Evaluation of Groundwater Protectiveness of Potential Surface Impoundment Closure Options

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INTRODUCTION

Coal-powered utilities are under increased pressure due to new regulations contained in the April 2015 Federal Coal Combustion Residual (CCR) Rule[1] to close unlined CCR surface impoundments (SIs). The CCR Rule requires the closure or retrofit of certain facilities that do not meet the Rule's technical criteria for SI location and structural integrity or cause exceedances of groundwater protection standards. A large number of SIs may be impacted by the CCR Rule. The two primary SI closure options are:

1. Closure-in-place (CIP), which includes dewatering, backfilling, and capping CCR within the existing SI; and
2. Closure-by-removal (CBR), which includes dewatering, CCR excavation, transportation, redisposal in a landfill, and backfilling.

This report documents a numerical modeling approach to quantify the potential impacts of CCR constituents on groundwater quality for both primary SI closure options under a range of potential hydraulic conditions and SI characteristics. We used MODFLOW and MT3DMS to simulate groundwater concentrations and contaminant transport underneath and downgradient of an unlined SI. With the models' results, we calculated the time-weighted average (TWA) groundwater concentrations of two representative risk-driving constituents of concern – arsenic(III) [As(III)] and arsenic(V) [As(V)] – downgradient of the SI under both closure options. Groundwater constituent concentrations were evaluated for the near-term (initial 30 years after SI closure activities are initiated) and long-term (100 years after SI closure activities are initiated) at the downgradient edge of the SI containment berm to compare the effectiveness of the two primary closure options. The model results were used to evaluate and contrast each closure option's effectiveness at improving downgradient groundwater quality.

MODEL DEVELOPMENT

Groundwater hydraulics were modeled using MODFLOW 2005[2] and solute transport was modeled using MT3DMS.[3] Both are approved by the United States Environmental Protection Agency (US EPA)[4] and are industry-standard models. Visual MODFLOW (Version 2011.1)[5] was used as a pre- and post-processor for specifying model inputs and presenting model results. Infiltration due to precipitation through the engineered cap for CIP scenarios was estimated using the Hydrologic Evaluation of Landfill Performance Model (HELP).[6]

The model was designed to initially simulate steady-state conditions prior to installation of the SI under both non-intersecting and intersecting groundwater conditions. Once the hydraulic boundary conditions creating both the non-intersecting and intersecting groundwater conditions were established, additional hydraulic and solute transport boundary conditions were added to simulate the impact of the active SI. After 40 years of operation, the boundary conditions representing the constant head in the SI were removed, dewatering was simulated, and then both the CIP and CBR closure options were simulated. Conceptual site models illustrating the hydraulic scenarios that were modeled are provided in Figures 1 and 2.

The solute transport model was constructed to simulate the migration of arsenic through the subsurface. We selected arsenic as the modeled constituent because it is a common risk-driver in groundwater associated with unlined CCR SIs.[7] Both species of arsenic, As(III) and As(V), were modeled to assess the differences in behavior between more rapidly migrating compounds, such as As(III), and more slowly migrating compounds, such as As(V).

Groundwater quality was simulated at an observation well 30 ft downgradient from the clay berm at the downgradient end of the hypothetical SI. The well was screened at a location that was 5 ft below the water table based on pre-SI, ambient conditions, although the water level at the well changed during the operational, closure, and post-closure time periods.

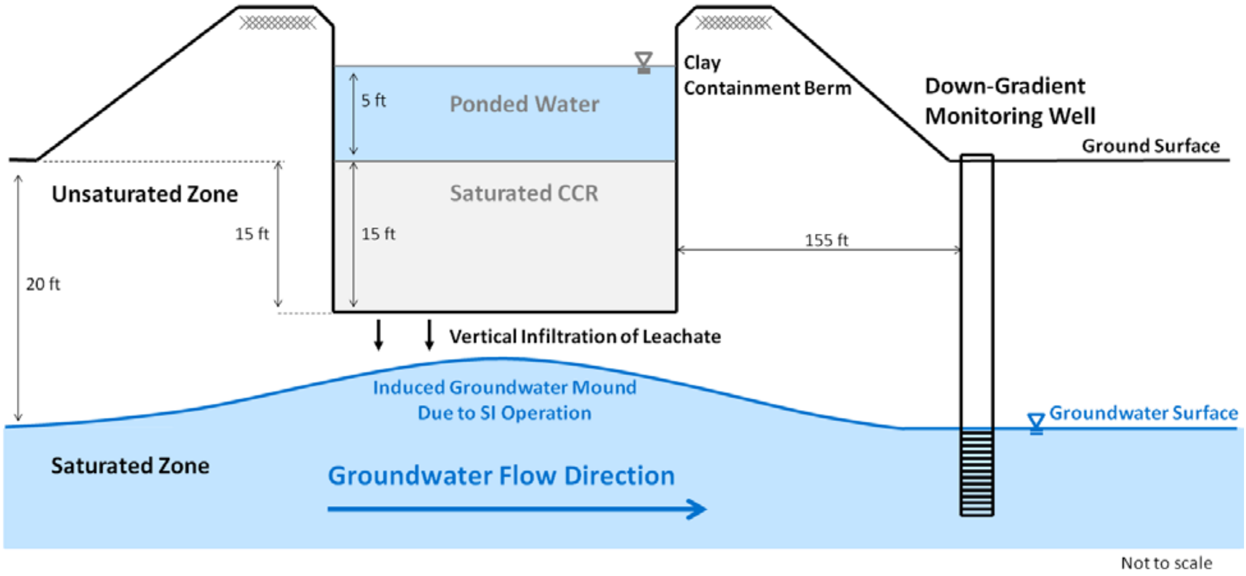

Figure 1 Surface Impoundment Conceptual Site Model – Non-Intersecting Groundwater Conditions

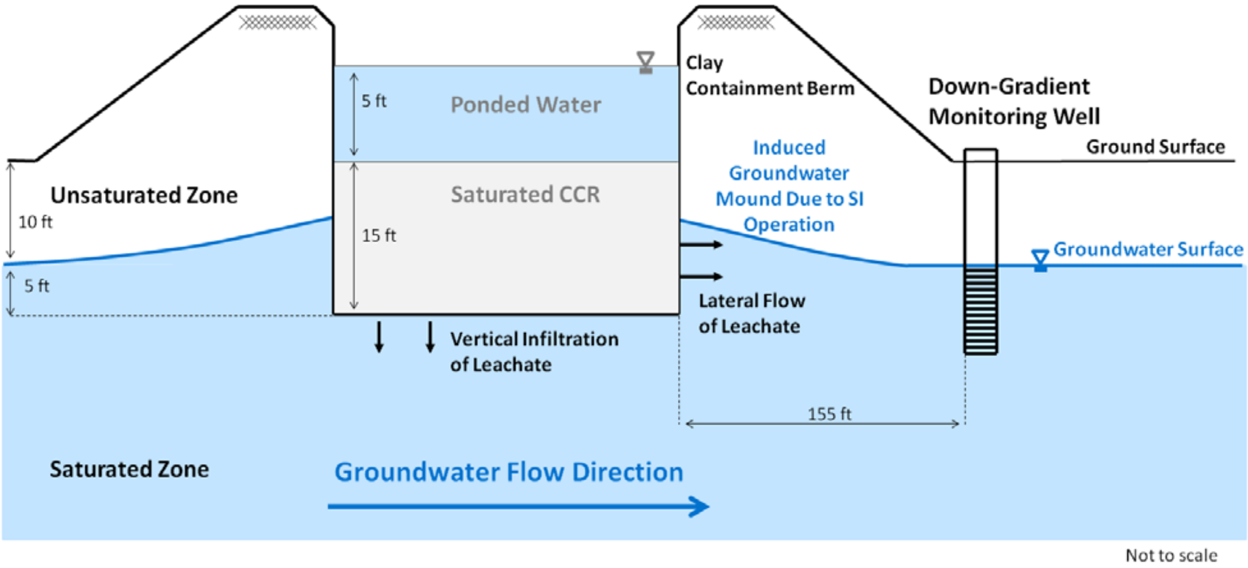

Figure 2 Surface Impoundment Conceptual Site Model – Intersecting Groundwater Conditions

Several different time periods were modeled for this evaluation. Each period required unique modeling assumptions. In total, we simulated solute transport over a 140-year period, which included 40 years of active SI operation and 100 years of closure and post-closure activities. Example simulation periods are provided in Figure 3.

Each closure option entails different work elements, which have different impacts on the structural composition of the model. The primary work elements associated with CIP are dewatering the SI and constructing an engineered cap over the dewatered CCR. The primary work elements associated with a CBR closure are dewatering the SI, excavation of the CCR, and transport of CCR to an existing or newly constructed landfill. Further details used to model each closure scenario are presented below.

- For the purposes of the modeling, it was assumed that dewatering of the SI under both closure options required 1 year to complete.
- The engineered cap was assumed to consist of 4 layers: (1) a geomembrane, (2) barrier soil, (3) a drainage sand layer, and (4) a silt loam topsoil layer.
- The time required to construct a cap under CIP and the time to excavate ash from the SI under CBR are dependent upon the size of the SI. The duration of cap construction and of CCR excavation were calculated based on the rate of material transport to or from the SI site, respectively.

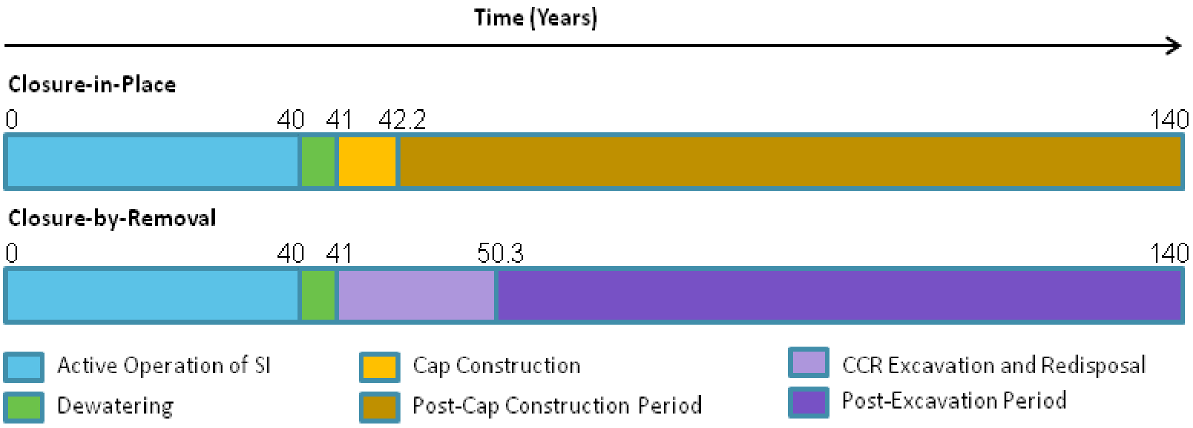

Figure 3 Example Simulation Periods for the 100-Acre SI

MODEL SCENARIOS

We used the above described model to quantify the potential impacts of arsenic on groundwater quality for a range of potential hydraulic conditions and SI characteristics, described below.

- We modeled impacts to groundwater resulting from SI closure for a range of aquifer hydraulic conductivities, including 5×10^{-4} cm/s, typical of a silty aquifer; 5×10^{-3} cm/s, typical of a silty-sand aquifer; and 5×10^{-2} cm/s, typical of a sandy aquifer.
- We evaluated impacts to groundwater for both intersecting and non-intersecting groundwater conditions.
    - For the non-intersecting groundwater scenario, the depth to groundwater (pre-SI, equilibrium conditions) is approximately 20 ft, although there is variation from the upgradient to downgradient edges of the SI.

  - For the intersecting groundwater scenario, the depth to groundwater (pre-SI, equilibrium conditions) is approximately 10 ft, although there is variation from the upgradient to downgradient edges of the SI.

- We modeled impacts to groundwater resulting from SIs of various sizes: 25 acres, 100 acres, and 200 acres. All SIs were assumed to be geometrically square. The total CCR volume in the SI varied, depending on size, ranging from 0.6 million cubic yards (M cy) (25-acre SI) to 4.8 M cy (200-acre SI).

MODEL RESULTS

TWA concentrations, presented as a unitless concentration ratio, C/C_o, were calculated for both arsenic species at the downgradient observation well over the first 30 years following SI closure (model years 40-70) and the first 100 years following SI closure (model years 40-140; Tables 1 and 2, respectively). For each scenario, shaded values represent the closure options that, based on model results, have the lowest TWA arsenic concentrations at the downgradient monitoring well.

Table 1 30-Year TWA Arsenic Concentrations at Downgradient Monitoring Well

Scenario	**30-Year TWA Concentration (C/C_o)**			
	CIP		**CBR**	
	As(III)	**As(V)**	**As(III)**	**As(V)**
25-acre SI; $K_h = 5 \times 10^{-3}$ cm/s				
Intersecting Groundwater	0.95	0.0035	0.9	0.0036
Non-intersecting Groundwater	0.87	0.0068	0.81	0.0069
100-acre SI; $K_h = 5 \times 10^{-3}$ cm/s				
Intersecting Groundwater	0.94	0.0026	0.93	0.0027
Non-intersecting Groundwater	0.86	0.0042	0.85	0.0043
200-acre SI; $K_h = 5 \times 10^{-3}$ cm/s				
Intersecting Groundwater	0.92	0.0025	0.94	0.0026
Non-intersecting Groundwater	0.85	0.0038	0.87	0.0039
100-acre SI; $K_h = 5 \times 10^{-2}$ cm/s				
Intersecting Groundwater	0.58	0.099	0.55	0.1
Non-intersecting Groundwater	0.55	0.15	0.55	0.15
100-acre SI; $K_h = 5 \times 10^{-4}$ cm/s				
Intersecting Groundwater	0.52	0.000024	0.52	0.000025
Non-intersecting Groundwater	0.59	0.000041	0.6	0.000042

Notes:

As = Arsenic; CBR = Closure-by-Removal; CIP = Closure-in-Place; K_h = Horizontal Hydraulic Conductivity; SI = Surface Impoundment; TWA = Time-Weighted Average.

Shaded cells indicate which closure strategy for a given scenario is most protective of groundwater.

Table 2 100-Year TWA Arsenic Concentrations at Downgradient Monitoring Well

Scenario	100-Year TWA Concentration (C/C_o)			
	CIP		CBR	
	As(III)	As(V)	As(III)	As(V)
25-acre SI; $K_h = 5 \times 10^{-3}$ cm/s				
Intersecting Groundwater	0.81	0.0062	0.62	0.0066
Non-intersecting Groundwater	0.75	0.01	0.54	0.011
100-acre SI; $K_h = 5 \times 10^{-3}$ cm/s				
Intersecting Groundwater	0.86	0.0047	0.67	0.0052
Non-intersecting Groundwater	0.79	0.0067	0.58	0.0072
200-acre SI; $K_h = 5 \times 10^{-3}$ cm/s				
Intersecting Groundwater	0.8	0.0044	0.69	0.0051
Non-intersecting Groundwater	0.72	0.0061	0.59	0.0068
100-acre SI; $K_h = 5 \times 10^{-2}$ cm/s				
Intersecting Groundwater	0.32	0.16	0.17	0.17
Non-intersecting Groundwater	0.17	0.22	0.17	0.22
100-acre SI; $K_h = 5 \times 10^{-4}$ cm/s				
Intersecting Groundwater	0.59	0.000038	0.6	0.000041
Non-intersecting Groundwater	0.61	0.000059	0.61	0.000062

Notes:
As = Arsenic; CBR = Closure-by-Removal; CIP = Closure-in-Place; K_h = Horizontal Hydraulic Conductivity; SI = Surface Impoundment; TWA = Time-Weighted Average.
Shaded cells indicate which closure strategy for a given scenario is most protective of groundwater.

The modeling results show that both CIP and CBR provide significant beneficial impacts to groundwater quality and that neither of the closure options is always more beneficial with respect to downgradient groundwater quality than the other. These results are consistent with US EPA's position in the CCR Rule that both closure options can be equally protective,[1] provided that they are implemented properly. Depending on the constituents of interest, the size of the SI, the time required to complete the closure option, and the hydrogeological conditions, CIP sometimes provides a greater degree of contaminant reduction in downgradient groundwater monitoring wells, and CBR sometimes provides a greater degree of contaminant reduction in downgradient groundwater monitoring wells. Thus, SI closure decisions should be evaluated on a case-by-case basis, considering site-specific SI conditions and hydrogeological characteristics.

Intersecting and non-intersecting groundwater conditions largely did not affect which closure option was more favorable. For high mobility compounds, *i.e.*, As(III), the intersecting groundwater scenario was associated with higher TWA concentrations under both closure options than the non-intersecting groundwater scenario, because the mass discharge that occurs due to groundwater-CCR contact during closure and post-closure has an impact on the long-term TWA concentrations. For low mobility compounds, *i.e.*, As(V), the intersecting groundwater scenario was associated with lower TWA concentrations than the non-intersecting groundwater scenario; this is because intersecting groundwater conditions are associated with lower mass flux to the aquifer during the SI operational period, due to the smaller vertical gradient. This lower mass flux during SI operation has an important impact on the TWA concentrations for low mobility compounds. However, the differences between CIP and CBR due to intersecting and non-intersecting groundwater conditions were generally small.

The level of groundwater protection provided by the two closure options was similar under all the scenarios modeled. In particular, based on the 30-year horizon, the relative percent difference (RPD) between TWA constituent concentrations for CIP and CBR was less than 10% for every scenario simulated. For the 100-year horizon, the long-term effects of SI closure were weighted more heavily in the TWA constituent concentrations, and, thus, the differences in model-predicted TWA constituent concentrations under the two closure options for the 100-year horizon are greater than for the 30-year horizon. Nonetheless, even for the 100-year horizon, the RPD between the TWA constituent concentrations under the two closure options was less than 10% in half of the scenarios simulated. Furthermore, there was only one scenario (high hydraulic conductivity and high mobility constituent) for which the model-predicted CBR TWA constituent concentration was more than 30% lower than the CIP TWA constituent concentration.

Although the differences in model-predicted constituent concentrations under the two closure options are slight, the following general trends are apparent from the model results:

- On a relative basis, CIP is generally more favorable when evaluating groundwater protectiveness over a 30-year timeframe compared to a 100-year timeframe. This is because the shorter timeframe highlights the differences in closure durations between CIP and CBR (*i.e.*, caps can be constructed much more quickly than CCR can be excavated).
- Generally, CIP is a slightly more favorable closure option for situations in which contaminant transport is slower, such as in lower conductivity aquifers or for lower mobility compounds, *e.g.*, As(V). In these scenarios, model-predicted TWA concentrations are more heavily influenced by mass flux resulting from the SI operation and remedy implementation periods. Similarly, CIP is generally slightly less favorable relative to CBR for situations in which contaminant transport is faster, such as in higher conductivity aquifers or for high mobility compounds, *e.g.*, As(III).
- CIP tends to be a slightly more favorable closure option for large SIs (*e.g.*, 200 acres), whereas CBR may be slightly more favorable for small SIs (*e.g.*, 25 acres). As SI size increases, the difference between the cap construction time and the excavation time increases; as this time difference increases, CIP becomes more favorable.

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