SAFETY EVALUATION REPORT

For the Proposed Groundwater Corrective Action Plan for the Sequoyah Fuels Corporation Site in Gore, Oklahoma

Materials License No. SUB-1010

Docket No. 40-8027
Sequoyah Fuels Corporation

U.S. Nuclear Regulatory Commission
Office of Federal and State Materials and
Environmental Management Programs

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1.0 *INTRODUCTION*

1.1 BACKGROUND

By letter dated June 16, 2003, Sequoyah Fuels Corporation (SFC) submitted to the U.S. Nuclear Regulatory Commission (NRC) staff the Groundwater Corrective Action Plan (CAP) Report describing the proposed groundwater remediation program for the SFC site in Gore, Oklahoma (MFG, 2003a). This CAP is part of an overall site reclamation program described in SFC's Reclamation Plan dated January 2003 (SFC, 2003). The Reclamation Plan primarily addresses the site decommissioning, disposal cell construction, and surface reclamation, while the CAP addresses residual contamination in groundwater. NRC staff reviewed the CAP and issued a request for additional information (RAI) by letter dated September 28, 2005 (NRC, 2005a). SFC responded to this RAI by letter dated December 16, 2005 (SFC, 2005). In April 2008, the staff issued a letter identifying open issues and confirmatory items to be addressed by SFC as part of the final stage of the review (NRC, 2008). SFC responded in July 2, 2009 (SFC, 2009) and July 31, 2009 (SFC, 2009). By letter dated August 18, 2010, SFC submitted a June 14, 2010 revision of the CAP that encompasses all of these supplements into a single document.

SFC's CAP specifies the use of interceptor trenches and recovery wells placed in hydrologically strategic positions to intercept groundwater contamination remaining onsite. The CAP does not draw back any contamination that has passed the extraction points. Consequently, the CAP allows small pollutant loads (defined as pollutant concentration x volumetric flow) to enter the surface water system. However, NRC staff determined that the pollutant loads to surface water pose little threat to human health and safety and the environment. This Safety Evaluation Report (SER) documents the NRC staff's technical review of the CAP to determine its compliance with 10 CFR Part 40, Appendix A.

1.2 REVIEW METHOD

The staff reviewed the CAP and supporting documents using Section 4.0 of the "Standard Review Plan for the Review of a Reclamation Plan for Mill Tailings Sites Under Title II of the Uranium Mill Tailings Radiation Control Act of 1978" (NUREG-1620, Rev. 1). The staff's review process included evaluating the site hydrogeology particularly with respect to the locations and types of groundwater restoration structures. Effectiveness of the proposed actions was then evaluated by reviewing flow and transport models, as wells as actual volume and concentration data from the current structures. Finally, the staff reviewed groundwater flow and contaminant transport models to evaluate the long-term groundwater contaminant concentrations and pollutant loads during and after corrective actions are completed.

1.3 LICENSE CONDITIONS

SFC conducted uranium conversion and other operations at the site pursuant to NRC Source Material License SUB-1010. License conditions related to this review include:

47. Deleted by Amendment 34 to remove requirement to submit a groundwater corrective action plan.

53. The licensee is authorized to implement the June 14, 2010 Groundwater Corrective Action Plan as described in its submittal dated, and August 18, 2010.

2.0 BACKGROUND

2.1 SITE DESCRIPTION AND HISTORY

The applicable site is located in Sequoyah County in mid-eastern Oklahoma near the town of Gore (Figure 1). The site occupies approximately 243 hectares (ha) (600 acres (ac)), and it consists of a 34.5 ha (85 ac) Process Area where SFC conducted most of its uranium processing operations, an adjoining 46.5 ha (115 ac) for managing storm water and storing byproduct materials, and approximately 162 ha (400 ac) of additional lands that are either forest lands, cattle pasture, or forage lands. The Process Area and the additional 46.5 ha (115 ac) are jointly referred to as the Industrial Area. Figure 2 presents the site layout. The site is bounded on the north by private property and Salt Branch, on the east by State Highway 10, on the south by Interstate 40, and on the west by floodplains owned by the U.S. Army Corps of Engineers (USACE) adjacent to the Illinois and Arkansas rivers.

SFC conducted uranium conversion and other operations from 1970 to 1993 in different areas of the site, pursuant to NRC Source Material License SUB-1010. Such operations included the following:

- recovery of uranium by concentration and purification processes
- conversion of concentrated and purified uranium into uranium hexafluoride (UF_6) between the years of 1970 and 1993
- reduction of UF_6 into uranium tetrafluoride (UF_4) from 1987 until 1993
- electrolytic production of fluorine from hydrofluoric acid
- treatment and storage of liquid waste streams
- land-treatment program utilizing waste ammonium nitrate solution as fertilizer on SFC property
- bulk storage of chemicals

In August 1990, SFC notified NRC staff that uranium was discovered in soils during the excavation of underground storage tanks within the Industrial Area. NRC staff initiated an investigation and SFC began an initial characterization of the area surrounding the contaminated soils. In late 1990, SFC expanded the characterization investigation to include the Main Process Building (MPB) and began to develop a comprehensive Facility Environmental Investigation (FEI) plan. This plan included an extensive soil sampling and groundwater sampling program. Details of the investigation, its findings, and corrective action taken as a result of the findings are reported in the SFC Facility Environmental Investigation Findings Report (Roberts/Schornick & Associates (RSA), 1990).

In February 1993, SFC notified the NRC staff of its intent to discontinue production and submitted a preliminary plan for completion of decommissioning (PPCD). In August 1993, SFC signed a Resource Conservation and Recovery Act (RCRA) Section 3008 (h) Administrative Order on Consent (AOC) with the U.S. Environmental Protection Agency (EPA). As a result, SFC was required to conduct a RCRA Facility Investigation (RFI) to establish the amount and location of hazardous wastes and constituents located onsite and released to the environment and to gather information necessary for the Corrective Measures Study (CMS). The RFI includes detailed information on site description and history, local geology and hydrogeology, monitoring activities, extent and concentration of site contamination, and the effects of contamination on the surrounding area and its inhabitants. The CMS described and evaluated corrective measures alternatives for the site (SFC, 1997).

In December 1998, SFC completed a Site Characterization Report (SCR) (SFC, 1998). Site characterization activities were designed to identify the source(s) of radiological contamination, establish the level of contamination in the environment where releases had occurred, and finalize environmental setting characterization to support a decommissioning plan. Additional site characterization provided information that updated the decommissioning alternatives. These alternatives, including environmental remediation and a conceptual design of a disposal cell, were presented in the Final Decommissioning Alternatives Study Report (SFC, 1998).

By February 2001, SFC determined that the site hydrogeologic model was inadequate and reevaluated the conceptual model to assess its deficiencies. SFC's characterization, which occurred in May 2001, included hydrogeologic, geochemical, and geophysical investigations. Data obtained and analyses performed in this study supported the development of a groundwater flow and transport model that was used to assess the impact of key constituents on the environment, both in the present and in the future. Findings for this site characterization were submitted by SFC in the Hydrogeological and Geochemical Site Characterization Report (SMI, 2001).

After releasing this report, several issues requiring further study were identified. As a result, SFC collected additional data in February 2002, and in October 2002, SFC submitted the revised Hydrogeological and Geochemical Site Characterization Report (HGSCR) (MFG, 2003b). The additional site characterization and modifications to the disposal cell construction design and strategy has resulted in a preliminary design report for the disposal cell, after which SFC submitted the reclamation plan and CAP as discussed in Section 1.0.

2.2 PURPOSE OF GROUNDWATER CAP

The groundwater CAP is intended to reduce the concentration of hazardous constituents in the groundwater onsite to levels at or below the groundwater protection standards (GPSs) specified in SFC's license. This reduction of contaminant concentrations will also result in the protection of offsite receptors from groundwater contamination that might migrate offsite. Table 1 presents the current GPSs.

Table 1: Groundwater Protection Standards

Parameters	Standards	Basis for Standard
Antimony (mg/L)	0.006	ACL[1]
Arsenic (mg/L)	0.01	MCL[2]
Barium (mg/L)	1.0	ACL
Beryllium (mg/L)	0.004	ACL
Cadmium (mg/L)	0.01	MCL
Chromium (mg/L)	0.05	MCL
Fluoride (mg/L)	4.0	ACL
Lead (mg/L)	0.05	ACL
Mercury (mg/L)	0.002	MCL
Molybdenum (mg/L)	0.0012	BACKGROUND[3]
Nickel (mg/L)	0.023	BACKGROUND
Nitrate (mg/L)	10	MCL
Radium-226 and -228 (pCi/L)	5.0	MCL
Selenium (mg/L)	0.01	ACL
Silver (mg/L)	0.05	MCL
Thallium (mg/L)	0.005	BACKGROUND
Thorium-230 (pCi/L)	1.2	BACKGROUND
Uranium (mg/L)	0.03	ACL

(NRC, 2005b)
[1.] ACL = Alternate Concentration Limit; [2.] MCL = Maximum Contaminant Level (EPA Drinking Water Standard); [3.] BACKGROUND = Agency approved background value

SFC intends to accomplish groundwater restoration through the source reduction as part of the surface reclamation and the use of groundwater extraction and treatment facilities. These facilities would be installed at strategic locations along areas hydraulically downgradient of contaminated portions of the site. This strategy will minimize pollutant loading to the Illinois River which receives groundwater from the site.

3.0 *ENVIRONMENTAL SETTING*

3.1 TOPOGRAPHY AND GEOLOGY

The site occupies gently rolling to level land with steep downward slopes on the northwest boundary and woodlands to the north and south. Elevations across the site range from 140 meters (m) (460 feet (ft)) above mean sea level (msl) near the Robert S. Kerr Reservoir (Arkansas and Illinois Rivers) to approximately 174 m (570 ft) msl within the eastern portion of the Process Area. Slopes over most of the uplands are less than 7 percent; steeper slopes of approximately 28 percent exist in the creek ravines and hillsides surrounding the Industrial Area. Slopes between the Process Area and the Kerr Reservoir are very steep, approximately 40 percent (Figure 3).

The uppermost bedrock at this site is the Pennsylvania Period (290 to 330 million years (MY) old) Atoka Formation, which is a series of alternating shale and sandstone units. Shale units are water-bearing and are more amenable to transporting groundwater; the sandstone units are more highly-cemented and impermeable forming aquicludes (Figure 4). In certain areas, however, the upper sandstone units are water bearing.

The Atoka Formation is overlain by Quaternary Period (present to 2 MY old) sediments (USGS, 1996). In the upland areas (primarily within the Industrial Area), Quaternary sediments consists of terrace sands, silts, and clays. Extending outward from this area, Quaternary colluvium sediments, (reworked terrace and Atoka Formation materials) occur on the steeper slopes. Alluvial sands, silts, and clays have been deposited upon the colluvium and Atoka Formation adjacent to the Arkansas and Illinois rivers. Within the Process Area, fill materials were added during the development of the uranium processing facilities. These fill materials are frequently preferential pathways for groundwater flow.

Terrace and colluvium deposits and upper units of shale and sandstone have been variably eroded. For example, Unit 1 Shale, Unit 1 Sandstone, Unit 2 Shale, Unit 2 Sandstone, Unit 3 Shale, and Unit 3 Sandstone are relatively thin and are not laterally extensive across the site. Unit 1 Shale, where present, is approximately 1.8 m (6 ft) thick, except, near the Emergency Pond and the Yellowcake Storage Pad where this unit is greater than 3 m (10 ft) (MFG, 2003b). Bedrock units from Unit 1 Sandstone downward through Unit 3 Sandstone, where present, are usually less than 0.9 m (3 ft) thick. Also, Unit 3 Shale frequently pinches out entirely, and the other upper units commonly thin to less than 0.3 m (1 ft) thick. Deeper bedrock units (Unit 4 Shale, Unit 4 Sandstone, and Unit 5 Shale) are laterally extensive across the site and frequently have thicknesses greater than 3 m (10 ft). The licensee has a thorough discussion of these deposits and units in Section 6.2 of its HGSCR (MFG, 2003b).

Soils have been developed upon most of the aforementioned geologic materials. The soils present at the site are predominantly loams and silty loams. Soil thickness ranges from zero to approximately 1.8 m (6 ft).

3.2 SURFACE WATER

The Illinois River is to the north and west of the site, while the Arkansas River is west and south of the site. The Arkansas River flows into the Robert S. Kerr Reservoir, which is formed by the Robert S. Kerr Dam and Lock on the Arkansas River downstream of the site. According to the Federal Emergency Management Agency (FEMA, 2001) floodplain maps, the site is outside the 100-year floodplain of the Arkansas and Illinois rivers; however, the 100-year floodplain extends up two tributaries to the SFC site boundary (FEMA, 2001) (Figure 5). The 100-year floodplain elevation is approximately 146 m (480 ft) msl.

Several small intermittent streams flow outward from the Industrial Area and eventually into the Illinois River. Streams 007, 005, 004, and 008 flow northwest to westward from the Process Area to the Illinois River. Streams 001 and 009 flow southward into the Storm Water Reservoir and then northwest into the Illinois River. Creek A flows northwest from south of the Fertilizer Pond Area into the Illinois River (Figure 6). East of the site, the Salt Branch flows northwest into the Illinois River and it forms the northeast boundary of the site. A small northeast flowing stream located east of Highway 10 flows into Salt Branch after paralleling the Carlile School Fault.

SFC has not measured the flow of these small intermittent streams. It has, however, estimated the stream flow for Streams 001, 004, 005, and 007 using an empirical equation, $Q_u = A_d\,0.89$ cfs/mile^2 (Table 2). Q_u is the mean annual stream flow (cfs), and A_d is the drainage area (mile^2). This formula is used to calculate annual stream flow using the drainage area and was developed by SFC (MFG, 2003b).

Table 2: Stream Flow Calculations

Stream	Drainage Area (mi^2)	Calculated Flow (cfs)
001	0.063	0.056
004	0.019	0.017
005	0.031	0.027
007	0.069	0.061

The licensee has also observed three seeps and pools. These are the Stream 007 pool, the Stream 005 seep and pool, and the Stream 008 seep and pool. Seeps and pools developed on top of the more impermeable sandstone units at a shale interface and represent horizontal flow preferential groundwater flow pathways from the site to the Illinois River.

SFC performed a search of surface water users within 2 miles of the site. According to information provided by the Oklahoma Water Resources Board (OWRB), there are two permitted stream water diversions within 2 miles downstream of the Facility. Both are used for irrigation purposes. Figure 7 is a map showing the location of the two permitted stream diversions.

3.3 HYDROGEOLOGY

3.3.1 REGIONAL HYDROGEOLOGY

Groundwater near the site is most abundant in the alluvium along the Arkansas and Illinois rivers and some terrace deposits along the Arkansas River. The only major bedrock aquifer near the site occurs approximately 10 miles to the northeast in the Mississippian age (330 to 360 MY old) Keokuk and Reed Springs formations. This hydrogeologic unit is considered to be moderately favorable for groundwater supplies, yielding as much as 20 gpm, locally more (MFG, 2003b).

Groundwater near the site flows radially away from the potentiometric high that corresponds to the topographic high in the pastureland east of Highway 10. Subsurface flow discharges to the surface waters that surround the watershed including Robert S. Kerr Reservoir to the west, Salt Branch to the north, and the Salt Branch tributary that parallels the Carlisle School Fault to the east (Figure 8).

3.3.2 SITE HYDROGEOLOGY

Underlying the site, groundwater flows radially northwest to southwest from a topographic high in the Industrial Area (Figure 9). Groundwater flow primarily occurs through the fissile shale units. The transmissivity of the shale units is highly heterogeneous due to large variations in unit thickness and hydraulic conductivity. In some locations higher conductivities could occur due to dissolution of carbonate compounds by acidic water originating from the Processing Area. Slug testing results indicate that the hydraulic conductivity varies from two to three orders of magnitude in individual shale units (Table 3).

Table 3: Mean, Minimum, and Maximum Hydraulic Conductivities

Unit	Mean Conductivity (ft/day/cms)	Maximum Conductivity (ft/day/cms*)	Minimum Conductivity (ft/day/cms)
Alluvium/Colluvium	8.30/0.003	19.9/0.007	0.02/7.1E-6
Terrace/Shale 1	0.05/1.8E-5	0.26/9.0E-5	0.004/1.4E-6
Shale 2	0.45/1.6E-4	1.35/5E-5	0.03/1.1E-5
Shale 3	0.17/1.1E-4	0.49/1.7E-4	0.01/3.5E-6
Shale 4	0.57/2.0E-4	1.88/6.6E-4	0.004/1.4E-6

(MFG, 2003b)
*centimeters per second

Groundwater in the shale units discharges laterally to streams that flow to the Robert S. Kerr Reservoir, hillside colluvium, and/or to Arkansas/Illinois River alluvium. Groundwater flow data indicates that Unit 5 Shale discharges directly to the Robert S. Kerr Reservoir adjacent to the northern portion of the site. Groundwater in the colluvium and alluvium also discharges to the Robert S. Kerr Reservoir and its tributaries.

The horizontal hydraulic gradient in the terrace/Unit 1 Shale in the MPB area is approximately 0.008. In the deeper shale units, the horizontal gradient ranges from 0.01 to 0.04 across the site. The horizontal hydraulic gradient in the alluvium ranges from 0.0059 to 0.0081.

Except where affected by acidic leaks and spills from the site processes, the sandstone units are highly cemented and transmit insignificant volumes of groundwater compared to the shale units. Hydraulic conductivity in the sandstones has only been assessed for the Unit 4 Sandstone, which exhibits a range from 7.9E-9 cms to 1.7E-8 cms (2.25E-5 ft/d to 4.75E-5 ft/day) (MFG, 2003b). At the site, sandstone conductivities are generally several orders of magnitude smaller than those observed in the shale units, and assuming unit continuity, would act as aquitards.

A downward vertical gradient, between 0.08 and 0.35, persists between all of the bedrock units over the majority of the site. The presence of such vertical gradients indicates a degree of hydraulic separation between the shale units. However, vertical flow could still occur either through the rock matrix or through boreholes and wells. Some vertical groundwater flow could occur through boreholes drilled in the late 1960's during site geotechnical exploration. SFC indicated that these boreholes, which number between 80 and 100, were not plugged. None of these boreholes penetrate the Unit 4 Sandstone. In its Reclamation Plan, SFC has committed to plugging these boreholes if they are encountered during reclamation activities.

Pathways for vertical groundwater flow also include monitoring wells that are screened across multiple shale units, thus penetrating the underlying aquitards. These features act as vertical conduits that hydraulically connect shale units that would be naturally isolated by the sandstone units. They are distributed over the entire site, excluding the Agland, but have the greatest density in the vicinity of the Process Area, Solid Waste Burial Areas, the Fertilizer Pond Area, and the Pond 2 area. Most wells will be plugged and abandoned during the reclamation phase. Only those wells used for compliance monitoring will remain operable. None of the wells that are screened across multiple shale units penetrate Unit 4 Sandstone.

3.4 WATER QUALITY

SFC only provided background groundwater quality data for the Unit 4 Shale because it is the uppermost aquifer of significant lateral extent, and it is the shallowest aquifer that could be used for drinking water. The background water quality of the Unit 4 Shale is poor to the extent that it would not reasonably be used for domestic purposes. Analytical results for Unit 4 Shale background water quality samples indicate a sulfate concentration of 1,750 mg/L and a total dissolved solids (TDS) concentration of 3,100 mg/L (Appendix K, MFG, 2003b). Groundwater with TDS concentrations between 3,000 and 5,000 mg/L is classified as Class III by the Oklahoma State Water Resources Board (Oklahoma Annotated Code (OAC) 35:45-1-4). Class III groundwater is of naturally poor quality.

Hazardous constituents at the site were identified during surface water, groundwater, and soil monitoring programs that have been ongoing since 1991. As of January 2003, the following constituents exceed the EPA National Drinking Water Standards (MCLs) in site groundwater: arsenic, fluoride, nitrate, and uranium. A comprehensive evaluation of the potential hazardous constituents in the source material was not performed; however, past dewatering studies for the raffinate sludge provided an opportunity to quantify hazardous constituents in the sludge. The following constituents exceed MCLs in a raffinate liquor sample: antimony, arsenic, cadmium, chromium, lead, nitrate, selenium, thallium, and uranium.

Of these constituents, the key mobile constituents that affect groundwater are arsenic, nitrate, and uranium, which are referred to in the application as constituents of concern (COCs). Antimony, cadmium, chromium, lead, selenium, and thallium have not impacted groundwater quality and are, therefore, not considered COCs. Fluoride concentrations only slightly exceed the MCL in very limited, small areas of shale units in the Industrial Area. All constituents that exceed MCLs in site groundwater or raffinate liquor, however, will be monitored as part of SFC's Groundwater Monitoring Program.

NRC staff reviewed uranium isoconcentration surface maps produced using data from October 2001 (SFC, 2005) and 2007 (SFC, 2008) to assess the migration of contaminants under the current conditions. A comparison of the October 2002 and 2007 uranium isoconcentration maps indicates that uranium concentrations have not spread appreciably in the Terrace/Shale 1, Shale 2, or Shale 3 systems. In 2001, most of the uranium contamination occurred in the Processing Area within 3 discrete areas. In 2007, uranium contamination still appears at those same 3 areas within the Processing Area. Regarding Shale 2, in 2002, uranium contamination occurred within 3 discrete areas of the Processing Area. However, in 2008, uranium contamination in Shale 2 only appears in one of the discrete areas indentified previously. This area was located in the northern portion of the site with slightly lower concentrations. Uranium contamination appears at the same locations within Shale 3 in both 2002 and 2008.

A comparison of the arsenic isoconcentration maps from October 2002 (SFC, 2005) and 2008 (SFC, 2008) indicate that arsenic contamination has spread substantially to the southern portion of the site. The 10,000 micrograms per liter (ug/L) concentrations of 2002 no longer appear in 2008. Arsenic concentrations in the northern Processing Area appear to higher in 2008 than in 2002.

A comparison of the nitrate isoconcentration maps from October 2002 (SFC, 2005) and 2008 (SFC, 2008) indicates that the nitrate plume in the southern portion of the site, within Shale 4, moved approximately 1,500 feet west and concentrations have decreased significantly. The 2008 data indicates that nitrate concentrations are close to the drinking water standard by the time contamination reaches the property boundary. In the northern portion of the site, within Shale 4, nitrate concentrations have decreased since 2002 and appear to exceed the drinking water standard slightly at the property boundary.

Regarding background surface water quality, SFC provided data for the Illinois and Arkansas rivers both upstream and downstream (SFC, 2005). This data is summarized in Table 4.

Table 4: Background COC Concentrations in Arkansas and Illinois Rivers

Mean Conc.	Illinois River Upstream	Illinois River Downstream	Arkansas River Upstream	Arkansas River Downstream
U (μg/L)	2.5	4.4	4.3	4.2
NO3 (mg/L)	1.19	1.13	1.05	1.01
As (mg/L)	ND	ND		

(SFC, 2005)

The data indicated that downstream uranium concentrations were higher on average than upstream concentrations in the Illinois River. A review of the data indicated that 13 of 79 downstream samples between 1991 and 2005 contained detectable concentrations of uranium, compared to 10 of 79 upstream samples for the same period. In the Illinois River, half of the downstream detections occurred between May 1991 and June of 1992, and one of these downstream samples contained uranium in concentrations exceeding the current GPS of 30 μg/L. Conversely, 8 of 10 upstream uranium detections occurred between 1995 and 2005 (MFG, 200b). From a review of this data, NRC determined that the site has not had any effect on surface water quality since 1992, and any pollutant loading that occurred prior to 1992 had little effect on surface water quality. According to the EPA Website (http://iaspub.epa.gov/tmdl_waters10/huc_rept.control?p_huc=11110104&p_huc_desc=Robert%20S.%20Kerr%20Reservoir) the Kerr Reservoir is an impaired waterbody. The EPA lists the cause of impairment as dissolved oxygen, pH, E. coli, Entrococcus bacteria, turbidity, total dissolved solids, and total phosphorus.

3.5 EVALUATION FINDINGS

NRC staff reviewed the site environmental setting information to determine whether sufficient site information existed to provide a basis for developing a corrective action strategy. Information that is particularly important to this evaluation is the geology, hydrogeology, and surface water. SFC provided detailed information regarding the geologic units underlying the facility, hydraulic properties, structural orientation and characteristics, surface water bodies near the facility, surface water characteristics, and water quality. Based on this review, NRC staff determined that SFC did sufficiently investigate the site and gathered the appropriate information to develop a corrective action strategy.

4.0 *GROUNDWATER CORRECTIVE ACTIONS*

4.1 CORRECTIVE ACTIVE STRATEGY

SFC's corrective action strategy includes the use of interceptor trenches and extraction wells to capture and remove contaminant mass from the subsurface. This strategy is designated as the hydraulic containment and pump back method in the Corrective Action Plan Report (MFG, 2003a). As stated in the Introduction, these corrective action structures are placed in strategic locations to take advantage of natural groundwater gradients, such as in ephemeral stream channels. Channels tend to draw groundwater in from surrounding areas, which is a desirable characteristic for corrective actions. SFC's strategy does not draw back contamination that has already passed the property boundary. NRC staff determined that this aspect of corrective action is not necessary because of technical infeasibility and practicality. Groundwater gradients would likely be too steep and the aquifer hydraulic conductivity would be too low to effectively draw back contamination. Also, any contamination that passes the property would migrate toward the Illinois River and dilute rendering the impact of the contaminant migration minimal.

4.1.1 CORRECTIVE ACTION PLAN FOR THE 005 DRAINAGE

The 005 Collection Trench was installed near the head of the 005 Drainage during July 2002. Figure 10 presents the location of the 005 Collection Trench and the adjacent 005 Monitor Trench. The trench was excavated in the same location as the investigation trench completed during the Supplemental Data Collection Trip activities of April 2002 (SMI, 2002). The 005 Collection Trench is deeper than the investigation trench, extends further to the south and was excavated in a straight line to facilitate installation of pond liner material. The 005 Collection Trench was excavated to the top of the Unit 3 Sandstone, 2.4 to 3 m (8 to 10 ft) below the surface. Figure 11 presents a profile of the 005 Collection Trench. The trench bottom, exposed sandstone surface, is 104 feet long.

4.1.2 CORRECTIVE ACTION PLAN FOR THE MW095A AREA

The MW095A Collection Trench was installed southwest of Pond 2 approximately 200 feet east of monitoring well MW095A in April 2003. Figure 12 shows the location of the MW095A Collection Trench, along with the MW095A Investigation Trenches. This collection was excavated along part of the investigation trench completed during the Monitoring Well MW095A Trench Investigation of November 2002. The MW095A Collection Trench trends approximately north to south perpendicular to Port Road and extends approximately 20 m (65 ft) north of the Port Road and approximately 73 m (240 ft) south of Port Road. The MW095A Collection Trench was excavated into the top of the Unit 4 Shale, approximately 7.6 m (25 ft) below the surface.

4.1.3 CORRECTIVE ACTION PLAN FOR THE MW010/SWALE AREA

Figure 13 presents the location of the MW0I0 Collection Trench. To control the southward migration of uranium impacted groundwater, the MW0I0 Collection Trench is located immediately north of the Decorative Pond. The trench was extended approximately 91.4 m (300 ft) westward from southwest of monitor well MW009A. The MW010 Collection Trench was excavated to the top of the Unit 1 Sandstone, approximately 2.4 m (8 ft) below the surface, and it was designed similarly to that of the MW005 Collection Trench. Groundwater from the Decorative Pond impacted the trench construction; however, a barrier trench was completed prior to the construction of the collection trench and concrete was placed into the trench down to the bedrock surface as the excavation advances. The collection trench was subsequently constructed adjacent to and north of the barrier trench. The hydraulic conductivity of the gravel fill material overlying the Unit 1 Sandstone is 0.03 centimeters per second (cms) (72.6 feet per second (fps)) (SMI, 2002).

4.1.4 CORRECTIVE ACTION PLAN FOR UTILITY TRENCH SYSTEM AND GRANULAR FILL AREAS

The objectives of the Utility Trench System corrective action plan is to remove groundwater from utility trench fill and granular backfill material in the Main Process Building Area by pumping, and then excavating fill material and impacted soils adjacent to the trenches. Excavated material will be placed within the proposed disposal cell. To remove groundwater from the trenches, pumping will occur in several stages. Initial pumping will occur in the French Drain northwest of the SX Building Vault, followed by pumping of TM wells adjacent to the SX Building. An assessment of the effectiveness of the initial pumping will provide the basis for additional pumping. After dewatering of the utility trenches and granular fill areas, fill material and soils adjacent to the trenches with natural uranium concentrations greater than 100 pCi/g will be excavated and placed within the disposal cell.

4.1.5 ADDITIONAL CORRECTIVE ACTIONS

SFC installed additional extraction wells in or near the Process Area between November 2005 and January 2006. Two wells were installed near the northwest corner of the Process Area and three wells were installed immediately north of the MW010 Collection Trench (Figure 13). SFC installed these wells to supplement collection trench recovery operations. SFC also plugged and abandoned 150 monitoring wells that were no longer needed for groundwater monitoring.

4.1.6 TREATMENT OF EXTRACTED GROUNDWATER

Figure 14 is a diagram of the water treatment plant. Recovered groundwater from various sources is transferred to the Receiving/Chem Treatment tank (vessel #1), which accumulates approximately 46,200 L (12,000 gal). The batch is then mixed, sampled and analyzed for uranium. If the uranium concentration is less than 250 µg/L, the batch is moved into the Treatment Feed Tank (vessel #3). If the uranium concentration is greater than 250 µg/L, phosphoric acid is added to convert the uranium to uranyl phosphate, a low solubility form of uranium. Then, sodium or potassium hydroxide is added to raise the pH to approximately 8 to promote precipitation and to prepare the water for subsequent ion exchange treatment. The treated water is then transferred to the Precipitate Settling Tank (vessel #2), where the solids will settle. Clarified wastewater will then be decanted to the Treatment Feed Tank where sodium carbonate will be added to convert the residual uranium to uranyl carbonate.

Wastewater from the treatment plant is pumped from the Treatment Feed Tank through a sand filter and a polishing filter, and then to the ion exchange columns (Columns C and D in series). Columns C and D will each contain approximately 50 cubic feet of resin. Treated effluent will then be routed into one of two Treated Water Receiving Tanks (vessels #4 and #5). Treated water will be sampled and analyzed for uranium and then either discharged through SFC's permitted outfall 001 (if nitrate (N) is less than 32 mg/L) or to Pond 5 for land application as a fertilizer. The cleanup goal for this system is to reduce the uranium concentration to less than 30 µg/L, the drinking water MCL.

When fully loaded with uranium, the ion exchange resin must be re-generated or replaced. The ion exchange resin is stripped and re-generated using sodium chloride or dilute hydrochloric acid and sodium hydroxide. Assuming an average feed uranium concentration of 250 µg/L, it is estimated that up to 100,000 bed volumes or 143,400,000 L (37,000,000 gal) of waste water can be processed before this would become necessary (MFG, 2003a).

The regeneration solutions and rinses are collected in one of the Treated Water Collection Tanks and re-cycled back to the Receiving/Chem Treatment Tank. SFC expects that the precipitation step would take out in excess of 95% of the uranium stripped from the ion exchange resin. Alternatively, the loaded resin may be shipped to a licensed uranium mill for uranium recovery. Uranium bearing sludge from the Precipitate Settling Tank will be periodically flushed out, dewatered using a small vacuum drum filter, and shipped offsite for uranium recovery and recycle. The sand filter and polishing filter will be backwashed as necessary to the Precipitate Settling Tank.

4.2 PREVIOUS CORRECTIVE ACTION PROGRAMS

In March 1984, SFC personnel discovered the presence of nitrates in concentrations up to 1,000 mg/L in seeps approximately 152 m (500 ft) south of Pond 2. Based on the location of the seeps and the magnitude of nitrate contamination in the area, two collection trenches and flow barrier slurry walls were constructed to intercept contaminated groundwater. All recovered groundwater was pumped back into Pond 2. In 1985, a French drain system was installed on the southern end of Pond 2. This system was designed with an automatic pumping system to constantly dewater the area.

The French drain system was constructed with a gravel-filled trench connected to a buried concrete tank installed approximately 1.2 m (4 ft) below ground level. Groundwater collected from the trench gravity flowed into the tank and was subsequently pumped back to Pond 2. Pumping was discontinued prior to 1990 after the area failed to yield enough water to pump. In 1991, liquids in the pond were removed and the pond sludges were removed to levels that exhibited uranium concentrations less than 2,000 pCi/g. A high-density polyethylene (HDPE) liner was then placed over the remaining sludges. In addition, a portion of the west pond embankment was breached to facilitate gravity drainage of rainwater. Intermittent pumping of the French drains was resumed during 1995 and automated pumping began in 1997.

4.3 POTENTIAL CORRECTIVE ACTION ALTERNATIVES

Potential corrective action alternatives (CAAs) were proposed during the Corrective Measures Study (SFC, 1997). Some CAAs were eliminated by SFC during the Corrective Measures Study, primarily because they are intended for the remediation of organics, and are not considered here. These include: bioreactors of recovered groundwater, airstripping of recovered groundwater, ultraviolet oxidation of recovered groundwater, nitrate enhancement, oxygen enhancement with air-sparging, oxygen enhancement with hydrogen peroxide, air sparging, free product recovery, hot water of steam flushing/stripping, and vacuum vapor extraction. Actions considered for further evaluation by SFC include:

- No Action
- Natural Attenuation
- Groundwater Recovery using Vertical Well Arrays
- Groundwater Recovery using Horizontal Well Arrays

- Groundwater Recovery using Containment Walls
- Slurry Walls
- Passive Treatment Walls
- Phytoremediation
- Co-Metabolic Processes

Natural Attenuation and Containment (Slurry) Walls were evaluated during the Corrective Measures Study (SFC, 1997). However, these alternatives were not reevaluated in the CAP because the nature of the current groundwater contamination is different now than in 1997. A comparison of six reevaluated remedial action alternatives is provided in Table 5.

TABLE 5 - SUMMARY OF CORRECTIVE ACTION ALTERNATIVESSEQUOYAH FUELS CORPORATION

ALTERNATIVE	PERFORMANCE	RELIABILITY	IMPLEMENTABILITY	SAFETY	OVERALL RATING[1]
NO-ACTION	This alternative would not be protective of human health or the environment and would not reduce contaminant loading to surface waters over the short or intermediate term.	No reliability assessment of this alternative can be made.	The no action alternative is technically feasible.	SFC states that there are no safety issues at present with this alternative. However, the no-action alternative allows contamination to enter the surface water system without reduction of the contaminant load.	This alternative is not rated.

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1 Overall Rating is a score that is the sum of the individual criteria scores. Higher numbers (>10) are considered the more feasible remedial actions.

ALTERNATIVE	PERFORMANCE	RELIABILITY	IMPLEMENTABILITY	SAFETY	OVERALL RATING[1]
GW REC. W/ VERTICAL WELLS	Through dewatering and impeding the downgradient advancement of impacted groundwater, combined with ex-situ treatment of recovered groundwater, this alternative will reduce contaminant loads to surface waters. Due to the very low hydraulic conductivity of the shale units and the proximity of contaminant plumes to exposure points, however, this method may not be able to capture all of the impacted groundwater flow in the Corrective Action Areas, without the use of a significantly greater number of wells along each well array. Due to the high hydraulic conductivity of the backfill materials associated with the utility trenches, dewatering within the Utility Trench System should occur fairly rapidly, probably within several months of initiation of pumping.	Submersible pumps will be required in each well as well as one or more ex-situ treatment plants. Proper maintenance of equipment should assure reliability of the system. Maintenance requirements for this alterative are similar to the groundwater recovery using horizontal wells alternative, but are higher than other alterative.	Installation of the pumping wells is highly feasible and has been successfully accomplished at the site for purposes of hydraulic testing. Any ex-situ technology used would be a highly feasible and demonstrated technology. Wells can be installed in any single array within a month or two. Wells can be placed to beneficial use by extracting groundwater as soon as they are completed and the pumps installed.	Installation of wells should not create undue hazard for the workers or the public. Practices employed by SFC during installing of monitoring well at the site have successfully prevented worker exposure to hazardous or radioactive material. Well cuttings can be easily handled and disposed of to prevent the spread of any hazardous materials from the job site. Treatment of recovered groundwater will result in an increase of risk of exposure for workers and for the potential of contaminated water spills.	No change in the overall technical rating of 10 provided by the Corrective Measures Study is warranted of the Groundwater Recovery using Vertical Wells alternative.

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1 Overall Rating is a score that is the sum of the individual criteria scores. Higher numbers (>10) are considered the more feasible remedial actions.

ALTERNATIVE	PERFORMANCE	RELIABILITY	IMPLEMENTABILITY	SAFETY	OVERALL RATING[1]
GW REC. W/ HORIZONTAL WELLS	Through dewatering and impeding the downgradient advancement of impacted groundwater, combined with ex-situ treatment of recovered groundwater, this alternative will reduce contaminant loads to surface waters from groundwater in Shale units. Because the horizontal transmissivity within unconsolidated surface aquifer material is much higher than the transmissivity within the Shale units, impacted groundwater flow in aquifer material overlying bedrock will not be effectively recovered by pumping from horizontal wells located within Shale units, increasing the likelihood of unacceptable loading to surface water. Because of the high hydraulic conductivity of the backfill materials associated with the utility trenches, dewatering of within the Utility Trench System should occur fairly rapidly, probably within several months of initiation of pumping.	A number of submersible pumps will be required in each well as well as one or more ex-situ treatment plants. Proper maintenance of equipment should assure reliability of the system. Maintenance requirements for this alterative are similar to the groundwater recovery using horizontal wells alterative, but are higher than other alternatives.	Installation of the horizontal wells requires special equipment and skills beyond that required for vertical well installation. Installation time of two or three wells at any single Corrective Action Area is likely to require several months. Wells can be placed to beneficial use by extracting groundwater as soon as they are completed and the pumps installed. Any ex-situ technology used would be a highly feasible and demonstrated technology.	Installation of wells should not create undue hazard for the workers or the public. Practices employed by SFC during installation of monitoring wells at the site have successfully prevented worker exposure to hazardous or radioactive material. Well cuttings can be easily handled and disposed of to prevent the spread of any hazardous materials from the job site. Treatment of recovered groundwater will result in an increase of risk of exposure for workers and for the potential of contaminated water spills.	Due to the ineffectiveness of wells constructed within bedrock units to contain groundwater flow through unconsolidated surface material, the effectiveness of this alternative is less than that suggested during the Corrective Measures Study (SFC, 1997b). Therefore, a change in the overall technical rating of 8 provided by the Corrective Measures Study to 7 is warranted. This evaluation is applicable to implementation of this CAA at any of the Corrective Action Areas.

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[1] Overall Rating is a score that is the sum of the individual criteria scores. Higher numbers (>10) are considered the more feasible remedial actions.

ALTERNATIVE	PERFORMANCE	RELIABILITY	IMPLEMENTABILITY	SAFETY	OVERALL RATING[1]
GW REC W/ CONT. WALLS	The interceptor trench is expected to effectively prevent any further downgradient movement of COC impacted groundwater provided the pumping system remains in operation. Ex-situ water treatment of recovered groundwater should effectively reduce COC concentrations to appropriate land application standards.	Once constructed, an interceptor trench is expected to last indefinitely. The gravel drainage zone and the overlying fill material would not be expected to deteriorate with time, other than some limited surface erosion which can easily be repaired. There is no reasonable mechanism identified that would result in plugging of the gravel bed in the proposed configuration. Riser pipes and submersible pumps are used extensively for recovering impacted groundwater. Maintenance requirements for this alternative are similar to other groundwater recovery methods.	Excavation of a trench and installation of the groundwater collection system is easily accomplished within one month. No significant amount of overburden needed to be excavated, nor was any excavation of sandstone required for the 005 Drainage and MW095A Collection Trench, and no excavation of significant amount of overburden sandstone is expected for the MWO10/Swale Collection Trench. Recovered groundwater from the Collection Trenches is pumped to storage for eventual treatment at the water treatment plant. Recovered groundwater will be treated to land application standards. Treated water will then be pumped to Pond 5 for application as fertilizer. Details of water treatment site, water treatment method, and the process for treatment and application, are discussed in detail in Appendix A.	Installation of the interceptor trench should not create any undue hazard for the workers of the public. Practices employed by SFC during installation of trench systems have successfully prevented worker exposure to hazardous or radioactive material in the past. Excavated material can be easily handled and disposed of to prevent the spread of any hazardous material from the job site. Normal industrial safety precautions would be used during construction to minimize the construction risk.	An overall technical rating of 10 was presented by the Corrective Measures Study this alternative (performance, reliability, implementability, and safety ratings of 2, 3, 2, and 3, respectively). However, performance and implementability were reassessed in MFG, 2003a. This alternative was, therefore, given a rating of 12.

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1 Overall Rating is a score that is the sum of the individual criteria scores. Higher numbers (>10) are considered the more feasible remedial actions.

ALTERNATIVE	PERFORMANCE	RELIABILITY	IMPLEMENTABILITY	SAFETY	OVERALL RATING[1]
PASSIVE WALLS	The interceptor trench is expected to effectively prevent any further downgradient movement of COC impacted groundwater as long as the adsorbent material remains effective. In-situ water treatment of groundwater should effectively reduce COC concentrations to appropriate standards.	Once constructed, the interceptor trench is expected to last indefinitely. The gravel drainage zone and the overlying fill material would not be expected to deteriorate with time, other than some limited surface erosion which can easily be repaired. There is no reasonable mechanism identified that would result in plugging of the gravel bed in the proposed configuration. Adsorbent bed life may be limited requiring replacement; especially in passive treatment systems installed in the 005 Drainage and the MWO1O/Swale area, increasing the maintenance requirements for this alterative compared to other groundwater recovery methods.	Excavation of a trench and installation of the groundwater collection system could be easily accomplished within one month. No significant amount of overburden would need to be excavated, nor would any excavation of sandstone be required at any of three Corrective Action Areas. Upon completion of the collection system, remediation of recovered groundwater will begin immediately.	Installation of the interceptor trench should not create any undue hazard for the workers of the public. Practices employed by SFC during installation of trench systems have successfully prevented worker exposure to hazardous or radioactive material in the past. Excavated material can be easily handled and disposed of to prevent the spread of any hazardous material from the job site. Normal industrial safety precautions would be used during construction to minimize the construction risk.	No change in the overall technical rating of 8 provided by the Corrective Measures Study is warranted or the Passive Treatment Walls alterative. This evaluation is applicable to implementation of this CAA at any of the Corrective Action Areas except the Utility Trench System.

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1 Overall Rating is a score that is the sum of the individual criteria scores. Higher numbers (>10) are considered the more feasible remedial actions.

ALTERNATIVE	PERFORMANCE	RELIABILITY	IMPLEMENTABILITY	SAFETY	OVERALL RATING[1]
PHYTOREMEDIATION	Phytoremediation is expected to be effective in reducing COC concentrations in groundwater as it exits the bedrock or where root systems can penetrate, i.e., shallow soils. Therefore, because of the time required for COC impacted groundwater to exit the bedrock aquifer, groundwater use restrictions would be required. The useful life of this CAA is dependent on the life span of the selected vegetation and whether or not periodic harvesting and disposal is required.	This CAA is very simple to implement (planting trees) and little or no maintenance would be required until such time as the vegetation might need to be harvested, disposed of, and the area replanted.	Implementation of this CAA would be easy and quick and beneficial results would begin occurring once the vegetation begins to establish a root system in the underlying soil.	Hazards during implementation are essentially nonexistent. If harvesting is required, the concentrations of COCs are not expected to pose a hazard to workers or the environment.	No change in the overall technical rating of 9 provided by the Corrective Measures Study is warranted for the Phytoremediation alternative. This evaluation is applicable to implementation of this CAA at any of the Corrective Action Areas except the Utility Trench System.
CO-METABOLIC	Limited lab scale testing of bioremediation indicates that bioremediation processes are effective in reducing arsenic and uranium in groundwater. Extensive lab scale testing would be required to determine the effectiveness of any bioremediation process given the site-specific conditions.	Introduction of the nutrients and inoculation of the groundwater with the appropriate species are straightforward steps utilizing existing wells, portable tanks and pumps. Once completed, extended groundwater monitoring would be required to confirm that the process is working.	This alterative is easily implemented, as indicated above. There is a possibility that additional nutrient injection points would be required, however, installation of additional wells can be completed very quickly. Based on lab testing, results near the wells should be realized within a few weeks of injection. The remedial results at distances further away from the wells will depend on how fast the nutrients and the bacteria migrate through the bedrock groundwater.	The nutrients and bacteria proposed for this alternative can be safely handled without exposure to workers. There is little or no chance for added risks to the public or the environment.	No change in the overall technical rating of 10 provided by the Corrective Measures Study is warranted for the Co-Metabolic Process alternative for implementation.

[1] Overall Rating is a score that is the sum of the individual criteria scores. Higher numbers (>10) are considered the more feasible remedial actions.

Groundwater Recovery using Containment Walls (Hydraulic Containment and Pump Back) is the proposed alternative and is discussed in Section 4.1. Descriptions of the remaining alternatives are provided below. Groundwater recovered by the groundwater recovery methods listed above is treated using an ex-situ treatment plant to meet applicable standards. Details of the ex-situ treatment method are provided in Section 4.1.5 and Appendix A of the CAP report (MFG, 2003a).

4.3.1 NO-ACTION

The no-action alternative would not provide any measures to mitigate groundwater loading to site and adjacent surface waters. This alternative requires no groundwater remediation or the establishment of groundwater restrictions or institutional controls. Concentrations of COCs above GPSs would persist into the future regardless of decommissioning activities, including construction of a disposal cell, in the Process Area. Information presented in the HGSCR indicated that uranium would be present onsite in concentrations above the GPS after 500 years (MFG, 2003b). Therefore, SFC rejected this alternative because it does not protect human health and the environment.

4.3.2 GROUNDWATER RECOVERY USING VERTICAL WELLS

In this alternative, COC impacted water would be recovered by pumping from a series of vertical wells located along the leading edge of the plume and/or through the center of the plume in the areas of highest COC concentration. Within the Process Area, groundwater would be pumped from Utility Trench fill material. Recovered groundwater would be piped to a collection area for ex-situ treatment.

The vertical well configuration involves the installation of wells at approximately 30.5-m (100-ft) intervals, along with associated pumps, collection tanks, and controls. Because the shale units underlying the site exhibit limited yield, pumping would slowly drawdown the saturated zones and reduce arsenic or uranium concentrations. The main effect of this alternative, however, would be to impede downgradient contaminant migration, allowing both dewatering and natural attenuation to reduce COC concentrations. Ex-situ treatment would further reduce contaminant concentrations.

This alternative was not selected because pumping from low hydraulic conductivity shales would not significantly reduce the time required to complete the remedial action. Pumping from low conductivity formations also places great strains on pumps resulting in more frequent repairs or replacements. Thus, the added cost of remediation would not provide commensurate results. However, this method was deemed most suitable for corrective actions in the Utility Trench System and is being utilized, as such, because the hydraulic conductivity of the trench fill is significantly higher than that of the shales.

4.3.3 GROUNDWATER RECOVERY USING HORIZONTAL WELLS

This alternative involves the installation of horizontal wells along the leading edge of the contaminant plume and one horizontal well through the center of the plume with the highest COC concentration, along with associated pumps, collection tanks, and controls. Because the shale units underlying the site have limited yield, pumping will slowly drawdown the saturated zones and reduce arsenic or uranium concentrations. Similar to the vertical well alternative, the main effect of this alternative would be to impede the downgradient advancement of the plume, allowing both dewatering and natural attenuation to reduce COC concentrations. Ex-situ treatment alternatives would further reduce contaminant concentrations. This alternative was rejected because use of hydraulic wells might not capture all the contaminated groundwater prior to reaching surface discharge points, because of the difficulty in placing wells in each saturated shale unit.

4.3.4 PASSIVE TREATMENT WALLS

This alternative involves the installation of a passive containment and treatment system. An interceptor trench containing a bed of adsorbent material is installed downgradient of contaminant plume, creating a permeable reaction barrier across the flow path of a contaminant plume, allowing the water portion of the plume to passively move through the wall. These barriers allow the passage of water while prohibiting the movement of contaminants by utilizing such agents as zero-valent metals, chelators (ligands, or molecular complexes, selected for their specificity for a given metal), sorbents, microbes, and others.

The contaminants will either be degraded or retained in a concentrated form by the barrier material. The wall could provide permanent containment for relatively benign residues or provide a decreased volume of the more toxic contaminants for subsequent treatment. Modifications to the basic passive treatment walls may involve a funnel-and-gate system or an iron treatment wall. The funnel-and-gate system for *in-situ* treatment of contaminant plumes consists of low hydraulic conductivity cutoff walls (the funnel) with a gate that contains a zone of reactive medium. Groundwater primarily flows through high conductivity gaps (the gates). The types of cutoff walls most likely to be used in the current practice are slurry walls or sheet piles. Innovative methods such as deep soil mixing and jet grouting are also being considered for funnel walls. SFC rejected this alternative because passive treatment walls may lose effectiveness or permeability requiring expensive maintenance in the future.

4.3.5 PHYTOREMEDIATION

Phytoremediation is a process that uses plants to remove, transfer, stabilize, and destroy contaminants in soil and sediment. The mechanisms of phytoremediation include enhanced rhizosphere biodegradation, phyto-extraction (also called phyto-accumulation), phytodegradation, and phyto-stabilization. Selected species of vegetation that have the ability to assimilate arsenic would be planted in the area southwest of Pond 2. Selected species of vegetation that have the ability to assimilate uranium would be planted in the 005 Drainage and MW010/Shale areas. Because the fill material in the Utility Trench System would probably not be able to support a healthy growth of vegetation, the Phytoremediation alternative would not be a feasible corrective action method for remediation of the Utility Trench System. Nitrates present in groundwater are expected to stimulate growth of these plants. Long term monitoring of surface water and near-surface groundwater below the elevation of planted vegetation would be required in order to verify effectiveness. In addition, periodic analysis of the vegetation would be required to determine if the levels of bio-accumulation would require that the plants be harvested and appropriately disposed. Phytoremediation was rejected as an alternative because groundwater contamination would be too deep to be affected by plant root zones. Also, in some instances, soil quality is too poor to promote plant growth. Although nitrates in the shallow groundwater could stimulate growth despite poor soil conditions, plant health would still diminish due to poor soil. Thus, it has limited use on the site.

4.3.6 CO-METABOLIC PROCESS

Co-Metabolic Process, or enhanced bioremediation, is a process by which indigenous or inoculated micro-organisms (e.g., fungi, bacteria, and other microbes) degrade (metabolize) contaminants found in soil and/or groundwater, converting them to innocuous end products. Nutrients, oxygen, or other amendments may be used to enhance bioremediation and contaminant desorption from subsurface materials. While it cannot degrade inorganic contaminants, bioremediation can be used to change the valence state of inorganics and cause adsorption, immobilization onto soil particulates, precipitation, uptake, accumulation, and concentration of inorganics in micro or macroorganisms. These techniques, while still largely experimental, show considerable promise of stabilizing or removing inorganics from soil. Nutrients and carbon substrate would be injected into the groundwater to facilitate remediation processes. The injection wells at each Corrective Action Area would have an arrangement similar to the pattern and number described for the Groundwater Recovery using Vertical Wells method. SFC rejected this alternative because of uncertainties associated with the effectiveness of this technology to remediate inorganics. Furthermore, bioremediation can also be problematic due to issues with delivering microbes and nutrients to contaminated portions of the groundwater.

4.3.7 EFFECTIVENESS OF SELECTED CORRECTIVE ACTIONS

4.3.7.1 HYDRAULIC EFFECTIVENESS

To assess the effectiveness of the current corrective actions, NRC staff reviewed information regarding the ability of the remediation structures to capture groundwater within a sufficient area to minimize the pollutant loads to downgradient aquifers and surface water. Capture zone data was provided by SFC in the form of particle tracking analyses from its groundwater flow model (SFC, 2005). Particle tracking traces, in a computer model, particles of groundwater from one location to another and is used to assess flow paths and capture zones for groundwater extraction structures (i.e., wells and trenches). Attachment CAP2B in the December 2005 response to NRC staff's RAI (SFC, 2005) presents capture zones for all wells and trenches based on SFC's particle tracking data.

A review of these figures indicates that SFC placed groundwater recovery trenches and wells at strategic locations to take advantage of natural groundwater flow patterns. However, the spacing between trenches MW-95 and 005 is approximately 305 m (1000 ft); therefore, some contamination could pass between the trenches and subsequently migrate offsite. Furthermore, no remediation, except for surface reclamation, is being performed or proposed in the southern portion of the site near the fertilizer ponds. However, mixing calculations performed by SFC and supported by groundwater monitoring data indicate that the net result will be an estimated 0.004 mg/L increase in nitrate concentrations (SFC, 2009). This is 3 orders of magnitude less than the current nitrate concentrations in the Arkansas and Illinois Rivers. Therefore, the affect of this increased load on the Arkansas and Illinois Rivers is negligible considering that these waterways are currently impaired due to activities unrelated to the SFC facility. Furthermore, neither arsenic nor uranium is very mobile in the subsurface and surface reclamation will remove most of the source. Therefore, contaminant concentrations at the site boundaries are expected to reduce overtime with a negligible effect on offsite receptors.

During inspections at the site by NRC staff, the staff observed that current series of trenches appear to be dewatering the saturated zones underlying the site. The staff observed that the trenches contained only minor amounts of water or were dry. Dewatering the saturated zones is an important mechanism in controlling contamination migration, because without water, migration will not occur.

4.3.7.2 CONTAMINANT REMOVAL

In addition to hydraulic effectiveness, remediation structures must be capable of actually removing contaminant mass. SFC has measured mass removal during the operation of the remediation structures by measuring the volume of water removed and analyzing samples to obtain the contaminant concentrations in extracted water. According to its records, SFC has removed 9.1 kg (20 lbs) of uranium, 2,566 kg (5,645 lbs) of nitrate, and 0.14 kg (0.3 lbs) of arsenic between January 2004 and September 2005 (SFC, 2005). SFC estimated the initial contaminant mass for each of the contaminants as 64 kg (141 lbs) of arsenic, 227,314 kg (500,090 lbs) of nitrate, and 48 kg (106 lbs) of uranium (SFC, 2009).

4.4 EVALUATION FINDINGS

NRC staff reviewed SFC's process for selecting the corrective actions and studied the performance of the selected corrective actions to determine if they are sufficient to restore groundwater quality to the GPSs, without adversely impacting the environment. NRC staff determined that the current corrective actions are sufficient to address uranium, arsenic and nitrate contamination. While some trace quantities of uranium, arsenic, and nitrate might migrate offsite into the Illinois River, current monitoring data indicate that the concentrations will not likely exceed the GPSs and will be quickly diluted due to the significant difference between groundwater and surface water flow.

<u>5.0 *GROUNDWATER MODELING*</u>

The purpose of the groundwater modeling effort was to predict the effectiveness of the remedial actions in restoring groundwater quality onsite and protecting offsite receptors. NRC staff first reviewed the construction and calibration of the model, then compared short-term predictions to the most recent groundwater monitoring data. This comparison provided the staff insight into the effectiveness of the remedial actions and the accuracy of model predictions.

SFC's groundwater modeling effort consisted of developing and calibrating groundwater flow and contaminant transport models for uranium, nitrate, and arsenic (COCs). After calibrating these models, SFC used them to predict future groundwater flow and COC groundwater concentrations for a 1,000-year time period. Details on model development, calibration, and predictive analysis, are discussed in the following sections.

5.1 GROUNDWATER FLOW MODEL

5.1.1 MODEL DEVELOPMENT

For the purpose of model development, SFC developed a hydrostratigraphic (geologic) model containing 10 geologic layers from the surface Quaternary deposits stratigraphically down to Unit 5 Shale of the Atoka Formation. The hydrostratigraphic model was developed from monitoring well and borehole logs, survey data from outcrop exposures, and topographic data. This model is presented in the updated version of the HGSCR (Gard, 2009).

SFC simplified this conceptual model by combining hydrogeologic units, as appropriate. The simplified layers are, as follows: Layer 1 - the terrace, colluvium, and alluvial deposits and the fill materials; Layer 2 - Unit 1 Shale; Layer 3 - Unit 2 Shale; Layer 4 - Unit 3 Shale; Layer 5 - Unit 4 Shale; and Layer 6 - Unit 5 Shale. The four sandstone units that lie between the shale units were modeled implicitly as low-permeability layers where they are represented by vertical conductance between the shale units. No lateral water flux or lateral solute transport was calculated in the sandstone units.

SFC utilized MODFLOW (McDonald and Harbaugh, 1988), a finite-difference, three-dimensional, numerical groundwater flow model. SFC's model contains 6 layers, 122 columns, and 123 rows. A majority of the model cells are 15.2 m x 15.2 m (50 ft x 50 ft) within the center portion of the model. The model has a telescoping grid on the fringes where the grid spacing expands from 15.2 m (50 ft) to 30.5 m (100 ft) and then to 61 m (200 ft). Also, SFC has decreased the size of some cells to 3.8 m (12.5 ft) to address the reclamation activities. The model contains over 90,000 model cells, with approximately 65,000 being active. Only Layer 6, the Unit 5 Shale, extends across the entire model grid. The other layers are truncated against upper younger deposits. Thus, the model has some cells with a thickness of 0.2 feet which represent the model pinching out along the boundaries.

SFC represented the aquifer system as a three-dimensional, steady-state, unconfined and confined model with six layers; layers 1 through 5 are separated by impermeable sandstone units. Boundary conditions used in the flow model are constant head cells for the rivers and ponds, streams, drains, recharge, and evapotranspiration; no-flow cells are used for primarily the base of Layer 6.

Surface water features were simulated in MODFLOW using its Stream package to simulate stream-aquifer interactions. Constant head cells were used to represent the Arkansas and Illinois rivers, the Kerr Reservoir, Salt Branch and its tributary, and the surface water ponds (Storm Water Reservoir, Decorative Pond, and Emergency Basin/North Ditch). Constant head cells have their initial hydraulic heads maintained by an inflow or outflow flux at each cell.

The Stream package in MODFLOW simulates groundwater gains or losses for each cell, and it will generate stream discharges and inflows at specified cells. Streams (Outfalls) 001, 004, 005, and 007, Creek A, and an unnamed stream north of the Storm Water Reservoir were all modeled as streams not as constant head cells. Stream discharges were compared against calculated values obtained from an empirical stream flow model discussed earlier (Harlin, 2001). This comparison was qualitative in nature and was not part of the calibration. Empirical stream flow calculations are generally not suitable for performing calibrations since such calculations are estimates not measurements.

Four drain systems were installed prior to the corrective actions discussed in Section 4.1. These corrective actions were installed to remove groundwater by gravity drainage within or near the Process Area. SFC simulated these systems using the Drain package in MODFLOW. A description of these drains is as follows. Conduits excavated to install the Combination Stream Discharge (CSD), a 31- to 76-cm (12- to 30-inch) diameter concrete pipe at a depth of 1.5 to 9.1 m (5 to 30 ft) below land surface, provide preferential groundwater pathways from the Process Area to Outfall 001. Concrete pipes were installed on the surface of the Unit 1 Sandstone; thus, the drains are simulated in Unit 1 Shale (Layer 2). Figure 8-12 in the HGSCR (MFG, 2003b) delineates the CSD path in the Process Area. Two drains were developed in the terrace deposits (Layer 1) located near the northwest corner of Pond 2 and along the southern edge of Pond 2 (Figure 8-11 in the HGSCR (MFG, 2003b)). Another drain is located on top of Unit 1 Sandstone within Layer 2 near Stream 005 between the Emergency Basin and the Outfall 005. Also, an additional French drain system near Stream 005 was simulated in Layer 2. In addition to the drains, extraction wells were also simulated to represent the recovery wells installed, as part of the CAP.

Initial recharge in the groundwater flow model was based on the infiltration of precipitation through the root and unsaturated zones. The initial estimate of recharge is 0.87 cm/yr (2.2 in/yr); however, the final recharge has been adjusted to account for other factors that modify this value. For example, in the Agland area the recharge 20 cm/yr (7.9 in/yr) is increased by infiltration of irrigation waters. In the valley bottoms and oak woodland, recharge 20 cm/yr (7.9 in/yr) is increased because some of the runoff is captured in these areas as additional infiltration (Gard, 2009).

Evapotranspiration (ET) values used in the groundwater flow model are based upon the ET rates of the different land covers at the SFC site and the ET extinction depths (the maximum depth at which the plant roots will extract groundwater from the saturated zone). The model assumed ET rates for the oak woodland, Bluestem prairie grasslands, and Bermuda grass pasturelands were 0.0015, 0.0009, 0.007 meters per day (m/d) (0.005, 0.003, 0.024 feet per day (f/d)), respectively. ET extinction depths are 8.0, 4.5, and 6.5 feet, respectively, for the aforementioned land covers. In many cases, the depth to groundwater is greater than the extinction depth. Thus, there are no ET losses when this occurs.

The hydraulic conductivity (K) of the water-bearing and sandstone units are also important input parameters used in the groundwater flow model. These K values are as follows:

- alluvium/colluvium – 2.5 m/d (8.3 f/d)
- Shale 1/Terrace – 0.016 m/d (0.0527 f/d)
- Shale 2 – 0.14 m/d (0.445 f/d)
- Shale 3 – 0.05 m/d (0.174 f/d)
- Shale 4 – 0.17 m/d (0.571 f/d)

SFC designated special high conductivity cells (HCCs), within the model domain to simulate conditions where monitoring wells and/or boreholes are either screened or open in multiple shale and sandstone units. These cells 15.2 m x 15.2 m (50 ft x 50 ft) simulated mixing of groundwater between these units that occurs in the physical system because SFC developed groundwater monitoring wells and boreholes that permitted the cross-contamination and mixing of the groundwater between these units. HCC conductivities are as follows: Kx = 0.15 m/d (0.5 f/d), Ky = 0.015 m/d (0.05 f/d), and vertical leakance was also assumed to be 0.015 m/d (0.05 f/d) (Gard, 2009).

SFC stated that the location of the HCCs is based upon the spatial distribution and density of the monitoring wells and boreholes that are completed in multiple units. The majority of the HCCs are located within the Process Area, Solid Waste Burial Area, Fertilizer Pond Area, and adjacent to Pond 2 (Figure 8-17 of the HGSCR). SFC has also indicated that the location of the HCCs was not used as a calibration factor.

SFC used equivalent porous media (EPM) modeling methods to model groundwater flow. EPM is a method of modeling that assumes flow in fractured rock behaves similarly to flow in unconsolidated coarse sediments. EPM is generally applicable if rock is highly fractured and the fracture patterns exhibit a high degree of interconnectivity. Flow in the sandstone units was restricted to low flow only in the vertical direction.

5.1.2 CALIBRATION OF GROUNDWATER FLOW MODEL

SFC calibrated both the steady-state and transient groundwater flow models. The steady-state model was first calibrated to 161 primary wells, then calibration statistics were calculated using all 307 wells regardless of whether the wells were screened in more that one layer. Primary wells are those that were screened in one hydrogeologic unit. The models were also compared, but not calibrated to, stream flows. Reclamation activities after January 2003 (i.e., the installation of drains, French drains, clay wall, and recovery wells) have modified the hydrogeologic conditions at SFC. These features were incorporated into the calibrated flow and transport models and are simulated in the predictive groundwater flow and transport models.

The flow model was calibrated by modifying the K, recharge, leakance, and drain conductance in the original model. A review of the latest modeling results indicates that was decreased in layer 1 to represent the gravel fill north of the decorative pond, since the upper part of the fill was clay. K was also modified for the conductive zone between MW-95A and Pond 2 to account for rock decomposition that occurred because of the high pH fluid that leaked from Pond 2. This adjustment generated a better calibration. A final K adjustment was made to the high conductivity zone representing the buried portion of the 005 drainage that extends from the Emergency Pond; K was decreased from 7.6 m/d (25 f/d) to 0.76 m/d (2.5 f/d) achieving a better calibration (Gard, 2009).

Leakance and recharge were also adjusted to achieve an acceptable calibration. Leakance through the Unit 2 Sandstone was decreased from 3E-3 to 8.8E-5 m/d (0.01 to 2.9E-4 f/d). Recharge in Pond 2 was increased from 1.6 E-4 to 2.1E-3 m/d (5.3E-4 to 7E-3 f/d).

A comparison of the observed heads to the simulated heads (Table 4) provides an indication of the quality of the calibration of the groundwater flow model. In all layers, the absolute value for the difference between the target (observed) and simulated heads is predominately less than 3 m (10 ft). The average of the absolute values within each layer was less than 1.8 m (6 ft), which is a good match between the observed and simulated heads. These are good indicators that the model is adequately calibrated. Additional calibration statistics for the groundwater flow model, provides information on the quality of the calibration. The residual mean (0.21 m/0.7 ft), absolute residual mean (1.3 m/4.25 ft), and residual standard deviation divided by the range in the hydraulic heads (0.06) are reasonable values that are indicative of an adequate calibration. Based on the staff's review of the model steady-state model development and calibration, the staff determined that the steady-state model was acceptable for use in the transient flow modeling.

For the transient flow model the calibration statistics for the dataset are found in Table 6; calibration statistics for the individual targets are, as follows. Of the 307 wells in the database, REs for 229 well (75 percent) were less than 0.05 and are categorized as good. REs for 58 wells (19 percent) were between 0.05 and 0.10 and are considered satisfactory. REs for 20 wells were less than satisfactory.

Table 6. Comparison of Observed to Simulated Groundwater Levels for the Groundwater Flow Model

Layer	Number of Wells	Number with Absolute Value of (Observed-Simulated Water Levels) Less than 3 m (10 ft)	Average - Absolute Values of (Observed-Simulated Water Levels) (m/ft)
1	2	1	1.63/5.34
2	24	24	0.85/2.78
3	6	6	0.96/3.16
4	6	6	1.14/3.73
5	15	11	1.74/5.71
6	11	10	1.77/5.81

5.1.3 EVALUATION FINDINGS

NRC staff reviewed SFC's groundwater flow model to determine if it adequately represents the aquifer system at the site. Information reviewed included input parameters, calibration data, and statistics of residuals. Simulated potentiometric surfaces for each layer (Figures 7-9 through 7-13 in (Gard, 2009)) were also examined for their shape and flow directions. NRC staff determined that the potentiometric surfaces are reasonable and that the calibration of the groundwater flow model is adequate. Therefore, results from this model can be used as input to the transport model.

5.2 GROUNDWATER TRANSPORT MODEL

5.2.1 MODEL DEVELOPMENT

SFC's transport model is based upon the hydrogeologic conceptual model and the groundwater flow model discussed previously. The transport model utilizes MT3DMS (Zheng and Wang, 1999) a finite-difference, three-dimensional, multi-species transport model that uses the output from MODFLOW and is operated within the Groundwater Vistas Version 4.12 platform (Rumbaugh and Rumbaugh, 2004). MT3DMS simulates advection, dispersion, and chemical reactions of contaminants in the groundwater flow system.

Input parameters for the transport simulations include the linear distribution coefficient (K_d); longitudinal, transverse, and vertical dispersivity; effective porosity; and bulk density of the media. Horizontal and vertical groundwater flux terms and heads are imported from the MODFLOW results and used in the MT3DMS simulations.

5.2.2 TRANSPORT MODEL CALIBRATION

SFC calibrated the transport model by comparing the observed concentrations of the COCs to the simulated concentrations at selected monitoring wells during the time period from January 1990 to January 2009 (Gard, 2009). SFC modified the simulated transport of the COCs by adjusting the input parameters and the source terms of the COCs. SFC calibrated the transport model by first adjusting porosity and dispersion, then uranium and arsenic simulations were used to estimate the K_d. No K_d was calculated for nitrate since SFC assumed that nitrates would migrate in groundwater without retardation.

For nitrates, effective porosity and dispersivity values (Table 7) were modified based upon their impact on the simulated nitrate concentrations from multiple runs of the transport model. It was not necessary to use K_d or retardation values for the nitrate transport, because nitrate is a conservative groundwater constituent, meaning that geochemical reactions neither reduce its concentration nor its migration velocity. The aforementioned effective porosity and dispersivity values were also used in the uranium and arsenic transport models. However, uranium and arsenic are reactive in the groundwater; therefore, K_d values were determined for uranium and arsenic by reviewing their simulated concentrations for multiple transport model runs (Table 8). Also, the licensee selected bulk density of the shale and the unconsolidated units as 2.69 and 1.76 g/cm^3, respectively.

Table 7: Calibrated Effective Porosity and Dispersivity - Transport Model

Unit / Layer	Parameter	Value
Unconsolidated units	Effective porosity	25 percent
Shale units	Effective porosity	10 percent
All layers	Dispersivity - longitudinal	4.6 m / 15 ft
All layers	Dispersivity - transverse	0.46 m / 1.5 ft
All layers	Dispersivity - vertical	0.046 m / 0.15 ft

Table 8: Calibrated Uranium and Arsenic K_d Values - Transport Model

Layer	Uranium K_d (L/kg)	Arsenic K_d (L/kg)
1	0.92	0.83
2	0.33	1.5
3	0.16	1.5
4	0.33	1.5
5/6	0.23	1.05

SFC used COC groundwater concentrations from 1990 as initial source terms in the transport model. These source terms were modified based upon their impact on the revised transport model results. However, source term modifications were kept to a minimum to maintain integrity with the original site conditions in 1990.

Staff performed a qualitative comparison of the observed uranium, nitrate, and arsenic concentrations from a 2001 sampling event (MFG, 2003b) to the simulated uranium, nitrate, and arsenic maximum initial concentrations (SFC, 2005). The comparison was acceptable, which indicates that the licensee's initial source terms are a reasonable match to the observed concentrations of the COCs.

Staff reviewed the model calibration output to determine the degree to which the calibration was successful. This review is summarized in Tables 9, 10, and 11 below. For uranium, almost all the calibration results were good or the RE was below 0.05. For nitrates, 90 percent of the calibration results were good, and for arsenic, 95 percent of the calibration results were good. Therefore, the NRC staff determined that the calibration for all three COCs was adequate.

Table 9: Comparison of Observed to Simulated Concentrations - Uranium

Layer Number	Poor	Satisfactory	Good	Total
1	0	0	59	59
2	1	0	42	43
3	0	0	45	45
4	0	0	48	48
5	0	0	68	68
6	0	0	16	16
Total	1	0	278	279

Table 10: Comparison of Observed to Simulated Concentrations - Nitrates

Layer Number	Poor	Satisfactory	Good	Total
1	2	1	44	47
2	1	2	36	39
3	0	0	45	45
4	4	2	37	43
5	4	7	47	58
6	0	1	14	15
Total	11	13	223	247

Table 11: Comparison of Observed to Simulated Concentrations - Arsenic

Layer Number	Poor	Satisfactory	Good	Total
1	4	1	54	59
2	0	2	40	42
3	0	1	42	43
4	1	1	46	48
5	3	1	63	67
6	0	0	15	15
Total	8	6	260	274

5.2.3 EVALUATION FINDINGS

NRC staff reviewed the contaminant transport model to determine if it was adequate for use in predictive modeling. Staff reviewed the input parameters, calibration results, and associated statistics. Based on our review, NRC staff determined that the licensee's transport model for the COCs is adequate. Therefore, the SFC transport model along with the groundwater flow model can be used in predictive transport scenarios.

5.3 PREDICTIVE MODELING

The purpose of predictive groundwater flow and transport modeling was to estimate the effects of remedial actions on long-term contaminant transport and the concentrations of COCs at receptor locations during the 1000-year compliance period (SFC, 2009a). As part of this modeling effort SFC assumed that corrective actions would primarily continue until 2015. Some corrective actions will likely be removed during site reclamation.

NRC staff assessed the predicted effectiveness of the corrective actions at points of exposure (POEs). POEs include the site boundary, onsite streams, and the Illinois and Arkansas rivers. NRC staff assessed effectiveness by identifying the concentrations of COCs leaving the site through groundwater and surface water and comparing those concentrations to the current GPSs. Data for this assessment was included in the HGSCR (MFG, 2003b) and the revised HGSCR (Gard Water Consultants, Inc., 2009).

5.3.1 CORRECTIVE ACTIONS AND MODEL SETUP

The existing and proposed corrective actions are the following: 1) Outfall 005 Collection Trench; 2) MW-95A Collection Trench and Pit; 3) Decorative Pond French Drain, and clay barrier; 4) construction of a disposal cell in the Process Area; 5) Recovery Well MWRW-2; 6) Recovery Well MWRW-4; 7) Recovery Well MWRW-5; 8) Recovery Well MWRW-8; 9) Catchment Trench #3; and 10) SX Trench (French Drain B) (see Figure 8.1 in SFC, 2009a). All of the above activities have been completed except for item 4 – disposal cell construction.

The groundwater flow and transport models were adjusted to address the corrective actions discussed above except for the disposal cell. During model calibration, the model grid was refined to address these new features and the K values were modified based upon the hydrogeologic investigations that were associated with these new features. However, these corrective actions required additional adjustments in the calibrated flow and transport models.

SFC provided tables that summarize the changes in the revised groundwater flow and transport models used in the predictive scenarios (SFC, 2009). This information will include the following items: 1) specific yield and storage values for the six layers (these input parameters present a potential problem because the flow model was not calibrated with them); 2) recharge values at the disposal cell footprint and along the north, west, and south sides of the disposal cell; 3) any new K values associated with the corrective actions; and 4) new boundary conditions due to the corrective actions.

The staff reviewed the model input for the flow and transport models and found general agreement between the actual model and descriptions of the various parameters in the modeling report including, hydraulic conductivity, recharge, evapotranspiration, and boundary conditions (SFC, 2009). The staff executed the models and examined the results for degree of convergence, degree of calibration and agreement with the report.

5.3.2 MODEL RESULTS

Staff has reviewed the predictive transport models for the existing and proposed reclamation actions (Gard, 2009). NRC staff concludes the following:

Uranium

Uranium contamination remains within the SFC property boundary; therefore, contamination never reaches the Illinois or the Arkansas Rivers. The maximum uranium concentrations vary from 50,000 μg/L at year 0 (the first year of the predictive transport) to 30 μg/L at year 500. Uranium contaminant plumes intersect the drainage of Stream 005 during parts of the predictive period. According to the HGSCR, uranium concentrations in streams remain below the 30 μg/L GPS for the entire compliance period. Therefore, the CAP would meet the requirements for groundwater protection specified in 10 CFR 40, Appendix A.

A review of uranium isoconcentration maps in the 2007 annual groundwater monitoring report (SFC, 2008) indicates that a general agreement between the model predictions and the actual data. The data shows that uranium is a short distance south of the Decorative Pond. In the northern portion of the Industrial Area, 2006 data indicates that contamination has spread over a wider area than that represented on the 5-year map. These conflicts may indicate that the model underestimates uranium migration velocity from the Industrial Area. However, the model appears to be a reliable predictive tool for uranium at this point.

Nitrate

The nitrate plume has already reached the Illinois River in the northern portion of the site at year 0, and the maximum concentration of one of the four plumes, at this time is less than 5,000 mg/L (Figure 9-58 in Gard, 2009). Maximum nitrate concentrations entering the Illinois River exceed 100 mg/L in the northern portion of the site. Nitrate loading in the southern part of the site is negligible since nitrate concentrations entering the Illinois River are generally below 10 mg/L. At Year 5, the Illinois River is still receiving nitrate-contaminated groundwater from the northern portion of the site and a trace amount of nitrate concentration from the southern portion (Figure 9-59 in Gard, 2009).

By year 25, the concentration of nitrates appears to have decreased significantly. Trace quantities of nitrates are reaching the Illinois River from the northern portion of the site, and no nitrates are reaching the river from the southern portion (Figure 9-60 in Gard 2009), By year 50, small areas of nitrates exceeding 100 mg/L exist, and only trace quantities of nitrates are reaching the river (Figure 9-61 in Gard, 2009). By year 100, nitrate contamination in the northern portion no longer appears, and contamination in the southern portion continues to decrease (Figure 9-62 in Gard, 2009).

Although, the model predicts that contamination apparently decreases to levels below the GPS at the POEs, much of the nitrate contamination is allowed to migrate offsite in concentrations of hundreds of mg/L. A mixing analysis performed by SFC indicates that concentration loading to the Illinois River will be 0.004 mg/L, which is significantly below the 10 mg/L drinking water standard. This concentration is also significantly below current nitrate background concentrations in the Illinois River.

NRC staff compared the 2007 data to the 5-year nitrate isoconcentration map (Figure 17 in SFC, 2008). A direct comparison is difficult since the model results and the isoconcentration maps are presented differently. However, the staff concludes that the 2007 isoconcentration data reasonably represents modeled conditions. The staff notes that the model appears to overestimate the nitrate loading to the Illinois River.

Arsenic

Arsenic has one large plume in the western Process Area at Year 0 (Figure 9-68 in Gard, 2009). The plume has reached Streams 001, 004, and 005, but not the Illinois River. The maximum concentration is less than 4,000 µg/L. The arsenic plume has expanded and reached the Illinois River by the year 5; the concentration of arsenic entering the river is 10 µg/L. The plume is similar for years 5 and 100 with the maximum concentration approximately 1,000 µg/L.

Arsenic persists longer at the SFC site than either uranium or nitrate at concentrations greater than the maximum contaminant limit (MCL). A comparison of the 2007 arsenic data (Figure 15 in SFC, 2008) with the 5-year arsenic isoconcentration map (Figure 15 in Gard, 2009) indicates that the predictive model reasonably represents conditions at the site. The model also appears to overestimate the residual arsenic groundwater concentrations and the arsenic loading to the Illinois River. No significant variations were identified during this review.

5.3.3 EVALUATION FINDINGS

NRC reviewed the predictive model to assess the simulated results compared with actual groundwater data collected as part of SFCs groundwater compliance monitoring program. Results indicate that the predictive model are sufficient for predictive purposes and appears to overestimate the residual contamination and loads to the Illinois River

6.0 *CONCLUSIONS*

SFC submitted its CAP in June 2003, and revised it in March 2005, based on comments by NRC staff. The CAP documents contain site characterization information including geology, hydrogeology, and surface water hydrology, and information regarding SFC's model development and calibration. Based on the documents submitted and the analyses performed, the NRC staff concludes that that the CAP will meet the requirements in 10 CFR 40, Appendix A.

The CAP, as proposed, takes advantage of site geology and hydrogeology to strategically place groundwater extraction wells and trenches. These structures have removed contaminants from the groundwater and have intercepted groundwater flow minimizing the amount of contamination flowing offsite. The CAP, combined with the reclamation plan, will continue to remove contamination and minimize offsite impacts.

One potential shortcoming is the fact that the CAP does not appear to address nitrate contamination originating in the fertilizer ponds. However, modeling results and monitoring data indicate that nitrates exit the site and enter the Illinois River at 10 mg/L, which is the drinking water standard. Mixing between the Illinois River and groundwater reduces the potential increase in nitrates to approximately 0.004 mg/L; this is 3 orders of magnitude lower than current nitrate concentrations in the river. Therefore, the NRC staff determines that the CAP will be protective of human health and the environment.

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FIGURES

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