and some can affect the use of water by wildlife and livestock by imparting strong tastes to the water. These types of effects, however, are not addressed in this risk assessment.

As seen in Table 2, all 13 nonradiological constituents identified as E-COPCs in the BLRA and continued in the 2000–2001 sampling events were still found to be E-COPCs in the ground water at the UC site. At the NC site, only chloride, molybdenum, nitrate, selenium, and uranium were found to exceed the background data range. (Selenium had not been identified as an E-COPC at this site in the BLRA). Of the four radiological analytes assessed for ground water in the BLRA, only radium-226 was identified as an E-COPC (at both sites). Among the new radiological analytes, radium-228, uranium-234, and uranium-238 exceeded their background ranges at both sites, and gross alpha and gross beta activities were greater than background at the NC site. Finally, the four BTEX compounds were detected in ground water at the UC site, establishing them as E-COPCs for ground water.

Table 3 presents the E-COPC selection results for surface water in the Dolores River. For surface water, only the data from the sampling location upstream of the NC site (location 0696) was considered as representing background conditions because the location that is upstream of the UC site (location 0693) is approximately 1 mile downstream of the NC site and may be influenced by that site. The evaluation of E-COPCs is based on surface water data collected through March 2001. The number of analytes included in the recent surface water sampling rounds was greatly expanded over the ten that were used as the basis for the BLRA. Many of these new analytes, however, were not detected in the surface water samples.

A constituent was considered an E-COPC if its maximum detected concentration at either site exceeded the maximum concentration from the upstream (background) location. As with ground water, the essential nutrients calcium, magnesium, potassium, and sodium, as well as phosphorus (as phosphate) and silica were excluded from the E-COPC selection process due to their low toxicities. No background data were available for aluminum, fluoride, and nickel; however, these constituents were not identified as E-COPCs because their concentrations essentially remained constant across downstream sampling locations, indicating no site-specific influence is occurring. A similar pattern was also observed for barium and silica; however, these two constituents had background concentrations, which were exceeded by the downstream concentrations. In the case of barium, this exceedence was not considered to be significant and barium was not identified as an E-COPC (also in part due to its absence as an E-COPC in ground water at both sites). Silica was not identified as an E-COPC because of its low potential toxicity.

Strontium and sulfate were found to exceed the background maximum concentration only at the UC upstream location (location 0693), and therefore, were not considered to exceed background at either of the sites.

Of the nine radiological parameters used to characterize the Dolores River surface water samples, only thorium-230 and uranium-234 did not result in maximum values greater that the background maximum. Gross alpha, lead-210, radium-226, and uranium-238 exceeded background at both sites. In addition, gross beta, polonium-210, and radium-228 exceeded background at the NC site.

Because no additional sediment sampling has taken place on the Dolores River since the 1993 and 1994 samples that were reported in the BLRA (DOE 1995), the E-COPCs for sediment used in this assessment are unchanged from those of the BLRA. These E-COPCs are presented in Table 4. All sediment analytes were identified as an E-COPC in either one or both sites. Of note is that uranium was found to be only slightly above background in the sediments from the NC site, and within background at the UC site.

Table 3. Constituents Retained for Evaluation in the Dolores River Surface Water at the Slick Rock Site Based on Sampling Data through March 2001

Constituent	Maximum Concentration in Surface Water					Ecological COPC? (site)	Reason
	NC Site Upstream	NC Site	UC Site Upstream	UC Site	UC Site Downstream		
Nonradiological Analytes (mg/L)							
Ammonium	0.0799	0.0569	0.0388	**0.0906**	**0.0827**	UC	Exceeds background range
Aluminum	--	0.14	0.14	--	0.13	No	(see text)
Antimony	--	<0.003	<0.003	--	<0.003	No	Not detected
Arsenic	--	<0.01	<0.01	--	<0.01	No	Not detected
Barium	0.127	**0.2**	**0.2**	--	**0.2**	No	(see text)
Beryllium	--	<0.01	<0.01	--	<0.01	No	Not detected
Boron	--	<0.1	<0.01	--	<0.01	No	Not detected
Bromide	0.0911	0.0894	**0.124**	**0.0965**	0.0749	UC	Exceeds background range
Cadmium	0.0003	<0.001	<0.001	<0.0003	<0.001	No	Not detected
Calcium	81.2	**113**	**96.9**	56.3	**84.0**	No	Essential nutrient
Chloride	36.2	**49**	**44.2**	30.2	**40.0**	NC, UC	Exceeds background range
Chromium	--	<0.01	<0.01	--	<0.01	No	Not detected
Cobalt	--	<0.05	<0.05	--	<0.05	No	Not detected
Copper	--	<0.02	<0.02	--	<0.02	No	Not detected
Cyanide	--	<0.01	<0.01	--	<0.01	No	Not detected
Fluoride	--	0.2	0.2	--	0.2	No	(see text)
Iron	0.0241	**0.0594**	**0.0937**	**0.302**	**0.177**	NC, UC	Exceeds background range
Magnesium	36.6	33.4	**47.6**	14.8	33.0	No	Essential nutrient
Manganese	0.01	**0.02**	**0.0122**	**0.0234**	**0.02**	NC, UC	Exceeds background range
Mercury	--	<0.0002	<0.0002	--	<0.0002	No	Not detected
Molybdenum	0.0025	**0.02**	**0.02**	**0.0028**	**0.02**	NC, UC	Exceeds background range
Nickel	--	0.02	0.03	--	0.03	No	(see text)
Nitrate	1.55	1.0	0.766	**2.23**	**3.70**	UC	Exceeds background range
Phosphorus (as PO_4)	0.063	0.0342	<0.1	--	<0.1	No	Within background range
Potassium	2.82	**3.7**	**3.0**	1.92	**3.1**	No	Essential nutrient
Selenium	0.0059	0.0043	0.0047	0.001	0.0031	No	Within background range
Silica	4.84	**7.9**	**7.7**	--	**8.0**	No	(see text)
Silver	--	<0.01	<0.01	--	<0.01	No	Not detected
Sodium	87.7	79.2	**115**	33.4	75.7	No	Essential nutrient
Strontium	0.928	0.885	**1.1**	0.637	0.868	No	Within background range
Sulfate	335	316	**460**	147	334	No	Within background range
Sulfide	--	<0.1	<0.1	--	<0.1	No	Not detected
Thallium	--	<0.01	<0.01	--	<0.01	No	Not detected
Tin	--	<0.005	<0.005	--	<0.005	No	Not detected
Uranium	0.0023	**0.003**	**0.006**	0.0017	0.0023	NC	Exceeds background range
Vanadium	<0.01	**0.03**	**0.03**	<0.0015	**0.03**	NC, UC	Exceeds background range
Zinc	<0.05	<0.05	0.034	--	<0.05	No	Within background range
Radiological Analytes (pCi/L)							
Gross Alpha	0.5	**2.4**	**2.4**	<3.75	**2.4**	NC, UC	Exceeds background range
Gross Beta	4.37	**5.26**	**5.42**	<3.97	3.67	NC	Exceeds background range
Lead-210	0.3	**1.5**	**0.8**	--	**0.9**	NC, UC	Exceeds background range
Polonium-210	<0.25	**0.4**	0.2	--	0.0	NC	Exceeds background range
Radium-226	0.16	**0.4**	**0.2**	<0.14	**0.3**	NC, UC	Exceeds background range
Radium-228	1.0	**1.4**	**1.4**	<0.91	0.6	NC	Exceeds background range
Thorium-230	<1.7	0.1	1.0	--	0.1	No	Within background range
Uranium-234	0.99	0.77	0.52	0.69	0.66	No	Within background range
Uranium-238	0.73	**0.77**	0.77	0.71	**0.78**	NC, UC	Exceeds background range

NC = North Continent; UC = Union Carbide.
Text in shaded cells indicates value exceeds the maximum NC site upstream concentration, which is considered to be background.

Table 4. Ecological Constituents of Potential Concern for Sediments of the Dolores River Based on the 1993-1994 Sampling Data

Constituent	Maximum Concentration (mg/kg)			Ecological-COPC? (site)	Reason
	NC Site Upstream[a]	NC Site	UC Site		
Cadmium	1.3	1.2	1.7	UC	Exceeds background
Copper	3.0	--	15	UC	Exceeds background
Molybdenum	4.8	6.3	5.2	NC, UC	Exceeds background
Selenium	1.2	3.1	3.2	NC, UC	Exceeds background
Uranium	2.0	2.2	1.9	NC	Exceeds background
Vanadium	33	46	43	NC, UC	Exceeds background
Zinc	53	75	86	NC, UC	Exceeds background

[a]Used as the reference site for background conditions.
NC = North Continent; UC = Union Carbide.
Text in shaded cells indicates value exceeds the maximum NC site upstream concentration.

A summary of the results of the reevaluation of E-COPCs is presented in Table 5. These lists of E-COPCs are media-specific and location-specific.

Table 5. Summary of Ecological Contaminants of Potential Concern at the Two Sites Associated with the Slick Rock Site as Based on Most Recent Analytical Data

Dolores River				Ground Water	
North Continent Site		Union Carbide Site		North Continent Site	Union Carbide Site
Surface Water	Sediment	Surface Water	Sediment		
Chloride	Molybdenum	Ammonium	Cadmium	Chloride	Ammonium
Iron	Selenium	Bromide	Copper	Molybdenum	Bromide
Manganese	Uranium	Chloride	Molybdenum	Nitrate	Cadmium
Molybdenum	Vanadium	Iron	Selenium	Selenium	Chloride
Uranium	Zinc	Manganese	Vanadium	Uranium	Iron
Vanadium		Molybdenum	Zinc	Gross Alpha	Manganese
Gross Alpha		Nitrate		Gross Beta	Molybdenum
Gross Beta		Vanadium		Radium-226	Nitrate
Lead-210		Gross Alpha		Radium-228	Selenium
Polonium-210		Lead-210		Uranium-234	Strontium
Radium-226		Radium-226		Uranium-238	Sulfate
Radium-228		Uranium-238			Uranium
Uranium-238					Vanadium
					Benzene
					Ethylbenzene
					Toluene
					Xylenes
					Radium-226
					Radium-228
					Uranium-234
					Uranium-238

1.2 Ecological Site Conceptual Model

The conceptual model for an ecological risk assessment (ERA) is developed from information about stressors, predicted exposure pathways, and the potential effects of exposure on ecological receptors. Conceptual models consist of two principal components (EPA 1998):

- A set of risk hypotheses that provide descriptions of predicted relationships among stressor, exposure, and assessment endpoint response, along with the rationale for their selection.

- A diagram that illustrates the relationships presented in the risk hypotheses.

A complete exposure pathway is the mechanism by which a contaminant in an environmental medium (i.e., the source) can contact an ecological receptor. A complete exposure pathway includes:

- Contaminant source
- Release mechanism that allows contaminants to become mobile or accessible
- Transport mechanism that moves contaminants away from the release
- Ecological receptor
- Route of exposure (e.g., dermal or direct contact, inhalation, or ingestion).

Because the stressors at the Slick Rock site are chemical contaminants, the risk hypotheses are considered to be stressor-initiated.

As part of the initial problem formulation in the BLRA, a generalized site conceptual model was developed for the Slick Rock site. That model has since been revised to address current and potential exposure pathways based on all the available data (Figure 1). At this site, the movement of contaminated ground water from the sites is not known to have resulted in surface expressions of this ground water; however, contact with the Dolores River is possible. For this reason, risk hypotheses are developed for the Dolores River based on this possible contact.

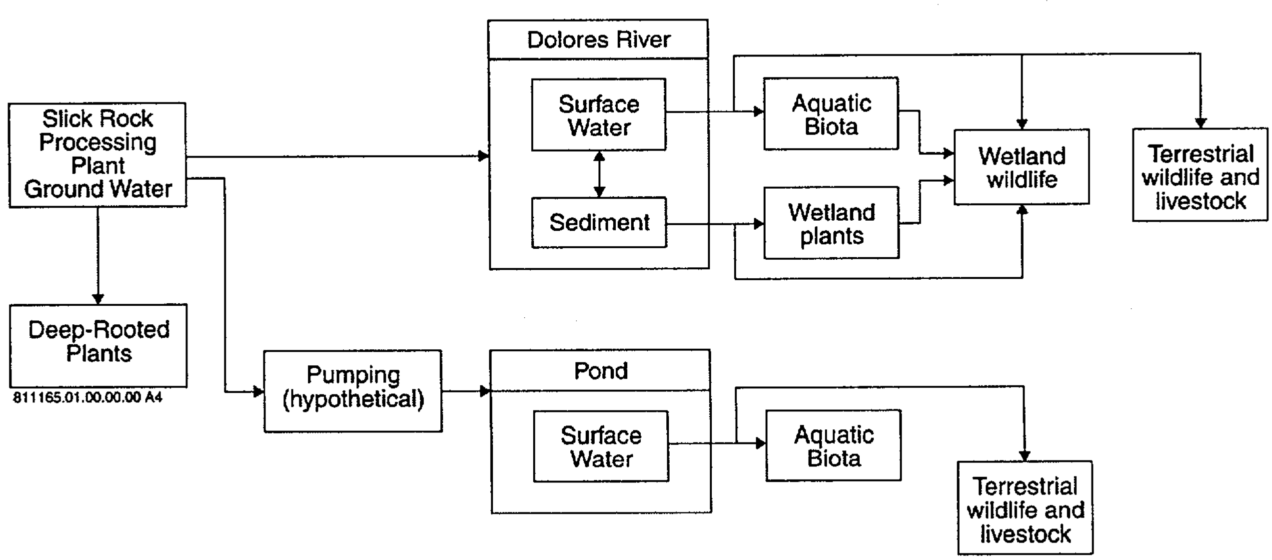

Figure 1. Slick Rock Ecological Site Conceptual Model

1.2.1 Risk Hypotheses Based on Current Exposure Scenarios

The following are the risk hypotheses proposed for the Slick Rock site where complete exposure pathways to ecological receptors may exist based on the current site conditions. Contaminants in the near-surface ground water of the processing plants may be taken up by deep roots of phreatophytes. These may result in phytotoxic effects on the plant and/or be transported to plant tissues that are accessible to wildlife and foraging livestock. Contaminated ground water may be discharging into the Dolores River, thereby adversely affecting surface water and sediment quality of the area. Aquatic organisms in direct contact with these media may be affected and/or may provide a link for bioaccumulation of the contaminants up the food chain. Further, wildlife and livestock may be directly exposed to these contaminants through the ingestion of this water and/or the food items exposed to the water and sediment and the incidental ingestion of the sediment.

1.2.2 Risk Hypotheses Based on Hypothetical Future Exposure Scenario

Without institutional controls, ground water could possibly be pumped and used for irrigation, livestock watering, or industrial uses. This practice would create a source for potential ingestion of ground water, direct contact with terrestrial vegetation, and deposition of ground water on the soil. The soil would then represent an additional source medium for ingestion and direct contact.

1.2.3 Ecological Receptors

Ecological receptors that could potentially be exposed to E-COPCs were identified in the BLRA (DOE 1995) and include mammalian and avian species. Section 1.1 summarizes the habitats and populations that may be affected by exposures to E-COPCs at the Slick Rock site. The food web for the Slick Rock site (Figure 2) illustrates the significant dietary interactions among and between the wetland and aquatic receptors associated with the Dolores River. The food web also depicts the major trophic interactions and shows nutrient flow and transfer of matter and energy through the trophic levels. This food web model was developed from the species lists and consideration of the exposure pathways. The food web diagram was used to portray potential routes of E-COPCs from the ground water to biota at various trophic levels, with potential receptor species being specific areas identified as having potentially complete ecological exposure pathways. These potential receptors are as follows:

The Dolores River. The habitat of the river channel is primarily riparian. The potential receptors of these areas include:

- Plants—Wetland and riparian plants that grow along the channel course in direct contact with water and sediments.
- Aquatic receptors—Aquatic receptors include fish, aquatic invertebrates, and aquatic plants that live in direct contact with water and sediments.
- Wetland wildlife—Wetland wildlife may be exposed to E-COPCs along the river as a result of drinking surface water and feeding on the aquatic organisms and wetland plants. Potential receptors include insectivorous birds, such as swallows and flycatchers; shorebirds, such as sandpipers and killdeer; piscivorous birds, such as belted kingfishers and herons; and mammals that are associated with wetland habitats, including muskrats and raccoons.

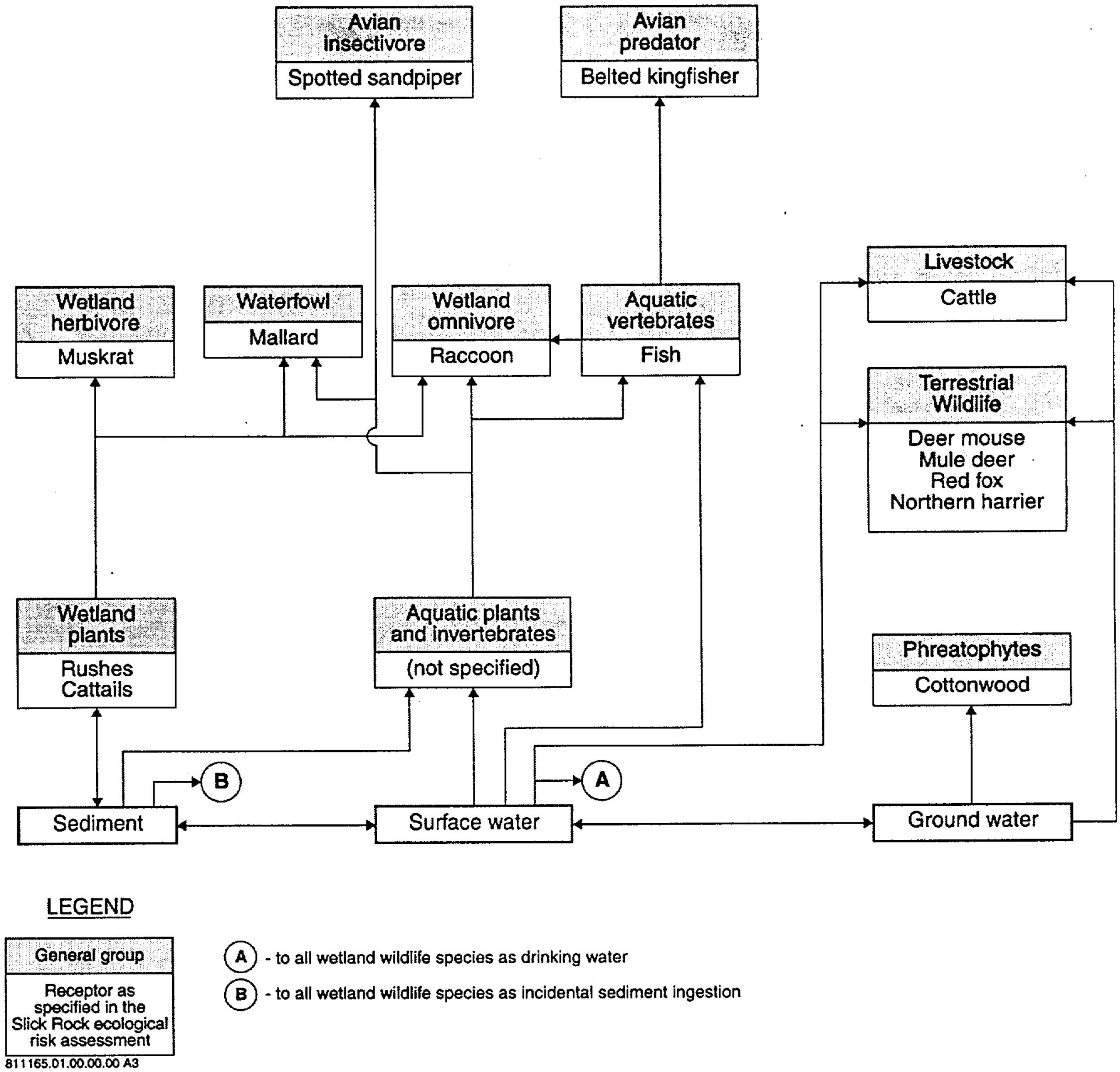

Figure 2. Generalized Food Web for Slick Rock Ecological Receptors

Potential receptors associated with the Dolores River at this site also include three threatened or endangered species. As described in Section 1.1, the bald eagle and southwestern river otter are potential receptors on the Dolores River that are also listed as threatened or endangered species. In addition, based on habitat conditions along the Dolores River, the endangered southwestern willow flycatcher may occur there. However, based on the lack of recent evidence of occurrence in the river, none of the four species of endangered fish species discussed in Section 1.1 are considered potential receptors at this site.

The Dolores River Floodplain and the Uplands. The habitats of the Dolores River floodplain and adjacent uplands are primarily terrestrial; however, many of the wildlife receptors that occur in these habitats live and feed in close association with the aquatic habitats of the river. These receptors may use the river as a source of drinking water, and may thereby be exposed to

E-COPCs. Because the floodplain and upland areas are used for grazing, cattle are considered potential receptors for this site with regard to exposures through drinking water from the Dolores River.

1.2.4 Management Goals and Endpoints

Table 6 presents the primary goals for the protection of environmental resources at the Slick Rock site with respect to contaminants associated with ground water, and the assessment and measurement endpoints that will be used to evaluate potential risk to these resources in support of achieving these goals.

Table 6. Management Goals, Assessment Endpoints, and Measurement Endpoints for the Evaluation of Ecological Risks at the Slick Rock Site

Management Goals	Assessment Endpoints	Measurement Endpoints
Maintain the quality of aquatic habitats in the Dolores River	Surface water quality of the Dolores River	Concentrations of ecological COPCs in the surface water of the Dolores River meet applicable water quality criteria or equivalent benchmarks for the protection of aquatic life.
	Sediment quality of the Dolores River	Concentrations of ecological COPCs in the sediment of the Dolores River meet applicable sediment quality benchmarks for the protection of benthic organisms.
Maintain habitat quality of the floodplain for the protection of wildlife diversity	Potential for adverse effects on survival and reproduction in wildlife from exposures to ecological COPCs in various environmental media of the Dolores River floodplain and adjacent uplands	Hazard quotients comparing estimated exposure to toxicity benchmarks for key indicator receptor species are less than unity.
	Ground water quality of the Dolores River floodplain	Concentrations of ecological COPCs in the ground water of the Dolores River floodplain meet benchmarks for the protection of riparian plants.

2.1 Analysis

2.1.1 Exposure Assessment

2.1.1.1 Exposure Modeling and Assumptions

Only complete exposure pathways are quantitatively and qualitatively evaluated in an ERA. In this assessment, the following potential exposure pathways were considered for evaluation:

- Surface water—ingestion and direct contact
- Sediment—ingestion and direct contact
- Dietary—ingestion of forage or prey, as appropriate, by receptor

The contaminants associated with the Slick Rock site are principally inorganics and are associated with water (surface water and ground water) and sediments. Estimations of potential exposures to key ecological receptors are based on the dominant pathways from these media for the specific receptor. Exposures in wetland plants are dominated by direct contact with the sediment in which they are rooted. Phreatophytes may be exposed through direct contact with the ground water. Exposures to aquatic organisms (those that live within the water column) and benthic organisms (those that live within the sediment) are dominated by direct contact with the external media (water and sediment) in which they live, but in the cases of aquatic and benthic animals also include the ingestion of food associated with these media. In all of these cases (plants and animals), potential exposure to an E-COPC is based on the concentration of that E-COPC in the media of principal contact (water or sediment).

Exposures in wildlife involve multiple potential pathways that may include ingestion of food, water, and sediment; direct contact and dermal absorption; and inhalation. In this assessment, the inhalation and dermal absorption pathways are assumed to be minor pathways with respect to the combined exposures based on ingestion (food, water, and sediment ingestion). Most wildlife of the area have very little and infrequent direct dermal contact with potentially contaminated media due to their protective covers of feathers or fur and their habits and behaviors, such as preening and grooming, and (in the cases of most birds) living principally in trees and shrubs. With the exception of the BTEX compounds, which are confined to the ground water, the E-COPCs are not highly volatile. Therefore, their occurrence in the air is minimal. For the assessment of exposures in wildlife through inhalation was considered a minor exposure pathway relative to sediment ingestion. Although both dermal absorption and inhalation will contribute to the overall exposure in these receptors, these contributions are assumed to be included within the conservatisms incorporated in the estimation of exposures through the ingestion pathways.

In the estimation of ingestion-related exposure for the wildlife receptors, the E-COPCs are assumed to be 100 percent bioavailable and the receptors are assumed to be exposed only at the selected exposure point concentration, regardless of home range size or seasonal use patterns. The exposure through multiple ingestion pathways is modeled using the methods described in the U.S. Environmental Protection Agency's (EPA's) *Wildlife Exposure Factors Handbook* (EPA 1993). The basic model for estimating the daily intake of an E-COPC per kilogram of body weight (i.e., the estimated daily dose of the E-COPC) through these ingestion pathways is

$$D_x = \frac{\sum_{k=1}^{m}(C_k \cdot F_k \cdot I_k) + C_s \cdot F_s \cdot I_s + C_w \cdot F_w \cdot I_w}{W}$$

where

D_x = the estimated daily dose (mg/kg-day) of E-COPC x,
C_k = the concentration of E-COPC x in the kth food type (mg/kg dry weight),
F_k = the fraction of the kth food type that comes from the site,
I_k = the ingestion rate of the kth food type (kg dry weight/day),
m = the number of food items in the receptor's diet,
C_s = the concentration of E-COPC x in the sediment or soil (mg/kg dry weight),
F_s = the fraction of ingested sediment or soil that comes from the site,
I_s = the ingestion rate of sediment or soil (kg dry weight/day),
C_w = the concentration of E-COPC x in water (mg/L),
F_w = the fraction of the ingested water that comes from the site,
I_w = the ingestion rate of water (L/day), and
W = the body weight of the receptor (kg wet weight).

F_k, F_s, and F_w are commonly assumed to be the area use factor (the area of the site divided by the home range of the receptor or 1, whichever is smaller) but may also be modified by a seasonal use factor (number of days at the site divided by 365 days per year) if the home range is used for only part of the year. For estimating risk in this assessment, both area use and seasonal use are conservatively assumed to be 100 percent; therefore, F_k, F_s, and F_w are assumed to be 1.

For the purposes of estimating exposure in wildlife, the E-COPC concentrations in plants were principally based on the empirically-derived uptake models (nonlinear or linear) as recommended by Oak Ridge National Laboratory (Bechtel Jacobs Company 1998a). The nonlinear form of the uptake model is

$$C_{plant} = B_0 \cdot C_{soil}^{B_1}$$

where

C_{plant}	=	the concentration of the E-COPC in the plant (mg/kg dry weight),
C_{soil}	=	the soil concentration of the E-COPC (mg/kg dry weight), and
B_0 and B_1	=	empirically derived model parameters for the E-COPC.

In the linear form of this model, B_1 is assumed to be exactly 1 and B_0 becomes a soil-to-plant transfer factor, where

$$C_{plant} = B_0 \cdot C_{soil}$$

In cases where parameters were not available in the Oak Ridge National Laboratory uptake model documents, soil-to-plant transfer factors from other literature sources (e.g., Baes and others 1984) were used in this linear model.

For aquatic prey species (invertebrates and fish), linear uptake models based on bioaccumulation factors (BAFs) were used to estimate concentrations of E-COPCs in tissues. These models are of the form:

$$C_{organism} = BAF \cdot C_{water}$$

where

$C_{organism}$	=	the concentration of the E-COPC in the invertebrate or fish prey species(mg/kg dry weight),
C_{water}	=	the concentration of the E-COPC in the water (mg/L), and
BAF	=	the bioaccumulation factor for the E-COPC.

BAFs account for all exposure pathways (dermal absorption, uptake through respiratory organs, and ingestion). In contrast, bioconcentration factors (BCFs) account for uptake through pathways other than ingestion. However, for most inorganic constituents, uptake through ingestion is insignificant, and BAFs are considered to be equal to BCFs. Therefore, BCFs are used as BAFs in this assessment when the latter values are not available. Whenever possible, however, BAFs and BCFs specific to either invertebrates or fish were used to model the concentrations in these respective prey types. Data specific to ammonium and nitrate uptake could not be found; however, because of its high biological activity, ammonium was assumed not to accumulate in tissues or be transferred through the food web. Nitrate concentrations in the prey species were assumed to equal its concentration in the surrounding media. Table 7 presents the uptake model parameters (B_0, B_1, BAF, and/or BCF values) used in modeling the concentrations of E-COPCs through the food chain at the Slick Rock site.

Table 7. Uptake Model Parameters and Bioaccumulation Factors for Ecological Contaminants of Potential Concern

Ecological Contaminant of Potential Concern	Plant Uptake Model Parameters		Bioaccumulation Factors	
	B_0	B_1	Invertebrates	Fish
Cadmium	0.621[a]	0.546[a]	NA[b]	NA[b]
Copper	1.95[a]	0.394[a]	NA[b]	NA[b]
Iron	0.004[c]	1.0[d]	200[e]	200[f]
Manganese	3.0[g]	1.0[d]	65[h]	17.8[h]
Molybdenum	0.8[f]	1.0[d]	10[e]	10[f]
Nitrate	1.0[i]	1.0[i]	1.0[i]	1.0[i]
Selenium	0.508[a]	1.10[a]	269[j]	129[k]
Uranium	0.023[f]	1.0[d]	27.1[e]	27.1[h]
Vanadium	0.0055[c]	1.0[d]	3,000[l]	10[l]
Zinc	4.831[a]	0.555[a]	NA[b]	NA[b]

[a]From Bechtel Jacobs Company (1998a).
[b]Not applicable. The E-COPC was limited to sediment, and was not modeled into fish and invertebrate prey.
[c]From Baes and others (1984).
[d]The uptake model is linear; therefore, $B_1 = 1.0$.
[e]Invertebrate bioaccumulation factor based on fish bioaccumulation factor.
[f]From IAEA (1994).
[g]From NCRP (1989).
[h]From AQUIRE (EPA 2000).
[i]Default value.
[j]Geometric mean of selenite bioaccumulation factors for water fleas based on 14-day exposure from AQUIRE (EPA 2000).
[k]From NMED (2000).
[l]From Bodek and others (1988).

2.1.2 Key Indicator Receptors

The receptors used to evaluate potential risks were selected based on their potential presence in the habitats of the site, their potential for exposure to E-COPCs in the media at the site, and their potential for conservatively representing potential exposures to a range of other receptors at the site. Receptors for the habitats identified as having potentially complete ecological pathways are discussed in Section 1.2.3. The indicator receptors are representative of key links in the food webs associate with these habitats.

These indicator receptors are as follows:

- Terrestrial habitats—deep-rooted plant (phreatophyte), deer mouse (herbivorous), red fox, mule deer, northern harrier, cattle

- Wetland habitats—wetland plant, muskrat, river otter, mallard, spotted sandpiper, belted kingfisher
- Aquatic habitats—aquatic and benthic organisms

Terrestrial exposure pathways are found on the floodplain and adjacent uplands. Deep-rooted plants (e.g., cottonwood) are considered only as potential receptors for E-COPCs in the ground water underlying the floodplain. For the terrestrial wildlife and livestock on the floodplain, surface water is considered to be the primary source medium for E-COPC exposures, and therefore, risks to all terrestrial receptors listed above are evaluated based on the potential consumption of drinking water from the various sources, including the hypothetical pumping of ground water to a surface pond. The terrestrial wildlife receptors used represent both mammals and birds, with the mammals being represented by a range of body sizes, from a deer mouse to a mule deer. In addition, livestock (cattle) are also used to evaluate potential risk from drinking water on the floodplain.

For the wetland habitats, emergent plants are considered to be the primary producers and the muskrat and mallard are considered to be representative of herbivores that may consume such plants. The river otter represents a carnivore in this habitat. The spotted sandpiper represents an insectivorous bird and the belted kingfisher represents a piscivorous bird. All animal prey of these wildlife receptors (the muskrat being the only one modeled as purely herbivorous) are assumed to be aquatic (invertebrates or fish).

Receptors in the aquatic habitats are not specified. Risk to these receptors is based on comparisons of the media E-COPC concentrations (water and sediment) to broad-based benchmark values, such as ambient water quality criteria (AWQC), that are protective of a wide range of aquatic and benthic organisms. For the Dolores River, fish are assumed to be included as potential aquatic receptors within this broad categorization. All wildlife receptors are modeled as potential receptors of E-COPCs in surface water through the consumption of that water at all sites where surface water is present as a medium of concern.

The species-specific parameters used to model exposures to these key indicator receptors (wildlife only) are presented in Table 8.

2.1.3 Effects Characterization

The potential for adverse effects to ecological receptors resulting from exposures to E-COPCs at the Slick Rock site was evaluated through the comparison of the potential exposure in the receptor to a toxicity-based benchmark of exposure representing the threshold of potential adverse effects.

For aquatic and benthic receptors and plants, the exposure to an E-COPC is characterized by the concentration of that E-COPC in the medium (water or sediment, respectively) with which the receptor is principally in direct contact. Therefore, the benchmarks by which the potential for adverse effects is evaluated are also based on media concentrations. For surface water, either AWQC (EPA 1999b) or Colorado Department of Public Health and Environment (CDPHE) Water Quality Standards (whichever was lesser) were used as the principal benchmarks for evaluating potential risk to aquatic life. When neither was available for an E-COPC, Tier II secondary values (Suter and Tsao 1996) were used. It should be noted that these water quality standards are lower than, and therefore inclusive of, the CDPHE standards for agricultural uses of the water. Sediment benchmarks were principally based on the lowest threshold effect levels (TELs) as presented in Buchman (1999), and supplemented from other sources (e.g., Haines and others 1994). Table 9 and Table 10 present these water and sediment quality benchmark values, respectively.

Table 8. Exposure Parameters for Livestock and Wildlife Receptors

Receptor	Body weight (kg)[a]	Food ingestion rate (kg [dry wt.]/day)[b]	Soil/sediment ingestion rate (percent of food ingestion)[c]	Water ingestion rate (L/day)[d]	Dietary Composition (percent)[e]
Deer mouse (*Peromyscus maniculatus*)	0.0239[f]	NA	NA	0.00344	NA
Muskrat (*Ondatra zibethicus*)	1.135	0.0772[g]	9.4[h]	0.111	Plant: 100
River otter (*Lutra canadensis*)	7.4[f]	0.356	9.4[h]	0.600	Invertebrate: 26 Fish: 74
Red fox (*Vulpes vulpes*)	4.54	NA	NA	0.386	NA
Mule deer (*Odocoileus hemionus*)	65[f]	NA	NA	4.24	NA
Northern harrier (*Circus cyaneus*)	0.180[i]	NA	NA	0.0187	NA
Mallard (*Anas platyrhynchos*)	1.134	0.0592	3.3	0.0642	Plant: 90 Invertebrate: 10
Spotted sandpiper (*Actitis macularia*)	0.0425	0.00503	18[j]	0.0711	Invertebrate: 100
Belted kingfisher (*Ceryle alcyon*)	0.147	0.0128	2.0[k]	0.0163	Invertebrate: 20 Fish: 80

[a]From EPA (1993), except where noted.
[b]Based on allometric equations from Nagy (1987), as presented in EPA (1993), except where noted.
[c]From Beyer and others (1994). Data are species-specific except where noted.
[d]Based on allometric equations from Calder and Braun (1983), as presented in EPA (1993), except where noted.
[e]Diets are generalized to emphasize specific trophic levels. Dietary compositions of the river otter, mallard, and belted kingfisher are based on species-specific information presented in EPA (1993) and Martin and others (1951) and have generally been rounded to increments of 10 percent.
[f]From Silva and Downing (1995).
[i]From Dunning (1993).
[g]Based on species-specific food intake rate from EPA (1993), with assumed water content of food of 80 percent.
[h]Based on soil/sediment ingestion for raccoon from Beyer and others (1994).
[i]From Dunning (1993).
[j]Based on the mean soil/sediment ingestion rate of four species of sandpipers as reported by Beyer and others (1994).
[k]No data available. Assumed value of 2 percent is based on the detection limit of the method used by Beyer and others (1994).

Table 9. Surface Water Quality Benchmarks for Ecological Contaminants of Potential Concern for the Protection of Freshwater Aquatic Life

Contaminant of Potential Concern	Water Quality Benchmarks (mg/L)		
	AWQC[a]	CDPHE SWQS[b]	Tier II[c]
Ammonium	--	0.026[d]	--
Bromide	--	--	--
Cadmium	0.0022	0.0011[d]	--
Chloride	230	250[d]	--
Iron	1.0	1.0[d]	--
Manganese	--	0.05[d]	--
Molybdenum	--	--	0.24
Nitrate	--	10[d]	--
Selenium	0.005	0.005[d]	--
Strontium	--	--	1.5
Sulfate	--	250[d]	--
Uranium	--	1.5	--
Vanadium	--	--	0.019
Benzene	--	--	0.046
Ethylbenzene	--	--	0.29
Toluene	--	--	0.13
Xylenes	--	--	0.0018

[a]EPA ambient water quality criteria (EPA 1999b, Buchman 1999). Hardness of 100 mg/L $CaCO_3$ was used for all hardness-dependent values.
[b]Colorado Department of Public Health and Environment Surface Water Quality Standard for aquatic life.
[c]Tier II secondary chronic value from Suter and Tsao (1996).
[d]Standard for the Dolores River above Montrose County line. Ammonium converted from standard for ammonia as N (0.02 mg/L).
-- = No value available.

Table 10. Sediment Quality Benchmarks for Ecological Contaminants of Potential Concern

Contaminant of Potential Concern	Sediment Quality Benchmark (mg/kg)
Cadmium	0.596[a]
Copper	35.7[a]
Molybdenum	4.0[b]
Selenium	5.0[c]
Uranium	--
Vanadium	--
Zinc	123.1[a]

[a]From Buchman (1999) (Threshold Effects Level)
[b]Sediment quality guideline for the protection of agricultural uses (from Haines and others 1994).
[c]Sediment quality criterion from British Columbia (Haines and others 1994).
-- = No benchmark available.

For plants, toxicity benchmarks are based primarily on the information provided in Efroymson and others (1997). These benchmarks are based on lowest-observed-adverse-effect levels (LOAELs) using 20 percent reduction in growth as the endpoint. Both the soil-based and solution-based benchmarks were used. Soil-based benchmarks were used to evaluate risk to wetland exposed to sediments, while solution-based benchmarks were used to evaluate potential risk to phreatophytes that may be in contact with ground water. Although based on LOAELs, these benchmarks are considered conservative. The endpoint is sublethal and reductions in plant growth may have no significant effect on the reproductive potential or the continued existence of a plant population. Further, these benchmarks are primarily based on studies in which the chemical of interest is added freshly to a soil (often as a soluble salt) and is typically more bioavailable than the COPCs in field situations where they have had time to bind more strongly with soil particles. The plant toxicity benchmarks are presented in Table 11.

Table 11. Plant Toxicity Benchmarks for Ecological Contaminants of Potential Concern

Ecological Contaminant of Potential Concern	Plant Toxicity Benchmark for Soil[a] (mg/kg)	Plant Toxicity Benchmark for Water[a] (mg/L)
Ammonium	NA	---
Bromide	NA	---
Cadmium	4.0	0.1
Chloride	NA	---
Copper	100	NA
Iron	NA	10
Manganese	NA	4.0
Molybdenum	2.0	0.5
Nitrate	NA	---
Selenium	1.0	0.7
Strontium	NA	---
Sulfate	NA	---
Uranium	5.0	40
Vanadium	2.0	0.2
Zinc	50	NA
Benzene	NA	---
Ethylbenzene	NA	---
Toluene	NA	10
Xylenes	NA	100

[a]From Efroymson and others (1997).

NA = Not applicable
--- = No benchmark available.

For the wildlife receptors, no-observed-adverse-effect levels (NOAELs) for chronic oral exposure are used as benchmarks for toxic effects. The endpoints of particular interest in this assessment are those associated with reproductive health, development, and mortality. Therefore, NOAELs are defined as the maximum dosage tested that produced no effect that would be considered adverse to the receptor's survival, growth, or reproductive capacity. Because the NOAELs for the wildlife receptor species are based on NOAELs from test species, the latter are scaled to NOAELs specific to the wildlife receptor species using a power function of the ratio of body weights, as described by Sample and others (1996) and Sample and Arenal (1999). This scaling is based on the equation:

$$NOAEL_W = NOAEL_T \left(\frac{BW_T}{BW_W}\right)^s$$

where

$NOAEL_W$	=	the no-observed-adverse-effect level for the wildlife receptor species (mg/kg-day),
$NOAEL_T$	=	the no-observed-adverse-effect level for the test species (mg/kg-day),
BW_T	=	the body weight of the test species (kg),
BW_W	=	the body weight of the wildlife receptor species (kg), and
s	=	the body weight scaling factor; (s = 0.06 for mammals and s = -0.2 for birds (Sample and Arenal 1999).

Toxicity studies were considered to be chronic if they are conducted over a period of 26 weeks (one-half year) or more. This period represents the period of seasonal use by migratory and hibernating species and is sufficient time for small animals to complete their reproductive cycles. Studies of lesser duration (i.e., 1 to 25 weeks) are considered subchronic, unless they specifically included reproductive effects as endpoints (Sample and others 1996). When only subchronic oral $NOAEL_T$ values were available, these are converted to chronic $NOAEL_T$ values by applying an uncertainty factor of 0.1 (Sample and others 1996).

When only a chronic LOAEL value was available for test data, an uncertainty factor of 0.1 was used to convert it to the chronic $NOAEL_T$. If only a subchronic LOAEL was available, then an uncertainty factor of 0.01 was used to estimate the chronic $NOAEL_T$. This uncertainty factor is the product of two uncertainty factors of 0.1, one to convert the subchronic value to a chronic value and the other to convert the LOAEL to an NOAEL. NOAELs were not determined if toxicity data could not be found for test species within the same class. Therefore, NOAELs for mammalian receptors are derived only from mammalian test species data and NOAELs for avian receptors are derived only from avian test species data. The toxicity data and receptor-specific NOAELs used in this assessment for mammalian and avian receptors are presented in Table 12 and Table 13, respectively.

3.1 Risk Characterization

The potential for risk to ecological receptors is determined through hazard quotients (HQs). HQs are specific to a particular receptor for exposure to a particular E-COPC. An HQ is defined by:

$$HQ = \frac{Exposure}{Benchmark}$$

For aquatic and benthic organisms and plants, exposures are equivalent to media concentrations (surface water or sediment) with which the organism is in contact. For wetland wildlife, exposures are modeled from multiple pathways by the methods described in Section 2.1.1. The methods for determining toxicity benchmark values for these receptors are discussed in Section 2.1.3.

Table 12. Mammal Toxicity Benchmarks for Ecological Contaminants of Potential Concern

Ecological Contaminant of Potential Concern	Mammalian Test Data[a]			Mammalian Receptor NOAELs (mg/kg-day)					
	Test Species	Body weight (kg)	NOAEL (mg/kg-day)	Deer mouse	Red fox	Mule deer	Muskrat	River otter	Cow
Ammonium	---	---	---	---	---	---	---	---	---
Bromide	---	---	---	---	---	---	---	---	---
Cadmium	Rat	0.303	1.0	1.16	0.850	0.725	0.924	0.826	0.641
Chloride	---	---	---	---	---	---	---	---	---
Copper	Mink	1.0	11.7	14.6	10.7	9.11	11.6	10.4	8.06
Iron	---	---	---	---	---	---	---	---	---
Manganese	Rat	0.35	88.0	103	75.5	64.3	82.0	73.3	56.9
Molybdenum	Mouse	0.03	0.26	0.264	0.192	0.164	0.209	0.187	0.145
Nitrate	Guinea pig	0.86	507	629	459	391	499	446	346
Selenium	Rat	0.35	0.20	0.235	0.171	0.146	0.186	0.167	0.129
Strontium	Rat	0.35	263	309	226	192	NA	NA	170
Sulfate	---	---	---	---	---	---	---	---	---
Uranium	Mouse	0.028	3.07	3.10	2.26	1.93	2.46	2.20	1.71
Vanadium	Rat	0.26	0.21	0.242	0.177	0.151	0.192	0.172	0.133
Zinc	Rat	0.35	160	188	137	117	149	133	103
Benzene	Mouse	0.03	26.36	26.7	19.5	16.6	NA	NA	14.7
Ethylbenzene	Rat	0.35	19.4[b]	22.8	16.6	14.2	NA	NA	12.5
Toluene	Mouse	0.03	26.0	26.4	19.2	16.4	NA	NA	14.5
Xylenes	Mouse	0.03	2.1	2.13	1.55	1.32	NA	NA	1.17

[a]From Sample and others (1996), except where noted.
[b]Based on information from the Integrated Risk Information System database (EPA 2001).

NA = Not applicable.
--- = Insufficient toxicity information.

Table 13. Avian Toxicity Benchmarks for Ecological Contaminants of Potential Concern

Ecological Contaminant of Potential Concern	Avian Test Data[a]			Avian Receptor NOAELs (mg/kg-day)			
	Test Species	Body weight (kg)	NOAEL (mg/kg-day)	Northern harrier	Mallard	Spotted sandpiper	Belted kingfisher
Ammonium	---	---	---	---	---	---	---
Bromide	---	---	---	---	---	---	---
Cadmium	Mallard	1.153	1.45	1.00	1.45	0.749	0.960
Chloride	---	---	---	---	---	---	---
Copper	Chicken	0.534	47.0	37.8	54.6	28.3	36.3
Iron	---	---	---	---	---	---	---
Manganese	Japanese quail	0.072	977	1,170	1,700	879	1,130
Molybdenum	Chicken	1.5	3.53	2.31	3.34	1.73	2.22
Nitrate	---	---	---	---	---	---	---
Selenium	Mallard	1.0	0.40	0.284	0.410	0.213	0.273
Strontium	---	---	---	---	---	---	---
Sulfate	---	---	---	---	---	---	---
Uranium	Black duck	1.25	16.0	10.9	15.7	8.14	10.4
Vanadium	Mallard	1.17	11.4	7.84	11.3	5.87	7.53
Zinc	Chicken	1.935	14.5	9.02	13.0	6.76	8.66
Benzene	---	---	---	---	---	---	---
Ethylbenzene	---	---	---	---	---	---	---
Toluene	---	---	---	---	---	---	---
Xylenes	---	---	---	---	---	---	---

[a]From Sample and others (1996).

NA = Not applicable.
--- = Insufficient toxicity information.

The value of the HQ is greater than 1.0 if the magnitude of the exposure is greater than the corresponding benchmark, and conversely, the HQ is less than or equal to 1.0 if the exposure is less than or equal to the benchmark. An HQ value less than or equal to 1.0 is interpreted as evidence of no potential risk to that receptor for that E-COPC. If the HQs for an E-COPC are less than unity for all receptors, that E-COPC is eliminated from further consideration as a potential ecological risk driver. However, because exposure for the screening of E-COPCs is conservatively estimated, an HQ value greater than unity is not interpreted as evidence of risk, but only as evidence that the potential for risk cannot be ruled out.

For the purposes of this evaluation, potential exposures were conservatively based on the maximum measured E-COPC in each medium of ecological concern (surface water, sediment, and ground water) at each of the two sites. When sufficient data existed, the UCL_{95} concentrations were used to calculate HQs that better reflect average (yet still conservatively estimated) risks to receptors in these areas. UCL_{95} concentrations were not determined for the sediment data, which were limited to three data points for the UC site and only one for the NC site. The following are summaries of the risk assessment results for specific media and associated receptor groups.

3.1.1 Risk to Ecological Receptors Associated with the Dolores River

Table 14 presents the comparison of surface water concentrations from the Dolores River at the NC and UC sites to water quality benchmarks for the protection of aquatic life. These data represent existing surface water conditions at the Slick Rock site. Comparisons are made with both the maximum measured concentration and UCL_{95} values. Of the E-COPCs identified for the NC and UC areas, only ammonium (at the UC site) and vanadium (at both sites) exceeded their respective water quality benchmarks. In all cases, this was true for both the maximum and UCL_{95} concentrations. However, in all cases, the HQ values were relatively low (less than 3.5).

Although the ammonium concentrations at the UC site indicate a potential exceedence of the CDPHE standard for ammonia in the Dolores River, it should be noted that the maximum measured concentration at this site (0.0906 mg/L) was only marginally above the maximum measured ammonium concentration from upstream of the NC site (0.0799 mg/L), which also exceeded the CDPHE standard (0.026 mg/L, as converted to ammonium from the standard of 0.02 mg/L ammonia as N). The UCL_{95} from downstream of the UC site (0.0583 mg/L) is within the range of the upstream samples, and is only slightly elevated above the UCL_{95} for water in the Dolores River above the NC site (0.05106 mg/L). In the case of vanadium, it should be noted that although this element was not detected in any of the nine surface water samples collected from upstream of the NC site, it was only detected in one of 12 samples from each of the locations adjacent to the NC site, upstream of the UC site, and downstream of the UC site; and it was not detected in any of the three samples adjacent to the UC site. Therefore, the contribution of ammonium and vanadium from the NC and UC sites appear to be small and of questionable significance with regard to potential risk to the aquatic communities of the river.

Table 15 presents the comparison of the maximum measured E-COPC concentrations in sediment (from 1993 and 1994 data) to sediment quality benchmarks. The maximum cadmium concentration at the UC site and the maximum molybdenum concentrations at both sites exceeded their respective benchmark values; however, the HQs were relatively low (less than 3). In both cases, the maximum values were marginally elevated above the maximum concentration measured from sediment upstream of the NC site (1.3 mg/kg for cadmium and 4.8 mg/kg for molybdenum), and in both cases, these upstream concentrations also exceeded the sediment benchmarks. Therefore, the contribution of the NC and UC sites appear to be small with regard to potential risk to the benthic communities of the river.

Table 16 shows the comparison of the maximum sediment concentrations to plant toxicity benchmarks. Here, molybdenum, selenium, vanadium, and zinc all resulted in HQs greater than unity at both sites. In all four of these cases, the maximum upstream concentrations also exceeded the plant toxicity benchmarks. Vanadium, which showed the highest HQ for the sites (23.0), would have a HQ of 16.5 based on the maximum upstream sediment concentration. This indicates the conservative nature of the plant toxicity benchmarks.

Table 14. Hazard Quotients for Aquatic Communities of the Dolores River Based Upon Comparison of Water Concentrations to Water Quality Benchmarks for the Protection of Aquatic Life

Ecological Contaminant of Potential Concern	Water Quality Benchmark (mg/L)	Dolores River Surface Water at the North Continent Site				Dolores River Surface Water at the Union Carbide Site			
		Maximum		UCL_{95}		Maximum		UCL_{95}[a]	
		Concentration (mg/L)	Hazard Quotient	Concentration (mg/L)	Hazard Quotient	Concentration (mg/L)	Hazard Quotient	Concentration (mg/L)	Hazard Quotient
Ammonium	0.026[b]	Not an E-COPC for surface water at this site				0.0906	**3.48**	0.0583	**2.24**
Bromide	--	Not an E-COPC for surface water at this site				0.0965	ND	0.0552	ND
Chloride	230[c]	49	0.213	31.5	0.137	40	0.174	29.6	0.129
Iron	1.0[b]	0.0594	0.0594	0.0288	0.0288	0.302	0.302	0.0541	0.0541
Manganese	0.05[b]	0.02	0.4	0.0114	0.228	0.0234	0.468	0.0138	0.276
Molybdenum	0.24[d]	0.02	0.0833	0.0158	0.0658	0.02	0.0833	0.0150	0.0625
Nitrate	10[b]	Not an E-COPC for surface water at this site				3.7	0.37	1.37	0.137
Uranium	1.5[b]	0.003	0.0020	0.00189	0.00126	Not an E-COPC for surface water at this site			
Vanadium	0.019[d]	0.03	**1.58**	0.0275	**1.45**	0.03	**1.58**	0.0275	**1.45**

[a]Due to the low number of surface water samples from adjacent to the Union Carbide site, the UCL_{95}s for this site are based on the downstream data set.
[b]Colorado Department of Public Health and Environment Surface Water Quality Standard for aquatic life.
[c]U.S. Environmental Protection Agency Ambient Water Quality Criterion.
[d]Tier II secondary chronic value from Suter and Tsao (1996).

-- = No benchmark available
ND = Not determined
E-COPC = Ecological contaminant of potential concern.
Hazard quotient values in shaded cells are greater than 1.

Table 15. Hazard Quotients for Benthic Communities of the Dolores River Based Upon Comparison of Sediment Concentrations to Sediment Quality Benchmarks

Ecological Contaminant of Potential Concern	Sediment Quality Benchmark (mg/kg)	Dolores River Sediment at the North Continent Site		Dolores River Sediment at the Union Carbide Site	
		Maximum Concentration (mg/kg)	Hazard Quotient	Maximum Concentration (mg/kg)	Hazard Quotient
Cadmium	0.596	Not an E-COPC for sediment at this site		1.7	**2.85**
Copper	35.7	Not an E-COPC for sediment at this site		15	0.420
Molybdenum	4.0	6.3	**1.58**	5.2	**1.30**
Selenium	5.0	3.1	0.62	3.2	0.64
Uranium	--	2.2	ND	Not an E-COPC for sediment at this site	
Vanadium	--	46	ND	43	ND
Zinc	123.1	75	0.609	86	0.699

[a]Due to the low number of surface water samples from adjacent to the Union Carbide site, the UCL_{95}s for this site are based on the downstream data set.

-- = No benchmark available
ND = Not determined
E-COPC = Ecological contaminant of potential concern.
Hazard quotient values in shaded cells are greater than 1.

Table 16. Hazard Quotients for Wetland Plants Based Upon Comparison of Sediment Concentrations to Plant Toxicity Benchmarks

Ecological Contaminant of Potential Concern	Soil-Based Plant Toxicity Benchmark (mg/kg)	North Continent Site		Union Carbide Site	
		Maximum Concentration (mg/kg)	Hazard Quotient	Maximum Concentration (mg/kg)	Hazard Quotient
Cadmium	4	Not an E-COPC		1.7	0.425
Copper	100	Not an E-COPC		15	0.15
Molybdenum	2	6.3	**3.15**	5.2	**2.60**
Selenium	1	3.1	**3.10**	3.2	**3.20**
Uranium	5	2.2	0.44	Not an E-COPC	
Vanadium	2	46	**23.0**	43	**21.5**
Zinc	50	75	**1.50**	86	**1.72**

E-COPC = Ecological contaminant of potential concern.
Hazard quotient values in shaded cells are greater than 1.

Table 17 and Table 18 present the risk results for wetland wildlife exposed to E-COPCs in surface water of the Dolores River at the NC and UC sites (respectively) through ingestion of water and food. These results indicate that only vanadium has been detected in water at concentrations sufficient to indicate potential risk to wildlife. However, as discussed above, the low frequency of detection for vanadium in this medium makes the actual existence of risk to these receptors at the Slick Rock site questionable. Table 19 presents the HQs for the wetland wildlife receptors as based on exposures through the ingestion of sediment and wetland plants exposed to these sediments (as based on the maximum sediment concentrations from the 1993–1994 data). HQs greater than unity are again indicated for vanadium (for the two mammalian receptors), as well as for molybdenum (for the muskrat only). These HQs, however, are relatively low (all less than 2).

Table 20 and Table 21 present the results of the risk analysis for terrestrial wildlife and livestock (specifically, cattle) for drinking from the Dolores River at each of the two sites. Based on these HQs, both for the maximum measured concentration and the UCL_{95}, no risk is expected to result from the direct ingestion of water from the river by these receptors. HQs could not be determined for ammonium, chloride, bromide, or iron due to the lack of sufficient toxicity data for these constituents. However, significant risk from these E-COPCs is not expected due to the low toxic potentials of iron and chloride and the facts that ammonium (as previously described) and bromide only marginally exceeded the maximum upstream concentrations, and both have UCL_{95} values from the NC site, UC upstream site, and UC downstream site that are within the background range.

3.1.2 Risk to Ecological Receptors Associated with Ground Water

Few complete exposure pathways potentially exist between ground water at the Slick Rock site and ecological receptors. The most credible of these is the potential contact between ground water and deep-rooted plants, such as phreatophytes (e.g., cottonwoods). Potential risk to such plants was assessed by the comparison of ground water concentrations (maximum and UCL_{95}) to plant toxicity benchmarks based on water concentrations. Table 22 presents the results of these comparisons for both the NC and UC sites. For the NC site, no risk was indicated for three of the five E-COPCs for ground water (molybdenum, selenium, and uranium), while HQs could not be determined for the other two (chloride and nitrate). Nitrate, which is not in high concentration at this site, would be used as a nutrient by these plants. Chloride is not expected to be toxic to the plants, but may affect the plants through increased osmotic potential in the soil solution. For the UC site, HQs greater than unity were found for iron, manganese, molybdenum, selenium, vanadium, and toluene based on the maximum concentrations of these E-COPCs. Although the HQs for iron, vanadium, and toluene were less than 1 when based on the UCL_{95}, those of manganese, molybdenum, and selenium were still slightly greater than 1.

Table 17. Hazard Quotients for Wetland Wildlife Along the Dolores River at the North Continent Site[a]

Ecological Contaminant of Potential Concern	Muskrat		River Otter		Mallard		Spotted Sandpiper		Belted Kingfisher	
	Maximum	**UCL_{95}**	**Maximum**	**UCL_{95}**	**Maximum**	**UCL_{95}**	**Maximum**	**UCL_{95}**	**Maximum**	**UCL_{95}**
Chloride	---	---	---	---	---	---	---	---	---	---
Iron	---	---	---	---	---	---	---	---	---	---
Manganese	0.00326	0.00186	0.00093	0.00053	0.000113	6.43×10^{-5}	0.000179	0.00010	0.00011	6.26×10^{-5}
Molybdenum	0.113	0.0896	0.175	0.138	0.00516	0.00408	0.0156	0.0123	0.0276	0.0218
Uranium	0.00098	0.00062	0.00584	0.00368	0.00013	8.25×10^{-5}	0.00124	0.00078	0.00233	0.00147
Vanadium	0.0182	0.0167	**6.82**	**6.25**	0.0417	0.0382	**1.81**	**1.66**	0.219	0.201

[a]Exposure based on surface water-based pathways only, including direct ingestion of water and ingestion of plants, invertebrates, and fish with tissue concentrations estimated from water concentrations.

--- = No toxicity benchmark available.
Hazard quotient values in shaded cells are greater than 1.

Table 18. Hazard Quotients for Wetland Wildlife Along the Dolores River at the Union Carbide Site[a]

Ecological Contaminant of Potential Concern	Muskrat		River Otter		Mallard		Spotted Sandpiper		Belted Kingfisher	
	Maximum	**UCL_{95}**	**Maximum**	**UCL_{95}**	**Maximum**	**UCL_{95}**	**Maximum**	**UCL_{95}**	**Maximum**	**UCL_{95}**
Ammonium	---	---	---	---	---	---	---	---	---	---
Bromide	---	---	---	---	---	---	---	---	---	---
Chloride	---	---	---	---	---	---	---	---	---	---
Iron	---	---	---	---	---	---	---	---	---	---
Manganese	0.00381	0.00225	0.00109	0.00064	0.00013	7.78×10^{-5}	0.00020	0.00012	0.00012	7.58×10^{-5}
Molybdenum	0.113	0.0851	0.175	0.131	0.00516	0.00387	0.0156	0.0117	0.0276	0.0207
Nitrate	0.00123	0.00045	0.00196	0.00072	---	---	---	---	---	---
Vanadium	0.0182	0.0167	**6.82**	**6.25**	0.0417	0.0382	**1.81**	**1.66**	0.219	0.201

[a]Exposure based on surface water-based pathways only, including direct ingestion of water and ingestion of plants, invertebrates, and fish with tissue concentrations estimated from water concentrations.

--- = No toxicity benchmark available.
Hazard quotient values in shaded cells are greater than 1.

Table 19. Hazard Quotients for Wetland Wildlife Along the Dolores River Based on Sediment Data from 1993 and 1994 Sampling[a]

Ecological Contaminant of Potential Concern	North Continent Site					Union Carbide Site				
	Muskrat	River Otter	Mallard	Spotted Sandpiper	Belted Kingfisher	Muskrat	River Otter	Mallard	Spotted Sandpipe r	Belted Kingfisher
Cadmium	Not an E-COPC					0.0729	0.00931	0.0290	0.0483	0.00308
Copper	Not an E-COPC					0.0415	0.00654	0.00536	0.0113	0.00072
Molybdenum	**1.83**	0.152	0.0742	0.0775	0.00493	**1.51**	0.126	0.0613	0.0640	0.00407
Selenium	0.752	0.0842	0.216	0.310	0.0198	0.779	0.0869	0.224	0.320	0.0204
Uranium	0.00712	0.00453	0.00039	0.00576	0.00037	Not an E-COPC				
Vanadium	**1.62**	**1.21**	0.00805	0.167	0.0106	**1.51**	**1.13**	0.00752	0.156	0.00992
Zinc	0.0274	0.00255	0.201	0.236	0.0150	0.0298	0.00292	0.218	0.271	0.0173

[a]Exposure based on sediment-based pathways, including direct ingestion of sediment and ingestion of plants with tissue concentrations estimated from sediment concentrations.

--- = No toxicity benchmark available.
NC = UCL not calculated (frequency of detection less than 50%).
Hazard quotient values in shaded cells are greater than 1.

Table 20. Hazard Quotients for Terrestrial Wildlife and Livestock from Drinking Water Along the Dolores River at the North Continent Site[a]

Ecological Contaminant of Potential Concern	Deer Mouse		Red Fox		Mule Deer		Northern Harrier		Cow	
	Maximum	UCL_{95}	Maximum	UCL_{95}	Maximum	UCL_{95}	Maximum	UCL_{95}	Maximum	UCL_{95}
Chloride	---	---	---	---	---	---	---	---	---	---
Iron	---	---	---	---	---	---	---	---	---	---
Manganese	2.78E-05	1.59E-05	2.26E-05	1.29E-05	2.03E-05	1.16E-05	1.77E-06	1.01E-06	4.22E-05	2.40E-05
Molybdenum	1.09E-02	8.62E-03	8.85E-03	6.99E-03	7.95E-03	6.28E-03	9.00E-04	7.11E-04	1.65E-02	1.31E-02
Uranium	1.39E-04	8.77E-05	1.13E-04	7.11E-05	1.01E-04	6.39E-05	2.87E-05	1.81E-05	2.11E-04	1.33E-04
Vanadium	1.78E-02	1.63E-02	1.44E-02	1.32E-02	1.30E-02	1.19E-02	3.98E-04	3.64E-04	2.70E-02	2.47E-02

[a]Exposure limited to surface water ingestion from the Dolores River adjacent to the NC site.

--- = No toxicity benchmark available.

Table 21. Hazard Quotients for Terrestrial Wildlife and Livestock from Drinking Water Along the Dolores River at the Union Carbide Site[a]

Ecological Contaminant of Potential Concern	Deer Mouse		Red Fox		Mule Deer		Northern Harrier		Cow	
	Maximum	UCL_{95}	Maximum	UCL_{95}	Maximum	UCL_{95}	Maximum	UCL_{95}	Maximum	UCL_{95}
Ammonium	---	---	---	---	---	---	---	---	---	---
Bromide	---	---	---	---	---	---	---	---	---	---
Chloride	---	---	---	---	---	---	---	---	---	---
Iron	---	---	---	---	---	---	---	---	---	---
Manganese	3.26E-05	1.92E-05	2.64E-05	1.56E-05	2.37E-05	1.40E-05	2.07E-06	1.22E-06	4.93E-05	2.91E-05
Molybdenum	1.09E-02	8.18E-03	8.85E-03	6.64E-03	7.95E-03	5.96E-03	9.00E-04	6.75E-04	1.65E-02	1.24E-02
Nitrate	8.46E-04	3.13E-04	6.86E-04	2.54E-04	6.17E-04	2.28E-04	---	---	1.28E-03	4.75E-04
Vanadium	1.78E-02	1.63E-02	1.44E-02	1.32E-02	1.30E-02	1.19E-02	3.98E-04	3.64E-04	2.70E-02	2.47E-02

[a]Exposure limited to surface water ingestion from the Dolores River adjacent to and downstream of the UC site.

--- = No toxicity benchmark available.

Table 22. Hazard Quotients for Deep-Rooted Plants Based Upon Comparison of Ground Water Concentrations to Plant Toxicity Benchmarks

Ecological Contaminant of Potential Concern	Plant Toxicity Benchmark (mg/L)	Ground Water at the North Continent Site				Ground Water at the Union Carbide Site			
		Maximum		UCL_{95}		Maximum		UCL_{95}	
		Concentration (mg/L)	Hazard Quotient	Concentration (mg/L)	Hazard Quotient	Concentration (mg/L)	Hazard Quotient	Concentration (mg/L)	Hazard Quotient
Ammonium	--	Not an E-COPC for ground water at this site				118	ND	59.1	ND
Bromide	--	Not an E-COPC for ground water at this site				14.7	ND	3.10	ND
Cadmium	0.1	Not an E-COPC for ground water at this site				0.0097	0.097	0.00246	0.0246
Chloride	--	890	ND	498	ND	5,470	ND	1,090	ND
Iron	10	Not an E-COPC for ground water at this site				32	**3.20**	6.48	0.648
Manganese	4.0	Not an E-COPC for ground water at this site				12.8	**3.20**	4.30	**1.08**
Molybdenum	0.5	0.0546	0.109	0.0204	0.0408	1.83	**3.66**	0.724	**1.45**
Nitrate	--	2.45	ND	0.874	ND	3,510	ND	1,090	ND
Selenium	0.7	0.0367	0.0524	0.0105	0.0150	2.52	**3.60**	0.764	**1.09**
Strontium	--	Not an E-COPC for ground water at this site				11.8	ND	4.87	ND
Sulfate	--	Not an E-COPC for ground water at this site				1,160	ND	724	ND
Uranium	40	1.31	0.0328	0.718	0.0180	0.1	0.0025	0.0507	0.00127
Vanadium	0.2	Not an E-COPC for ground water at this site				0.556	**2.78**	0.178	0.890
Benzene	--	Not an E-COPC for ground water at this site				17.4	ND	6.46	ND
Ethylbenzene	--	Not an E-COPC for ground water at this site				0.584	ND	0.234	ND
Toluene	10	Not an E-COPC for ground water at this site				13.6	**1.36**	5.15	0.515
Xylenes	100	Not an E-COPC for ground water at this site				6.54	0.0654	3.14	0.0314

-- = No benchmark available
ND = Not determined
E-COPC = Ecological contaminant of potential concern.
Hazard quotient values in shaded cells are greater than 1.

Another way by which ecological receptors could be exposed to ground water would be under the hypothetical situation whereby ground water is pumped to a surface pond, thereby being made available to livestock and wildlife as a source of drinking water, and being a potential habitat for the development of an aquatic community. To assess potential risk to these receptors under this hypothetical scenario, the ground water data were evaluated by comparing the maximum and UCL_{95} concentrations to the surface water quality benchmarks for the protection of aquatic life and by evaluating the potential risk to terrestrial wildlife and livestock based on using this water as a sole drinking water source. Table 23 and Table 24 present the results of these evaluations, respectively.

At the NC site, only chloride and selenium in ground water (both maximum and UCL_{95} concentrations) were found to exceed the water quality criteria for the protection of aquatic life. At the UC site, however, all E-COPCs exceeded their respective water quality benchmarks at their maximum concentrations except uranium (no benchmark was found for bromide). When based on the UCL_{95} concentrations, all except uranium and ethylbenzene exceeded their respective benchmark values. For ammonium and total xylenes, the HQs exceeded 1,000, while for manganese, nitrate, selenium, benzene, and toluene, HQs greater than 100 were found. Although no HQs greater than unity were found at the NC site for wildlife and livestock from drinking the ground water, HQs greater than 1 were found for the three mammalian wildlife based on drinking the ground water if selenium were present at its maximum measured concentration. Potential risk to cattle was also indicated at this site based on drinking water at the maximum measured concentrations of molybdenum, nitrate, and selenium. None of the HQs for terrestrial wildlife and livestock exceeded unity when the ground water concentrations were based on the UCL_{95}.

3.1.3 Potential Risks from Radionuclides

Potential risks from radiological E-COPCs were evaluated using the screening-level benchmarks for aquatic biota (specifically large and small fish) derived for Oak Ridge National Laboratory (Bechtel Jacobs 1998b), as based on the methodology for estimating dose rates for aquatic biota developed by Blaylock and others (1993). In addition to these ecological-based benchmarks, the CDPHE has established a water quality standard for radium-226 and -288 (total) at 5 pCi/L and for uranium (total) at 40 pCi/L (the latter being specific to the Gunnison and lower Dolores River basins).

Radiological analyses in surface water and ground water samples from the Slick Rock site have included uranium-238 and four of its daughter isotopes (radium-226, thorium-230, lead-210, and polonium-210), as well as uranium 234, radium-228, gross alpha, and gross beta activity. As shown in Table 25, all of these analytes except thorium-230 and uranium-234 have been identified as E-COPCs in the Dolores River surface water at the NC site; however, only gross alpha, lead-210, radium-226, and uranium-238 were identified as E-COPCs in the Dolores River surface water at the UC site. Ecological benchmarks were available for all radiological analytes except gross alpha, gross beta, and radium 228. All of the HQs that can be determined for these radiological E-COPCs in the Dolores River surface water are well below 1. Further, the sum of the radium-226 and –228 concentrations for the NC site is 1.8 pCi/L and for the UC is 0.9 pCi/L (0.6 pCi/L being the maximum concentration measured at or below this site). Both of these totals are less than the CDPHE standard for these isotopes. Similarly, total uranium (uranium-234 plus uranium-238) for the NC site is 1.54 pCi/L and that for the UC site is 1.44 pCi/L. Both of these are also well below the CDPHE water quality standard of 40 pCi/L.

Table 23. Hazard Quotients for Aquatic Communities Based Upon Comparison of Ground Water Concentrations to Water Quality Benchmarks for the Protection of Aquatic Life[a]

Ecological Contaminant of Potential Concern	Water Quality Benchmark (mg/L)	Ground Water at the North Continent Site				Ground Water at the Union Carbide Site			
		Maximum		UCL_{95}		Maximum		UCL_{95}	
		Concentration (mg/L)	Hazard Quotient	Concentration (mg/L)	Hazard Quotient	Concentration (mg/L)	Hazard Quotient	Concentration (mg/L)	Hazard Quotient
Ammonium	0.026[b]	Not an E-COPC for ground water at this site				118	**4,540**	59.1	**2,270**
Bromide	--	Not an E-COPC for ground water at this site				14.7	ND	3.10	ND
Cadmium	0.0011[b]	Not an E-COPC for ground water at this site				0.0097	**8.82**	0.00246	**2.24**
Chloride	230[c]	890	**3.87**	498	**2.17**	5,470	**23.8**	1,090	**4.73**
Iron	1.0[b]	Not an E-COPC for ground water at this site				32	**32**	6.48	**6.48**
Manganese	0.05[b]	Not an E-COPC for ground water at this site				12.8	**256**	4.30	**86**
Molybdenum	0.24[d]	0.0546	0.228	0.0204	0.0850	1.83	**7.63**	0.724	**3.02**
Nitrate	10[b]	2.45	0.245	0.874	0.0874	3,510	**351**	1,090	**109**
Selenium	0.005[b,c]	0.0367	**7.34**	0.0105	**2.10**	2.52	**504**	0.764	**153**
Strontium	1.5[d]	Not an E-COPC for ground water at this site				11.8	**7.67**	4.87	**3.25**
Sulfate	250[b]	Not an E-COPC for ground water at this site				1,160	**4.64**	724	**2.90**
Uranium	1.5[b]	1.31	0.873	0.718	0.479	0.10	0.0667	0.0507	0.0338
Vanadium	0.019[d]	Not an E-COPC for ground water at this site				0.556	**29.3**	0.178	**9.37**
Benzene	0.046[d]	Not an E-COPC for ground water at this site				17.4	**378**	6.46	**140**
Ethylbenzene	0.29[d]	Not an E-COPC for ground water at this site				0.584	**2.01**	0.234	0.807
Toluene	0.13[d]	Not an E-COPC for ground water at this site				13.6	**105**	5.15	**39.6**
Xylenes	0.0018[d]	Not an E-COPC for ground water at this site				6.54	**3,630**	3.14	**1,740**

[a]Ground water comparisons are made to evaluate potential risk associated with the use of ground water in a surface pond.
[b]Colorado Department of Public Health and Environment Surface Water Quality Standard for aquatic life.
[c]U.S. Environmental Protection Agency Ambient Water Quality Criterion.
[d]Tier II secondary chronic value from Suter and Tsao (1996).

-- = No benchmark available
ND = Not determined
E-COPC = Ecological contaminant of potential concern.
Hazard quotient values in shaded cells are greater than 1.

Table 24. Hazard Quotients for Terrestrial Wildlife and Livestock from Drinking Water Pumped from Ground Water at the Slick Rock Site[a]

Ecological Contaminant of Potential Concern	Deer Mouse		Red Fox		Mule Deer		Northern Harrier		Cow	
	Maximum	UCL_{95}	Maximum	UCL_{95}	Maximum	UCL_{95}	Maximum	UCL_{95}	Maximum	UCL_{95}
North Continent Site										
Chloride	---	---	---	---	---	---	---	---	---	---
Molybdenum	2.98E-02	1.11E-02	2.42E-02	9.02E-03	2.17E-02	8.11E-03	2.46E-03	9.18E-04	4.52E-02	1.69E-02
Nitrate	5.61E-04	2.00E-04	4.54E-04	1.62E-04	4.09E-04	1.46E-04	---	---	8.50E-04	3.03E-04
Selenium	2.25E-02	6.43E-03	1.82E-02	5.21E-03	1.64E-02	4.68E-03	1.34E-02	3.84E-03	3.40E-02	9.74E-03
Uranium	6.08E-02	3.33E-02	4.93E-02	2.70E-02	4.43E-02	2.43E-02	1.25E-02	6.87E-03	9.21E-02	5.05E-02
Union Carbide Site										
Ammonium	---	---	---	---	---	---	---	---	---	---
Bromide	---	---	---	---	---	---	---	---	---	---
Cadmium	1.20E-03	3.04E-04	9.71E-04	2.46E-04	8.73E-04	2.21E-04	1.01E-03	2.56E-04	1.82E-03	4.60E-04
Chloride	---	---	---	---	---	---	---	---	---	---
Iron	---	---	---	---	---	---	---	---	---	---
Manganese	1.78E-02	5.98E-03	1.44E-02	4.85E-03	1.30E-02	4.36E-03	1.13E-03	3.81E-04	2.70E-02	9.07E-03
Molybdenum	9.99E-01	3.95E-01	8.09E-01	3.20E-01	7.28E-01	2.88E-01	8.23E-02	3.26E-02	**1.51E+00**	5.99E-01
Nitrate	8.03E-01	2.49E-01	6.51E-01	2.02E-01	5.85E-01	1.82E-01	---	---	**1.22E+00**	3.78E-01
Selenium	**1.54E+00**	4.68E-01	**1.25E+00**	3.79E-01	**1.12E+00**	3.41E-01	9.22E-01	2.80E-01	**2.34E+00**	7.09E-01
Strontium	5.49E-03	2.27E-03	4.45E-03	1.84E-03	4.00E-03	1.65E-03	---	---	8.33E-03	3.44E-03
Sulfate	---	---	---	---	---	---	---	---	---	---
Uranium	4.64E-03	2.35E-03	3.76E-03	1.91E-03	3.38E-03	1.71E-03	9.57E-04	4.85E-04	7.03E-03	3.57E-03
Vanadium	3.30E-01	1.06E-01	2.67E-01	8.56E-02	2.40E-01	7.70E-02	7.37E-03	2.36E-03	5.00E-01	1.60E-01
Benzene	9.36E-02	3.48E-02	7.59E-02	2.82E-02	6.82E-02	2.53E-02	---	---	1.42E-01	5.27E-02
Ethylbenzene	3.69E-03	1.48E-03	2.99E-03	1.20E-03	2.69E-03	1.08E-03	---	---	5.59E-03	2.24E-03
Toluene	7.42E-02	2.81E-02	6.02E-02	2.28E-02	5.41E-02	2.05E-02	---	---	1.12E-01	4.26E-02
Xylenes	4.42E-01	2.12E-01	3.58E-01	1.72E-01	3.22E-01	1.55E-01	---	---	6.70E-01	3.22E-01

[a]Exposure limited to the ingestion of ground water under the assumption that is it pumped to the surface and made available to livestock and wildlife.

--- = No toxicity benchmark available.
Hazard quotient values in shaded cells are greater than 1.

Table 25. Hazard Quotients for Radiological E-COPCs in Surface Water Based on Maximum Measured Activities

Ecological Contaminant of Potential Concern	Ecological Benchmark Value[a] (pCi/L)[b]	North Continent Site		Union Carbide Site	
		Maximum Measured Activity (pCi/L)	Hazard Quotient	Maximum Measured Activity (pCi/L)	Hazard Quotient
Gross Alpha	---	2.4	ND	2.4	ND
Gross Beta	---	5.26	ND	Not an E-COPC	
Lead-210	30,200	1.5	4.97×10^{-5}	0.9	2.98×10^{-5}
Polonium-210	725	0.4	5.52×10^{-4}	Not an E-COPC	
Radium-226	160	0.4	0.00250	0.3	0.00188
Radium-228	---	1.4	ND	Not an E-COPC	
Uranium-238	4,550	0.77	1.69×10^{-4}	0.78	1.71×10^{-4}

[a]Benchmark is the minimum for large and small fish (from Bechtel Jacobs 1998b)
[b]Picocuries per liter
--- = No benchmark available
ND = Not determined

In the ground water at the NC site, gross alpha and beta, radium-226 and –228, and uranium-234 and -238 were identified as E-COPCs. In the ground water at the UC site, the same four radionuclides were also identified as E-COPCs, but gross alpha and gross beta were found to be within the background (upgradient) range. Table 26 presents the comparison (as HQs) of the maximum concentrations of these radionuclides to their ecological screening benchmark values. Although no benchmark was available for radium-228, the HQs for the other radionuclides are less than unity. Therefore, potential doses to aquatic biota (particularly to fish) from ground water pumped to a surface pond should not pose a risk to these receptors. However, it should be noted that the total uranium concentration in the ground water at the NC site (904 pCi/L) and the total radium and uranium concentrations in the ground water at the UC site (7.26 and 75.4 pCi/L, respectively) exceed the CDPHE standards for surface water. Therefore, these waters should not be used as a source of surface water.

Table 26. Hazard Quotients for Radiological E-COPCs in Ground Water Based on Maximum Measured Activities

Ecological Contaminant of Potential Concern	Ecological Benchmark Value[a] (pCi/L)[b]	North Continent Site		Union Carbide Site	
		Maximum Measured Activity (pCi/L)	Hazard Quotient	Maximum Measured Activity (pCi/L)	Hazard Quotient
Gross Alpha	---	1,390	ND	Not an E-COPC	
Gross Beta	---	355	ND	Not an E-COPC	
Radium-226	160	0.27	0.00169	3.22	0.0201
Radium-228	---	1.27	ND	4.04	ND
Uranium-234	4,040	445	0.110	35.4	0.00876
Uranium-238	4,550	459	0.100	40.0	0.00879

[a]Benchmark is the minimum for large and small fish (from Bechtel Jacobs 1998b)
[b]Picocuries per liter
--- = No benchmark available
ND = Not determined

3.1.4 Potential Risks to Sensitive Species

As stated in Section 1.1, the southwestern river otter, bald eagle, and southwestern willow flycatcher are special status (threatened or endangered) that have the potential for occurring in the riparian habitat along the Dolores River at or near the Slick Rock site. Because the river otter is most likely to occur at either of the sites due to the reintroduction program, it was included directly as a receptor in this risk assessment. The bald eagle and southwestern willow flycatcher are represented in this assessment by the belted kingfisher and spotted sandpiper, respectively, based on their diets. The bald eagle would principally be exposed to E-COPCs at the Slick Rock site through the consumption of fish (and water) from the river. The kingfisher represents a piscivorous bird that, because of its smaller size, would have a higher exposure to such fish than an eagle wintering in the area. The diet of the southwestern willow flycatcher principally consists of flying insects, at least some of which possibly having been exposed to water or sediment of the site during their development. The spotted sandpiper, being modeled as having a diet consisting entirely of invertebrates exposed to surface water of the Dolores River, conservatively represents potential exposure and risk to the southwestern willow flycatcher individuals that may occur at the site.

The HQs exceeding unity for the river otter and spotted sandpiper were limited to vanadium exposure at both the NC and UC sites. No HQs for the belted kingfisher exceeded unity. As previously described, the frequency of detection of vanadium in the Dolores River was low (only three detections out of 39 samples collected at or below the NC site). All three detections were at 0.03 mg/L and all were from different sampling locations. These detected concentrations were from 20 to 30 times greater than the lowest detection limits for these samples (0.001 to 0.0015 mg/L), calling into doubt whether they reflect actual variability in vanadium concentrations in the Dolores River, and further, whether these vanadium concentrations are being influenced by the sites to the degree indicated by these data.

In the case of the spotted sandpiper, no risk was indicated from the ingestion of sediment and HQs based on exposure to water and food at these sites were low (1.81 and less). Because the actual average vanadium concentrations in the river are expected to be significantly less than that indicated by the maximum values, and because the exposure in the spotted sandpiper is expected to conservatively estimate that of the southwestern willow flycatcher, the potential for risk to the southwestern willow flycatcher is also expected to be very low. For the otter, the HQs from sediment ingestion (as based on the soil ingestion rate for a raccoon) were also low (1.21 and 1.13 for the NC and UC sites, respectively). The HQs were higher for exposure to water and food from the river (6.82 for both sites based on the maximum water concentrations). However, because the mean vanadium concentration is again expected to be much less than that indicated by the maximum concentration values, these HQs are expected to significantly overestimate the potential risk to these receptors. Further, studies reported by the EPA (1993) indicate river otters will use extensive areas of river bank habitat. The average for breeding adults is reported to be 28 km, or about 17 miles, of river bank. Because the HQs are calculated under the assumption that all exposure in these receptors is from the reach of the river included by the sampling (approximately 2 miles), it can be expected that the actual exposures to the river otters using much larger portions of the river will have lower exposure rates.

4.1 Ecological Risk Summary

For the purpose of summarization, the receptors are categorized into six groups: aquatic organisms, benthic organisms, deep-rooted plants, wetland plants, terrestrial wildlife and livestock, and wetland wildlife. One or more of these groups may be exposed to the different media evaluated in this assessment at each of the two sites. These media include surface water from the Dolores River, sediment from the Dolores River, and ground water. Further, the potential risk to each group as based on the HQs presented earlier in this section was categorized as follows:

- None: HQs less than or equal to 1 for both the maximum and UCL_{95} concentrations
- Very low: Maximum HQs less than 10 but greater than 1; UCL_{95}-based HQs less than 1
- Low: Both maximum and UCL_{95}-based HQs less than 10, but greater than 1
- Medium-Low: Maximum HQ greater than or equal to 10 but less than 100; UCL_{95}-based HQs less than 10
- Medium: Both maximum and UCL_{95}-based HQs greater than or equal to 10 but less than 100
- High: Maximum HQ greater than or equal to 100 but less than 1,000; UCL_{95}-based HQs greater than 10
- Very high: Maximum HQs greater than or equal to 1,000.

The results of this categorization of potential risk are presented in Table 27. In the cases where multiple receptors are included in the receptor group (i.e., the terrestrial and wetland wildlife groups), the risk is based on the highest worst-case risk result among the receptors. Because many conservatisms were incorporated in the calculation of these HQs, including the use of maximum and UCL_{95} values as exposure point concentrations, the use of conservative toxicity benchmarks, such as water quality criteria and NOAELs, and the assumption of 100 percent area and seasonal use, the HQs are expected to overestimate actual risk to most individual receptors, and therefore, risks categorized as medium-low to none are not expected to represent significant potential risks to populations of nonsensitive species. However, for those receptor groups that may include sensitive species, risk categorizations of medium-low to low are still considered to be of concern (see Section 3.1.4).

In the Dolores River, the potential for ecological risk was generally low. A medium potential for risk to wetland plants was found to be associated with vanadium in the sediment. For ground water, low potential for risk to ecological receptors was found at the NC site; however, the ground water at the UC site was found to exceed water quality benchmarks for several E-COPCs, including radiological E-COPCs (see Section 3.1.3), although this water does not appear to pose a significant risk to either deep-rooted plants or terrestrial wildlife.

Table 27. Summary of Potential Ecological Risks at the Slick Rock Site (see text for definition of risk categories)

Ecological Contaminant of Potential Concern	Aquatic Organisms	Wetland Wildlife	Terrestrial Wildlife and Livestock	Benthic Organisms	Wetland Plants	Wetland Wildlife	Deep-Rooted Plants	Aquatic Organisms	Terrestrial Wildlife and Livestock
(principal exposure media)	surface water	surface water food	surface water	sediment	sediment	sediment	ground water	ground water (pumped to surface)	ground water (pumped to surface)
North Continent Site									
Chloride	none	--	--	NA	NA	NA	--	low	--
Iron	none	--	--	NA	NA	NA	NA	NA	NA
Manganese	none	none	none	NA	NA	NA	NA	NA	NA
Molybdenum	none	none	none	low	low	low	none	none	none
Nitrate	NA	NA	NA	NA	NA	NA	--	none	none[a]
Selenium	NA	NA	NA	none	low	none	none	low	none
Uranium	none	none	none	--	none	none	none	none	none
Vanadium	low	low	none	--	medium	low	NA	NA	NA
Zinc	NA	NA	NA	none	low	none	NA	NA	NA
Union Carbide Site									
Ammonium	low	--	--	NA	NA	NA	--	very high	--
Bromide	--	--	--	NA	NA	NA	--	--	--
Cadmium	NA	NA	NA	low	none	none	none	low	none
Chloride	none	--	--	NA	NA	NA	--	medium-low	--
Copper	NA	NA	NA	none	none	none	NA	NA	NA
Iron	none	--	--	NA	NA	NA	very low	medium-low	--
Manganese	none	none	none	NA	NA	NA	low	high	none
Molybdenum	none	none	none	low	low	low	low	low	very low
Nitrate	none	none[a]	none[a]	NA	NA	NA	--	high	very low[a]
Selenium	NA	NA	NA	none	low	none	low	high	very low
Strontium	NA	NA	NA	NA	NA	NA	--	low	none
Sulfate	NA	NA	NA	NA	NA	NA	--	low	--
Uranium	NA	NA	NA	NA	NA	NA	none	none	none
Vanadium	low	low	none	--	medium	low	very low	medium-low	none
Zinc	NA	NA	NA	none	low	none	NA	NA	NA
Benzene	NA	NA	NA	NA	NA	NA	--	high	none[a]
Ethylbenzene	NA	NA	NA	NA	NA	NA	--	very low	none[a]
Toluene	NA	NA	NA	NA	NA	NA	very low	high	none[a]
Xylenes	NA	NA	NA	NA	NA	NA	none	very high	none[a]

[a]Avian benchmark not available. Risk based on mammalian receptors only.
-- = No hazard quotients available
NA = Not applicable to this area

4.2 Summary of Risk Assessments

To evaluate ecological risks, surface water and sediment concentrations from the two areas potentially affected by the Slick Rock site, surface water and ground water were compared with data from reference areas and elevated levels of some analytes were found. These analytes were designated as E-COPCs. A screening-level risk assessment based on calculated HQs was used to evaluate potential risks to ecological receptors at each of the two areas from exposures to these E-COPCs as well as potential risks from direct exposures to ground water. Receptors included aquatic and benthic organisms, wetland and deep-rooted plants, livestock, and wetland and terrestrial wildlife. HQs were calculated based on both maximum and UCL_{95} (or mean) concentrations, as available. Surface water and ground water data were also compared to radiological benchmarks and CDPHE standards.

Risks were considered low if all HQs based on maximum concentrations were less than 10, very low if all HQs based on UCL_{95} concentrations were less than 1, and none if all HQs (based on maximum and UCL_{95} concentrations) were less than 1. E-COPCs showing no or very low risk are dropped from further consideration, and those with low risks are also dropped provided that the receptors showing the low risk do not include or represent potential risks to endangered or threatened species. Because conservatisms have been incorporated into the exposure models and toxicity benchmarks, HQs are expected to overestimate the actual risks posed by these E-COPCs. Therefore, HQs less than 10 are expected to be protective of populations and communities, but may not be protective of individuals in the cases where threatened or endangered species may be exposed. Table 28 summarizes the E-COPCs that remain at each of the evaluated areas. These constituents are considered to be of potential concern because their concentrations in environmental media indicate a potential exists for adverse toxicological effects to ecological receptors. Although there is no visible evidence to date that indicates toxic effects are occurring, the lack of evidence does not exclude the possibility that effects are occurring. Of the E-COPCs listed in this table, vanadium in the sediments of the Dolores River is only marginally above background levels, and risk may be exaggerated by the corresponding benchmark values used in the assessment. The potential for risk to the endangered southwestern willow flycatcher and river otter is considered to be low at this site, with potential for significant exposures to vanadium at these sites being highly uncertain based on the current data. High concentrations of E-COPCs in the ground water at the UC site may limit its potential use in surface ponds based on the exceedences of surface water quality standards.

Table 28. Summary of Ecological Contaminants of Potential Concern at the Slick Rock Processing Plant Sites Based on the Ecological Risk Screening Results

Dolores River				Ground Water	
NC Site		UC Site		NC Site	UC Site
Surface water	Sediment	Surface water	Sediment		
(none)	Vanadium	(none)	Vanadium	Uranium	Ammonium Chloride Iron Manganese Nitrate Selenium Vanadium Benzene Toluene Xylenes Radium Uranium

References

Bechtel Jacobs Company, 1998a, "Empirical Models for the Uptake of Inorganic Chemicals from Soil by Plants," *BJC/OR-133*, Oak Ridge National Laboratory, Oak Ridge, Tennessee.

———, 1998b. "Radiological Benchmarks for Screening Contaminants of Potential Concern for Effects on Aquatic Biota at Oak Ridge National Laboratory, Oak Ridge, Tennessee," *BJC/OR-80*, Oak Ridge National Laboratory, Oak Ridge, Tennessee.

Baes, III, C.F., R.D. Sharp, A.L. Sjoreen, and R.W. Shor, 1984. *A Review and Analysis of Parameters for Assessing Transport of Environmentally Released Radionuclides through Agriculture,* ORNL-5786, Oak Ridge National Laboratory, Oak Ridge, Tennessee.

Beyer, W.N., E.E. Connor, and S. Gerould, 1994. "Estimates of Soil Ingestion by Wildlife," *Journal of Wildlife Management*. 58: 375–382.

Blaylock, B.G., M.L. Frank, and B.R. O'Neal, 1993. *Methodology for Estimating Radiation Dose Rates to Freshwater Biota Exposed to Radionuclides in the Environment*, ES/ER/TM-78, Oak Ridge National Laboratory, Oak Ridge, Tennessee.

Bodek, I, W.J. Lyman, W.F. Reehl, and D.H. Rosenblatt, 1988. *Environmental Inorganic Chemistry, Properties, Processes, and Methods*, Pergamon Press, New York.

Buchman, M.F., 1999. "NOAA Screening Quick Reference Tables," NOAA HAZMAT Report 99-1, Coastal Protection and Restoration Division, National Oceanographic and Atmospheric Administration, Seattle, Washington.

Calder, W.A., and E.J. Braun, 1983. "Scaling of Osmotic Regulation in Mammals and Birds," *American Journal of Physiology*, 244:R601-R606.

Dunning, J.B., 1993. *CRC Handbook of Avian Body Masses*, CRC Press, Boca Raton, Florida.

Efroymson, R.A., M.E. Will, G.W. Suter II, and A.C. Wooten, 1997. *Toxicological Benchmarks for Screening Potential Contaminants of Concern for Effects on Terrestrial Plants*, 1997 Revision, ES/ER/TM-85/R3, Oak Ridge National Laboratory, Oak Ridge, Tennessee.

Haines, M.L., K. Brydges, M.J. MacDonald, S.L. Smith, and D.D. MacDonald, 1994. "Fraser River Action Plan: Review of Environmental Quality Criteria and Guidelines for Priority Substances in the Fraser River Basin," Environment Canada, DOE FRAP 1994-31.

International Atomic Energy Agency (IAEA), 1994. "Handbook of Parameter Values for the Prediction of Radionuclide Transfer in Temperate Environments," *Technical Reports Series No. 364*, International Atomic Energy Agency, Vienna, Austria.

Martin, A.C., H.S. Zim, and A.L. Nelson, 1951. *American Wildlife and Plants: A Guide to Wildlife Food Habits,* McGraw-Hill Book Company, Inc., reprinted (1961) by Dover Publications, Inc., New York.

Nagy, K.A., 1987. "Field Metabolic Rate and Food Requirement Scaling in Mammals and Birds," *Ecological Monographs*, 57(2):111–128.

National Council on Radiation Protection and Measurements (NCRP), 1989. "Screening Techniques for Determining Compliance with Environmental Standards: Releases of Radionuclides to the Atmosphere," *NCRP Commentary No. 3*, Revision of January 1989, National Council on Radiation Protection and Measurements, Bethesda, Maryland.

New Mexico Environment Department (NMED), 2000. *Guidance for Assessing Ecological Risks Posed by Chemicals: Screening-Level Ecological Risk Assessment*, Hazardous and Radioactive Materials Bureau, New Mexico Environment Department, Santa Fe, New Mexico.

Sample, B.E., D.M. Opresko, and G.W. Suter II, 1996. *Toxicological Benchmarks for Wildlife*, 1996 Revision, ES/ER/TM-86/R3, Risk Assessment Program, Health Sciences Research Division, Oak Ridge National Laboratory, Oak Ridge, Tennessee.

Sample, B.E., and C.A. Arenal, 1999. "Allometric Models for Interspecies Extrapolation of Wildlife Toxicity Data," *Bulletin of Environmental Contamination and Toxicity*, 62:653–663.

Silva, M., and J.A. Downing, 1995. *CRC Handbook of Mammalian Body Masses*, CRC Press, Boca Raton, Florida.

Suter, G.W., II and C.L. Tsao, 1996. *Toxicological Benchmarks for Screening Potential Contaminants of Concern for Effects on Aquatic Biota*, 1996 Revision, ES/ER/TM-96/R2, Oak Ridge National Laboratory, Oak Ridge, Tennessee.

U.S. Department of Energy (DOE), 1995. *Baseline Risk Assessment of Groundwater Contamination at the Uranium Mill Tailings Site Near Slick Rock, Colorado,* DOE/AL/62350–147 Rev. 1, prepared for the U.S. Department of Energy Environmental Restoration Division UMTRA Project Team, Albuquerque, New Mexico, September.

———, 1998c. Characterization work plan (p.4)

———, 1994. *The Environmental Assessment of Remedial Action at the Slick Rock Uranium Mill Tailings Sites Slick Rock, Colorado* (p.4)

U.S. Environmental Protection Agency, 1992. "Framework for Ecological Risk Assessment," EPA/630/R-92/001, U.S. Environmental Protection Agency Risk Assessment Forum.

———, 1993. *Wildlife Exposure Factors Handbook*, Volume I of II, EPA/600/R-93/187a, Office of Research and Development, U.S. Environmental Protection Agency, Washington, D.C.

———, 1998. "Guidelines for Ecological Risk Assessment," EPA/630/R-95/002F, Risk Assessment Forum, U.S. Environmental Protection Agency, Washington, D.C.

———, 1999a. "Health Effects from Exposure to High Levels of Sulfate in Drinking Water Study and Sulfate Workshop; Notice," *Federal Register*, Volume 64, Number 28, pp. 7027-7030, February 11, 1999.

U.S. Environmental Protection Agency (EPA), 1999b. "National Recommended Water Quality Criteria-Correction," EPA 822-Z-99-001, Office of Water, U.S. Environmental Protection Agency, Washington, D.C.

———, 2000. Aquatic Toxicity Information Retrieval Database (Aquire), part of the Ecotoxicology (EcoTox) Database, U.S. Environmental Protection Agency, Washington, D.C.

———, 2001. Integrated Risk Information System (IRIS) Database, U.S. Environmental Protection Agency, Washington, D.C.

End of current text

Final Site Observational Work Plan for the Slick Rock, Colorado, UMTRA Project Site Appendices B, C, D, E, and F