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Idaho National Laboratory Water Conservation Project Evaluation—Impact of Reducing Discharge to the Advanced Test Reactor Cold Waste Pond on Sulfate Concentrations in the Snake River Plain Aquifer

A. Jeffrey Sondrup

August 2013

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ABSTRACT

In support of the water conservation goals of the U.S. Department of Energy's Strategic Sustainability Performance Plan, a number of water conservation projects have been proposed that would reduce the volume of wastewater currently discharged to the Advanced Test Reactor Complex's Cold Waste Pond at the Idaho National Laboratory. This evaluation provides an approximation of the potential impact to groundwater quality from reducing raw or "clean" water discharges to the Cold Waste Pond and concentrating chemicals (e.g., sulfate) in the effluent.

To assess the impact, relatively simple computer models were used to simulate water flow and sulfate transport from the Cold Waste Pond through the unsaturated zone and underlying aquifer. The models were used to predict sulfate concentrations at the nearest downgradient aquifer monitoring well (i.e., USGS-065) used for Industrial Wastewater Reuse Permit compliance purposes. The total discharge was reduced by one-third and one-half from the current average values by reducing the volume of "clean" water discharged. The results indicate that sulfate concentrations in the aquifer would increase but would not exceed the secondary constituent standard of 250 mg/L.

While the modeling performed for this evaluation estimates diversion of "clean" wastewater from the Cold Waste Pond will not cause the sulfate secondary constituent standard to be exceeded downgradient in the aquifer, the diversion is predicted to worsen the impact on groundwater quality.

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ACRONYMS

ATR	Advanced Test Reactor
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CWP	Cold Waste Pond
DOE	Department of Energy
INL	Idaho National Laboratory
MCM	Mixing Cell Model
MG	million gallons
SCS	secondary cooling system

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1. INTRODUCTION

In support of the water conservation goals of the U.S. Department of Energy (DOE) Strategic Sustainability Performance Plan, a number of water conservation projects have been proposed that would reduce the volume of wastewater currently discharged to the Advanced Test Reactor (ATR) Complex Cold Waste Pond (CWP) (INL 2013a). The portion of the cold waste effluent stream recommended for diversion/reduction in these proposals consists of raw well water or "clean" water. If implemented, the diversion of "clean" water will increase concentrations of certain chemicals in the wastewater discharged to the CWP and potentially have an adverse impact on groundwater quality. This evaluation provides an approximation of the potential impact to groundwater quality from reducing "clean" water discharges to the CWP and concentrating chemicals in the effluent.

2. BACKGROUND

The ATR Complex (see Figure 1) is located on approximately 100 acres in the southwestern portion of the Idaho National Laboratory (INL), approximately 47 miles west of Idaho Falls, Idaho, in Butte County. The ATR Complex consists of buildings and structures utilized to conduct research associated with developing, testing, and analyzing materials used in nuclear and reactor applications and both radiological and non-radiological laboratory analyses.

The CWP is located approximately 450 ft from the southeast corner of the ATR Complex compound (see Figure 1). The existing CWP was excavated in 1982 and it consists of two cells, each with dimensions of 180 × 430 ft across the top of the berms and a depth of 10 ft. Total surface area for the two cells at the top of the berms is approximately 3.55 acres. Maximum capacity is approximately 10,220,000 gal (31.3 acre ft).

Wastewater discharged to the CWP consists primarily of noncontact cooling tower blowdown, once-through-cooling water for air conditioning units, coolant water from air compressors, secondary system drains, and other nonradioactive drains throughout the ATR Complex. The wastewater flows through collection piping to the TRA-764 Cold Waste Sample Pit (see Figure 1), where the flow rate is recorded and State of Idaho Industrial Wastewater Reuse Permit compliance monitoring samples are collected. Wastewater then flows to the Cold Waste Sump Pit (TRA-703). The sump pit contains submersible pumps that route the water to the appropriate CWP cell through 8-in. valves.

Wastewater enters the pond through concrete inlet basins located near the west end of each cell. Most of the water percolates into the porous ground within a short distance from the inlet basins. If the water level rises significantly in a cell (e.g., 5 ft), flow would be diverted to the adjacent cell, allowing the first cell to dry out. An overflow pipe connects the two cells at the 9-ft level. Normal operation is to route the wastewater to one cell at a time.

To determine potential impacts to groundwater from the CWP, groundwater samples are collected semiannually during April and October from five monitoring wells (i.e., USGS-065, TRA-07, USGS-076, TRA-08, and Middle-1823) in the Snake River Plain Aquifer downgradient of the CWP in accordance with the Industrial Wastewater Reuse Permit (Johnston 2008). Figure 2 shows the locations of the five wells and the inferred groundwater flow direction based on water level measurements conducted in April 2012 (INL 2013b). Note the groundwater flow direction is nearly perpendicular to the southwest side of the CWP. Also, Well Middle-1823 is screened deeper (below the water table), which may explain why the water table is slightly higher than upgradient Well TRA-08.

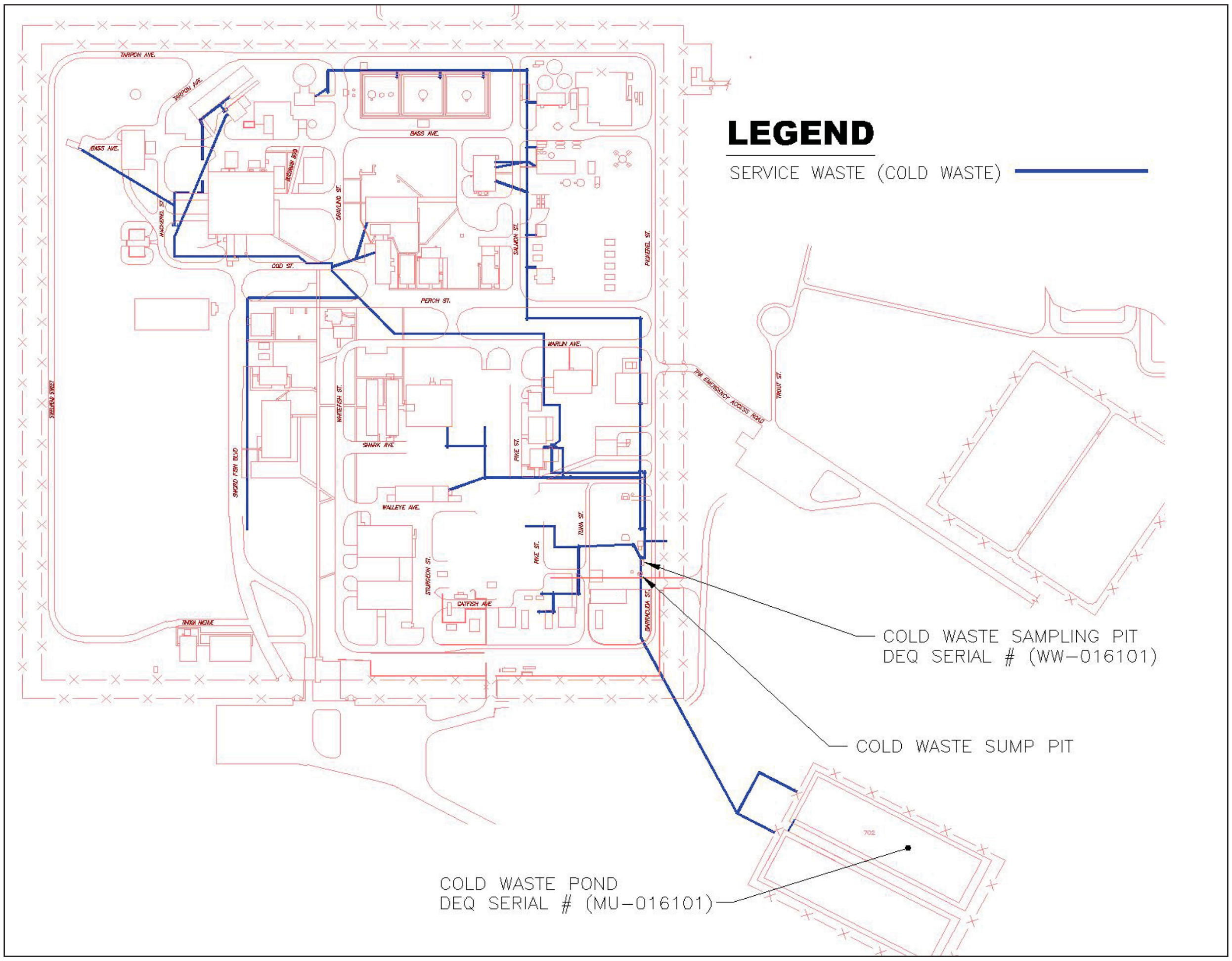

Figure 1. Advanced Test Reactor Complex cold waste system flow schematic (figure from INL [2013b]).

The majority of water discharged to the CWP is raw or "clean" water pumped from the aquifer and used as cooling water for air conditioning units and air compressors. Raw water also is used to cool the ATR primary cooling system via heat exchangers and a cooling tower, but the evaporative cooling process for the cooling tower concentrates naturally occurring dissolved solids in the cooling tower blowdown (discharge) to the CWP. Raw water contains low levels of sulfate (about 24 mg/L), but sulfate also is generated by reactions between sulfuric acid additives placed in the cooling tower water to control pH and calcium and magnesium carbonates in the water. Total dissolved solids and sulfate in the wastewater is of concern because of elevated levels in the aquifer downgradient of the CWP.

The Idaho Ground Water Quality Rule (IDAPA 58.01.11) Secondary Constituent Standards for sulfate and total dissolved solids are 250 mg/L and 500 mg/L, respectively. Secondary Constituent Standards generally are based on aesthetic qualities, including odor, taste, color, and foaming (EPA 1992). Sulfate is listed for causing a "salty taste" in drinking water. Total dissolved solids are listed for "hardness deposits, colored water, staining, and salty taste." This effort focuses on sulfate because of the lower Secondary Constituent Standard and because transport is not complicated by sorption. Conclusions drawn from the sulfate results also are likely to apply to other constituents.

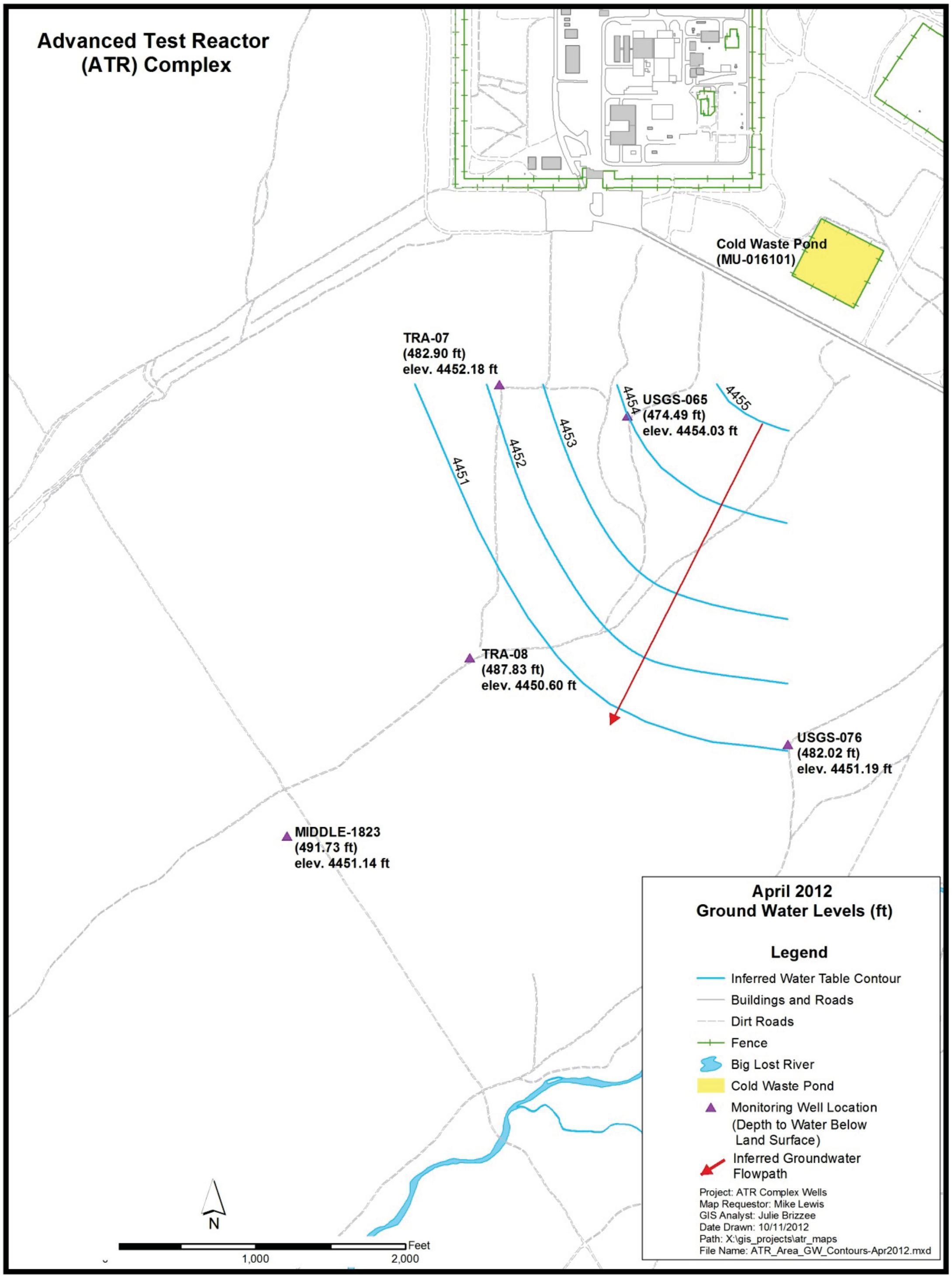

Figure 2. Locations of the Industrial Wastewater Reuse Permit monitoring wells at the Advanced Test Reactor Complex Cold Waste Pond and the inferred groundwater flow direction based on April 2012 water level measurements (figure from INL [2013b]).

Table 1 shows sulfate concentrations in the aquifer from 2008 to 2012. Not surprisingly, the highest concentrations are in the nearest monitoring well (USGS-065) with an average concentration of 160 mg/L (64% of the Secondary Constituent Standard of 250 mg/L). Sulfate concentrations also are elevated in Well TRA-07. Beyond these two wells, the sulfate concentrations in the groundwater dissipate quickly with distance from the CWP. The range of background concentrations for sulfate in the south-central part of the INL Site is approximately 10 to 40 mg/L (Davis 2010). The local background for sulfate is approximately 24 mg/L, based on samples of raw well water (Ashland 2013) that are pumped from one of three deep wells (TRA-01, TRA-03, and TRA-04) located near the northeast corner of the ATR Complex upgradient from the CWP. Sulfate concentrations in Wells USGS-076 and Middle-1823 are slightly above the local background, but within the range of background concentrations for south-central INL.

Table 1. Sulfate concentrations in the aquifer (mg/L) downgradient of the Cold Waste Pond.

Sample Date	Well USGS-065	Well TRA-07	Well TRA-08	Well USGS-076	Well Middle-1823
Oct-08	160	77.7[a]	NS	32.1	35.8
Apr-09	156	155	92.7[a]	31.7	34.0
Oct-09	161	157	NS	32.8	34.3
Apr-10	158	155	47.1	33.2	35.1
Oct-10	160	155	51.4	32.4	34.3
Apr-11	160	154	49.4	32.3	34.3
Oct-11	162	158	49.7	32.8	34.6
Apr-12	163	160	50.5	33.0	34.1
Oct-12	162	155	49.5	32.7	35.6
Average	160	156	50	33	35

a. Outlier value not included in average calculation.

NS = Not sampled due to lack of water (dry well).

3. METHODOLOGY

This evaluation provides a first-level approximation of the potential impact to groundwater from reducing “clean” water discharges to the CWP and concentrating chemicals in the effluent. To assess the impact, relatively simple computer models were used to simulate water flow and sulfate transport from the CWP through the unsaturated zone and underlying aquifer. The models were used to predict sulfate concentrations at the nearest downgradient aquifer monitoring well (i.e., USGS-065) used for Industrial Wastewater Reuse Permit compliance purposes.

Flow and transport through the unsaturated zone was simulated with the one-dimensional mixing cell model (MCM) (Rood 2010); and transport through the underlying aquifer to a downgradient monitoring location was simulated using the two-dimensional GWSCREEN computer code (Rood 2003). GWSCREEN models both the unsaturated zone and aquifer, but does not model transient water fluxes. MCM models transient water fluxes in the unsaturated zone, but does not model flow in the aquifer. Therefore, MCM was used to model the transient water and contaminant fluxes in the unsaturated zone and GWSCREEN was used to model the aquifer. In this case, flow in the aquifer was steady-state, but contaminant transport was transient. By using MCM, the time it takes for contaminants to reach the aquifer and achieve a steady concentration could be estimated.

The overall conceptual model implemented by the MCM and GWSCREEN models is shown in Figure 3. In this case, the pond sediment is the surface alluvium above the first basalt contact. Flow and transport through the unsaturated zone is assumed to be one-dimensional. Given the large discharges to the CWP and the existence of perched water bodies below the CWP, the flow is not one-dimensional throughout the entire unsaturated zone. However, the size of the one-dimensional flow column was an approximation between the size of the CWP and the extent of the perched water body. This is discussed in Section 3.2.1.1.

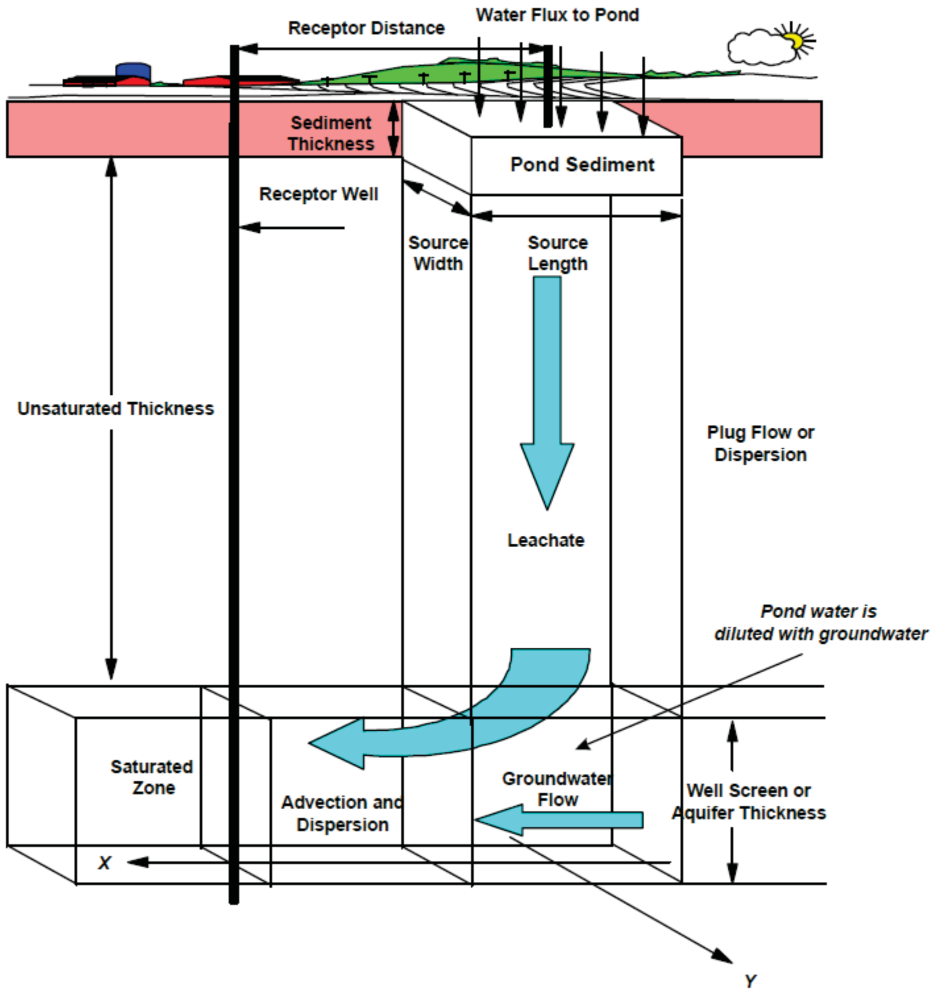

Figure 3. Conceptual model of flow and transport (figure from Rood [2003]).

MCM outputs both the time-dependent water flux and the contaminant fluxes from the base of the model (or any other layer). For this evaluation, the time-dependent sulfate fluxes from MCM were input to a single very thin unsaturated layer atop the aquifer in GWSCREEN. The size of the unsaturated zone layer in GWSCREEN was the same as the one-dimensional column modeled with MCM.

3.1 Model Descriptions

3.1.1 Mixing Cell Model

MCM models the unsaturated zone as a series of individual mixing cells (see Figure 4). Within each mixing cell, the moisture content (fraction of the mixing cell volume composed of water) and contaminant concentration are uniform and assumed to equilibrate instantaneously in response to a change in the amount of water or contaminant entering the cell. Each mixing cell may have its own unique properties that include vertical dimensions, bulk density, hydraulic characteristics (e.g., porosity, residual moisture content, and hydraulic conductivity), and sorptive properties. Water balance within each cell is maintained by the difference between inflow and outflow. The water flux or specific discharge entering the uppermost mixing cell (q) is assumed to be the net infiltration rate from the pond. The net infiltration rate is allowed to change with time and, in turn, affect the specific discharge through all remaining cells below it. Water movement is assumed to be downward and under unit gradient conditions within a mixing cell. Specific discharge is assumed to be less than the saturated hydraulic conductivity of any of the materials comprising the unsaturated zone.

The MCM conceptual model for contaminant transport considers two processes: advection and dispersion. Advective processes move the contaminant downward while dispersive processes can move the contaminant upward or downward depending on the concentration gradient between two adjacent cells. Dispersion results in greater spreading of the contaminant among the mixing cells. Contaminants entering a cell can mix, sorb, decay, and are eventually removed by the downward movement of water.

As formulated, contaminants may be present in each of the mixing cells at the start of the simulation or, alternatively, the contaminant may be placed over time through an external source. Concentrations of contaminants in pore water are not allowed to exceed their element or compound-specific solubility limit. Contaminant fluxes from the unsaturated zone model are used as input into the aquifer flow model as a time-varying contaminant source.

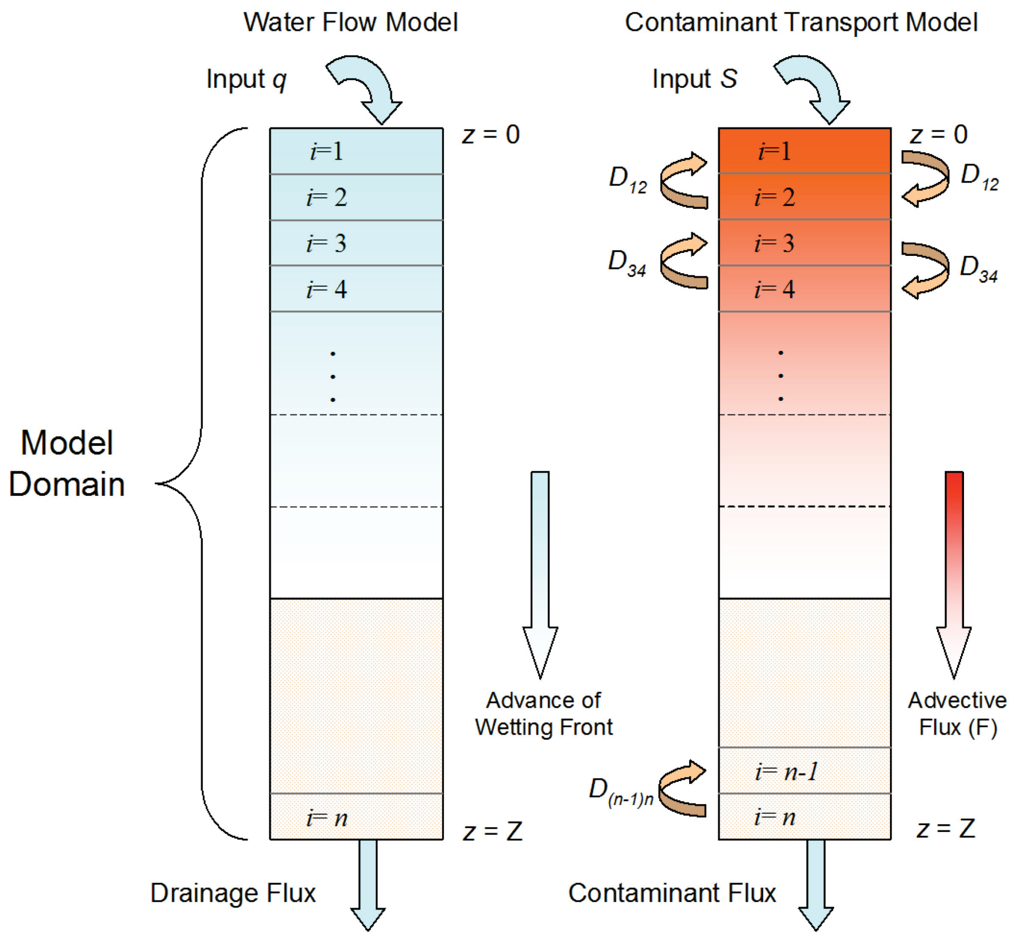

Figure 4. The Mixing Cell Model conceptual model for water flow (left) and contaminant transport (right). The model domain is discretized into n cells and extends to a depth of $z = Z$. Interchange between cells is indicated the variable $D_{i,j}$ where i is the index of the donor cell and j is the index of the receiving cell (figure from Rood [2010]).

3.1.2 GWSCREEN Model

The GWSCREEN model is capable of simulating flow and transport in both the unsaturated and saturated zones, but, in this case, only the saturated, or aquifer portion was used. The aquifer model is based on an analytic solution to the advection dispersion equation for contaminants in a saturated porous media. These solutions were originally developed by Codell et al. (1982) and have been used for assessment of radionuclide transport in groundwater. These solutions apply equally as well to non-radiological contaminants. GWSCREEN assumptions and limitations that are applicable to this evaluation are listed as follows:

- The model uses a Cartesian coordinate system (x, y, z) as a frame of reference. The positive x direction is in the direction of flow.
- The flow is uniform and unidirectional. No sources or sinks are accounted for.
- The aquifer is modeled as an isotropic, homogeneous porous media of infinite lateral extent and finite thickness.
- Molecular diffusion is assumed to be negligible.
- The source can be represented by a rectangular area of length L and width W and centered at the origin (0, 0, 0).
- The dispersion coefficients remain constant over time.
- Transport is limited to a single species that may decay or degrade as a function of time.
- The contaminant is assumed to move as a dissolved substance. Transport in liquid and vapor phases is not considered.
- The two-dimensional solution assumes that the contaminant is mixed vertically (z direction) in a zone defined by the length of a typical well screen for a drinking water well.

3.1.3 Quality Assurance for Software and Calculations

Calculations performed for this evaluation are viewed as scoping in nature. They currently are not used to support environmental permitting, but may be in the future. As a result, the work is being performed at a Quality Level-3 (low risk) level of rigor according to INL LWP-13014 (2013). The software for this evaluation is maintained for use at a Quality Level-2 (medium risk) and managed as safety software according to the quality assurance plan (PLN-3359 2012).

All computer modeling and calculations for the this evaluation were performed on a Dell® Precision Workstation T5500 computer (Intel® Xeon® CPU X5450 @ 3.00 GHz) running Microsoft® Windows® 7 Enterprise Service Pack 1. Computer input files for the current discharge case are provided in Appendix A. MCM output files (mcmf.out, mcmf.flx, mcmt.out) are not provided in Appendix A due to their size and format (files are binary), but can be provided upon request. The MCM sulfate output file (sulfate.rel) and the GWSCREEN output file (GWSCREEN.OUT) for the current discharge case are provided in Appendix A.

The MCM computer code (Rood 2010), Version 020805f_091604t, was developed at INL and used to model the release of radionuclides from the source zone and flow and contaminant transport through the unsaturated zone. It also was used for the Radioactive Waste Management Complex Performance Assessment (DOE-ID 2007) and the Idaho Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) Disposal Facility Performance Assessment (DOE-ID 2011) at INL. The MCM software theory, verification and validation, test plan, and configuration management plan are documented in Rood (2010).

The GWSCREEN computer code (Rood 2003), Version 2.5a Version date 01/23/2007, was used to model radionuclide transport in the saturated zone. It also was used to model radionuclide release and transport through the unsaturated zone and aquifer for the groundwater pathway Phase 3 screening. GWSCREEN also was used for the Radioactive Waste Management Complex Performance Assessment (DOE-ID 2007) and the Idaho CERCLA Disposal Facility Performance Assessment (DOE-ID 2011) at INL. Installation and validation of the software is documented in Software Verification and Validation Plan for the GWSCREEN Code (Rood 1993) and the GWSCREEN configuration management, validation test plan, and validation test report (EDF-7372 2006).

Microsoft® Office Excel® 2007 (12.0.6545.5000) SP2 (12.0.6545.5004) was used for graphing and simple supporting calculations. To validate the calculations performed with Excel, the formulas in all calculation cells were checked for accuracy and a sample of the calculations were checked by hand.

3.2 Model Parameterization

Important parameters needed for this evaluation include pond characteristics (i.e., pond size, water discharge rates, and sulfate mass loading rates), unsaturated zone characteristics (i.e., thickness and flow hydraulic properties of the interbeds and basalt flows), and aquifer characteristics (i.e., thickness, groundwater velocity, and dispersion properties). As previously mentioned, sorption is not considered because sulfate is a conservative contaminant, meaning it moves with the water and does not sorb to the rock/soil matrix.

3.2.1 Cold Waste Pond Characteristics

3.2.1.1 Pond Size. The CWP (shown in Figure 5) was constructed as one percolation pond, with two cells, 180 ft (55 m) by 430 ft (131 m) (across the top of the berms) by 10-ft (3.05 m) deep. The bottom (basin) portion of each individual cell is 145 ft (44 m) by 395 ft (120 m) (D. Brett Lewis, personal communication). Discharges between the two cells generally rotate on an annual basis.

Normally, when modeling one-dimensional flow from a pond through the unsaturated zone, the dimensions of the pond define the column. However, shallow and deep perched-water bodies have formed in the unsaturated zone at the ATR Complex primarily in response to infiltration of wastewater discharged to unlined ponds (INL 2012). Historically, the CWP (in service since 1982) has been the largest source of water to the perched-water zones. Before constructing the CWP in 1982, the warm waste pond was the principle source of infiltration to the perched-water zones; however, operation of the warm waste pond ceased in 1993 when it was replaced with a lined evaporation pond (TRA-715). Discharge to the CWP currently is the largest contributor to the ATR Complex perched-water zone.

Figure 6 conceptually illustrates development of perched water at the ATR Complex. These perched-water bodies developed as the rate of infiltrating water exceeded the capacity of a low-permeability layer to transmit water. Barriers to the vertical migration of water induced a local saturated condition and lateral spreading of the perched water along the top of the low-permeability layer. The deep perched-water zone is much larger in size than the shallow-perched water zone. Figure 7 shows the estimated lateral extent of the deep perched-water zone based on water level measurements in 2003 (DOE-NE-ID 2005) and the average sulfate concentrations in perched-water samples based on samples collected from March 2004 through October 2011. Figure 8 shows deep perched water levels in October 2011. The shape of the deep perched-water zone in 2011 is similar to that of previous maps (RPT-737 2010; RPT-823 2011). However, the October 2011 perched water levels have declined when compared to the perched water levels in 2003.

Figure 5. Advanced Test Reactor Complex cold waste pond.

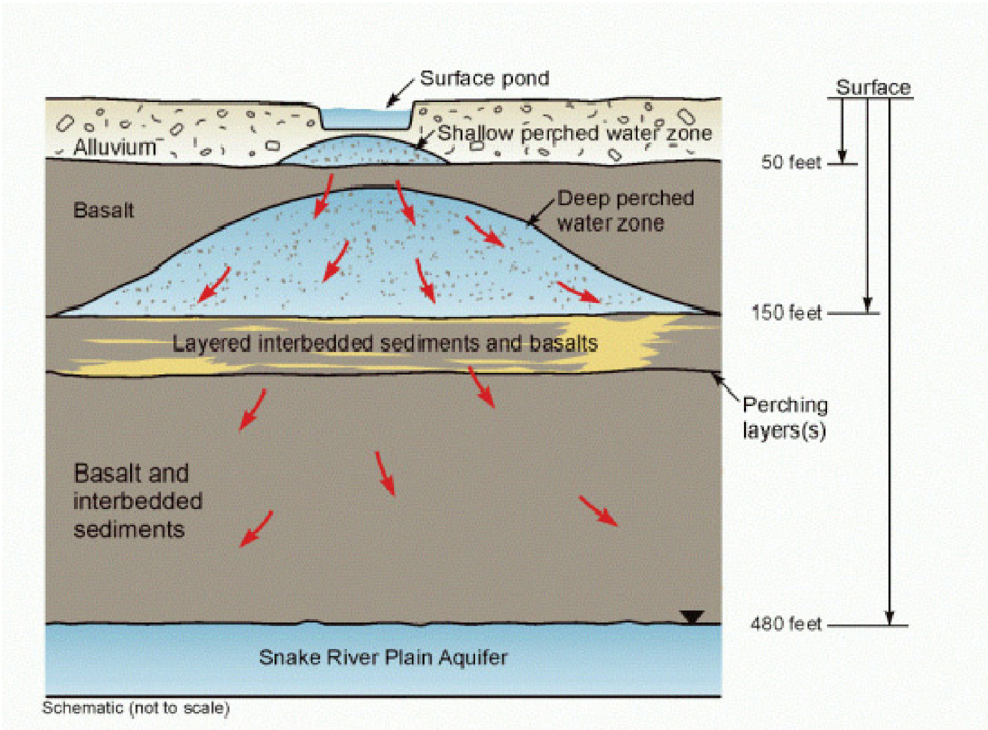

Figure 6. Conceptual diagram demonstrating the formation of shallow and deep perched water zones at the Advanced Test Reactor Complex (figure from INL [2012]).

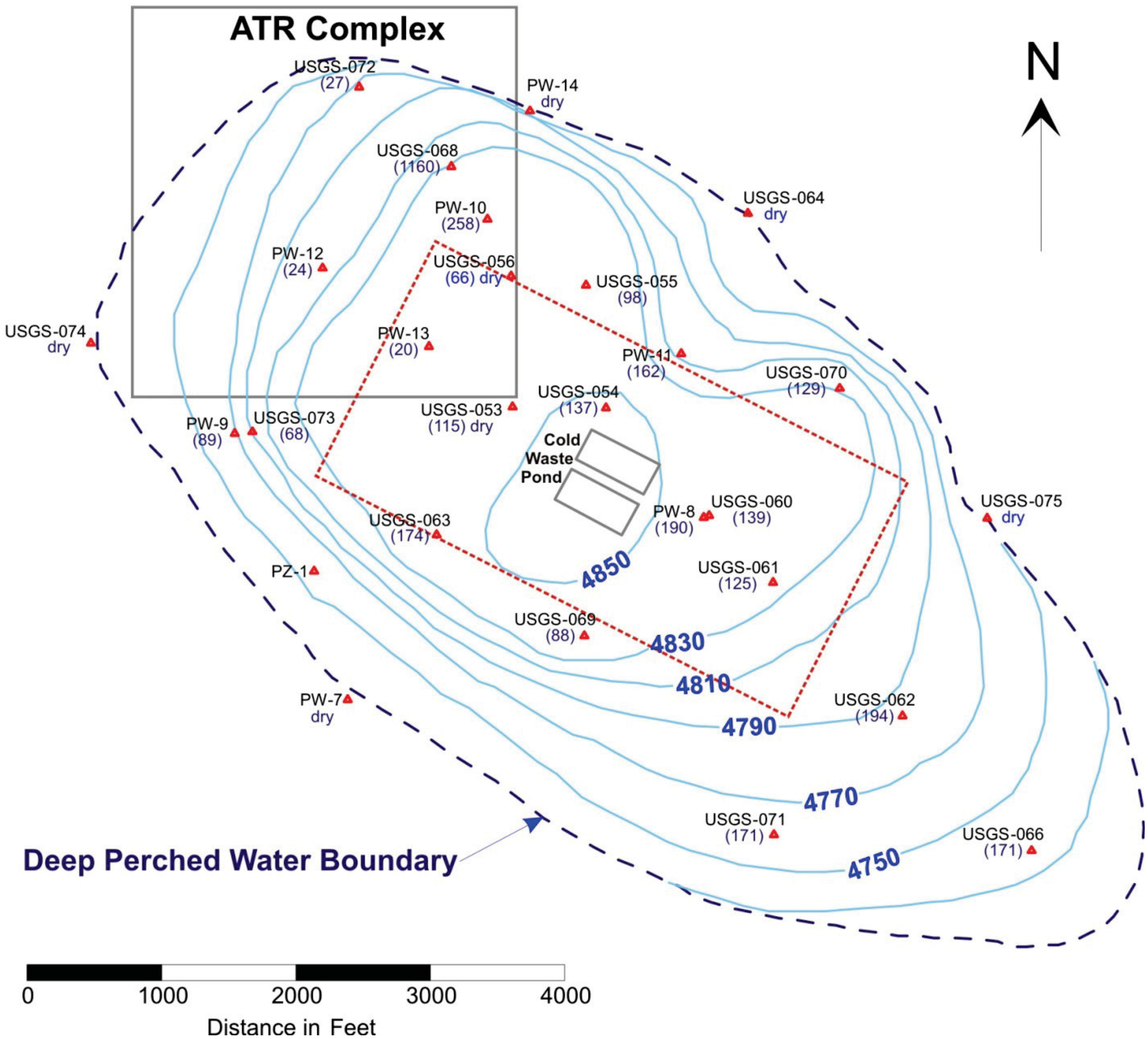

Figure 7. Deep perched water boundary below the ATR Complex Cold Waste Pond based on November 2003 data. Sulfate concentrations shown below each well (in parentheses) are average concentrations from 2004 through 2011. The size and orientation of the unsaturated zone flow column used in the modeling is shown by the red-dashed line. Figure adapted from DOE-NE-ID (2005).

As water moves from the CWP through the perched-water zones to the aquifer, the size or "footprint" of the wetted area becomes larger than the infiltration area within the CWP. However, the driving force for vertical water movement is greater where the water levels are deeper. Therefore, for this evaluation a rectangular box larger than the CWP and smaller than the boundary of the deep perched-water zone was chosen to simulate the infiltration area through the unsaturated zone. The area (shown as the red-dashed line in Figure 7) was assigned a width of 1200 m, approximately equal to the width of the 4830-ft contour level in both 2003 and 2011. The length (600 m) was assigned to be ½ the width to mimic the general width to length ratio of the perched water boundary as shown in Figure 7. The rectangular area was centered in the middle of the CWP and oriented with the long edge parallel to the southwest boundary of the CWP.

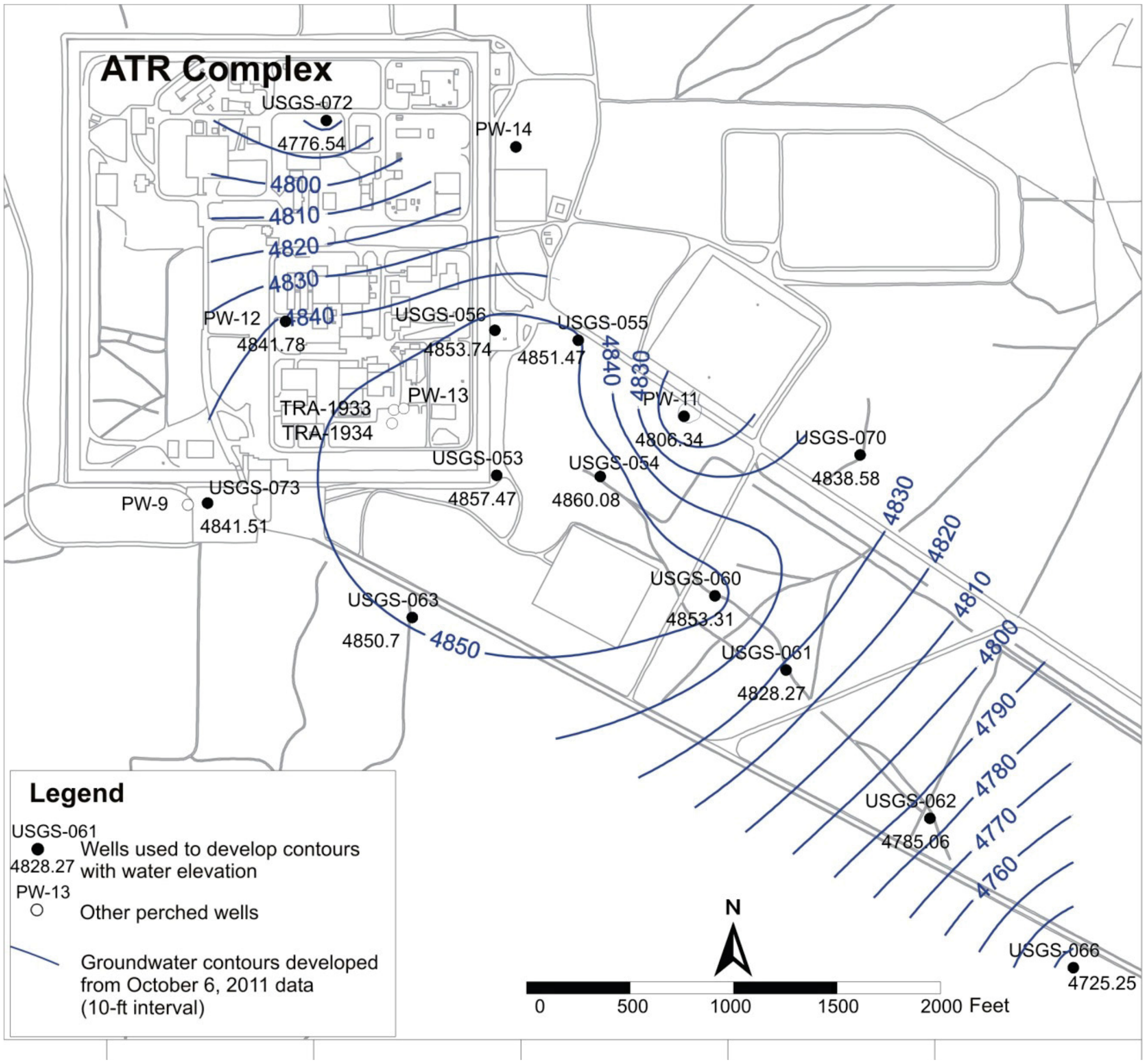

Figure 8. Deep perched water-levels at the Advanced Test Reactor Complex in October 2011 (figure from DOE-ID 2012a).

3.2.1.2 Cold Waste Pond Water Discharge. Over the 5-year period from 2008 through 2012, annual discharges to the CWP ranged from a low of 154 MG to a high of 202 MG, with an average annual discharge of 178 MG (6.75E+05 m^3) (data provided by D. Brett Lewis [ATR Programs Infrastructure Manager]). The average annual discharge through the 600-m x 1200-m area shown in Figure 7 results in a water flux of 0.94 m/year:

(6.75E+05 m^3/year) / (600 m * 1200 m) = 0.94 m/year

This is 94 times the background infiltration rate of 1 cm/year for vegetated undisturbed soils estimated at INL (Cecil et al. 1992). If the total discharge to the CWP is cut by one-third, the flux is 0.62 m/year. For a reduction of one-half, the flux would 0.47 m/year.

3.2.1.3 Cold Waste Pond Mass Loading. The sulfate concentration in the CWP effluent is measured once a month in the TRA-764 Cold Waste Sample Pit and is highly variable depending on the source of the water and whether ATR is operating. Water from the air conditioning units, compressors, and other non-cooling tower sources is raw or "clean" well water and contains approximately 24 mg/L sulfate (Ashland 2013). Sulfate in the ATR cooling tower blowdown or secondary cooling system (SCS) water gets concentrated by the evaporative cooling process and concentrations can be over 1,000 mg/L. Depending on the volume of water from each source at the time of sampling, the effluent concentrations for sulfate varied from 21 to a high of 724 from 2008 through 2012 (see Figure 9). The average concentration was 256 mg/L. Using the average annual discharge of 6.75E+08 L/year and the average concentration of 256 mg/L, an estimate of the average mass sulfate mass loading is 1.73E+05 kg/year:

6.75E+08 L/year * 256 mg/L = 1.73E+11 mg/year

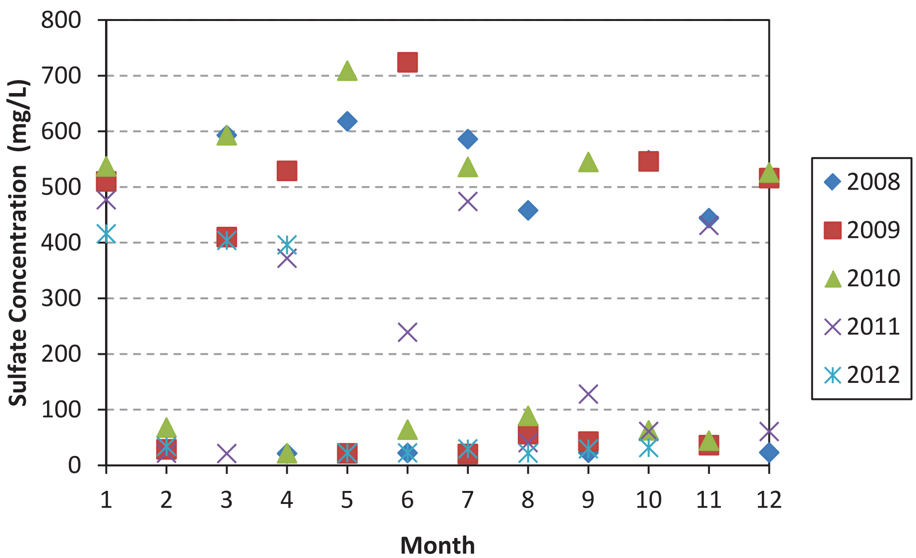

Figure 9. Sulfate concentrations in the cold waste pond effluent from 2008 through 2012.

Because of the high variability in effluent concentrations, mass loading was estimated by another method of considering the two primary sources of discharge (blowdown water and other sources). Table 2 shows an estimate of the discharge volumes to the CWP from the various sources for the year 2012. This is based on daily flows and the approximate number of days the cooling tower blowdown was established and the approximate number of days auxiliary cooling water was valved to the CWP. Based on this information, the SCS water coming from TRA-771 (ATR Cooling Tower) is 14% of the total CWP discharge volume. The remaining 86% consists of clean well water from various sources. Based on the average annual flow rate, the SCS and clean water flow volumes are 9.45E+07 L/year and 5.80E+08 L/year, respectively:

SCS water: 6.75E+08 L/year * (0.14) = 9.45E+07 L/year

Clean water: 6.75E+08 L/year * (0.86) = 5.80E+08 L/year.

Samples of SCS and raw water from January 5, 2013, show the sulfate concentration in the SCS water is 1,279 mg/L and the raw water concentration is 24 mg/L (Ashland 2013). Using the 5-year average annual discharge volume, the flow percentages from Table 2, and the sulfate concentration data from January 2013, the average annual mass loading rate for the CWP was calculated to be 1.35E+05 kg/year:

6.75E+08 L/year * [1279 mg/L * (0.14) + 24 mg/L * (0.86)] = 1.35E+11 mg/year.

This is 22% less than the estimate using the average sulfate concentration in the monthly effluent sample described earlier. Although the lower estimate relies on a single sample of SCS water, the variability of sulfate in the SCS water is likely less than the variability in the monthly effluent concentration data; therefore, this analysis used the value of 1.35E+11 mg/year.

Table 2. Average annual discharge volumes to the cold waste pond by source.

Cooling Water Source	Average Annual Volume[a] (MG/year)	Percent of Total
TRA-771 ATR Cooling Tower Blowdown[b]	27.6	14%
TRA-670 Auxiliary Equipment[c]	95.0	47%
TRA-609 Air Compressors[c]	42.0	21%
TRA-628 Heat Pumps[c]	31.5	16%
Miscellaneous Cooling Equipment[c]	5.3	3%
Totals	202	100%

a. Data provided by D. Brett Lewis (ATR Programs Infrastructure Manager).

b. SCS

c. Clean well water

When calculating the mass loading for reduced discharges, it must be kept in mind that only the clean water is being reduced and the volume of SCS water stays the same. For a one-third reduction in total discharge, the total discharge volume of clean water is 4.50E+08 L/year:

6.75E+08 L/year * (2/3) = 4.50E+08 L/year.

The percentage of SCS water is then 21%:

9.45E+07 L/year / 4.50E+08 L/year = 0.21.

This makes the volume percentage of clean water 79% and the total mass loading is 1.29E+05 kg/year:

6.75E+08 L/year * (2/3) * [1279 mg/L * (0.21) + 24 mg/L * (0.79)] = 1.29E+11 mg/year.

For a one-half reduction in total discharge, the volume percentages of SCS to clean water are 28% and 72% respectively, resulting in a total mass loading of 1.27E+05 kg/year:

6.75E+08 L/year * (1/2) * [1279 mg/L * (0.28) + 24 mg/L * (0.72)] = 1.27E+11 mg/year.

The water discharge and mass loading rates for the different cases examined are summarized in Table 3. The table also shows the average sulfate concentrations in the effluent for the different cases.

Table 3. Summary of water discharge rates, mass loading rates, and average sulfate concentrations in the effluent for the three cases examined.

Case Description	SCS Water Volume (L/year)	Clean Water Volume (L/year)	Total Water Volume (L/year)	Sulfate Mass Loading (kg/year)	Average Effluent Conc (mg/L)
1. Current discharge (based on 5-year annual average)	9.45E+07 (14%)[a]	5.80E+08 (86%)[a]	6.75E+08	1.35E+05	200
2. One-third reduction in current discharge (reducing clean water only)	9.45E+07 (21%)[a]	3.56E+08 (79%)[a]	4.50E+08	1.29E+05	287 (+44%)[b]
3. One-half reduction in current discharge (reducing clean water only)	9.45E+07 (28%)[a]	2.43E+08 (72%)[a]	3.37E+08	1.27E+05	377 (+89%)[b]

a. Numbers in parentheses are a percent of the total discharge.

b. Numbers in parentheses are a percent increase in concentration from the current discharge case

3.2.2 Unsaturated Zone Parameters

The unsaturated zone at the ATR Complex is comprised of interlayered basalt flows and sedimentary interbeds. The basalts readily transmit water vertically, while the sedimentary interbeds retain water and serve to retard water movement and downward migration of contaminants. Primary sedimentary interbeds have been identified and extensively characterized through activities supporting CERCLA actions at the ATR Complex and at the Idaho Nuclear Technology and Engineering Center (DOE-ID 1997a; DOE-ID 1997b; DOE-ID 2006; and Helm-Clark et al. 2005). The lateral continuity and variability in sediment thickness near the ATR Complex was evaluated in INL (2011).

For this evaluation, the stratigraphy from Well USGS-065 was used to construct the unsaturated zone model. Well USGS-065 is the nearest aquifer monitoring well downgradient from the CWP. Table 4 shows the thickness of each layer as implemented in the model.

Table 4. Lithology from Well USGS-065 as implemented in the unsaturated zone model.

Lithologic Description	Modeled As	Top Depth (m)	Bottom Depth (m)	Thickness (m)
Gravel and silt	Alluvium	0.0	18.3	18.3
Basalt/cinders/basalt	Basalt	18.3	46.3	28.0
Clay and basalt	Sediment	46.3	50.6	4.3
Basalt	Basalt	50.6	64.0	13.4
Sand/clay/cinders	Sediment	64.0	71.3	7.3
Basalt	Basalt	71.3	89.9	18.6
Cinders and clay	Sediment	89.9	93.0	3.0
Basalt	Basalt	93.0	100.6	7.6
Clay	Sediment	100.6	102.4	1.8
Basalt/cinders	Basalt	102.4	144.8	42.4
Total		NA	NA	145

Hydraulic properties describing the relationship between water content, capillary pressure, and hydraulic conductivity for alluvium and sedimentary interbeds were taken from DOE-ID (2006). The basalt properties were taken from Magnuson (1995). The values are shown in Table 5.

Table 5. Hydraulic properties assigned to the different material types representing the geostratigraphy.

Material	Saturated Hydraulic Conductivity (m/year)	Total Porosity	Residual Moisture Content	Van Genuchten Fitting Parameter *n*	Van Genuchten Fitting Parameter α (1/m)	Van Genuchten Fitting Parameter *m*	Van Genuchten Fitting Parameter *L*	Bulk Density (g/cm^3)
Alluvium[a]	8,798	0.32	0.0002	1.4	100	0.29	0.5	1.82
Interbed[a]	1,040	0.6	0.11	1.29	10.5	0.22	0.5	1.34
Basalt[b]	91	0.05	0.001	10	2.5	0.9	0.5	2

a. From DOE-ID (2006).

b. From Magnuson (1995).

The total thickness of the unsaturated zone model is 145 m and the domain was discretized into 100 layers, with each layer being 1.45 m thick. No additional dispersivity was assigned to the unsaturated zone model, other than the implicit dispersion inherent in the MCM code. The amount of implicit dispersion is approximated by the number of cells and the length of the model domain or total unsaturated thickness:

$\alpha_L = Z / 2n$

where α_L = the longitudinal dispersivity (m), Z = unsaturated zone thickness (m), and n = the number of cells. For all MCM simulations, 100 cells were used; therefore, for an unsaturated zone thickness of 145 m, the value of α_L is 0.725 m.

3.2.3 Aquifer Parameters

For this evaluation, transport in the aquifer was calculated using a two–dimensional, semi-analytical solution to the advection-dispersion equation in groundwater as implemented in GWSCREEN, where the concentrations are vertically averaged over a well screen thickness of 15 m (DOE-ID 1994). A constant water flux and a time-dependent sulfate flux from MCM were input to the 600 m x 1,200 m source area (see Section 3.2.1.1). This source area was a very thin (0.001 m) unsaturated layer placed atop the aquifer model centered in the middle of the CWP. Sulfate concentration as a function of time was calculated at Well USGS-065, which is located 470 m from the center of the source parallel to the direction of groundwater flow and 230 m from the center of the source perpendicular to the direction of groundwater flow (see Figure 10). The direction of groundwater flow was assumed to be perpendicular to the southwest boundary of the CWP (see Figure 2).

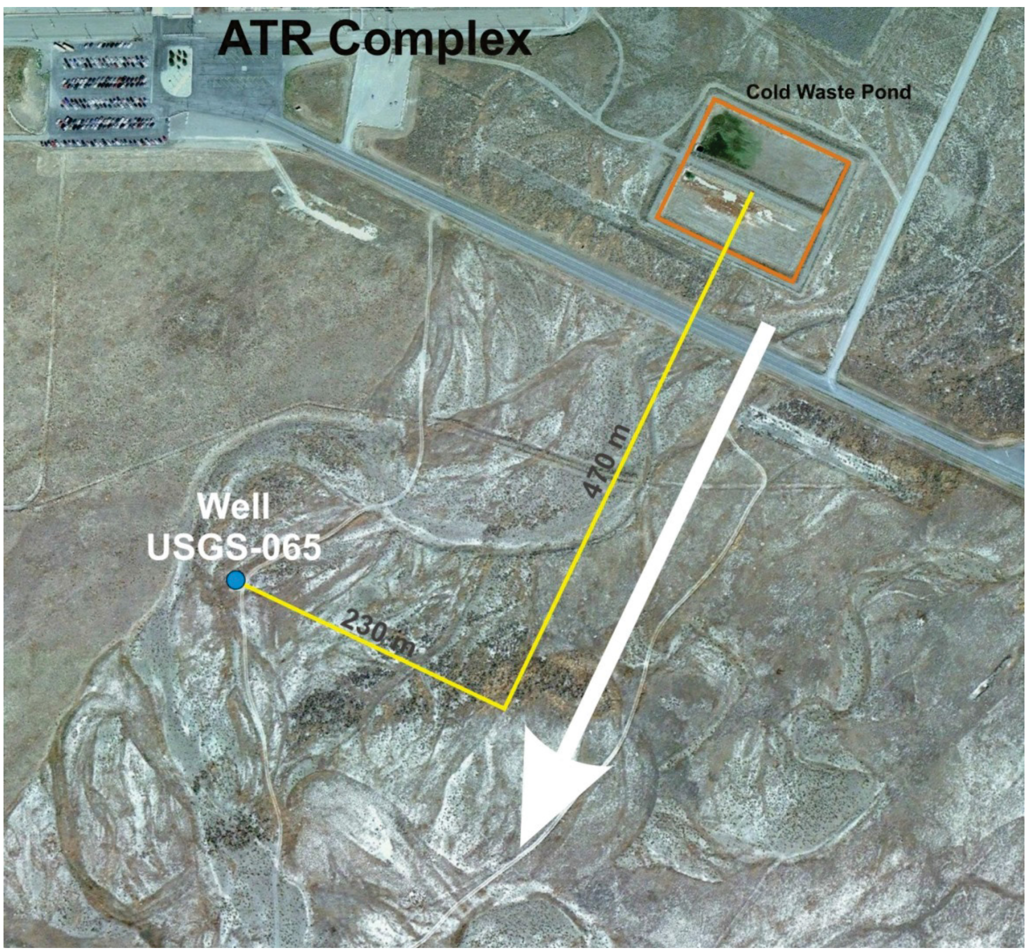

Figure 10. Location of Well USGS-065 relative to the cold waste pond showing distances along and transverse to the inferred flow direction. Groundwater flow direction is indicated by the large white arrow. Base map courtesy of Google Earth (2013).

Groundwater flow velocity, porosity, and dispersivity values were taken from a comprehensive subregional modeling study of the Snake River Plain Aquifer (DOE-ID 2008). The aquifer Darcy velocity was assigned a value of 16 m/year and the porosity was assigned a value of 0.06. The velocity is an average value of velocities in the vicinity of the ATR Complex as explained in DOE-ID (2012b). The longitudinal, horizontal transverse, and vertical transverse dispersivity values were assigned values of 91 m, 40 m, and 4.6 m, respectively (DOE-ID 2008). However, vertical dispersivity is much less important because the contaminant is confined to the upper 15 m of the aquifer and likely to be well mixed by the time it reaches the Well USGS-065 location.

3.2.4 Other Modeling Considerations

The unsaturated zone model was run for a period of 50 years to allow concentrations in the aquifer to reach a pseudo-steady condition. While the unsaturated zone transport calculations account for transients, the GWSCREEN calculations assume steady-state flow conditions. However, the discharge flux from the unsaturated zone to the aquifer is an important factor in controlling the concentrations within the aquifer and GWSCREEN incorporates algorithms to include the effect of dilution associated with mixing of vertical recharge with groundwater throughflow. Because the vertical water flux from the CWP was considered large compared to the groundwater throughflow, the dilution option (IDIL=2) was implemented in GWSCREEN.

4. RESULTS

Sulfate concentrations as a function of time are presented in Figure 11 for all three cases examined: (1) current total discharge, (2) one-third reduction in current total discharge by reducing the volume of clean water, and (3) one-half reduction in current total discharge by reducing the volume of clean water. The aquifer background concentration of 24 mg/L was added to all model-predicted concentrations because the model assumes a clean aquifer with respect to sulfate. For the current discharge case where the water volume and mass loading rate are based on current values, the maximum sulfate concentration at Well USGS-065 is predicted to be 156 mg/L. This is just slightly less than the average USGS-065 measured concentration of 160 mg/L (see Table 1). That the predicted concentrations match the measured concentrations reasonably well provides confidence that the model is appropriate.

The results indicate that for the case where the current discharge is reduced by one-third, the maximum predicted sulfate concentration is 189 mg/L. Although the effluent concentration for this case would increase 44%, the maximum predicted aquifer concentration increased only 21% over the current discharge case. For the final case where the current discharge is reduced by one-half, the maximum predicted sulfate concentration is 214 mg/L. Although the effluent concentration for this case would increase 89%, the maximum predicted aquifer concentration increased only 37% over the current discharge case.

The results of this evaluation indicate that reducing the volume of clean water discharged to the CWP will increase sulfate concentrations in the aquifer, but it is not expected to increase concentrations at the Industrial Wastewater Reuse Permit compliance monitoring Well USGS-065 above the Secondary Constituent Standard of 250 mg/L. The maximum discharge reduction evaluated in this study (one-half the total current discharge volume) increased the concentration from a baseline prediction of 156 mg/L to 214 mg/L.

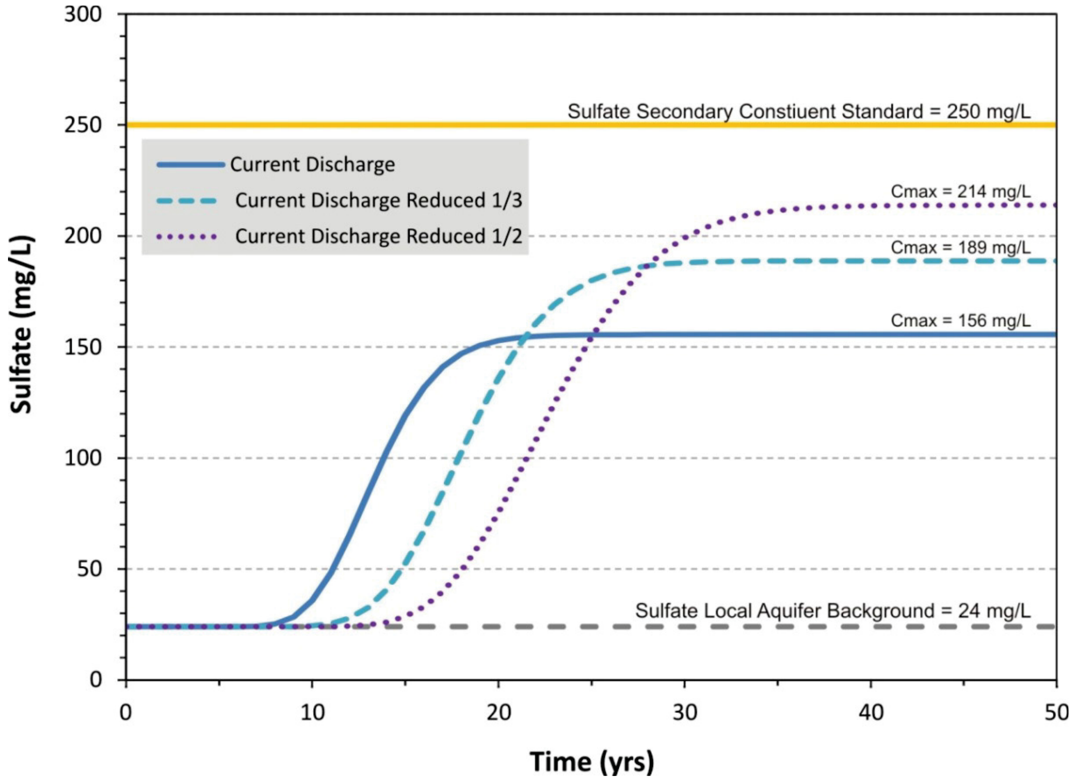

Figure 11. Model predicted sulfate concentration as a function of time at the USGS-065 well location for the three scenarios examined.

5. SUMMARY AND CONSIDERATIONS

A modeling study was conducted to determine the potential impact to groundwater from reducing "clean" water discharges to the CWP at the ATR Complex. The total discharge was reduced by one-third and one-half from current average values by reducing the volume of clean water discharged, which concentrated the chemicals (e.g., sulfate) in the effluent. The results indicate that sulfate concentrations in the aquifer would increase, but would not exceed the Secondary Constituent Standard of 250 mg/L.

While the modeling performed for this evaluation estimates diversion of "clean" wastewater from the ATR CWP to the sewage lagoons will not cause the sulfate Secondary Constituent Standard to be exceeded downgradient of the CWP, the diversion is predicted to worsen the impact on groundwater quality. The Idaho Department of Environmental Quality considers a wastewater to have a negative impact on groundwater if a constituent is 10% of the Secondary Constituent Standard above background and the well monitoring currently demonstrates a negative impact. Even though this evaluation primarily focused on sulfate, sulfate is not the only constituent of concern. It is possible that other constituent concentrations in the aquifer may increase in a manner similar to sulfate.

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Appendix A
Computer Code Input and Output Files

Computer input and select output files are provided for the current discharge case only. Minor changes were made to the MCMF.PTT file, the SULFREL.INP file, and the GWSCREEN.PAR file for the reduced water flux cases. The reduced flux and sulfate release parameters are contained in each file and identified with comments. MCM output files (mcmf.out, mcmf.flx, mcmt.out) are not provided due to their size and format (files are binary), but can be provided upon request. The MCM sulfate output file (sulfate.rel) and the GWSCREEN output file (GWSCREEN.OUT) are provided for the current discharge case.

MCMF Input File: MCMF.PAR

```
ATR CWP Sulfate Analysis             title [title of progect (a80)]
mcmf.flx                             fileout [name of MCMT water flux file (a80)]
mcmf.ptt                             fileppt [net infiltration rate file (a80)]
1.0e-6 .0001  1.0e-60                eps,h1,hmin [accuracy, initial time step, minimum time step]
100  10  500  91 0.05  0  B          mlayer,nmat,nkt,qmax,qmin,iflag,abin
$  [no# of layers, no# of materials, no# of pnts in vanG curves, max value of q, min value of q]
$  [iflag: (0) initial moisture based on first record in infiltration file (1) provide initial moisture]
$  [abin: (A)scii or (B)inary]
$  [read intial moisture contents if iflag(1)=1, 20 values per line are read for each cell begining with the uppermost cell]

$ [Material properities are input by defining the range of cells where they apply]
$ Material 1:  High Permeablity Alluvium
1    13                                h,j [begining cell, ending cell]
1.45   1.82                                 thick(h),rho(h), [thickness(m), bulk density(g/cm^3)]
8798.  0.32   0.0002   100 1.4              sk(h),ths(h),thr(h),alpha(h),rn(h) [Sat cond(m/yr), sat moist con, resid moist con,
vanG alpha, vanG n]

$ Material 2: Basalt
14   32                                h,j [begining cell, ending cell]
1.45   2.0                                  thick(h),rho(h) [thickness (m), bulk density (g/cm^3)]
91  0.05  0.001  2.5  10.                   sk(h),ths(h),thr(h),alpha(h),rn(h) [Sat cond(m/yr), sat moist con, resid moist con,
vanG alpha, vanG n]

$ Material 3: HP Interbed from DOE/ID-11227 OU 3-14 RI/BRA 2006
33   35                                h,j [begining cell, ending cell]
1.45    1.34                                thick(h),rho(h) [thickness (m), bulk density (g/cm^3)]
1040.  0.6  0.11  10.5  1.29  0.22  0.5     sk(h),ths(h),thr(h),alpha(h),rn(h) rm(h),rl(h) [Sat cond(m/yr), sat moist con, resid
moist con, vanG alpha, vanG n vanG m vanG l]

$ Material 4:  Basalt
36   44                                h,j [begining cell, ending cell]
1.45   2.0                                  thick(h),rho(h) [thickness (m), bulk density (g/cm^3)]
91  0.05  0.001  2.5  10.                   sk(h),ths(h),thr(h),alpha(h),rn(h) [Sat cond(m/yr), sat moist con, resid moist con,
vanG alpha, vanG n]

$ Material 5: HP Interbed from DOE/ID-11227 OU 3-14 RI/BRA 2006
45   49                                h,j [begining cell, ending cell]
1.45    1.34                                thick(h),rho(h) [thickness (m), bulk density (g/cm^3)]
1040.  0.6  0.11  10.5  1.29  0.22  0.5     sk(h),ths(h),thr(h),alpha(h),rn(h) rm(h),rl(h) [Sat cond(m/yr) sat moist con, resid
moist con, vanG alpha, vanG n vanG m vanG l]

$ Material 6:  Basalt
50   62                                h,j [begining cell, ending cell]
1.45   2.0                                  thick(h),rho(h) [thickness (m), bulk density (g/cm^3)]
91  0.05  0.001  2.5  10.                   sk(h),ths(h),thr(h),alpha(h),rn(h) [Sat cond(m/yr), sat moist con, resid moist con,
vanG alpha, vanG n]

$ Material 7: HP Interbed from DOE/ID-11227 OU 3-14 RI/BRA 2006
63   64                                h,j [begining cell, ending cell]
1.45    1.34                                thick(h),rho(h) [thickness (m), bulk density (g/cm^3)]
1040.  0.6  0.11  10.5  1.29  0.22  0.5     sk(h),ths(h),thr(h),alpha(h),rn(h) rm(h),rl(h) [Sat cond(m/yr), sat moist con, resid
moist con, vanG alpha, vanG n vanG m vanG l]

$ Material 8:  Basalt
65   70                                h,j [begining cell, ending cell]
1.45   2.0                                  thick(h),rho(h) [thickness (m), bulk density (g/cm^3)]
91  0.05  0.001  2.5  10.                   sk(h),ths(h),thr(h),alpha(h),rn(h) [Sat cond(m/yr), sat moist con, resid moist con,
vanG alpha, vanG n]

$ Material 9: HP Interbed from DOE/ID-11227 OU 3-14 RI/BRA 2006
71   71                                h,j [begining cell, ending cell]
1.45    1.34                                thick(h),rho(h) [thickness (m), bulk density (g/cm^3)]
1040.  0.6  0.11  10.5  1.29  0.22  0.5     sk(h),ths(h),thr(h),alpha(h),rn(h) rm(h),rl(h) [Sat cond(m/yr), sat moist con, resid
moist con, vanG alpha, vanG n vanG m vanG l]

$ Material 10:  Basalt
72   100                               h,j [begining cell, ending cell]
1.45   2.0                                  thick(h),rho(h) [thickness (m), bulk density (g/cm^3)]
```

```
91  0.05  0.001  2.5  10.                  sk(h),ths(h),thr(h),alpha(h),rn(h) [Sat cond(m/yr), sat moist con, resid moist con,
vanG alpha, vanG n]

$ [Time output parameters]
1            ntimes [number of output time periods]
$ [Repeat t1,t2,tp for each ntime]
0.0    100.  1.0           t1(i),t2(i),tp(i) [begining time of output ending time of output, print step]
1.0e6        tmax [maximum time of output]
1            ncout [number of flux traces]
$ [Read only if ncout>0]
66           ncoutput(i) [cell numbers for each flux trace]
$ [End of Parameter Definition File]
```

Infiltration file read in by MCMF.PAR: MCMF.PTT

```
Time (yr)   Flux (m/yr)
0.0         0.92 (CWP water flux = 0.92 1x, 0.62 2/3x, 0.47 1/2x)
50.0        0.92
50.001      0.1  (assume CWP operates 50 years and flux reduced to 1 cm/yr)
200.        0.1
```

MCMT Input File: MCMT.PAR

```
ATR CWP Sulfate Analysis                  title [title of project (a80)]
..\mcmf\mcmf.flx                          fileppt [water flux file from MCMF(a80)]
sulfrel.inp                               filerel [contaminant source term file (a80)]
1.0e-6  0.0001  1.0e-90                   eps,h1,hmin [accuracy, initial time step, minimum time step]
100  1   10  3   B                        mlayer,nprog,nmat,iunits,abin [number layers, number contaminants, number materials,
mass units, (A)scii or (B)inary output]
$ [iunits: (1) Ci (2) Bq  (3) mg]
$ [abin: (A)scii or (B)inary]

Sulfate         cname [contaminant names (6 characters)]
96              mw [ molecular weight (g/mol)]
1e9             sol [solubility limit (mg/m**3)]
1e18            thalf [half lives years]
0.0             bratio [branching ratio]
0.0             dwater [water diffusivity]

$ [intial inventories in each cell, 20 values per line are read begining with the uppermost cell]
$ [all values for the 1st member are read first, then the second and so on]
$ ---------------------------------------------------------------------------------------------------------------
$1     2     3     4     5     6     7     8     9     10    11    12    13    14    15    16    17    18    19    20
$ ---------------------------------------------------------------------------------------------------------------
$ sulfate
0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0
0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0
0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0
0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0
0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0

$ [kd values in each cell, 20 values per line are read begining with the uppermost cell]
$ [all values for the 1st member are read first, then the second and so on]
0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0
0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0
0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0
0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0
0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0

$ [kx values in each cell, 20 values per line are read begining with the uppermost cell]
$ [all values for the 1st member are read first, then the second and so on]
0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0
0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0
0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0
0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0
0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0

$ length and width same as gwscreen - zero explicit dispersivity. implicit dispersivity ~ Z/2n ~ 145 m/(2*100) = 0.725 m
600    1200  0.00                          lth,width,alphaL [length(m), width(m), longitudinal dispersivity(m)]

$ [Material properities are input by defining the range of cells where they apply]
$ Material 1:  High Permeablity Alluvium
1    13                           h,j [begining cell, ending cell]
1.45   1.82                            thick(h),rho(h), [thickness(m), bulk density(g/cm^3)]
8798.  0.32   0.0002   100 1.4         sk(h),ths(h),thr(h),alpha(h),rn(h) [Sat cond(m/yr), sat moist con, resid moist con, vanG
alpha, vanG n]

$ Material 2: Basalt
14   32                           h,j [begining cell, ending cell]
1.45   2.0                             thick(h),rho(h) [thickness (m), bulk density (g/cm^3)]
91  0.05  0.001  2.5  10.              sk(h),ths(h),thr(h),alpha(h),rn(h) [Sat cond(m/yr), sat moist con, resid moist con, vanG
alpha, vanG n]

$ Material 3: HP Interbed from DOE/ID-11227 OU 3-14 RI/BRA 2006
33   35                           h,j [begining cell, ending cell]
1.45    1.34                           thick(h),rho(h) [thickness (m), bulk density (g/cm^3)]
1040.  0.6  0.11  10.5  1.29  0.22  0.5  sk(h),ths(h),thr(h),alpha(h),rn(h) rm(h),rl(h) [Sat cond(m/yr), sat moist con, resid
moist con, vanG alpha, vanG n vanG m vanG l]

$ Material 4:  Basalt
```

```
36   44                             h,j [begining cell, ending cell]
1.45   2.0                               thick(h),rho(h) [thickness (m), bulk density (g/cm^3)]
91  0.05  0.001  2.5  10.                sk(h),ths(h),thr(h),alpha(h),rn(h) [Sat cond(m/yr), sat moist con, resid moist con, vanG
alpha, vanG n]

$ Material 5: HP Interbed from DOE/ID-11227 OU 3-14 RI/BRA 2006
45   49                             h,j [begining cell, ending cell]
1.45    1.34                             thick(h),rho(h) [thickness (m), bulk density (g/cm^3)]
1040.  0.6  0.11  10.5  1.29  0.22  0.5  sk(h),ths(h),thr(h),alpha(h),rn(h) rm(h),rl(h) [Sat cond(m/yr) sat moist con, resid
moist con, vanG alpha, vanG n vanG m vanG l]

$ Material 6:  Basalt
50   62                             h,j [begining cell, ending cell]
1.45   2.0                               thick(h),rho(h) [thickness (m), bulk density (g/cm^3)]
91  0.05  0.001  2.5  10.                sk(h),ths(h),thr(h),alpha(h),rn(h) [Sat cond(m/yr), sat moist con, resid moist con, vanG
alpha, vanG n]

$ Material 7: HP Interbed from DOE/ID-11227 OU 3-14 RI/BRA 2006
63   64                             h,j [begining cell, ending cell]
1.45    1.34                             thick(h),rho(h) [thickness (m), bulk density (g/cm^3)]
1040.  0.6  0.11  10.5  1.29  0.22  0.5  sk(h),ths(h),thr(h),alpha(h),rn(h) rm(h),rl(h) [Sat cond(m/yr), sat moist con, resid
moist con, vanG alpha, vanG n vanG m vanG l]

$ Material 8:  Basalt
65   70                             h,j [begining cell, ending cell]
1.45   2.0                               thick(h),rho(h) [thickness (m), bulk density (g/cm^3)]
91  0.05  0.001  2.5  10.                sk(h),ths(h),thr(h),alpha(h),rn(h) [Sat cond(m/yr), sat moist con, resid moist con, vanG
alpha, vanG n]

$ Material 9: HP Interbed from DOE/ID-11227 OU 3-14 RI/BRA 2006
71   71                             h,j [begining cell, ending cell]
1.45    1.34                             thick(h),rho(h) [thickness (m), bulk density (g/cm^3)]
1040.  0.6  0.11  10.5  1.29  0.22  0.5  sk(h),ths(h),thr(h),alpha(h),rn(h) rm(h),rl(h) [Sat cond(m/yr), sat moist con, resid
moist con, vanG alpha, vanG n vanG m vanG l]

$ Material 10:  Basalt
72   100                            h,j [begining cell, ending cell]
1.45   2.0                               thick(h),rho(h) [thickness (m), bulk density (g/cm^3)]
91  0.05  0.001  2.5  10.                sk(h),ths(h),thr(h),alpha(h),rn(h) [Sat cond(m/yr), sat moist con, resid moist con, vanG
alpha, vanG n]

$ [Time output parameters]
1                                      ntimes [number of output time periods]
$ [Repeat for each ntime]
0.0      100.       1.0                 t1(i),t2(i),tp(i) [begining time of output ending time of output, print step]
$ [End of Parameter Definition File]
```

Sulfate release file read in by MCMT.PAR: Sulfrel.inp

```
Time (yr) Sulfate (mg/yr)
0.0       1.35E11 (CWP mass = 1.35E11 1x, 1.29E11 2/3x, 1.27E11 1/2x)
50.0      1.35E11
50.001    0
```

Sulfate release file output by MCMT and read in by GWSCREEN: Sulfate.rel

```
  Time (y)     Flux (mg/y) Sulfat  Level: 072710 20130605   132334.294
  0.0000E+00  0.0000E+00
  1.0000E+00  2.5631E-20
  2.0000E+00  6.1399E-05
  3.0000E+00  7.5377E+01
  4.0000E+00  1.3045E+05
  5.0000E+00  1.2359E+07
  6.0000E+00  2.4401E+08
  7.0000E+00  1.8579E+09
  8.0000E+00  7.5835E+09
  9.0000E+00  2.0176E+10
  1.0000E+01  3.9665E+10
  1.1000E+01  6.2782E+10
  1.2000E+01  8.5084E+10
  1.3000E+01  1.0334E+11
  1.4000E+01  1.1643E+11
  1.5000E+01  1.2485E+11
  1.6000E+01  1.2978E+11
  1.7000E+01  1.3246E+11
  1.8000E+01  1.3382E+11
  1.9000E+01  1.3448E+11
  2.0000E+01  1.3478E+11
  2.1000E+01  1.3491E+11
  2.2000E+01  1.3496E+11
  2.3000E+01  1.3499E+11
  2.4000E+01  1.3499E+11
  2.5000E+01  1.3500E+11
  2.6000E+01  1.3500E+11
  2.7000E+01  1.3500E+11
  2.8000E+01  1.3500E+11
  2.9000E+01  1.3500E+11
  3.0000E+01  1.3500E+11
  3.1000E+01  1.3500E+11
  3.2000E+01  1.3500E+11
```

```
  3.3000E+01  1.3500E+11
  3.4000E+01  1.3500E+11
  3.5000E+01  1.3500E+11
  3.6000E+01  1.3500E+11
  3.7000E+01  1.3500E+11
  3.8000E+01  1.3500E+11
  3.9000E+01  1.3500E+11
  4.0000E+01  1.3500E+11
  4.1000E+01  1.3500E+11
  4.2000E+01  1.3500E+11
  4.3000E+01  1.3500E+11
  4.4000E+01  1.3500E+11
  4.5000E+01  1.3500E+11
  4.6000E+01  1.3500E+11
  4.7000E+01  1.3500E+11
  4.8000E+01  1.3500E+11
  4.9000E+01  1.3500E+11
  5.0000E+01  1.3500E+11
  5.1000E+01  1.2978E+11
  5.2000E+01  8.1205E+10
  5.3000E+01  5.0923E+10
  5.4000E+01  3.5392E+10
  5.5000E+01  3.3620E+10
  5.6000E+01  3.0885E+10
  5.7000E+01  2.4898E+10
  5.8000E+01  1.9175E+10
  5.9000E+01  1.5995E+10
  6.0000E+01  1.4791E+10
  6.1000E+01  1.4437E+10
  6.2000E+01  1.4342E+10
  6.3000E+01  1.4318E+10
  6.4000E+01  1.4312E+10
  6.5000E+01  1.4309E+10
  6.6000E+01  1.4307E+10
  6.7000E+01  1.4306E+10
  6.8000E+01  1.4305E+10
  6.9000E+01  1.4306E+10
  7.0000E+01  1.4307E+10
  7.1000E+01  1.4310E+10
  7.2000E+01  1.4314E+10
  7.3000E+01  1.4320E+10
  7.4000E+01  1.4327E+10
  7.5000E+01  1.4336E+10
  7.6000E+01  1.4346E+10
  7.7000E+01  1.4358E+10
  7.8000E+01  1.4371E+10
  7.9000E+01  1.4386E+10
  8.0000E+01  1.4403E+10
  8.1000E+01  1.4421E+10
  8.2000E+01  1.4440E+10
  8.3000E+01  1.4461E+10
  8.4000E+01  1.4483E+10
  8.5000E+01  1.4505E+10
  8.6000E+01  1.4528E+10
  8.7000E+01  1.4552E+10
  8.8000E+01  1.4574E+10
  8.9000E+01  1.4596E+10
  9.0000E+01  1.4617E+10
  9.1000E+01  1.4635E+10
  9.2000E+01  1.4650E+10
  9.3000E+01  1.4661E+10
  9.4000E+01  1.4667E+10
  9.5000E+01  1.4667E+10
  9.6000E+01  1.4661E+10
  9.7000E+01  1.4647E+10
  9.8000E+01  1.4623E+10
  9.9000E+01  1.4590E+10
  1.0000E+02  1.4546E+10
  1.0200E+02  0.0000E+00
```

GWSCREEN Input File: GWSCREEN.PAR

```
$ GWSCREEN Input File. Comments are indicated by a dollar sign in the FIRST column.
$ All input cards must be present and in the same order as presented in Table 3 of the GWSCREEN User's Manual
$ All integer variables must be integers (i.e., no decimal point)

$ Card 1
$ Title - Char*80  Title of project
'ATR CWP Sulfate Analysis'

$ Card 2 variables (all integer values)
$ IMODE --- INTEGER Defines type of impacts to be calculated and contaminant type: (1) Radiological Dose (2) Radiological
Carcinogenic Risk (3) MCL for radionuclides (4) MCL for non-radionuclides (5) Carcinogenic Risk for Non-radionuclides (6) Non-
carcinogenic Risk for Non-radionuclides
$ ITYPE --- INTEGER Defines type of vertical dispersion used in aquifer: (1) 2D vertically averaged solution, (2) 3D point
solution, (3) 3D vertically averaged solution.
$ IDISP --- INTEGER Defines long and trans dispersion options: (0) Fixed dispersivity, (1-3) Spatially variable dispersivity
based on 3 different algorithms (see Section 2.3.1).
$ KFLAG --- INTEGER Defines type of output: (1) Peak concentration and maximum impacts, (2) Concentration as function of time,
(3) Concentration as function of a spatial grid.
$ IDIL  --- INTEGER Computes additional dilution from infiltrating water: (1) no dilution correction, (2) dilution correction
(recommended for high inf sources, see Sect 2.1.3).
```

```
4  1  0  2  2      Card 2 imode itype idisp kflag idil

$ Card 3 variables (all integer values)
$ IMODEL  --- INTEGER Defines type of source model: (1) surface or buried source, (2) pond source model, (3) tabulated source
function.
$ ISOLVE  --- INTEGER Defines solution algorithm in aquifer: (1) Gauss-Legendre, (2) Simpsons Rule.
$ ISOLVEU --- INTEGER Defines solution algorithm in unsaturated zone: (1) Gauss-Legendre,  (2) Simpsons Rule.
$ IMOIST  --- INTEGER Defines how moisture content is determined in source zone: (1) user defined, (2) calculated using van
Genuchten fitting parameters.
$ IMOISTU --- INTEGER Defines how moisture content is determined in unsaturated zone: (1) user defined, (2) calculated using van
Genuchten fitting parameters.
3  2  2  1  1      Card 3 imodel isolve isolveu imoist imoistu

$ Card 4 variables
$ JSTART  --- INTEGER Number of iterations to perform in Simpson rule integration routine before convergence is checked. See
discussion in Section 3.2.4.
$ JMAX    --- INTEGER Max number of iterations to perform for Simpson rule integration. The maximum number of point
evaluations=[2jmax-1]. See discussion in Section 3.2.4.
$ EPS     --- REAL  Convergence criteria for Simpson rule integration. See discussion in Section 3.2.4.
6  13  1.0e-3      Card 4 jstart jmax eps

$ Card 5 variables
$ BW   REAL  Body mass (weight) of receptor (kg)
$ AT   REAL  Averaging time (days)
$ WI   REAL  Water intake rate (L d-1)
$ EF   REAL  Exposure frequency (d y-1)
$ ED   REAL  Exposure duration (y)
$ DLIM REAL  Acceptable level of health impacts. Depends on IMODE
$     IMODE = 1: dose in rem
$     IMODE = 2: carcinogenic risk for radionuclide
$     IMODE = 3: ratio of concentration to MCL for radionuclides
$     IMODE = 4: ratio of concentration to MCL for non-radionuclide
$     IMODE = 5: carcinogenic risk for non radionuclide
$     IMODE = 6: hazard quotient.
$ --- convert from m**3 to L.  Units of DCF are rem m**3/Ci
70. 2.555E+04  2.0  1.  1.  1        Card 5 bw,at,wi,ef,ed,dlim

$ Card 6 variables
$ X0  --  REAL  Coordinate of center of source parallel to groundwater flow relative to receptor grid coordinate system (m)
$ Y0  --- REAL  Coordinate of center of source perpendicular to groundwater flow relative to receptor grid coordinate system (m)
0.0   0.0          Card 6 x0 y0

$ Card 7 variables
$ AL --- REAL  Length of source parallel to groundwater flow (m)
$ WA --- REAL  Width of source perpendicular to groundwater flow (m)
$ PERC --- REAL  Percolation rate through source and into unsaturated zone (m y-1)
600.   1200.  0.94   Card 7 al wa perc (1x current disharge)
$600.   1200.  0.62   Card 7 al wa perc (2/3x current disharge)
$600.   1200.  0.47   Card 7 al wa perc (1/2x current disharge)

$ Card 8a variables  Read only if IMODEL=2
$ TOPER  --- REAL  Operation time of pond (y)
$ PNDFLX --- REAL  Water flux into pond (m3 y-1)
$ EVAP   --- REAL  Evaporation of other loss rate constant from pond (y-1)
$ THETAP --- REAL  Read only if IMOIST=1 Volumetric water content of pond (m3 m-3)
$                  Card 8a toper, pndflx, evap, thetap
$ no card 8a because IMODEL<>2

$ Card 8b variables  Read cards 8b, 8c, and 8d only if IMODEL=1 or 2
$ THICKS --- REAL  Thickness of Source or pond sediment thickness (m)
$ RHOS   --- REAL  Bulk density in source zone (g cm-3).
$ 0.515  1.5       Card 8b thicks rhos
$ no card 8b because IMODEL<>1 or 2

$ Card 8c variables  Read only if IMOIST=1
$ THETAS --- REAL    Volumetric water content of source or pond sediments after end of operation, (m3 m-3)
$ 0.30             Card 8c thetas
$ no card 8c because IMOIST<>1

$ Card 8d variables  Read only if IMOIST=2
$ ALPHA ---   REAL  van Genuchten fitting parameter for source (m-1)
$ N     ---   REAL  van Genuchten fitting parameter for source
$ KSAT  ---   REAL  Saturated hydraulic conductivity for source (m y-1)
$ PORS  ---   REAL  Total porosity for source (assumed to be equivalent to the effective porosity, m3 m-3)
$ THETAR ---  REAL  Residual moisture content for source (m3 m-3)
$                  Card 8d alpha, n, ksat, pors, thetar
$ no card 8d because IMOIST<>2

$ Card 9 variables
$ DEPTH --- REAL  Depth from base of source to top of aquifer (unsaturated thickness) (m)
$ RHOU  --- REAL  Bulk density in unsaturated zone (g cm-3)
$ AUX   --- REAL  Longitudinal dispersivity in unsaturated zone (m).  Set AUX=0 for plug flow model
0.001  1.9  0.0    Card 9 depth rhou aux

$ Card 9a variables  Read only if IMOISTU=1.
$ THETAU  --- REAL  Volumetric water content in unsaturated zone (m3 m-3)
0.03               Card 9a thetau

$ Card 9b variables   Read only if IMOISTU=2
$ ALPHAU  --- REAL  van Genuchten fitting parameter for unsaturated zone (m-1)
$ NU      --- REAL  van Genuchten fitting parameter for unsaturated zone
$ KSATU   --- REAL  Saturated hydraulic conductivity for unsaturated zone (m y-1)
$ PORSU   --- REAL  Total porosity for unsaturated zone (assumed to be the same as effective porosity, m3 m-3)
$ THETARU --- REAL  Residual moisture content for unsaturated zone (m3 m-3)
$                  Card 9b alphau nu ksatu porsu thetau
```

```
$ No card 9b because IMOISTU<>2

$ Card 10 variables
$ AX  --- REAL  Longitudinal dispersivity (m) if IDISP=0; otherwise ignored
$ AY  --- REAL  Transverse dispersivity (m) if IDISP=0; otherwise the ratio of the transverse to longitudinal dispersivity
$ AZ  --- REAL  Vertical dispersivity (m) if IDISP=0; otherwise the ratio of the vertical to longitudinal dispersivity
$ B   --- REAL  Aquifer thickness (m)
$ Z   --- REAL  If ITYPE=1 or 3, then z is the well screen thickness, else, z is the depth in the aquifer where concentrations
are evaluated.
91.  40.  4.55  76.  15.    Card 10 ax,ay,az,b,z(well screen thickness)

$ Card 11 variables - Use RHLLW parameters
$ U    --- REAL  Darcy velocity in aquifer (m y-1)
$ PHI  --- REAL  Porosity of aquifer (m3 m-3)
$ RHOA --- REAL  Bulk density of aquifer (g cm-3)
16.4  0.06  1.9    Card 11 u phi rhoa

$ Card 12a variables  Read only if KFLAG<3
$ NRECEPT --- INTEGER Number of receptors
1                  Card 12a nrecept

$ Card 12b  variables  Read only if KFLAG<3; Repeat card 12b NRECEPT times
$ XREC(I) --- REAL  Receptor distance from center of source parallel to groundwater flow for the ith receptor (m)
$ YREC(I) --- REAL  Receptor distance from center of source perpendicular to groundwater flow for the ith receptor (m)
470.    230.       Card 12b xrec yrec (USGS-065)

$ Card 12c   Read only if KFLAG=3
$ GRIDFILE  --- CHAR*40 File name containing the x and y coordinates of each receptor (maximum 2000)
$ no card 12c because KFLAG<>3

$ Card 13a variables Read only if KFLAG=2
$ NTIMES  --- INTEGER Number of time periods to calculate concentrations over
1                Card 13a ntimes

$ Card 13b  variables  Read only if KFLAG=2; Repeat card 13b NTIMES times
$ T1(I) --- REAL  Beginning time of the Ith time period to calculate concentration as a function of time (y)
$ T2(I) --- REAL  End time of the Ith time period to calculate concentration as a function of time (y)
$ TP(I) --- REAL  Print time step for the Ith time period (y)
0.     100.    1.0         Card 13b t1 t2 tp

$ Card 13c  variables Read only if KFLAG=3
$ GT  --- REAL  Time of concentration grid output (y)
$ no card 13c because KFLAG<>3

$ Card 14 variables
$ NCONTAM --- INTEGER Number of contaminants
1                  Card 14 ncontam

$ NOTE: Cards 14a, 14b, and 14c are read as a set for each contaminant
$ Card 14a variables  Repeat card 14a NCONTAM times
$  NPROG --- INTEGER Number of radioactive progeny; NPROG must be less than 8. NPROG=0 for non-radioactive contaminants.
$  KDS   --- REAL  Distribution coefficient in source zone (mL g-1)
$  KDU   --- REAL  Distribution coefficient in unsaturated zone (mL g-1)
$  ZMW   --- REAL  Molecular weight (g mol-1)
$  QI    --- REAL  Initial mass or activity (mg or Ci)
$  RMI   --- REAL  Mass or activity input rate to pond (mg or Ci y-1). Ignored if IMODEL=1 or 3.
$  SL    --- REAL  Solubility limit (mg L-1)
$  OTHER --- REAL  Loss rate constant from source for other mechanisms (y-1)

$ Card 14b variables  Repeat card 14b NPROG+1 times for radionuclides
$ CNAME(I,J)  --- CHAR*6  Name of the Ith contaminant, Jth decay chain member (Total decay chain members=NPROG+1)
$ THALF(I,J)  --- REAL  Half life of Ith contaminant for Jth decay chain member (Total decay chain members=NPROG+1)
$ KDA(I,J)    --- REAL  Distribution coefficient in aquifer for Ith contaminant and Jth decay chain member (Total decay chain
members=NPROG+1)
$ DCF(I,J)    --- Depends on IMODE. Values are for ith contaminant and jth decay chain member
$     IMODE = 1: Dose Conversion Factor (rem Ci-1)
$     IMODE = 2: carcinogenic SF for radionuclide (Ci-1)
$     IMODE = 3: MCL for radionuclide (Ci m-3)
$     IMODE = 4: MCL for non-radionuclide (mg m-3)
$     IMODE = 5: carcinogenic SF for non-radionuclide (kg-d mg-1)
$     IMODE = 6: reference dose for non-carcinogenic effects (mg (kg-d)-1)

$ Card 14c  variable Read only if IMODEL=3
$ RELFILE --- CHAR*40 Name of release file
$--------------------Sulfate--------------------
0  1.000E+01  1.000E+01  96  9.999E+02  0. 1.00E+06  0.0     Card 14a nprog, kds, kdu, zmw, qi, rmi, sl, other
          'Sulfate'     1.E+09     0     250000.             Card 14b cname(i,j), thalf(i,j), kda(i,j), dcf(i,j)
'..\mcmt\sulfate.rel'                                        Card 14c relfile
```

GWSCREEN Output File: GWSCREEN.OUT

```
   ***************************************************
   *                                                 *
   *     This output was produced by the model:      *
   *                                                 *
   *                   GWSCREEN                      *
   *                  Version 2.5a                   *
   *    A semi-analytical model for the assessment   *
   *    of the groundwater pathway from the leaching *
   *    of surficial and buried contamination and    *
   *  release of contaminants from percolation ponds *
   *                  01/23/2007                     *
```

```
 *                 Arthur S. Rood                 *
 *         Idaho National Engineering and         *
 *            Environmental Laboratory            *
 *                   PO Box 1625                  *
 *             Idaho Falls, Idaho 83415           *
 **************************************************
============================================================================
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 Cambridge University Press.
 ===========================================================================

 OUTPUT FILE NAME: GWSCREEN.OUT
 INPUT FILE NAME: GWSCREEN.PAR
Title: 'ATR CWP Sulfate Analysis'
----------------------------------------------------------------------------
Model Run Options
----------------------------------------------------------------------------
IMODE Contaminant Type and Impacts:                            4
ITYPE (1) Vert Avg (2) 3D Point (3) 3d Avg:                    1
IDISP (0) Fixed Dispersivity (1-3) Spatially Varying:          0
KFLAG (1) Max Conc (2) Conc vs Time (3) Grid Output:           2
IDIL (1) No dilution factor (2) Include Dilution Factor:       2
IMOIST Source Moisture Content Option:                         1
IMOISTU Unsaturated Moisture Content Option:                   1
IMODEL (1) Surface/Burried Src (2) Pond (3) Usr Def:           3
ISOLVE (1) Gaussian Quarature (2) Simpsons Rule: (Aquifer)     2
ISOLVEU (1) Gaussian Quarature (2) Simpsons Rule: (Unsat Zone)  2
JSTART:   6
JMAX  :  13
EPS   :  1.000E-03
Health Effects: Ratio of groundwater concentration to MCL
Output mass/activity units:   mg
Output concentration units:   mg/m**3
Dose/Risk Conversion Units:   mg/m**3
Output health effects units:  Ratio of Cp/Cmcl
Cp = Peak groundwater concentration, Cmcl = Maximum contaminant limit
----------------------------------------------------------------------------
Exposure Parameters
----------------------------------------------------------------------------
Body Mass (kg):              70.       Averaging Time (days):      25550.
Water Ingestion (L/d):       2.000E+00 Exposure Freq (day/year):  1.000E+00
Exposure Duration (y):       1.000E+00 Limiting Dose:             1.000E+00
----------------------------------------------------------------------------
Site Parameters
----------------------------------------------------------------------------
X Coordinate:                0.000E+00  Y Coordinate:              0.000E+00
Source Length (m):           6.000E+02  Source Width (m):          1.200E+03
Percolation Rate (m/y):      9.400E-01
----------------------------------------------------------------------------
Unsaturated Zone Parameters
----------------------------------------------------------------------------
Unsat Zone Thickness (m):    1.000E-03  Unsat Bulk Density:        1.900E+00
Unsat Dispersivity (m):      0.000E+00  Unsat Moisture Content:    3.000E-02
----------------------------------------------------------------------------
Aquifer Zone Parameters
----------------------------------------------------------------------------
Longitudinal Disp (m):       9.100E+01  Transverse Disp (m):       4.000E+01
Aquifer Thickness (m):       7.600E+01  Well Screen Thickness (m): 1.500E+01
Darcy Velocity (m/y):        1.640E+01  Aquifer Porosity:          6.000E-02
Bulk Density (g/cc):         1.900E+00
----------------------------------------------------------------------------
Calculated Flow Parameters
----------------------------------------------------------------------------
Percolation Water Flux (m3/y):  6.7680E+05
Unsat Pore Velocity (m/y):      3.1333E+01
Aquifer Pore Velocity (m/y):    2.7333E+02
Longitudinal Disp (m**2/y):     2.4873E+04
Transverse Disp (m**2/y):       1.0933E+04
----------------------------------------------------------------------------
Contaminant Data
----------------------------------------------------------------------------
 Contaminant Name:               Sulfate
 Half Life (y):                  1.000E+09
 Other Source Loss Rate (1/y):   0.000E+00
 Release File Name:              ..\mcmt\sulfate.rel
 Kd Unsat (ml/g):                1.000E+01
 Kd Aquifer (ml/g):              0.000E+00
 Risk/Dose Conversion Factor:    2.500E+05
----------------------------------------------------------------------------
Release File Contents
```

Year	Flux mg/y
0.000E+00	0.000E+00
1.000E+00	2.563E-20
2.000E+00	6.140E-05
3.000E+00	7.538E+01
4.000E+00	1.304E+05
5.000E+00	1.236E+07
6.000E+00	2.440E+08
7.000E+00	1.858E+09
8.000E+00	7.584E+09
9.000E+00	2.018E+10
1.000E+01	3.966E+10
1.100E+01	6.278E+10
1.200E+01	8.508E+10
1.300E+01	1.033E+11
1.400E+01	1.164E+11
1.500E+01	1.248E+11
1.600E+01	1.298E+11
1.700E+01	1.325E+11
1.800E+01	1.338E+11
1.900E+01	1.345E+11
2.000E+01	1.348E+11
2.100E+01	1.349E+11
2.200E+01	1.350E+11
2.300E+01	1.350E+11
2.400E+01	1.350E+11
2.500E+01	1.350E+11
2.600E+01	1.350E+11
2.700E+01	1.350E+11
2.800E+01	1.350E+11
2.900E+01	1.350E+11
3.000E+01	1.350E+11
3.100E+01	1.350E+11
3.200E+01	1.350E+11
3.300E+01	1.350E+11
3.400E+01	1.350E+11
3.500E+01	1.350E+11
3.600E+01	1.350E+11
3.700E+01	1.350E+11
3.800E+01	1.350E+11
3.900E+01	1.350E+11
4.000E+01	1.350E+11
4.100E+01	1.350E+11
4.200E+01	1.350E+11
4.300E+01	1.350E+11
4.400E+01	1.350E+11
4.500E+01	1.350E+11
4.600E+01	1.350E+11
4.700E+01	1.350E+11
4.800E+01	1.350E+11
4.900E+01	1.350E+11
5.000E+01	1.350E+11
5.100E+01	1.298E+11
5.200E+01	8.120E+10
5.300E+01	5.092E+10
5.400E+01	3.539E+10
5.500E+01	3.362E+10
5.600E+01	3.088E+10
5.700E+01	2.490E+10
5.800E+01	1.918E+10
5.900E+01	1.600E+10
6.000E+01	1.479E+10
6.100E+01	1.444E+10
6.200E+01	1.434E+10
6.300E+01	1.432E+10
6.400E+01	1.431E+10
6.500E+01	1.431E+10
6.600E+01	1.431E+10
6.700E+01	1.431E+10
6.800E+01	1.430E+10
6.900E+01	1.431E+10
7.000E+01	1.431E+10
7.100E+01	1.431E+10
7.200E+01	1.431E+10
7.300E+01	1.432E+10
7.400E+01	1.433E+10
7.500E+01	1.434E+10
7.600E+01	1.435E+10
7.700E+01	1.436E+10
7.800E+01	1.437E+10
7.900E+01	1.439E+10
8.000E+01	1.440E+10
8.100E+01	1.442E+10
8.200E+01	1.444E+10
8.300E+01	1.446E+10
8.400E+01	1.448E+10
8.500E+01	1.450E+10
8.600E+01	1.453E+10
8.700E+01	1.455E+10
8.800E+01	1.457E+10
8.900E+01	1.460E+10
9.000E+01	1.462E+10
9.100E+01	1.464E+10
9.200E+01	1.465E+10

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 9.300E+01  1.466E+10
 9.400E+01  1.467E+10
 9.500E+01  1.467E+10
 9.600E+01  1.466E+10
 9.700E+01  1.465E+10
 9.800E+01  1.462E+10
 9.900E+01  1.459E+10
 1.000E+02  1.455E+10
 1.020E+02  0.000E+00
-----------------------------------------------------------------------------
Calculated Contaminant Values
-----------------------------------------------------------------------------
Decay Constants (1/y):                   6.9315E-10
Unsaturated Retardation Factor:          6.3433E+02
Mean Unsaturated Transit Time (y):       2.0245E-02
Aquifer Retardation Factor:              1.000E+00
-----------------------------------------------------------------------------
Concentration vs Time Results for Receptor X =  4.70000E+02 Y = 2.30000E+02
-----------------------------------------------------------------------------
   Time        Flux     Conc Mbr 1
 (years)  (mg or Ci/y) (mg or Ci per cubic meter)
-----------------------------------------------------------------------------
 0.0000E+00  0.000E+00  0.000E+00
 1.0000E+00  2.511E-20  1.396E-27
 2.0000E+00  6.016E-05  3.345E-12
 3.0000E+00  7.385E+01  4.105E-06
 4.0000E+00  1.278E+05  7.129E-03
 5.0000E+00  1.211E+07  7.086E-01
 6.0000E+00  2.393E+08  1.670E+01
 7.0000E+00  1.825E+09  1.718E+02
 8.0000E+00  7.468E+09  9.954E+02
 9.0000E+00  1.992E+10  3.757E+03
 1.0000E+01  3.927E+10  1.022E+04
 1.1000E+01  6.231E+10  2.162E+04
 1.2000E+01  8.463E+10  3.763E+04
 1.3000E+01  1.030E+11  5.633E+04
 1.4000E+01  1.162E+11  7.513E+04
 1.5000E+01  1.247E+11  9.182E+04
 1.6000E+01  1.297E+11  1.052E+05
 1.7000E+01  1.324E+11  1.149E+05
 1.8000E+01  1.338E+11  1.216E+05
 1.9000E+01  1.345E+11  1.258E+05
 2.0000E+01  1.348E+11  1.284E+05
 2.1000E+01  1.349E+11  1.299E+05
 2.2000E+01  1.350E+11  1.307E+05
 2.3000E+01  1.350E+11  1.311E+05
 2.4000E+01  1.350E+11  1.313E+05
 2.5000E+01  1.350E+11  1.315E+05
 2.6000E+01  1.350E+11  1.315E+05
 2.7000E+01  1.350E+11  1.315E+05
 2.8000E+01  1.350E+11  1.316E+05
 2.9000E+01  1.350E+11  1.316E+05
 3.0000E+01  1.350E+11  1.316E+05
 3.1000E+01  1.350E+11  1.316E+05
 3.2000E+01  1.350E+11  1.316E+05
 3.3000E+01  1.350E+11  1.316E+05
 3.4000E+01  1.350E+11  1.316E+05
 3.5000E+01  1.350E+11  1.316E+05
 3.6000E+01  1.350E+11  1.316E+05
 3.7000E+01  1.350E+11  1.316E+05
 3.8000E+01  1.350E+11  1.316E+05
 3.9000E+01  1.350E+11  1.316E+05
 4.0000E+01  1.350E+11  1.316E+05
 4.1000E+01  1.350E+11  1.316E+05
 4.2000E+01  1.350E+11  1.316E+05
 4.3000E+01  1.350E+11  1.316E+05
 4.4000E+01  1.350E+11  1.316E+05
 4.5000E+01  1.350E+11  1.316E+05
 4.6000E+01  1.350E+11  1.316E+05
 4.7000E+01  1.350E+11  1.316E+05
 4.8000E+01  1.350E+11  1.316E+05
 4.9000E+01  1.350E+11  1.316E+05
 5.0000E+01  1.350E+11  1.316E+05
 5.1000E+01  1.299E+11  1.313E+05
 5.2000E+01  8.219E+10  1.272E+05
 5.3000E+01  5.154E+10  1.107E+05
 5.4000E+01  3.571E+10  8.722E+04
 5.5000E+01  3.366E+10  6.479E+04
 5.6000E+01  3.094E+10  4.923E+04
 5.7000E+01  2.502E+10  3.965E+04
 5.8000E+01  1.929E+10  3.263E+04
 5.9000E+01  1.606E+10  2.663E+04
 6.0000E+01  1.482E+10  2.177E+04
 6.1000E+01  1.444E+10  1.835E+04
 6.2000E+01  1.434E+10  1.626E+04
 6.3000E+01  1.432E+10  1.510E+04
 6.4000E+01  1.431E+10  1.450E+04
 6.5000E+01  1.431E+10  1.421E+04
 6.6000E+01  1.431E+10  1.407E+04
 6.7000E+01  1.431E+10  1.400E+04
 6.8000E+01  1.431E+10  1.397E+04
 6.9000E+01  1.431E+10  1.396E+04
 7.0000E+01  1.431E+10  1.395E+04
 7.1000E+01  1.431E+10  1.395E+04
 7.2000E+01  1.431E+10  1.395E+04
```

```
 7.3000E+01  1.432E+10  1.395E+04
 7.4000E+01  1.433E+10  1.395E+04
 7.5000E+01  1.434E+10  1.396E+04
 7.6000E+01  1.435E+10  1.396E+04
 7.7000E+01  1.436E+10  1.397E+04
 7.8000E+01  1.437E+10  1.398E+04
 7.9000E+01  1.439E+10  1.399E+04
 8.0000E+01  1.440E+10  1.400E+04
 8.1000E+01  1.442E+10  1.402E+04
 8.2000E+01  1.444E+10  1.403E+04
 8.3000E+01  1.446E+10  1.405E+04
 8.4000E+01  1.448E+10  1.407E+04
 8.5000E+01  1.450E+10  1.409E+04
 8.6000E+01  1.453E+10  1.411E+04
 8.7000E+01  1.455E+10  1.413E+04
 8.8000E+01  1.457E+10  1.415E+04
 8.9000E+01  1.460E+10  1.418E+04
 9.0000E+01  1.462E+10  1.420E+04
 9.1000E+01  1.463E+10  1.422E+04
 9.2000E+01  1.465E+10  1.424E+04
 9.3000E+01  1.466E+10  1.426E+04
 9.4000E+01  1.467E+10  1.427E+04
 9.5000E+01  1.467E+10  1.428E+04
 9.6000E+01  1.466E+10  1.429E+04
 9.7000E+01  1.465E+10  1.429E+04
 9.8000E+01  1.462E+10  1.428E+04
 9.9000E+01  1.459E+10  1.427E+04
Maximum Concentration and Time for Member #1:  1.316E+05  3.100E+01
Execution Time (Seconds):    0
```