NRC FORM 313 (3-2009)
10 CFR 30, 32, 33, 34, 35, 36, 39, and 40

U.S. NUCLEAR REGULATORY COMMISSION

APPLICATION FOR MATERIALS LICENSE

APPROVED BY OMB: NO. 3150-0120 **EXPIRES: 3/31/2012**

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1. THIS IS AN APPLICATION FOR *(Check appropriate item)*

- ☐ A. NEW LICENSE
- ☑ B. AMENDMENT TO LICENSE NUMBER **SUA-1139**
- ☐ C. RENEWAL OF LICENSE NUMBER

2. NAME AND MAILING ADDRESS OF APPLICANT *(Include ZIP code)*

Mahesh Vidyasagar
ExxonMobil Environmental Services Co.
14950 Heathrow Forest Parkway Room P022A-2
Houston, TX 77032

3. ADDRESS WHERE LICENSED MATERIAL WILL BE USED OR POSSESSED

Approx 25 mi. north of Douglas WY at
43 Deg 4 Min 9.35 Seconds North Latitude
105 Deg 29 Min 57.28 Seconds West Longitude

4. NAME OF PERSON TO BE CONTACTED ABOUT THIS APPLICATION

Mahesh Vidyasagar

TELEPHONE NUMBER

(281) 654-8458

SUBMIT ITEMS 5 THROUGH 11 ON 8-1/2 X 11" PAPER. THE TYPE AND SCOPE OF INFORMATION TO BE PROVIDED IS DESCRIBED IN THE LICENSE APPLICATION GUIDE.

5. RADIOACTIVE MATERIAL
   a. Element and mass number; b. chemical and/or physical form; and c. maximum amount which will be possessed at any one time.

6. PURPOSE(S) FOR WHICH LICENSED MATERIAL WILL BE USED.

7. INDIVIDUAL(S) RESPONSIBLE FOR RADIATION SAFETY PROGRAM AND THEIR TRAINING EXPERIENCE.

8. TRAINING FOR INDIVIDUALS WORKING IN OR FREQUENTING RESTRICTED AREAS.

9. FACILITIES AND EQUIPMENT.

10. RADIATION SAFETY PROGRAM.

11. WASTE MANAGEMENT.

12. LICENSE FEES *(See 10 CFR 170 and Section 170.31)*
FEE CATEGORY **N/A** AMOUNT ENCLOSED $

13. CERTIFICATION. *(Must be completed by applicant)* THE APPLICANT UNDERSTANDS THAT ALL STATEMENTS AND REPRESENTATIONS MADE IN THIS APPLICATION ARE BINDING UPON THE APPLICANT.

THE APPLICANT AND ANY OFFICIAL EXECUTING THIS CERTIFICATION ON BEHALF OF THE APPLICANT, NAMED IN ITEM 2, CERTIFY THAT THIS APPLICATION IS PREPARED IN CONFORMITY WITH TITLE 10, CODE OF FEDERAL REGULATIONS, PARTS 30, 32, 33, 34, 35, 36, 39, AND 40, AND THAT ALL INFORMATION CONTANED HEREIN IS TRUE AND CORRECT TO THE BEST OF THEIR KNOWLEDGE AND BELIEF.

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CERTIFYING OFFICER -- TYPED/PRINTED NAME AND TITLE	SIGNATURE	DATE
Mahesh Vidyasagar	Mahesh Viz	**05/12/2013**

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			$		
APPROVED BY				DATE	

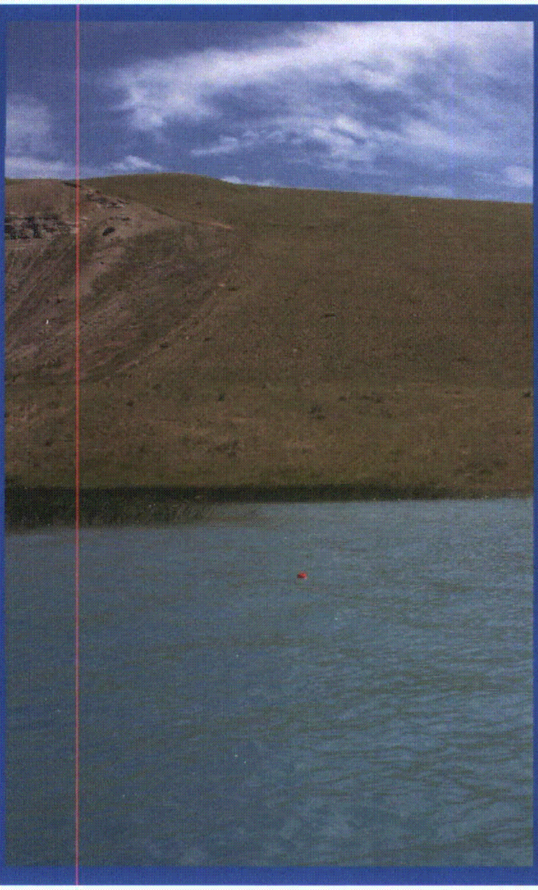
ExxonMobil
Environmental Services

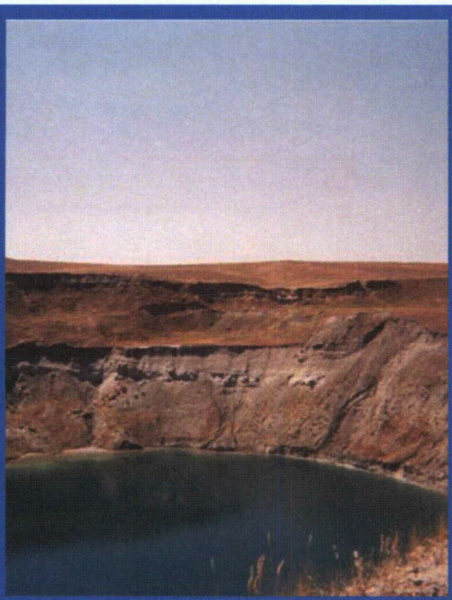
amec

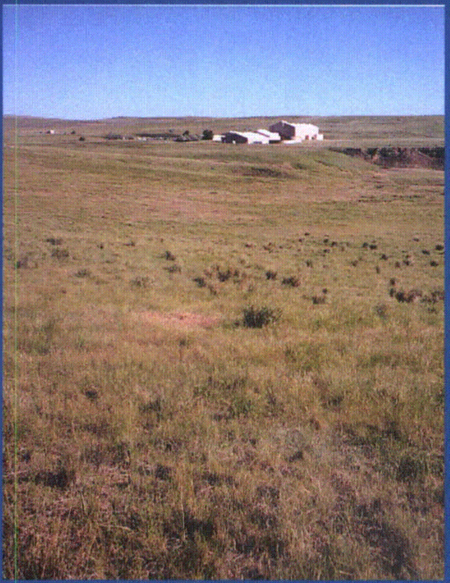
Highland Uranium Mine and Millsite

Request for Amendment to Radioactive Materials License SUA-1139

Application to Amend Existing Alternate Concentration Limits







May 2011

HIGHLAND URANIUM MINE AND MILLSITE
REQUEST FOR AMENDMENT TO
RADIOACTIVE MATERIALS LICENSE SUA-1139

APPLICATION TO AMEND EXISTING
ALTERNATE CONCENTRATION LIMITS

Prepared for
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12450 Greenspoint Drive
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Prepared by
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3801 Automation Way, Suite 100
Fort Collins, Colorado 80525

Executive Summary

ExxonMobil Environmental Services (ExxonMobil) is submitting this application to amend Source Material License SUA-1139, which covers the NRC-licensed material (i.e., 11e.(2) byproduct material) at the Highland Uranium Mine and Millsite (Highland). The Highland site is located approximately 25 miles north of Douglas, Wyoming and includes approximately 1,750 acres encompassing a pit lake, a tailings impoundment, and various waste rock piles. The purpose of this license amendment application is to request modification of the existing Alternate Concentration Limits (ACLs) and the groundwater monitoring program in License Condition 33. This application considers practicable corrective actions and evaluates the site specific conditions for present and potential hazards to human health and the environment and proposes an "alternative", as authorized in the Atomic Energy Act (AEA), as amended by the Uranium Mill Tailings Radiation Control Act of 1978 (UMTRCA) and in the Preamble to 10 CFR Part 40, Appendix A, to the specific criteria in Appendix A to the extent that the proposed point of exposure (POE) in the Pit lake does not fit the traditional ACL formula.

The requested modifications include:

- A supplemental groundwater point of compliance (POC) well;
- Updated ACLs for uranium at an existing POC well and at the proposed POC well;
- Expansion of the long-term surveillance boundary (LTSB) to include the Highland Pit Lake and the Southeast Drainage; and
- New POEs monitoring locations for ACLs.

The Highland site's uranium mill tailings (11e.(2) byproduct material) impoundment was constructed in 1972 behind an earthen dam in an unnamed tributary to North Fork Box Creek (now referred to as the Southeast Drainage). The tailings impoundment was constructed without a liner and is underlain by sandstone and shale. During the early stages of licensed operations, seepage from the tailings impoundment surfaced in the Southeast Drainage downstream of the earthen dam and was collected and recirculated to the impoundment. The seepage stopped within about three years of permanent shutdown of the Highland Mill in 1984, and the accompanying cessation of new tailings being added to the impoundment.

In License Amendment No. 27, the NRC selected four POC wells around the tailings impoundment. The four POC wells 176, 177, 125, and 175 established by NRC are located north, south, east, and west of the tailings impoundment, respectively.

ExxonMobil initiated additional Highland site studies in 2004 to confirm site-specific conditions in anticipation of license termination. These studies focused on 1) confirming groundwater conditions in the Southeast Drainage, the limited drainage directly southeast of the tailings impoundment embankment known to have had historical surface seepage of 11e.(2) byproduct

material from the tailings impoundment and 2) understanding the origins of uranium and selenium concentrations in the Highland Pit Lake.

As one of the initial steps in these recent studies, three wells were installed in 2004 at the toe of the tailings embankment to better understand potential 11e.(2) byproduct material seepage to the Southeast Drainage. Well MFG-1 was installed in the uppermost aquifer to replace Well 148 that went dry in 1994 and had previously been used to monitor seepage in the Southeast Drainage. Uranium was identified in MFG-1 above the requisite MCL value (0.03 mg/L), as well as elevated levels of sulfate and chloride. Wells MFG-2 and MFG-3 were installed directly adjacent to MFG-1 in the two underlying saturated units. No 11e.(2) byproduct material constituents of concern were identified in these wells above their respective MCLs.

Well MFG-1 is proposed as the new Southeast Drainage POC well and is located to the southeast of the tailings impoundment. In addition, an ACL of 0.7 mg/L for uranium is proposed for Well MFG-1. This proposed ACL is equal to one-half the risk-based concentration of 1.4 mg/L. Groundwater uranium concentrations at Well MFG-1 have ranged from 0.13 to 0.39 mg/L and are not anticipated to increase as tailings seepage rates continue to decline. Well TT-7 is proposed as a new POE monitoring well for the Southeast Drainage. Well TT-7 is located where the Southeast Drainage meets North Fork Box Creek. This location is currently monitored quarterly, and monitoring data at this location provides verification of protective conditions of the surface water receiving body North Fork Box Creek, which is the actual POE.

Updated ACLs are also are requested for POC well 175. POC well 175 is located on the western side of the tailings impoundment, between the reclaimed tailings impoundment and the Pit Lake and backfilled pits. The concentration of uranium at Well 175 has been increasing since about 2003 and now exceeds the 0.03 mg/L groundwater protection limit specified in the License Condition 33. This application proposes an ACL of 3 mg/L for uranium in Well 175. This concentration is roughly the modeled equilibrium concentration of uranium in the neutralized tailings seepage within the tailings dam sandstone (TDSS) and represents a maximum potential future concentration at this location. Groundwater uranium concentrations at POC well 175 are currently 0.034 mg/L.

ExxonMobil also has recently re-evaluated the Conceptual Site Model (CSM) to understand the origins and genesis of the elevated levels of 11e.(2) byproduct material constituents in the Highland Pit Lake. The revised CSM is based on recent water quality data, hydrologic and geochemical modeling, and is supported by the current literature in biogeochemistry of radium, selenium, and uranium. These studies have determined that uranium, selenium, sulfate, and chloride from 11e.(2) byproduct material originating in the tailings impoundment have entered the Highland Pit Lake, causing the concentration of uranium and selenium to be above their respective MCLs. In 2006, ExxonMobil discussed with NRC Staff its conclusion that the Pit Lake was impacted with 11e.(2) byproduct material derived from the tailings impoundment. ExxonMobil proposes to revise the LTSB for the Highland site proposed for transfer to the U.S. Department of Energy(DOE) at license termination to include the Pit Lake and areas immediately around the Pit Lake. In addition, ExxonMobil proposes to establish the Pit Lake as a POE monitoring location. Annual sampling and analysis of a single location in the Highland Pit Lake at a single shallow depth is proposed. Sampling of the Pit Lake has indicated that the water quality does not vary substantially with depth and it is the shallow depths that afford the greatest potential for ecological exposure.

An ecological risk assessment was conducted to assess potential risks from uranium and selenium to the Pit Lake biota via several exposure pathways. Terrestrial plants, aquatic biota, birds, and mammals were assessed as potential receptors. The ecological risk assessment concluded that risks to resident and migratory biota at Highland Pit Lake are very low due to its general configuration, which provides little habitat and accordingly limited primary and secondary biological activity.

Corrective actions considered and evaluated for remediation of water quality impacts to the Pit Lake and Southeast Drainage included active and passive, as well as in-situ and ex-situ, treatment technologies. The only practicable action that provides the requisite adequate reasonable assurance of protection of public health and safety, and the environment for at least 200 years, and to the extent practicable for 1,000 years per 10 CFR Part 40, Appendix A, Criterion 6(1), is the implementation of institutional controls over the area, including the Pit Lake, within the proposed LTSB. This alternative includes adoption of the new Southeast Drainage POC Well MFG-1 and POE performance monitoring Well TT-7 in conjunction with the proposed uranium ACL of 0.7 mg/L for MFG-1 and the proposed ACL of 3 mg/L for uranium in Well 175.

The proposed alternative ensures durable control of access to the impacted water resources in the Pit Lake and the Southeast Drainage to prevent long-term use of the water as a drinking water source. Exposure to these water resources by all other receptors remains adequately protective of the environment. Per the NRC guidelines, if the cost per person-rem averted dose is greater than $2,000, then the proposed action, which provides the reasonable assurance of protection of public health, safety and the environment, is considered to be as low as reasonably achievable (ALARA). The proposed action has a cost per person-rem averted dose significantly greater than this threshold, and therefore the proposed alternative is ALARA.

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Appendix B	Well Logs for Wells Installed in the Southeast Drainage
Appendix C	Highland Groundwater and Surface Data CD
Appendix D	PHREEQC Input Files
Appendix E	Detailed Corrective Action Assessment

ATTACHMENTS

Attachment 1	Long Term Pit Lake and Groundwater Hydrology at the Highland Mine Site: Tetra Tech, May 2007
Attachment 2	Long Term Geochemical Evolution of the Highland Pit Lake: Tetra Tech, May 2007
Attachment 3	Final Highland Pit Lake Ecological Assessment: Tetra Tech, Inc. and Redente Ecological Consultants, LLC, January 2011

ABBREVIATIONS

ACL	Alternate Concentration Limit
AEC	U.S. Atomic Energy Commission
ALARA	As Low as Reasonably Achievable
amsl	above mean sea level
AR	Activity Ratio
CAP	Corrective Action Program
COC	Constituent of Concern
CSM	Conceptual Site Model
DOE	U.S. Department of Energy
EPC	Exposure Point Concentration
GPL	Groundwater Protection Limit
gpm	gallons per minute
HQ	Hazard Quotient
ISR	In Situ Recovery

LOAEL	Lowest Observed Adverse Effects Level
LTSB	Long-Term Surveillance Boundary
MCL	Maximum Contaminant Level
MVS	Mining Visualization System
NOAEL	No Adverse Effect Level
NPV	Net Present Value
NRC	U.S. Nuclear Regulatory Commission
OBSS	Ore Body Sandstone
POC	Point of Compliance
POE	Point of Exposure
PRB	Permeable Reactive Barrier
RBC	Risk Based Concentration
TDSH	Tailings Dam Shale
TDSS	Tailings Dam Sandstone
TRV	Toxicity Reference Value
UCL	Upper Confidence Limit
WDEQ	Wyoming Department of Environmental Quality

1.0 GENERAL INFORMATION

1.1 Introduction

This submittal to the U.S. Nuclear Regulatory Commission (NRC) is an application for a license amendment to Source Material License SUA-1139, which covers the licensed material at the Highland Uranium Operations (Highland), located near Douglas, Wyoming (**Figure 1-1**). The Highland Site (the Site) includes approximately 1,750 acres encompassing a pit lake, tailings impoundment, waste rock piles, and millsite area. The purpose of this application is to request modification to the existing Alternate Concentration Limits (ACLs) and groundwater monitoring program in License Condition 33. The requested modifications include:

1. A supplemental groundwater point of compliance (POC) well and new point of exposure (POE) monitoring locations;

2. Updated ACLs for uranium at some existing POC wells and at the proposed POC well;

3. Expansion of the long-term surveillance boundary (LTSB) to include the Highland Pit Lake and the Southeast Drainage, an area larger than previously considered by NRC for transfer upon license termination.

Operations at the Highland Site began in the early 1970s. Uranium ore was mined from a series of connected open pits, milled, and the mill tailings were deposited in an unlined impoundment constructed behind an earthen embankment in a small local drainage valley. Tailings were deposited in the impoundment from 1972 until 1984. Though some of the pits were backfilled during mining, there remains a pit lake that has continued to fill with water since mining ended.

Groundwater impacts from tailings seepage were identified in 1988 and a groundwater corrective action program (CAP) was initiated in 1989. NRC approved cessation of the CAP and granted ACLs for nickel, radium-226+228, and uranium in May 1999, concluding that groundwater recovery was no longer practicable.

Since 1999, the mill and tailings impoundment have been fully reclaimed and all surface reclamation has been approved by NRC. In anticipation of license termination, ExxonMobil, the owner, has conducted additional studies to verify Site conditions. The studies have focused on the Pit Lake and the groundwater associated with the unnamed drainage directly southeast of the tailings impoundment (referred to as the Southeast Drainage). These studies have identified the 11e.(2) byproduct materials uranium, selenium, and radium-226+228 in both the Pit Lake and the Southeast Drainage groundwater system above their respective maximum contaminant levels (MCLs) (EPA, 2009). These results indicate that some portions of the conceptual site model (CSM) that supported the existing approved ACLs were inaccurate.

The information included in this application presents the results of new Site studies that update the CSM. This application also assesses the potential hazards associated with the Pit Lake and the Southeast Drainage groundwater to public health, safety and the environment and assesses a range of practicable corrective actions. A demonstration is provided to establish that the proposed action ensures that the hazardous constituent concentrations in groundwater are protective of public health, safety and the environment and have been reduced to as low as reasonably achievable (ALARA). The proposed action identifies additional POE locations, a new POC groundwater monitoring location, and proposes ACLs for uranium at selected POC wells. The proposed action also identifies an updated description of the lands necessary for the long-term stabilization of 11e.(2) byproduct material to be transferred to a custodian for long-term stewardship. The information included in this application provides the technical basis to support approval of the requested license amendment.

1.1.1 Report Organization

Section 1 of this application presents an overview of the operating and licensing history related to groundwater conditions, an overview of the general environmental conditions, and summarizes the proposed POC and POE monitoring locations and associated ACLs.

Section 2 assesses the potential hazards associated with current conditions including a description of the extent of hazardous constituents in the hydrogeologic system, their predicted long-term fate and transport in the environment, and an assessment of impacts of potential future exposure to the hazardous constituents.

Section 3 presents a summary of the groundwater corrective actions implemented to date and their effectiveness, as well as an analysis of potentially practicable corrective actions, including their costs and benefits.

Section 4 presents the proposed ACLs, monitoring locations, and control boundary for long-term stewardship of the lands necessary for disposal of the 11e.(2) byproduct material and associated hazardous constituents.

References for information discussed in this report but not attached are presented in ***Section 5***. ***Figures and Tables*** are included after Section 5. Supporting data are included in the ***appendices*** and supporting technical reports are included as ***attachments*** to this application.

1.2 Facility Description

Detailed descriptions of the facility, location and setting, and regional and local geology and hydrogeology have been provided in previous documents, primarily the 1998 ACL Application (ECMC, 1998). This information is summarized in the following sections as appropriate for the current objective of assessing the nature and extent of hazardous constituents in the Southeast Drainage and the Highland Pit Lake.

1.2.1 Operating and Licensing History

In 1968, Exxon Company, USA, then know as Standard Oil Company of New Jersey and operating as Humble Oil and Refining Company (Humble Oil) discovered a uranium deposit in the southern Powder River Basin of east-central Wyoming, approximately 20 miles north-northwest of Douglas, Wyoming (**Figure 1-1**). Humble Oil (which subsequently became Exxon with a name change in 1973) initiated mining and milling activities that became known as the Highland Uranium Operations. The uranium occurred as a roll-front deposit that trended roughly northwest in the area of the Highland Mine Site (Langden and Kidwell, 1973).

Exxon Coal & Minerals Company (ECMC) developed Highland as a surface and underground mining facility for recovery of uranium by milling of ore, as well as by solution mining. Surface mining began in 1970 and continued until 1984. Underground mining was conducted approximately 1 mile north of the Pit Lake from 1977 through 1982. Solution mining began north of the Site in 1972 and was transferred to another operator in 1983.

Overburden from surface mining operations was used for surface mine backfill, stockpiled on site, and used for reclamation work. Pits 1 and 2 were completely backfilled, with the North and Middle Dumps being the locations of additional mine overburden placement. Pits 3 and 4 were left open, with pit slopes reclaimed in 1986-1987 **(Figure 1-2)**. The groundwater, surface runoff, and precipitation that has accumulated in Pits 3 and 4 is referred to as the Highland Pit Lake.

The mill started operation in October 1972 under authorization from the U.S. Atomic Energy Commission (AEC) through License No. SUA-1132. The mill processed Highland ore from October 1972 through mid-1984. A conventional acid-leach process was used, processing approximately 11.3 million tons of ore during this 12-year operating period.

ECMC initiated a pilot-scale solution mining operation at the Site in 1972, with operations expanded in 1979. The solution mining operations were transferred to Everest Minerals in 1983. These operations were acquired by Cameco (formerly Power Resources Corporation), which continues solution mining and uranium recovery operations to the north and west of the millsite.

Highland Uranium Operations tailings were discharged into a tailings impoundment covering approximately 200 acres east of the millsite (**Figure 1-2**). The impoundment was constructed behind an earthen dam in an unnamed drainage (now referred to as the Southeast Drainage) tributary to North Fork Box Creek. The impoundment is unlined and is underlain by shale and sandstone. Tailings slurry (primarily fine-grained sand to silt-sized material) was conveyed by pipeline from the mill and discharged around the perimeter of the impoundment and from causeways that extended out into the tailings impoundment (WWL, 1984).

In 1986, the NRC sampled and analyzed the tailings impoundment liquid for organic, inorganic, and radioactive constituents (NRC, 1986). The NRC analyses detected some inorganic elements and radionuclides at concentrations high enough to pose potential hazards to public health, safety and the environment if uncontrolled. The hazardous constituents identified by

NRC were arsenic, cadmium, chromium, gross alpha, lead, nickel, radium-226+228, selenium, thorium-230, and natural uranium (U_{nat}; referred to hereon as uranium or U). No organic compounds were detected in significant concentrations. The 1986 results are the most complete set of analytical data available to describe the chemical composition of the tailings source.

Per NRC instructions in 1988 (Amendment No. 13), Exxon reported the results of a formal leak detection program that verified the tailings impoundment seeped liquid into the uppermost aquifer (ECMC, 1988a). This condition was predicted in the Final Environmental Statement (AEC, 1973) and a subsequent Supplemental Environmental Report (Exxon, 1977) and was observed in earlier groundwater monitoring data. In December 1988, the results of the groundwater monitoring program, approved via License Amendment 23, were reported to the NRC (ECMC, 1988b). The concentrations of major elements, trace metals, and radionuclides found in the NRC samples from 1986 were measured. The constituents beryllium, fluoride, mercury, molybdenum, silver and vanadium were not detected at the monitoring wells or were only found at insignificant concentrations and were therefore removed from the monitoring program. These elements are not considered hazardous constituents at Highland.

Consequently, the license was amended in 1988 (Amendment No. 27) to include groundwater protection limits (GPLs) for the hazardous constituents detected at significant concentrations. The four POC wells 125, 175, 176, and 177 were established by NRC and are located north, south, east, and west of the tailings impoundment (**Figure 1-2**). Amendment 27 also required the development of a groundwater CAP to address the hazardous constituents identified above the GPLs at the POCs.

A CAP with proposed ACLs was submitted to NRC in 1989 (ECMC, 1989a). The CAP involved surface reclamation to reduce tailings infiltration and monitored natural attenuation. NRC denied approval of the proposed ACLs and instructed Exxon to prepare another CAP (NRC, 1989). NRC identified the selective pumping of wells as a viable technology to achieve "considerable improvement in the future ground-water quality" and indicated that submittal of an ACL application based on the results of such a CAP would be appropriate in the future (NRC, 1989).

Exxon subsequently proposed a CAP that included pumping from the five wells (114, 117, 175, 177, and 178) (**Figure 1-2**) completed in the uppermost aquifer, which is hosted by the hydrostratigraphic unit called the Tailings Dam Sandstone (TDSS), and disposing of the water in a lined evaporation pond on the tailings impoundment (ECMC, 1989b). This program was approved in 1989 by NRC via License Amendment No. 32, although approval of proposed ACLs was withheld pending demonstration of the CAP effectiveness.

Tailings impoundment reclamation was initiated by Exxon Minerals Company after mill shutdown in 1984 and by Exxon Coal and Minerals Company after mid-1986. This work consisted of evaporation of residual ponded water, placement of random fill and interim cover to facilitate residual water management, and construction of a reclamation soil cover over the tailings surface.

In 1989, NRC approved the final reclamation plan for the Highland Uranium Project tailings impoundment. Most of the reclamation was completed in 1989 and 1990. With NRC approval, one area of the reclamation cover was left partially completed to allow additional tailings settlement to take place and to provide an area for evaporation of water from the groundwater CAP (ECMC, 1989b).

The reclamation work was documented by WWL (1991) and submitted by Exxon to the NRC. Follow-up items associated with tailings impoundment reclamation were identified by NRC (1992) and addressed by WWL (1993).

In 1990, NRC approved discontinuing pumping from CAP Well 114 due to very low recovery rates. In 1994, the NRC approved suspension of CAP winter operations from December 15 through April 15 (License Amendment No. 44) because by then the system produced too little water to prevent the CAP pipeline from freezing. In approving the seasonal shutdown, NRC concluded turning off the wells during the winter would not pose a threat to the environment or to the health and welfare of the public (ECMC, 1998).

In 1998, Exxon submitted an application for ACLs for POC Wells 125, 175, and 177 (**Figure 1-2**) (ECMC, 1998). At the time of the application, the CAP system had recovered approximately 16.6 million gallons and the water levels in the Tailings Dam Sandstone wells had fallen substantially; two of the four remaining CAP pumping wells had become incapable of producing a significant volume of water due to the low groundwater levels. Additionally, most of the hazardous constituent concentrations had decreased to below the standards in the license. The only hazardous constituents above the license standards were nickel and radium 226+228 at one POC well and uranium at two POC wells. NRC concurred that there remained no reasonably practicable corrective actions and approved the proposed ACLs in May 1999, via License Amendment No. 49 (NRC, 1999). Following a period of settlement monitoring and water evaporation, the CAP ponds were reclaimed and ExxonMobil completed reclamation of the tailings impoundment in 2000 and 2001.

In 2001 and 2006, ExxonMobil submitted a request for amendment of the license to provide updated GPLs for chromium, nickel, selenium, and uranium based upon current MCLs, as the existing GPLs were below the current MCLs. NRC concurred and approved the proposed amendment via License Amendment No. 58 (NRC, 2006b).

ExxonMobil initiated additional Site studies in 2004 to confirm Site conditions in anticipation of license termination. These studies focused on 1) confirming groundwater conditions in the Southeast Drainage, the limited drainage directly southeast of the tailings impoundment embankment known to have had historical surface seepage from the tailings and 2) understanding the origins of high uranium and selenium concentrations in the Highland Pit Lake. As one of the initial steps in these recent studies, Well MFG-1 was installed in 2004 at the toe of the tailings embankment in the uppermost aquifer to better understand potential seepage to the Southeast Drainage. Well MFG-1 replaced Well 148 that had gone dry in 1994 and had previously been used to monitor seepage in this direction (**Figure 1-2**). The hazardous constituent uranium was identified in MFG-1 above the MCL value (0.03 mg/L) as well as elevated levels of non-hazardous constituents (e.g., sulfate and chloride). Subsequently, ExxonMobil installed wells MFG-2 and MFG-3 directly adjacent to MFG-1 in the two underlying saturated units. No hazardous constituents were identified in these wells above their respective MCLs.

As a result of these new data, ExxonMobil installed four new wells (BBL-1, BBL-2, BBL-3, and BBL-4) in 2006 downgradient from MFG-1 and monitored these locations quarterly (**Figure 1-2**). The results from installation and sampling of these wells, presented to NRC in 2008 (ARCADIS, 2008), identified concentrations of uranium, selenium, and radium-226+228 above their respective MCLs in the Southeast Drainage.

In August 2008, NRC requested that ExxonMobil propose a plan to characterize groundwater impacts by 11e.(2) byproduct material in the Southeast Drainage (NRC, 2008). In response to NRC's request, in October 2008 ExxonMobil submitted a characterization plan with additional wells in the Southeast Drainage and surface water monitoring in North Fork Box Creek. The additional wells (TT-1, TT-2, TT-3, TT-4, TT-5, TT-6, TT-7, and TT-8) were installed in December 2008 and January 2009 and surface-water monitoring locations in North Fork Box Creek (BC-1, BC-2, BC-3, BC-4, BC-5, and BC-6) were established in 2008 (**Figures 1-2** and **1-3**). These locations have been monitored quarterly.

ExxonMobil has also recently re-evaluated the CSM based on recent water quality data and current literature in biogeochemistry and the chemical evolution of pit lakes to understand the origins and genesis of the elevated 11e.(2) byproduct material in the Highland Pit Lake. These studies have determined that substantial amounts of both hazardous (uranium and selenium) and non-hazardous (sulfate and chloride) constituents from tailings seepage have entered the Highland Pit Lake, causing the concentration of uranium and selenium to be above their respective MCLs. In 2006, ExxonMobil discussed with NRC their conclusion that the Pit Lake was contaminated with 11e.(2) byproduct material derived from the tailings. At that time, ExxonMobil proposed to revise the boundary of the site proposed for transfer to the U.S. Department of Energy (DOE) at license termination to include the area around the Pit Lake (NRC, 2006a).

ExxonMobil's assessment of the hydrologic data and water quality data collected from these recent studies of the Southeast Drainage and the Highland Pit Lake establish that portions of the conceptual model used to support the currently approved ACLs for uranium, selenium, nickel, and radium-226+228 were not completely accurate. ExxonMobil has used the results of these recent studies to update the CSM. The updated CSM, recent study results, and re-assessment of historical data provide the technical basis for this application.

In August 2009, ExxonMobil notified NRC of its intent to prepare and submit a license amendment application to the NRC to request approval of a new POC well, revised ACLs, and re-definition of the proposed LTSB (EMES, 2009).

1.2.2 Location and Setting

The Highland Mine and Millsite are located within the southern Powder River Basin, in east-central Wyoming, approximately 20 miles north-northwest of Douglas, Wyoming (**Figure 1-1**). The Site covers portions of Sections 20, 21, 22, 27, 28, and 29 in Township 36 North, Range 76 West in Converse County, Wyoming. The Site includes the mine and tailings area, which consists of approximately 1,750 acres encompassing the Pit Lake, tailings impoundment, waste rock piles, and millsite area.

1.2.2.1. Site Physiography

The topography surrounding the Site is characterized by gently rolling upland areas and broad stream valleys that are dissected by numerous draws with relatively steep slopes and rounded ridge crests (Dames & Moore, 1980). Headward erosion of streams since the late Tertiary has resulted in the present-day pattern of uplands and dissected stream valleys. Elevations in the vicinity of the Site range from a maximum of approximately 5,700 feet above mean sea level (amsl) north-northwest of the Site to approximately 4,500 feet amsl east of the Site. At the Site, surface elevations range from approximately 5,100 feet amsl in the drainages to the east of the tailings impoundment to as much as 5,400 feet amsl at some of the higher hills in the western portion of the Site.

The principal drainage of the area is North Fork Box Creek, an intermittent stream that drains higher elevations directly north and west of the Site. The creek generally drains easterly into the Lightning-Lance Creek system, eventually reaching the Cheyenne River (**Figure 1-4**). Both the backfilled mine pits and Pit Lake are located within an unnamed tributary to North Fork Box Creek, and the tailings impoundment is in a separate, roughly parallel tributary now referred to as the Southeast Drainage.

1.2.2.2. Land Use & Population (5 mile radius)

Land use near the Site historically consisted of ranching, including sheep and cattle grazing. Some areas were settled by homesteaders for dry-land farming, but most of these farms have been abandoned. Current land uses in the vicinity of the Site include agriculture (grazing) surrounding the Site, uranium in-situ recovery (ISR) mining to the north and west of the Site, and oil and gas production east of the Site. **Figure 1-5** shows current land ownership in the direct vicinity of the Site. Parcels within and adjacent to the Site are owned by ExxonMobil Corporation, the Boner Family, the Fowler Family, and Cameco Resources (formerly Power Resources, Inc.).

The nearest residence is located approximately 5 miles from the Site. Historically, the population density of Converse County and the State of Wyoming has been low. In 2000, Converse County was inhabited by 12,052 residents with a population density of 2.8 persons per square mile (U.S Census, 2000). The majority of county residents live within the towns of

Douglas (5,288 residents) and Glenrock (2,231 residents), with limited occupancy outside these areas.

1.2.2.3. Climate & Meteorology

The regional climate is generally semi-arid and cool and is influenced by the presence of the Rocky Mountains, which affect frontal storms moving from the west and result in generally dry conditions east of the mountain ranges. Climate statistics are available from two stations in Converse County: Glenrock (approximately 23 miles south of the Site) and Dull Center (approximately 37 miles northeast of the Site). In addition, long-term climate records are available from the Natrona County Airport in Casper (approximately 43 miles southwest of the Site).

Table 1-1 presents the 30-year climate normals for the stations based on data collected for 1971 through 2000 (NOAA, 2004). Mean annual precipitation, derived from both rainfall and snow, for this period ranged from 12.19 inches/year at Glenrock to 13.44 inches/year at Dull Center. The maximum mean monthly precipitation occurs during May at all three stations. Mean annual and monthly temperatures are generally similar for the three stations, as summarized in **Table 1-2.** Mean annual winter snow accumulation totals vary widely between the stations, ranging from 23 inches in Glenrock to 85 inches in Dull Center.

Mean evaporation rates for eastern Wyoming generally range from 40 to 45 inches per year (Curtis and Grimes, 2004). Mean annual evaporation based on data collected at the Casper station is approximately 42 inches. As such, the regional semi-arid climate has a net annual evaporation (accounting for precipitation) of approximately 30 inches.

Actual climate conditions at the Highland Site have not been measured, but can be estimated based on the regional conditions described above. **Table 1-3** presents monthly and average precipitation for the Site estimated by averaging the three closest regional climate stations. These averages are based on observed conditions for 1971 through 2000. The average annual precipitation developed from the three stations is 12.89 inches.

A review of precipitation data indicates that both Glenrock and Dull Center have increasing periods of missing daily data from the late 1990s, which impacts the accuracy of monthly and annual totals. As such, monthly and annual total precipitation data (derived from both rainfall and snow) from the Casper station were used to assess variations since 1984, when reclamation activities began. **Figure 1-6** presents the annual precipitation totals for Casper for the period 1949 through 2008. The figure includes the long-term average from Casper for this period (12.29 inches). As shown on the **Figure 1-6**, 11 of the first 14 years of reclamation activities (1984 through 1998) had above average precipitation, while 8 of the next 10 years (1999 through 2008) had below average precipitation.

1.2.2.4. Regional Geology

The Highland Site is located near the southern margin of the Powder River Basin. The basin is expressed as both a topographic and structural low, bounded on three sides by structural highs. The basin covers an area of approximately 12,000 square miles and is flanked on the east by the Black Hills Uplift, on the west by the Bighorn Mountains, and on the south by the Laramie Mountains and Hartville Uplift (Sharp and Gibbons, 1964; Dames & Moore, 1980).

The basin morphology is representative of an asymmetric syncline that gradually opens and broadens to the north-northwest. The axis of the basin is displaced several miles west of the center of the basin, trending approximately N30°W (Hotchkiss and Levins, 1986). The Powder River Basin was filled in the early Tertiary with continental deposits of the Fort Union and Wasatch Formations. Measured dips on the Wasatch Formation in the central portion of the basin range from less than one degree to two and one-half degrees. At some areas on the margin of the basin, dips steepen to as much as 20 degrees. Dips near the project area are usually less steep and oriented to the north and east.

The Fort Union and Wasatch Formations are the principal units of interest in terms of uranium deposits in the southern Powder River Basin. The Fort Union Formation of Paleocene age is composed of approximately 2,200 to 3,500 feet of semi-consolidated sandstones and siltstones with some minor beds of coal. This unit outcrops at the margins of the basin as a peripheral band surrounding the overlying Wasatch Formation. The Wasatch Formation, of early Eocene age, principally occupies the central portion of the Powder River Basin. It is made up of approximately 1,000 to 3,000 feet of clays and silts, containing thick lenses of coarse, cross-bedded arkosic sandstone. The Wasatch Formation also contains thin seams of coal.

1.2.2.5. Regional Hydrology

Surface Water

The Highland Site is located near the headwaters of North Fork Box Creek. As noted, North Fork Box Creek flows generally west to east and drains into the Lightning-Lance Creek system and ultimately into the Cheyenne River (**Figure 1-4**). The headwaters of the Cheyenne River are north of the Site, separated from the North Fork Box Creek drainage by an upland area known as Highland Flats. The Cheyenne River flows generally east to southeastward (**Figure 1-4**) and ultimately discharges into the North Platte River. Surface flow in the vicinity of the Site is generally limited to ephemeral runoff in response to snowmelt and limited rainfall during spring and summer months.

Groundwater

The Highland Site is located at the southwestern edge of the Northern Great Plains aquifer system, which underlies most of the Dakotas and parts of Montana and Wyoming (Downey, 1986). The major aquifers of the Northern Great Plains aquifer systems system are sandstones of Tertiary and Cretaceous age, along with carbonate rocks of Paleozoic age. These are generally overlain by unconsolidated deposits of Quaternary age, some of which are locally highly permeable.

The Tertiary age Wasatch and Fort Union Formations act as regional aquifers within the Powder River Basin (Hotchkiss and Levins, 1986). The Wasatch Formation includes generally shallow aquifers fed by surface infiltration. In general, the upper Wasatch aquifers are under water table, or unconfined conditions. Confined conditions can occur near the base of the formation where groundwater flows beneath local impermeable claystone or mudstone layers. The Wasatch Formation is considered a good source of water supply for limited development.

The Fort Union Formation underlies the Wasatch Formation in the vicinity of the Highland Site, and contains the principal uranium-bearing sandstone units. As such, most of the wells in the vicinity of the Site, including regional ISR mine wells, penetrate these sandstone units. Substantial volumes of water can be produced from various sandstones in the Fort Union Formation near the Site, as evidenced by high flows produced from dewatering activities during active mining at Highland, along with historic dewatering at nearby underground mines (Dames & Moore, 1978).

1.2.2.6. Local Geology

The local mine site geology consists of lithologies from the Eocene and Paleocene Epochs. The Eocene Wasatch Formation overlies the Paleocene Fort Union Formation. The generalized stratigraphy is shown in **Figure 1-7**. The primary geologic units at the Site, in order of increasing depth are:

- Undifferentiated interbedded sandstones, siltstones, and claystones of the lower Wasatch and upper Fort Union geologic units. The undifferentiated sandstones (sometimes referred to as the Fowler Sands) are comprised of generally discontinuous medium to coarse-grained sandstones interbedded with finer-grained siltstones and claystones, and generally occur from the surface to depths ranging from zero to approximately 350 feet. The undifferentiated sands as a unit are laterally continuous across the Site except in drainage areas (e.g., North Fork Box Creek and the Southeast Drainage) where the sandstones have been eroded. The undifferentiated sandstones are typically dry at the Site;
- Tailings Dam Sandstone (TDSS). The TDSS is comprised of medium- to coarse-grained sand channel and floodplain facies (Hunter, 1999) and is typically 30 to 50 feet in thickness across the Site. The TDSS and underlying shale and sandstone strata generally dip to the northwest at shallow dips. The TDSS is generally continuous within the footprint of the tailings impoundment, but is thought to pinch out approximately one mile west of the Pit Lake (Hunter, 1999). The TDSS outcrops underneath the tailings impoundment and within the Southeast Drainage. The TDSS is of primary interest in that perched groundwater was encountered within it prior to mining, it is the uppermost aquifer at the Site, and it received significant seepage from the tailings impoundment during milling operations;

- Tailings Dam Shale (TDSH). The TDSH is a laterally continuous interval of fine-grained siltstone and claystone that ranges from 20 to 50 feet in thickness. The TDSH was identified in early studies as a key geologic unit that would potentially restrict vertical seepage from the tailings impoundment based on observations of groundwater perched above the shale and unsaturated material below the shale. As such, the tailings dam was keyed into the TDSH within the Southeast Drainage;
- Ore Body Sandstones (OBSS). The OBSS (sometimes referred to as the Highland Sandstone Unit) are the host rock of the majority of uranium ore in the area. The OBSS as a whole ranges from approximately 120 to 150 thick and consists of sand channel deposits and floodplain facies (Hunter, 1999). The OBSS at the Highland Site is divisible into three primary sandstone members separated by intervals of claystone and siltstone. Site nomenclature refers to the sandstones from stratigraphically highest to lowest as the 50-Sand (50SS), 40-Sand (40SS), and the 30-Sand (30SS), with the intervening fine-grained intervals referred to as the 45-Shale (45SH) and the 35-Shale (35SH) as depicted on **Figure 1-7**. All sandstones and shales are laterally extensive throughout the study area and are generally composed of fine-to-medium grained, poorly lithified arkosic sandstone that typically range from 20 to 50 feet in thickness. The fine-grained intervals range from 9 to 35 feet in the area of the Pit Lake, but pinch out and are absent in areas north and west of the Site. Thus the orebody sandstones can be in direct vertical contact in off-site areas.

In order to better understand and visualize Site geology, a three-dimensional geologic framework model was constructed using the Mining Visualization System (MVS) (C TECH Development Corporation, 2010). This application includes geostatistical algorithms that allow the user to convert a collection of raw data points into a coherent 3-D geologic model. In addition, MVS allows the user to employ advanced visualization and analysis techniques in order to extract useful information from the models. The model was designed to represent and help visualize the Site geology in relation to the open pit mine, the tailings impoundment, and the Southeast Drainage.

Data used in the model consisted of:

- Geologic logs from all known boreholes at the Site;
- Available cross sections and borehole data for other mine sites to the north and west;
- Digital elevation data for pre-mining, mid-mining, and post-mining topography; and
- Existing geologic maps.

The stratigraphic borehole data were gridded using the KRIG_3D-GEOLOGY module within MVS to create a block model of the Site geology. The digital elevation data were then used to cut into the surface of the block model using the SURF_CUT module as a way to illustrate how the local topography cuts into the existing geologic units. The post-mining topography includes the existing natural topography as well as the open pit, tailings impoundment, waste rock piles, and the Southeast Drainage.

As a whole, the model represents the regional stratigraphy and land surface topography. Detailed geologic cross sections were developed from the 3-D model to illustrate the primary geologic conditions at the Site. **Figure 1-8** shows cross-section locations through the model across the Site, while **Figures 1-9** through **1-12** show various cross sections representing stratigraphic and lithologic conditions through the Site area. The relative proximity can clearly be seen between the tailings impoundment, the backfilled section of the open pit, and the current Pit Lake (**Figures 1-9** and **1-10**). In addition, the regional dip of the stratigraphy can be seen in relation to the tailings impoundment, the backfilled section of the open pit, and the current Pit Lake (**Figures 1-10** and **1-12**).

1.2.2.7. Local Hydrology

The following sections describe the primary components of local hydrology as they relate to understanding the past and current extent of hazardous constituents in the Southeast Drainage and the Pit Lake. Key components include Site surface water conditions, conditions related to the backfilled pits and the Pit Lake, seepage from the tailings impoundment into the TDSS, impacts from dewatering of the OBSS near the pit, and conditions within the Southeast Drainage.

Surface Water

As noted, this Application assesses the transport of the hazardous constituents as well as their potential for posing hazards to public health, safety and the environment in the Highland Pit Lake and the Southeast Drainage. Descriptions of overall Site hydrology and hydrogeology have been provided in numerous previous studies and ACL related documents (ECMC, 1998). The following discussions are thus focused on flow and transport related to the Pit Lake and the Southeast Drainage.

Surface water and groundwater hydrology related to the Pit Lake and Southeast Drainage have been significantly impacted by mining and milling activities at the Site. As such, it is important to understand pre-mining conditions and the changes that occurred in response to Site activities. Surface water runoff and flow in the small local watersheds have been impacted by the presence of the open and backfilled pits and the development of waste rock piles. Additionally, closure activities have resulted in modifications and routing of surface flows. Conditions in the groundwater system have been significantly altered by both dewatering activities and seepage from the tailings impoundment. Current conditions may not be reflective of past flow and transport conditions and any understanding of long-term flow and seepage transport must account for changes in Site hydrology over time. Numerous assessments of groundwater flow and seepage transport have been developed over the life of the mill that reflect the changing surface water and groundwater conditions at the site. A detailed summary of past assessments and models is provided in **Appendix A**.

Backfilled Pits and Pit Lake

The Highland Site is generally located within two unnamed drainages that are tributary to North Fork Box Creek. **Figure 1-13** presents the pre-mining Site topography showing surface water drainages. The backfilled pits (Pits 1 and 2) and the current Pit Lake (Pits 3 and 4) are located in one of the ephemeral drainages, while the tailings impoundment is located within the Southeast Drainage, a second, roughly parallel drainage. Mining activities resulted in significant modifications to the topography within both of the watersheds. Current topography and drainage areas are shown on **Figure 1-14**.

Prior to mining, groundwater at the Site was observed to occur primarily in the lower orebody sandstone units (the 30SS and 40SS), with variably saturated to unsaturated conditions observed within the 50SS and the TDSS (AEC, 1973). The presence of unsaturated material below the TDSH was used to identify the TDSH as a primary unit separating flow from overlying perched groundwater within the TDSS into the deeper orebody sandstones, and provided rationale for keying the tailings dam into the TDSH.

Perched water within the TDSS was thought to be derived from limited recharge from the surface and from periodic recharge at outcrop locations. This groundwater was thought to have limited lateral flow and was generally stagnant (WWL, 1989). Based on observations provided in the early stages of mine development (AEC, 1973), it is likely that both the TDSS and 50SS had limited saturation near outcrop areas to the south and east, with increasing saturations occurring down-dip toward the north and northwest.

Development of the open pits and operation of the mine and mill resulted in significant changes to the groundwater system at the Site. The two primary impacts to groundwater flow at the Site were seepage from the tailings impoundment to the TDSS and dewatering of the pit areas during mining.

Seepage from the Tailings Impoundment into the TDSS

The presence of tailings seepage entering the pits was clearly noted in early mine and mill related reports (**Appendix A**). Dames & Moore (1978) presented a water balance for the mine that clearly recognized the presence of tailing seepage flowing into the open pits at that time, and included an estimate of 100 gallons per minute (gpm) of seepage entering the pits. Exxon Production Research Company (EPRCO, 1982) estimated that the total seepage during active mining (1972 estimated through 1984) averaged approximately 120 gpm. WWL (1988) noted that it was "likely that most of the active seepage from the tailings impoundment flowed toward the pits during active operations," and provided estimates of flow ranging from approximately 45 to 100 gpm. Based on these estimates, as much as 660 million gallons of tailings seepage flowed into backfill and pits during active mining and milling.

A review of hydrogeologic conditions both prior to and during mining and milling activities supports the early observations that significant seepage was flowing toward and entering the open pits. As noted, the tailings dam was keyed into the TDSH at the center foundation within the Southeast Drainage. The TDSS outcropped both upstream underneath the impoundment and along the dam abutments. **Figure 1-15** presents a generalized map showing the TDSS outcrop beneath the dam and along the North Fork Box Creek drainage near the Site. As the tailings impoundment filled with mill water and tailings, there was a direct hydraulic connection between fluids in the impoundment and the TDSS. This resulted in significant seepage into previously unsaturated to variably saturated portions of the TDSS, causing the TDSS to become fully saturated beneath the impoundment and near TDSS outcrop areas.

The primary direction of groundwater flow from the tailings impoundment was radially away from the impoundment with the primary direction of seepage being perpendicular to dip (i.e., along strike) within the TDSS, as evidenced by high groundwater levels and the presence of chemical constituents from tailings seepage in wells installed near outcrop areas in the early 1980s. Tailings seepage flowed to the northeast and primarily to southwest along strike, with some seepage occurring into the Southeast Drainage both through the TDSS outcrops and through the dam footprint.

The open pits penetrated the TDSS above the primary ore zones and provided for discharge of tailings seepage into the open pits. **Figures 1-16** and **1-17** present cross sections showing the TDSS and underlying orebody sandstones along these flow paths. Flow arrows illustrating the primary seepage transport pathways are included on the cross sections, as are monitoring wells that were installed after significant transport had occurred.

Figure 1-18 presents a potentiometric surface map for the TDSS from data collected from wells installed in 1982, as presented by WWL (1988). As shown on the figure, flow was generally radially away from the impoundment with generally high hydraulic gradients existing between the tailings impoundment and the TDSS outcrop areas in the pit areas. Seepage entering the TDSS flowed into the open pit area as the pits were mined and seepage continued into the pits after they were backfilled.

It should be noted that groundwater monitoring at the Site was generally not initiated until the early to mid 1980s, as active mining and milling were ending. Therefore, no data exist for specific characterization of the tailings seepage to the pits until near the end of active mining, after Pits 1 and 2 had been backfilled. However, data collected in wells installed in the TDSS between the tailings dam and the pit area in the early 1980s show high water levels and chemical constituents indicative of tailings seepage.

Dewatering of Orebody Sandstones

As the open pits were mined, groundwater from the OBSS in the vicinity of pits was pumped to lower the water table in advance of mining. This resulted in significant drawdown and the creation of a local groundwater sink in the vicinity of the open pits. This was occurring at the same time the overlying TDSS was receiving significant recharge from seepage from the tailings impoundment. This resulted in increased vertical gradients in the vicinity of the open and backfilled pits that penetrated both the TDSS and the underlying OBSSs.

After mining and milling activities were discontinued and closure activities were completed for the tailings impoundment, water levels within the TDSS declined by 20 to 40 feet, with much of the decline occurring in the late 1980s and early 1990s. **Figure 1-19** presents long-term hydrographs for a number of wells currently monitored within the TDSS, showing the long-term decline in water levels. As the water levels have declined, some monitoring wells near TDSS outcrops have become dry, indicating the TDSS has returned to an unsaturated condition in those areas. **Figure 1-20** presents a map showing older monitoring wells within the TDSS that became dry since mining and milling activities were discontinued. These are Wells 015, 111, 117, 123, 127, 147, 148, 177, and 180.

As groundwater levels in the TDSS have declined, the magnitude and direction of tailings seepage has changed over time. As shown in **Figure 1-19**, groundwater levels within the TDSS declined by 30 to 40 feet between 1982 and the late 1980s. This decline led to a significant decrease in the hydraulic gradient driving seepage flow toward the pit area. **Figure 1-21** presents groundwater levels and flow directions developed from groundwater levels measured in 1987 (WWL, 1988). As shown on the figure, hydraulic gradients generally decreased between the tailings impoundment and the open pit area relative to 1982 (**Figure 1-18**).

Figure 1-22 shows the current saturated thickness of monitoring wells in the TDSS. As shown on the figure, current saturations are minimal in areas near where the TDSS outcrops, with increasing saturation down-dip to the north and northwest. This is indicative of a return to conditions similar those that occurred prior to mining, and is evidence that the higher saturations within the TDSS were a result of tailings seepage. Monitoring wells 117 and 177 (**Figure 1-16**) have dried out, while the saturation in Well 178 has decreased to approximately 2 feet. This indicates that seepage flow is no longer occurring along this flow path, and that the majority of tailings seepage entered the backfilled and open pit areas during active mining and milling, and in the early post-closure period. **Figure 1-23** shows current water level conditions within the TDSS, based on data collected in August, 2010 indicating that current groundwater flow as the unit is de-saturating is generally downdip, toward the northwest.

Long-term flow through the tailings impoundment will be limited to recharge occurring through the cover material placed during closure. Given the surface drainage design, cover material, and vegetation cover on the impoundment, infiltration through the cover is expected to be similar to natural background infiltration (WWL, 1984). Dames & Moore (1980) estimated natural background infiltration to be approximately 0.4 inches per year, which results in an estimated long-term infiltration flow through the impoundment of approximately 3.5 gpm. Numerical modeling suggests the recharge may be on the order of 5 gpm, based on model calibration (see Tetra Tech, 2007 included as **Attachment 1**). As such, long-term seepage from the tailings impoundment into underlying groundwater is expected to be minimal (3.5 to 5 gpm) with flows too low to sustain saturated groundwater flow conditions in the TDSS, as indicated from current groundwater level data.

As groundwater levels have declined significantly within the TDSS, groundwater levels in the OBSS near the Pit Lake and the backfill have risen since the cessation of dewatering activities.

Figure 1-24 presents hydrographs for all dewatering wells showing the rise in groundwater levels since the early 1980s. Locations of these wells are shown on **Figure 1-25**. Groundwater levels in these wells have increased by as much as 50 feet (e.g., Well 170). **Figure 1-26** presents representative water level declines in the TDSS plotted with water level increases in the OBSS to illustrate variations in groundwater level recovery during the post-mining period.

The rise in groundwater levels within the OBSS has contributed flow into the Pit Lake, as the Pit Lake is in hydraulic communication with the OBSS. The lake has risen since the cessation of active dewatering. **Figure 1-27** presents measured lake levels over time. The lake is currently at an elevation of approximately 5,035 feet amsl and covers an area of approximately 116 acres. The estimated volume of water currently in the lake is approximately 3.9 billion gallons. The current Pit Lake represents a local hydraulic sink, as the lake level is below local groundwater levels within the orebody sandstones.

The lake will continue to fill until a general steady-state is reached between the inflows of surface and groundwater and water lost to evaporation. A number of previous studies have assessed the potential long-term rate of Pit Lake filling, the ultimate elevation at which steady-state conditions occur, and the long-term interaction of the lake with the local groundwater system. A detailed summary of these studies is included in **Appendix A**, along with discussion related to key methods and assumptions that impacted predictions of long-term conditions within the Pit Lake. Some of the past studies have predicted the Pit Lake would continue to rise to elevations that would result in long-term groundwater flow through the lake (ECMC, 1998). However, the observed rise in Pit Lake elevation (**Figure 1-27**) is far slower than previously predicted. As described in **Appendix A**, early predictions were constrained by the regional conceptual model of groundwater flow that assumed high water levels and high hydraulic gradients would be reflective of long-term flow conditions at the site. Recent numerical modeling presented in **Attachment 1**, which is based on more recent groundwater level data and Pit Lake elevation data, predicts that the lake will remain a long-term hydraulic sink at a final elevation of approximately 5,060 feet amsl.

Southeast Drainage

This section presents assessments related to the Southeast Drainage developed based on recently collected data not presented in previous submittals. Assessments since 2006 have indicated the presence of hazardous constituents within the Southeast Drainage downstream of the tailings dam and impoundment.

Tailings seepage from the TDSS along the dam abutments and through the dam footprint was noted to have caused springs downstream of the dam early in the mine life and created surface flow in the Southeast Drainage. A sump system was constructed in 1975 to capture this seepage and pump it back to the tailings impoundment. This system was operated until approximately 1987 (WWL, 1989). Constituents within tailings seepage recharged the local groundwater and continued seepage of tailings through the dam footprint may also be occurring.

A total of 13 monitoring wells have been installed in the Southeast Drainage and along North Fork Box Creek, as shown on **Figure 1-28**. An additional three wells (TT-1, TT-2, and TT-3) have been installed in nearby unnamed tributary drainages to assess potential impacts to groundwater and water quality conditions farther east of the tailings impoundment (**Figure 1-28**). **Table 1-4** presents a summary of well completion details; detailed lithologic logs for the wells are provided in **Appendix B** (note that logs were developed during three drilling programs, as described in Section 1.2.1).

Geologic logging of wells installed in the Southeast Drainage indicates that the material within the drainage is near-surface bedrock weathered in-situ to form regolith, with a minimal covering of soil (one to three feet away from channel areas). This is consistent with descriptions provided prior to mining (Dames & Moore, 1970). The presence of regolith in the drainage is in contrast to alluvium, which consists of weathered material carried by surface water from one location and deposited at a downstream location. Material within the main channel system of North Fork Box Creek is alluvium, while material within the Southeast Drainage is primarily regolith.

Groundwater within the Southeast Drainage downgradient of the tailings dam generally flows within regolith underneath and near the primary channel. Wells MFG-1, TT-8, BBL-2, BBL-3, and BBL-4 are installed within regolith in the Southeast Drainage. Wells MFG-2, MFG-3, and BBL-1 are installed in deeper units that likely are not in hydraulic communication with near-surface groundwater. Wells TT-4, TT-5, TT-6, and TT-7 are installed within the alluvium of the North Fork Box Creek drainage.

Figure 1-29 presents a general geologic cross section along the Southeast Drainage into the North Fork Box Creek alluvial system. The cross section was developed from borings installed within the tailings material and from wells installed within the Southeast Drainage, and shows interpreted zones of the OBSS units within the drainage. Wells installed in the drainage are completed in regolith derived from various OBSS units.

Hydrogeologic conditions within the Southeast Drainage have changed significantly since mining activities ended. During mining, active seepage from the tailings impoundment provided both surface flows and enhanced recharge to the groundwater system within the drainage. As noted, much of this seepage was collected near the dam and pumped back to the impoundment. In addition, other seeps were noted within the drainage. Upon closure of the tailings impoundment, seeps providing surface water to the drainage dried out, and recharge to the groundwater system diminished significantly.

Figures 1-30 through **1-32** present photographs of the Southeast Drainage area and channel downstream of the tailings dam. As shown on the photographs, the primary incised channel has a limited width, approximately 6 to 10 feet. Moving away from the incised channel is a higher bench ranging in width from approximately 50 to 75 feet. Wells have been installed primarily on this bench, and have encountered weathered material to depths ranging from 35 up to potentially 60 feet, although the contrast between weathered and unweathered material is generally unclear from the geologic logs.

Groundwater flow in the Southeast Drainage is assumed to be limited to the regolith. This groundwater discharges into the larger alluvial system associated with the main channel of North Fork Box Creek. Wells in the North Fork Box Creek drainage (TT-4 through TT-7) were installed to determine water table conditions and generally do not penetrate the entire alluvial thickness. In Well TT-4, located near the margin of the alluvium, weathered bedrock was encountered at approximately 32 feet (**Figure 1-28**). It is considered likely that thicker alluvium exists closer to the creek channel. The width of the North Fork Box Creek alluvial system generally ranges from 150 feet above the confluence with the Southeast Drainage to approximately 250 feet downstream of the confluence.

Estimates of hydraulic properties within Southeast Drainage regolith and North Fork Box Creek alluvium are limited to a slug test performed in Well TT-8 (**Figure 1-28**). Slug tests performed in Wells TT-2 and TT-3, located in nearby drainages, may also be representative of conditions within the Southeast Drainage regolith. **Table 1-5** presents a summary of hydraulic conductivity estimates from these tests. The slug test in Well TT-8 resulted in an estimated hydraulic conductivity of 7 ft/day. The geometric mean of the three slug tests is 6.7 ft/day.

Figure 1-33 presents groundwater levels measured within the Southeast Drainage and the North Fork Box Creek alluvial system, as measured in fall 2009. As noted, groundwater flow within the Southeast Drainage is generally isolated within permeable regolith underneath and adjacent to the channel. This groundwater moves downgradient within the drainage and ultimately mixes with alluvial groundwater within the North Fork Box Creek drainage.

Development of the tailings impoundment within the drainage has significantly impacted runoff and surface water flow conditions, as surface water originating within the drainage upstream of the dam is collected and routed out of the drainage. The pre-mining surface area within the Southeast Drainage was approximately 2,450 acres. The undisturbed portion of the watershed downstream of the of the tailings impoundment that flows to the original confluence with North Fork Box Creek is approximately 150 acres, or approximately 94% less than the pre-mining drainage area. There is significantly less surface water runoff and groundwater recharge within the drainage downstream of the dam than occurred prior to mining. As such, the only upgradient source to the Southeast Drainage groundwater system is underflow through the tailings dam. Seasonal surface runoff within the drainage downstream of the tailings dam recharges the groundwater system between the dam and the confluence with North Fork Box Creek alluvium.

Figures 1-34 and **1-35** present hydrographs showing water level fluctuations within the Southeast Drainage and the North Fork Box Creek alluvium. Water levels within the Southeast Drainage show seasonal variations of 1 foot or less, with slightly higher water levels in the late spring and summer and lower water levels in the fall. More pronounced seasonal changes are observed within the North Fork Box Creek alluvium, with water level increases of up to 4.4 feet after seasonal runoff (Well TT-5, **Figure 1-35**). This is expected, as the North Fork Box Creek drainage is significantly larger than the Southeast Drainage.

Estimates of general groundwater flux within the Southeast Drainage are summarized here and are discussed in detail in Section 2.2.1. Underflow from the tailings dam into the Southeast Drainage is minimal, as the tailings have drained and the majority of long-term natural infiltration through the impoundment likely recharges the TDSS and flows northward, or down-dip. Underflow from the tailings dam into the Southeast Drainage is estimated at approximately 0.13 gpm.

Groundwater within the Southeast Drainage is recharged from precipitation and runoff within the small drainage area of approximately 150 acres. Groundwater flow from the Southeast Drainage to the North Fork Box Creek alluvium in the vicinity of BBL-4 (**Figure 1-28)** has been estimated at approximately 0.24 gpm. Upgradient groundwater flow within the North Fork Box Creek alluvium has been estimated at approximately 19 gpm. Based on this estimate, the amount of groundwater flow from the Southeast Drainage is approximately 1.3% of the flow in North Fork Box Creek alluvium.

1.3 Conceptual Site Model (CSM)

This section provides a summary of the current hydrologic and geochemical CSM.

1.3.1 Geologic Environment and Uranium Mineralization

Sediments of the Fort Union Formation were deposited as part of a large-scale fluvial system (Houston, 1969; Langden and Kidwell, 1973) creating distinct zones within the OBSS that preferentially transport groundwater. Dominant mineralogies of these sandstones consist of quartz, feldspar, chert and rock fragments, various clay minerals (e.g., montmorillonite), mica-chlorite, and up to 3% organic matter occurring as disseminated carbonized wood and lignite. The majority of uranium ore at the Highland Site was recovered from three distinct sandstone units: the upper, middle, and lower ore body sandstones (Langden and Kidwell, 1973). Pyrite commonly occurs within the ore zones. Unaltered protore occurs at an average concentration of 1%, and calcite is present as a cement matrix along the top and base of the mineralized sandstones (Dahl and Hagmaier, 1974).

Uranium mineralization in the OBSS formed in the high-permeability units as roll-front deposits. The roll-front deposits were formed by dynamic biogeochemical oxidation-reduction (redox) processes, in which uranium leached from tuffaceous debris by oxygenated alkaline groundwater was transported downgradient where it contacted zones that were geochemically reducing. Under reducing conditions, biological and/or chemical reduction caused the precipitation of various uranium minerals along the interface between the oxidized and reduced zones (DeVoto, 1978; Lovley et al., 1991; Langmuir, 1997). The ore-grade uranium at the Highland Site consists of the U(IV)-containing minerals coffinite ($USiO_4$) with lesser amounts of uraninite (UO_2). Radiochemical properties of the ore indicate that the deposit is in secular equilibrium ($^{234}U/^{238}U = 1.0 \pm 0.1$). Other metals which may be associated with uranium in roll-front deposits (selenium, molybdenum, vanadium, lead, zinc, manganese, nickel, cobalt) are not generally found, or occur in low concentrations, at the Highland Site (Dahl and Hagmaier, 1974).

Previous investigations in the Powder River Basin have shown that groundwater chemistry can be naturally modified as it passes through a uranium orebody. Chemical reductants, such as organic matter or pyrite, facilitate the reduction of sulfate, and the water changes from a high-sulfate, low-bicarbonate water to a low-sulfate, high-bicarbonate water as it transverses the orebody (Dahl and Hagmaier, 1974). Elevated uranium concentrations in groundwater typically only occur in oxidizing upgradient, sulfate-rich waters, and are not usually observed in the more reducing downgradient bicarbonate-rich waters (Hagmaier, 1971; Cowart and Osmond, 1977). However, the $^{234}U/^{238}U$ activity ratio (AR) values in groundwater have been shown to increase as water moves through an orebody. Cowart and Osmond (1977) reported AR values ranging from 1.36 upgradient of an orebody to 5.73 downgradient of an orebody. Even though the Highland orebody is in secular equilibrium (AR = 1.0 ± 0.1), elevated AR values exist in groundwater due to both preferential leaching of ^{234}U, and direct alpha recoil of short-lived ^{234}Th into groundwater which causes enrichment of ^{234}U relative to ^{238}U (Cowart and Osmond, 1977).

1.3.2 Uranium Milling Impacts to Groundwater

Approximately 11.3 million tons of ore were processed at the Highland Mill using a sulfuric acid (H_2SO_4) leach circuit. Mill tailings were deposited in an above-grade tailings impoundment constructed in the ephemeral drainage adjacent to the pit area. Tailings slurry (fluids and fine-grained solids) was deposited in direct hydraulic contact with the TDSS, which provided a direct pathway between the tailings impoundment and the pit area **(Figures 1-16 and 1-17)**. During active mining and milling operations, it is estimated that seepage from the tailings impoundment into the TDSS ranged from 50 to more than 200 gpm, averaging approximately 120 gpm between 1972 and 1984. As such, up to 660 million gallons of seepage are estimated to have migrated from the tailings impoundment to the open and backfilled pits during active milling, primarily through the TDSS. After mining and milling operations ceased, an additional 400 million gallons is estimated to have migrated to the backfilled pits and Pit Lake through the TDSS. In total, it is estimated that up to 1 billion gallons of tailings seepage may have migrated to the backfilled pits and Pit Lake based on hydrologic assessments of seepage.

The resulting tailings and process water that were discharged to the tailings impoundment contained low pH and elevated concentrations of chloride, sulfate, uranium, selenium, and metals (iron, aluminum, copper, zinc) (**Figure 1-36**). Tailings seepage migrated downward where it reacted with calcite ($CaCO_3$) in the TDSS. Reaction with calcite increased the pH to approximately 7, and the calcium released from calcite dissolution combined with sulfate to form gypsum ($CaSO_4 \cdot 2H_2O$). Under these conditions, dissolved iron and aluminum precipitated as hydroxide phases [$Fe(OH)_3$ and $Al(OH)_3$] and attenuated trace metals through surface adsorption and/or co-precipitation (**Figure 1-36**). As a result, the concentrations of hazardous trace metal constituents (arsenic, cadmium, chromium, lead, nickel, and thorium-230) are typically below detectable concentrations and not readily transported in the TDSS.

Selenium exists primarily as selenate (SeO_4^{2-}) and the majority of the uranium is complexed with carbonate [$UO_2(CO_3)_2^{2-}$] under oxidizing conditions. These oxidized forms of selenium and uranium do not exhibit a strong affinity for mineral surfaces and therefore remain as mobile constituents, provided that groundwater conditions remain relatively oxidizing (e.g., Eh >200 mV at near-neutral pH). Because the tailings solution contains residual uranium resulting from aggressive extraction of the ore, the tailings retain the characteristic uranium isotopic composition of the original ore (AR = 1.0 ± 0.1) (Zielinski et al., 1997).

As the oxidizing, neutralized tailings seepage continued to migrate through the TDSS, it may have encountered less-impacted waters (down-dip) with locally-reducing conditions induced by the presence of disseminated lenses of organic matter present in the Highland sandstones (Dahl and Hagmaier, 1974). Under reducing conditions (e.g., Eh <200 mV at near-neutral pH) with, uranium will exist primarily as uranium (IV), where it generally precipitates as insoluble uraninite (UO_2) or coffinite ($USiO_4$), and selenium will be reduced to the elemental form (Se^0). This scenario is analogous to the original ore-forming process, where uranium that is transported in oxidizing waters encounters a redox interface containing a reductant such as organic matter or pyrite. Uranium precipitation, rather than adsorption, is more important in this case due to the low solubility of the uranium (IV) minerals and the instability of Fe(III)–hydroxide adsorbent under reducing conditions. Under these conditions, tailings-impacted groundwater is expected to contain low to non-detectable uranium and selenium concentrations but with measurable iron, while the concentrations of sulfate and chloride would remain unchanged.

The presence of locally reducing conditions in the impacted TDSS, together with the tortuous nature of seepage migration, results in a wide range in groundwater uranium concentrations at the Site. However, groundwater conditions are expected to become more reducing over time as the tailings cover continues to limit infiltration of oxidizing surface waters. As a result, uranium concentrations in some wells have decreased, suggesting that continued migration of uranium in the TDSS will be limited, especially off-site where unimpacted groundwater is expected to be more reducing. Consequently, the concentrations of additional milling-related constituents, such as chloride and sulfate, become useful as tracers when evaluating potential tailings impacts to groundwater.

1.3.3 Extent of Groundwater Contamination

The extent of groundwater contamination at the Site has been characterized through regular monitoring from a network of groundwater wells completed in the TDSS, OBSS, and backfill. Chloride has been used historically as an indicator to identify the position of the tailings seepage front, which has reached the backfilled pit areas to the west and southwest (Wells 170 and 180), and areas to the north (Wells 179 and 183) (ECMC, 1998).

1.3.4 Identification of COCs

The Highland tailings impoundment was sampled and analyzed for COCs in 1982 and 1986 (EPRCO, 1982; ECME, 1998). The results of the 1982 and 1986 sampling identified numerous inorganic and radioactive constituents associated with the tailings. The results from subsequent groundwater monitoring at the Site indicated that the concentrations of beryllium, fluoride, mercury, molybdenum, silver, and vanadium were insignificant and could be removed from the monitoring program as hazardous constituents. Consequently, the Site license was amended in 1988 to include GPLs for the remaining hazardous constituents at the four NRC-specified POC wells located to the north, south, east, and west of the tailings impoundment. Based on the historical tailings sampling and groundwater monitoring data, the NRC has set the current hazardous constituents in the Site groundwater monitoring program as: arsenic, cadmium, chromium, gross alpha, lead, nickel, radium-226+228, selenium, thorium-230, and uranium.

1.3.5 Current Extent of COCs

A detailed evaluation of COCs at the Site is presented in Section 2.1.1. The average 2009-2010 COC concentrations in the POC wells were below the MCLs or existing ACLs with the exception of radium-226+228 in POC Well 176 which showed a slight exceedance. However, uranium concentrations have been consistently increasing in POC Well 175, and a single measurement in 2010 (0.0325 mg/L) exceeded the uranium MCL of 0.03 mg/L.

In the Southeast Drainage, uranium concentrations consistently exceeded the MCL from the tailings dam downgradient to the North Fork Box Creek alluvium.

In the Pit Lake, uranium exceeded the MCL of 0.03 mg/L and selenium exceeded the MCL of 0.05 mg/L. Sampling as a function of depth shows that Pit Lake COC concentrations are constant with depth.

Other slight or one-time COC exceedances are thorium-230 in POC Well 125, selenium in Southeast Drainage monitoring well BBL-2, and radium-226+228 in Southeast Drainage monitoring well BBL-3.

1.4 Current Groundwater Protection Standards

The current groundwater protection standards for the Highland Site are presented in License SUA 1139, Condition 33, which states:

> "The licensee shall implement a compliance monitoring program containing the following:
>
> - Sample wells 015, 112, 114, 116, 117, 120, 125, 127, 128, 129, 134, 148, 171, 172, 173, 174, 175, 176, 177, 178, 179, 180, 181, 182 and 183 on a quarterly frequency for chloride, nitrate, sodium, sulfate, pH, TDS and water level, and on

a semiannual frequency for arsenic, cadmium, chromium, gross alpha, lead, nickel, radium-226 and 228, selenium, thorium-230 and uranium.

- Comply with the following ground-water protection standards at point of compliance well Nos. 125, 175, 176 and 177, with background being recognized in well No. 182: arsenic = 0.05 mg/L, cadmium = 0.01 mg/L, chromium = 0.1 mg/L, gross alpha = 15.0 pCi/L, lead= 0.05 mg/L, nickel = 0.1 mg/L, radium-226 and 228 = 5.0 pCi/L, selenium = 0.05 mg/L, thorium-230 = 0.55 pCi/L and uranium = 0.03 mg/L with the exceptions of: well 125 uranium = 0.089 mg/L; well 175 nickel = 1.8 mg/L and radium 226 and 228 = 25 pCi/L; and well 177 uranium =0.11 mg/L."

The uranium standards for well 125 (0.089 mg/L) and well 177 (0.11 mg/L), and the nickel and radium 226+228 standards for well 175 (1.8 mg/L and 25 pCi/L, respectively) are the ACLs established via License Amendment 49 approved in May of 1999.

1.5 Proposed Alternate Concentration Limits

Modifications to the existing ACLs and the current groundwater monitoring program in License Condition 33 are proposed. These modifications are proposed due to new understanding of the extent of hazardous and non-hazardous constituent movement from the tailings to the Southeast Drainage directly east of the tailings impoundment and to the Highland Pit Lake.

Specifically, the hazardous constituent uranium has recently been identified at concentrations greater than the MCL of 0.03 mg/L within the limited groundwater system of the Southeast Drainage. Further, recent Pit-Lake modeling and geochemical studies have indicated that sufficient amounts of uranium and selenium from tailings seepage have migrated into the Highland Pit Lake to cause Pit Lake uranium and selenium concentrations to exceed their respective MCLs. Previous submittals to the NRC did not contemplate hazardous constituent transport in substantive quantities or concentrations to either of these areas.

By virtue of approving cessation of the groundwater CAP and approving the current groundwater protection monitoring program and ACLs, NRC has concurred that there remain no practicable corrective actions for mitigating tailings seepage impacts to the groundwater in the uppermost aquifer around the tailings. Further, the Corrective Action Assessment presented in Section 3 of this application demonstrates that the only practicable corrective action for the Southeast Drainage and the Highland Pit Lake that provides the requisite reasonable assurance of protection and that meets the ALARA requirement is to implement ACLs with institutional controls. The following sections describe the existing POC, POE and ACLs and requested NRC actions.

1.5.1 Existing POC, POE, and ACLs

Condition No. 33 of Source Material License SUA-1139 requires a groundwater monitoring program involving 25 wells, of which wells 125, 175, 176, and 177 are the four designated POC wells. These wells monitor the uppermost aquifer around the perimeter of the tailings impoundment (**Figure 1-2**). The current compliance standards for the four POC wells are listed in **Table 1-6**.

As discussed in Section 1.4, the current ACLs are identified in License Condition 33B and include the following:

- Well 125 uranium = 0.089 mg/L;
- Well 175 nickel = 1.8 mg/L and radium 226+228 = 25 pCi/L;
- Well 177 uranium = 0.11 mg/L (this well has become completely unsaturated and has not been sampled since 1996).

1.5.2 Proposed POC, POE, and ACLs

Proposed POC

MFG-1 is proposed as a new POC well for the Southeast Drainage groundwater system. This well is located at the toe of the tailings embankment at the head of the Southeast Drainage. This location is where historical seepage was greatest and current seepage is greatest (**Figure 1-28** and **1-29**). Well MFG-1 is screened in the uppermost aquifer at the center of the drainage through which the tailings seepage enters the limited Southeast Drainage groundwater system. Groundwater quality in MFG-1 currently meets MCLs for all the hazardous constituents identified in License Condition 33A, with the exception of uranium. No other new POC monitoring locations are proposed.

Proposed POE

The proposed LTSB illustrated in **Figure 1-37** defines the proposed POE locations for the Site and the area over which institutional controls will be applied. Hazardous constituents from tailings seepage have accumulated in the Southeast Drainage and Pit Lake at concentrations above their MCLs and the sole practicable alternative identified necessitates inclusion of the Pit Lake and the Southeast Drainage within the LTSB. The area encompassed by the proposed LTSB ensures control over access to the 11e.(2) byproduct material and associated potential hazards as well as long-term access to environmental monitoring locations at the Site.

Two specific POEs are identified for this application. The first relates to the hazardous constituents from tailings seepage that has migrated down the Southeast Drainage, where uranium, selenium and radium concentrations exceed the MCLs. The second relates to the hazardous constituents that have migrated into the Pit Lake.

The POE for the Southeast Drainage is at the LTSB where the Southeast Drainage meets North Fork Box Creek (**Figure 1-28**). This location is currently monitored by Well TT-7.

The Pit Lake is another POE for hazardous constituents. This location is currently monitored at a single location **(Figure 1-2)** but at three discrete depths.

Proposed ACLs

An ACL of 0.7 mg/L for uranium is proposed at Well MFG-1 in the Southeast Drainage. An ACL of 3 mg/L for uranium in Well 175 on the western side of the tailings impoundment is also proposed. In addition, ExxonMobil requests that NRC accept the proposed LTSB (**Figure 1-37**) expanded to include the Highland Pit Lake and the Southeast Drainage, which is an area larger than previously considered by NRC for transfer upon license termination.

The Exposure Assessment presented in Section 2.3 establishes the protective concentration for uranium for the Southeast Drainage as 1.4 mg/L, based on the recently rescinded Wyoming Department of Environmental Quality value for aquatic life. This assessment determined that there is no reasonable potential for use of the limited groundwater systems associated with the Southeast Drainage and North Fork Box Creek as a human drinking water source, and that only ecological and livestock receptors are plausible. The proposed ACL for MFG-1 is conservatively proposed as half the protective concentration at the POE. This proposed ACL is roughly two times the highest measured concentration in MFG-1.

The Exposure Assessment establishes that the Highland Pit Lake water quality does not and will not present unacceptable risks to ecological receptors. With long-term institutional controls, no human drinking water pathway would be allowed. Current discharge of hazardous constituents from the TDSS into the Highland Pit Lake has diminished to very low levels and long-term discharges are anticipated to be below 5 gpm. This volume and mass flux is small relative to the 3.9 billion gallons currently in the Pit Lake. The Pit Lake currently has a uranium concentration of roughly 3.2 mg/L; the uranium concentration in POC Well 175 could vary greatly and still not pose a risk to public health, safety and the environment. The proposed ACL for Well 175 is based on the modeled equilibrium concentration of uranium from tailings seepage in the neutralized TDSS aquifer (Section 2.1.2.6) and represents a concentration that is below the current uranium concentrations at the POE and is not likely to be exceeded.

2.0 HAZARD ASSESSMENT

This section assesses the potential hazards associated with current conditions including a description of the extent of hazardous constituents in the hydrogeologic system, their predicted long-term fate and transport in the environment, and an assessment of impacts of potential future exposure to the hazardous constituents.

2.1 Source and Contamination Characterization

Historic Highland tailings water compositions have been reported by EPRCO (1982) and NRC (1986). The tailings water was acidic (pH = 2) and contained elevated concentrations of total dissolved solids (mainly sulfate, chloride, magnesium), metals (including aluminum, chromium, iron, manganese, uranium), and ammonia-N (**Table 2-1**). No organic compounds were detected in significant concentrations, although various metals and radionuclides were present at sufficient concentration to be considered COCs.

The groundwater monitoring program specifying the hazardous constituents and other monitoring parameters was set by NRC based on NRC's 1986 sampling of the tailings and the results of Exxon's leak detection program (ECMC, 1988a). The initial list of hazardous constituents was established in License Amendment 23 in June 1988. The constituents beryllium, fluoride, mercury, molybdenum, silver, and vanadium were later dropped from the list because they were not detected at the monitoring wells or were present at insignificant concentrations.

The current list of hazardous constituents identified in License Condition 33 includes arsenic, cadmium, chromium, gross alpha, lead, nickel, radium-226+228, selenium, thorium-230 and uranium. NRC also currently requires monitoring of the non-hazardous constituents which include chloride, nitrate, sodium, sulfate, pH, and total dissolved solids (TDS).

2.1.1 Distribution of COCs

This section presents the current distributions and concentrations of COCs as monitored at historic monitoring wells and in the new monitoring wells installed in the Southeast Drainage. **Tables 2-2** and **2-3** summarize recent water quality monitoring data. Tabulated values of all historic monitoring data from the Site are provided on a CD in **Appendix C**.

2.1.1.1. COC Distribution at Historic Monitoring Locations

Although the tailings constituents chloride and sulfate indicate that some seepage has migrated to the north and, to a lesser extent, down the Southeast Drainage, it is likely that most of the seepage has migrated toward the Pit Lake and backfilled pits, which represent the closest hydrologic sink. **Figures 2-1** through **2-4** show average 2009-2010 concentrations of chloride, sulfate, uranium, and radium-226+228, respectively, in the TDSS and backfill. Most other COCs identified in License Condition 33 are below their MCLs and have not been plotted but are included in **Table 2-2**. Exceptions to this include thorium-230 in TDSS POC well 125, nickel in TDSS monitor well 114, and selenium in OBSS monitor well 129 (**Table 2-2**).

Prior evaluation of the 1996 seepage front location (ECMC, 1998) showed that the tailings seepage had migrated to the backfilled mine areas to the west and southwest, and areas to the north (Wells 176, 179 and 181). The seepage front as delineated by chloride in the TDSS is shown in **Figure 2-1**. The location of the 2009-2010 chloride front is similar to that observed in 1996 (ECMC, 1998), although the concentration of chloride has increased at Wells 179 and 183 to the north. Sulfate shows a similar distribution with the highest concentrations in wells directly west of the tailings impoundment (**Figure 2-2**). Although chloride and sulfate concentrations indicate tailings seepage has migrated slightly to the north, the concentrations of hazardous constituents to the north of the impoundment are below their MCLs in Wells 179, 181, and 183.

Figure 2-3 shows the highest uranium concentrations to the east (Well 112) and west (backfill Well 170) of the tailings. **Figure 2-4** shows the highest radium-226+228 concentrations in TDSS Well 175 located at the western edge of the tailings impoundment and backfill Well 170.

During 2009 and 2010, the concentrations of COCs in all POC wells were below the Site GPLs, with the exception of thorium-230 in Well 125, uranium in Well 175, and radium-226+228 in Well 176 (**Table 2-2**). Thorium-230 showed concentrations slightly above the GPL of 0.55 pCi/L in 2009 and 2010 in Well 125. Radium-226+228 activities in Well 176 have historically fluctuated above and below the GPL of 5 pCi/L, with a mean 2009-2010 activity of 5.30 pCi/L. However, uranium concentrations have been increasing in POC Well 175 since 2003, and a single measurement in 2010 (0.0325 mg/L) exceeded the uranium MCL of 0.03 mg/L. Prior to 2003, the redox state of groundwater at Well 175 was predominantly reducing, based on the low uranium concentrations. The elevated concentrations of chloride and sulfate indicated that the groundwater in Well 175 was impacted by seepage from the tailings impoundment. Continued desaturation of the TDSS has resulted in transient flow conditions in the vicinity of Well 175 which appear to be bringing groundwater from different zones within the aquifer, resulting in the mixing of oxidizing and reducing waters (**Figure 1-35**). Mixing of oxidizing and reducing waters is supported by the observed relationship between uranium and iron at Well 175 as discussed in detail in Section 2.2.3.1.

2.1.1.2. COC Distribution in the Southeast Drainage

A summary of groundwater monitoring well data for the hazardous constituents (arsenic, cadmium, cadmium, chromium, lead, nickel, selenium, uranium, radium-226+228, thorium-230, gross alpha), as well as chloride and sulfate in the Southeast Drainage is presented in **Table 2-3**. The groundwater summary includes the minimum, maximum, and mean values for each constituent calculated using all available data collected since well installation through the end of 2010.

The calculated statistical value for each constituent and the MCLs are presented in Table 2-3. Uranium was the only constituent whose concentration exceeded the MCL at the proposed POC Well MFG-1. Uranium concentrations also exceeded the MCL in numerous downgradient monitoring wells (BBL-2, BBL-3, BBL-4, TT-4, TT-5, TT-7, and TT-8). Uranium concentrations in MFG-1 typically exceed the MCL (0.03 mg/L) by more than a factor of 10, with a mean concentration of 0.32 mg/L. Uranium concentrations have been consistently below the MCL in the deeper (OBSS) wells MFG-2 and MFG-3 (**Figure 2-5**).

The mean and maximum observed selenium concentration (0.0563 mg/L and 0.0777 mg/L, respectively) in Well BBL-2 in the Southeast Drainage regolith exceed the MCL (**Table 2-3**). In addition, mean and maximum radium-226+228 activity (5.45 pCi/L and 8.90 pCi/L, respectively) in Well BBL-3 in the Southeast Drainage regolith exceed the MCL (**Table 2-3**). All other COCs are at very low or non-detectable concentrations at all wells in the Southeast Drainage and below their respective MCLs.

In 2008, surface water monitoring locations in North Fork Box Creek (BC-1, BC-2, BC-3, BC-4, BC-5, and BC-6; **Figure 1-3**) were established to monitor the concentrations of COCs upgradient and downgradient from the Southeast Drainage. The mean concentration of uranium at upstream locations BC-1 and BC-2 (0.0203 mg/L and 0.0648 mg/L, respectively) are equivalent to or slightly higher than those measured at BC-4 (0.0208 mg/L), which is adjacent to TT-7, the proposed POE monitoring well (**Table 2-4**).

2.1.1.3. COC Distribution in the Highland Pit Lake

Transport of COCs through groundwater to the west from the tailings impoundment has led to elevated levels of several constituents in the Pit Lake, including chloride, sulfate, radium, selenium, and uranium. The average concentration of uranium (3.19 mg/L) and selenium (0.073 mg/L) in the Highland Pit Lake exceed their respective MCLs (**Table 2-2**).

Selenium concentrations in the Pit Lake also exceed the Wyoming Department of Environmental Quality (WDEQ) acute (0.02 mg/L) and chronic (0.005 mg/L) surface water standards (WDEQ, 2005). WDEQ does not currently have surface water standards for uranium.

2.1.2 Pit Lake Geochemistry

The geochemistry of the Highland Pit Lake is complex owing to the various potential sources of chemical mass loading to the Pit Lake, which include chemical constituents in:

- Non-impacted groundwater influx;
- Surface runoff and runoff from exposed pit wall surfaces;
- Infiltration of rainfall and snowmelt through the backfilled areas;

- Groundwater influx through residual ore zone material; and
- Seepage from the tailings impoundment.

In this section we provide a summary of current Pit Lake chemistry, a summary of the predicted chemical evolution of the lake, and a discussion of data that indicate the Pit Lake contains 11e.(2) byproduct material from the tailings impoundment.

2.1.2.1. Current Geochemical Conditions

The Highland Pit Lake is currently monitored for 11 constituents, which include pH, TDS, chloride, sulfate, sodium, selenium, gross alpha, radium-226, radium-228, thorium-230, and uranium (**Table 2-2**). The additional potentially hazardous constituents monitored routinely in Site groundwater monitoring wells were dropped from the Pit Lake sampling as these constituents were consistently near or below the analytical detection limit. The mean concentrations of the measured constituents for 2009-2010 are shown in **Table 2-2**. The mean value for each of the constituents is presented in comparison to its respective EPA MCL and Site GPL.

As discussed above, the average concentration of uranium (3.19 mg/L) and selenium (0.073 mg/L) in the Pit Lake currently exceed the MCLs for selenium and uranium. The selenium concentration exceeds the WDEQ aquatic life acute and chronic surface water quality standards. The average concentration for gross alpha (2.99 pCi/L) and radium-226+228 (3.93 pCi/L) are currently below the MCL (**Table 2-2**).

2.1.2.2. Modeled Evolution of Pit Lake Chemistry

The current hydrological model of the Pit Lake indicates that the ultimate water level will be about 5,060 feet amsl in Year 2054 and that the Pit Lake will remain a groundwater sink (Section 1.2.2.7 and **Attachment 1**). Because the Pit Lake will remain a sink, the concentrations of chemical constituents are expected to increase over time due to the effects of evapoconcentration. Modeling was previously conducted to predict the long-term evolution of the Pit Lake chemistry (see Tetra Tech, 2007 included as **Attachment 2**). The modeling was conducted using the Dynamic Systems Model Stella® (version 7.0.2) coupled with the geochemical equilibrium-speciation model PHREEQC (Parkhurst and Appelo, 1999).

Model results predict that the concentrations of uranium, radium-226+228, and selenium will increase from present levels to 4.5 mg/L, 4.5 pCi/L, and 0.14 mg/L, respectively, over 1,000 years. The modeling also predicts that the Pit Lake will become saline as total dissolved solids (TDS) and sulfate increase over 1,000 years to concentrations of >10,310 mg/L and >7,200 mg/L, respectively (**Attachment 2**).

The Pit Lake geochemical model uses a chemical mass-balance approach to evaluate the likely contribution of tailings solution to the Pit Lake water quality. The results of the mass balance evaluation indicated that 53% of the chloride and 30% of the sulfate in the Pit Lake were derived from tailings solution influx. In addition, the mass balance calculations and modeling indicate that up to 27% and 11% of the uranium and selenium in the Pit Lake were derived from tailings solution influx, respectively. These percentages of uranium and selenium alone would provide sufficient mass to provide a concentration in the Pit Lake that would exceed the uranium MCL and the selenium aquatic life standard. Thus, the model predicts that a significant amount of tailings derived 11e.(2) byproduct material, including hazardous constituents, migrated to the Pit Lake. This is in contrast to the conceptual model presented in previous reports (SMI, 1998) and the 1998 ACL application (ECMC, 1998), which concluded that tailings seepage had reached the Pit Lake but that the migration of hazardous constituents had been attenuated. Additional data and observations are presented below in support of the current conceptual model and the geochemical model results. The hydrological evaluation (Section 2.2) also supports this model. A detailed summary of past assessments and models is provided in **Appendix A**.

2.1.2.3. Mass Balance of Major Ions and COCs

The concentrations of chloride and sulfate in the Highland Pit Lake during early filling were substantially greater than the average concentrations of these constituents in the non-impacted groundwater that entered the Pit Lake during filling (**Table 2-5**). Therefore, to satisfy the chemical mass balance in the model there is a requirement to input additional chemical mass and the only viable source identified for these constituents is the tailings solution. Chloride is especially useful for estimating mass from various sources as it is transported conservatively in most groundwater and surface water systems and is often used as a tracer. In addition, there is no other known source for the chloride. Note that in **Table 2-5** the groundwater and Pit Lake data are from 1987. The early data set was selected as the effects of evapoconcentration would be minimized during the early years of filling. The fitted concentration of constituents in the Pit Lake calculated in the model incorporated a term that accounted for evapoconcentration.

Several researchers have estimated the volume of groundwater impacted by the tailings impoundment. Early estimates suggested that the seepage from the tailings reached a maximum of approximately 180 to 200 gpm in 1984 as the Pit Lake initially began to fill, decreasing to 3.5 gpm by 1992 (WWL, 1984). Estimates suggest that the seepage mound under the tailings will naturally disappear in 20 to 60 years, and that a portion of the seepage mound water will flow through the TDSS and OBSS aquifers to backfilled areas of the pits, eventually reaching the Pit Lake itself (WWL, 1989).

In the modeling conducted by Tetra Tech (2007) (**Attachment 2**), inflow of tailings impoundment seepage was represented in the CSM in a conservative manner, where it was assumed that seepage from the tailings impoundment flowed into the Pit Lake at a rate of 30 gpm for 20 years (WWL, 1989). Using these assumptions and a concentration of chloride equal to 217 mg/L that was measured in the tailings solution in 1982 (EPRCO, 1982) the mass balance for chloride was satisfied; indicating that approximately 53% of the chloride in the lake was tailings-derived. The mass balance for sulfate was also satisfied using similar flow assumptions.

The concentrations of uranium, radium and selenium in the Pit Lake are also significantly higher than their respective concentrations in the groundwater (**Table 2-5**), and therefore additional mass for these constituents must be added to satisfy the mass balance. Like chloride and sulfate, the concentration of these elements is also elevated in the tailings solution and this is considered a likely source of additional chemical mass loading because a significant volume of seepage flowed from the tailings to the pits and backfilled pits. Uranium and selenium are expected to be mobile under conditions present at the Site during mining as discussed in Section 1.3.2.

2.1.2.4. Isotopic Data

Determination of uranium sources in Pit Lake and groundwater at the Site is complicated by the historical changes in Site hydrologic conditions, coupled with various potential sources of uranium that have existed. The Site contains a long history of mining and milling and therefore it is difficult to differentiate groundwater impacts related to natural sources, mining (backfill source), and ore processing (tailings source). Determination of uranium isotopic ratios ($^{234}U/^{238}U$) is a tool that can be used to evaluate uranium sources, in addition to physical mixing and geochemical processes affecting groundwater uranium concentrations.

Theoretical Application of $^{234}U/^{238}U$ Ratios

The most important requirement for application of $^{234}U/^{238}U$ ratios when evaluating sources of uranium in a mine or mill setting is the presence of isotopic distinction between uranium in mined materials (ore and waste rock), uranium in process solutions (tailings), and uranium in the native groundwater. Several geochemical processes have been identified which are responsible for the isotopic fractionation of uranium commonly observed in groundwater systems. The principles are based on an assumption of secular equilibrium in the uranium ore, where the rate of decay of ^{234}U is equal to that of the ^{238}U parent yielding an activity ratio (AR) of 1.0. Previous chemical analyses of drill core and equivalent uranium calculated from gamma logs confirmed that the Site deposits are in secular equilibrium (Cowart and Osmond, 1977).

A generally oxidizing environment is also required for application of $^{234}U/^{238}U$ ratios. The mobility of uranium in groundwater is enhanced in the presence of measurable dissolved oxygen and carbonate alkalinity so preferential removal of isotopes does not occur (Zielinski et al., 1997). Average chemical compositions reported for non-impacted TDSS/OBSS wells, representative backfill wells (Well 170), and tailings-impacted wells (Wells 177 and 178) (bicarbonate, elevated sulfate, and measurable uranium and selenium concentrations), indicate oxidizing conditions (**Attachment 2**). In the Pit Lake, oxidizing conditions exist throughout the water column, as indicated by dissolved oxygen concentrations ranging from 7 to 10.3 mg/L (82 to 112 percent saturation) to a depth of 109 feet (**Attachment 2**). The presence of oxidizing conditions contributes to the chemical stability and conservative behavior of uranium, and therefore favorable conditions exist at the Site for source characterization using $^{234}U/^{238}U$ ratios.

$^{234}U/^{238}U$ Signatures in Various Water Types

Secular equilibrium between ^{234}U and ^{238}U in the Highland ore represents a condition of equal alpha activity and therefore a $^{234}U/^{238}U$ alpha AR of 1.0. Tailings solution produced during ore processing contains residual amounts of uranium resulting from aggressive physical and chemical extraction of the ore, and as a result, fractionation of the uranium isotopes does not occur. Therefore, tailings fluids typically retain the characteristic U isotopic composition of the original ore (AR = 1.0 ± 0.1) (Zielinski et al., 1997).

The U isotopic signature in natural groundwaters differs from tailings in that radioactive disequilibrium (AR > 1) between ^{234}U and ^{238}U is commonly observed due to enrichment of ^{234}U. Disequilibrium between ^{234}U and ^{238}U in deep groundwaters develops over periods of hundreds to thousands of years, and is attributed to alpha-recoil displacement of ^{234}Th from ^{238}U across the mineral-water interface, followed by rapid decay of ^{234}Th to ^{234}U (Fleischer, 1980). Consequently, the alpha-recoil displacement produces enrichment of ^{234}U in solution. Typical AR values for natural groundwater range from >1 to 3, but AR values in excess of 10 have been reported (Zielinski et al., 1997; Suski et al., 2006).

Natural weathering of uranium minerals also produces ^{234}U enrichment in receiving waters due to processes other than alpha-recoil displacement. Additional mechanisms to explain enrichment of ^{234}U in groundwater include: (1) damage to the U mineral crystal lattice where $^{234}U(IV)$ resides, so that it is more vulnerable for oxidation to $^{234}U(VI)$ and subsequently leached, and (2) preferential precipitation or adsorption of $^{238}U(IV)$ as it is released during weathering, with the $^{234}U(VI)$ oxidized during the recoil process being more soluble and remaining in solution (Chabaux et al., 2003; Porcelli and Swarzenski, 2003). The resulting enrichment of ^{234}U to produce AR values above 1.0 in various types of leachate and groundwater has been described by several investigators. At the Pēna Blanca Uranium District (Mexico), both adit seepage and perched water in the vadose zone contained AR values greater than 2.0, and higher AR values observed during the wet season were attributed to rinsing of ^{234}U which had accumulated during the dry season (Ku et al., 2009).

Site Source Evaluation Using $^{234}U/^{238}U$ Activity Ratios

Sampling and analysis of the Pit Lake and selected groundwater monitoring wells for U isotopic composition were conducted in December 2009. Pit Lake samples were collected from three depths in the water column (surface, 1/3 depth, and 2/3 depth). Groundwater samples were collected from 25 locations including alluvial, backfill, TDSS, and OBSS wells. The samples were filtered (0.45 μm) and preserved using nitric acid (pH < 2) prior to shipping to the ALS Laboratory Group (Fort Collins, CO) for determination of total uranium and isotopic U composition. Sampling location descriptions and U isotopic results are given in **Table 2-6**.

The U isotopic data shows that samples with the highest U concentrations have the lowest AR values (**Table 2-6**). Four samples had low AR values consistent with a tailings signature (AR = 1.0 ± 0.1): three Pit Lake samples contained AR values ranging from 1.02 to 1.12, and Well MFG-1 completed in regolith, and located at the southeast toe of the tailings impoundment, contained an AR value of 1.18. The highest AR value in **Table 2-6** (AR = 3.64) is strongly suggestive of background conditions, and was measured in TDSS Well 172, which contained 0.412 ug/L U. This AR value is consistent with an average AR value of 4.12 for groundwater associated with the Fort Union Formation in the Highland Area, previously reported by Cowart and Osmond (1977). Uranium in the designated Site background well (182) was below detection (<0.115 ug/L).

The Pit Lake and groundwater U isotopic results (**Table 2-6**) are shown on a plot of AR relative to the reciprocal of the U concentration (**Figure 2-6**). This plot shows the expected AR range for tailings (0.90 to 1.1) and the relationship allows for evaluation of potential mixing, dilution, and attenuation processes. Relative to other groundwater at the Site, the Pit Lake and MFG-1 contain the lowest measured AR values and some of the highest U concentrations. Groundwater in the backfill (Wells 170 and 171) contained higher AR values and lower U concentrations compared to the Pit Lake (**Table 2-2 and Figure 2-6**), indicating a degree of isotopic fractionation during oxidative weathering of U-bearing materials at the Site (ore, waste rock, pit walls). Because both native groundwater and water in the backfill contain AR values greater than 1.4 and U concentrations less than 3 mg/L, an additional source of U from tailings must be present to produce the low AR values and high uranium concentrations observed in the Pit Lake.

2.1.2.5. Other Potential Sources of Uranium

Uranium, radium, and selenium activities/concentrations in Site monitoring wells are low compared to the concentrations measured in the Pit Lake. Initial Pit Lake model simulations (SMI, 1998 and **Attachment 2**) used measured concentrations from the monitoring wells for the groundwater inflow and underestimated the concentrations of these three constituents relative to measured levels in the Pit Lake. At least three possibilities exist for additional sources of these constituents including:

- Generation of oxidizing conditions in the surrounding aquifer due to dewatering allowing for the mobilization of these constituents in the slightly alkaline groundwater passing through the oxidized ore zones (e.g., an oxidized rind);
- Infiltration through the backfill and release of chemical mass; and
- Influx of these constituents via tailings impoundment seepage.

These three potential additional sources are discussed below.

Groundwater influx through oxidized ore zone

In both previous models the initial influx concentration for uranium, radium, and selenium were fitted parameters with mass added to the groundwater influx at a level sufficient to calibrate the model results to the observed concentrations in the Pit Lake. Mass was added to the groundwater input with the assumption that oxidation of the dewatered residual ore zone adjacent to the pit could release the constituents to the inflowing groundwater. This is generally accepted as a reasonable assumption and is a component of numerous Pit Lake models (Schafer and Eary, 2009).

However, Synthetic Precipitation Leaching Procedure (SPLP; EPA Method 1312) tests conducted on OBSS samples on average yielded relatively low concentrations of uranium and selenium, 0.164 mg/L and <0.02 mg/L, respectively (SMI, 1998). In addition, as discussed above (Section 2.1.2.4), natural weathering of uranium ore typically produces an AR value greater than 1.0. These data are inconsistent with a working hypothesis that provides for a large mass of uranium with an AR of 1.0 being derived by weathering of the OBSS.

Infiltration of meteoric water through the backfill

A similar process as described above (i.e., oxidation of residual uranium-bearing and selenium-bearing minerals), could also occur in the backfilled pits and provide a source of mass loading. The average concentration of these constituents would likely be significantly lower in the waste rock than in the residual ore, but there are large volumes of waste rock available. Weathering by-products that accumulate within the backfill could be transported to the pit via infiltrating meteoric water.

Samples from the backfill collected in 1997 were also analyzed in SPLP tests for leachable constituents. In these tests, four backfill samples were analyzed providing average uranium and selenium leachate concentrations of 0.0065 mg/L and <0.02 mg/L, respectively (SMI, 1998). From the results of these analyses, it was concluded that the backfill material was unlikely to be an important source of uranium, radium, or selenium to the Pit Lake (SMI, 1998). In addition, groundwater collected from backfill wells has higher AR values (1.42 to 2.04) than the Pit Lake (AR 1.06). Collectively, these data indicate that flushing of weathering products from the backfill is unlikely a significant source of mass loading to the Pit Lake.

Influx of constituents from the tailings seepage

An obvious possible source of mass loading of uranium, radium, and selenium (as well as chloride and sulfate) to the Pit Lake is seepage from the tailings impoundment, which is the only known source to have concentrations of these constituents high enough to produce the concentrations observed in the Pit Lake and an AR consistent with that of the Pit Lake. In addition, based on previous estimates, as much as 660 million gallons of tailings solution flowed into the open/backfilled pits during active mining as discussed in Section 1.2.2.7 (EPRCO, 1982; WWL, 1988).

Early models did not include influx of these constituents to the Pit Lake from the tailings seepage, primarily due to data collected in static batch studies that indicated that the migration of selenium and uranium would be attenuated on contact of tailings solution with the TDSS and TDSH (EPRCO, 1982). The use of simple static batch tests can be problematic especially when the elements that are being evaluated are redox sensitive, as are selenium and uranium. As discussed in Section 2.2.3.1, the mobility of both uranium and selenium is highly dependent on redox conditions, both being highly mobile under oxidizing conditions and significantly less mobile under reducing conditions. At the Site there appears to be a redox boundary present that controls uranium migration to the north of the Site where reducing conditions prevail. The apparent redox boundary allows for greater migration to the south (up-dip) and in the oxidized regolith in the Southeast Drainage. Data from wells located along the primary flow paths shown in **Figures 1-16** and **1-17** indicate that oxidizing tailings solution migrated toward the pit at the southern portion of the Site, especially towards the current backfilled pits (Pits 1 and 2). Wells 117, 177, and 178 along cross section A-A' (**Figure 1-16**) have elevated concentrations of sulfate, chloride and uranium as shown in **Figures 2-7** and **2-8**. Wells 175 and 180 in the TDSS and backfill, respectively, along cross section B-B' (**Figure 1-17**) also show elevated concentrations of these constituents (**Figures 2-9** and **2-10**). These data clearly show that tailings solution containing uranium migrated through the TDSS into the open pits and backfilled pits.

The mass balance on the conservatively transported element chloride constrains how much tailings solution can be contained in the Pit Lake at about 0.3 to 0.5 billion gallons. For example, in 1987 the mass of chloride in the Pit Lake calculated from the Pit Lake volume and the chloride concentration totalled about 176,000 lbs. Using the average groundwater concentrations provided in **Table 2-5** and the flux from each lithologic unit, the total calculated mass of chloride from the combined groundwater sources would equal about 83,000 lbs. The addition of 30 gpm from the tailings impoundment at a concentration of 218 mg/L (**Table 2-5)** would bring the total mass of chloride to about 168,000 lbs, which is in reasonable agreement with the actual mass. If this flux of tailings solution is added to the Pit Lake for a total of 20 years at a concentration equal to 218 mg/L, there is good agreement between the calculated mass and the measured mass in the Pit Lake. If additional tailings seepage beyond 20 years is added the calculated mass begins to deviate from the measured mass. This indicates that the maximum amount of tailings solution that could have contributed to chloride mass is about 315 million gallons.

Given the concentration of uranium and selenium in the tailings solution, this amount of water would not be sufficient to satisfy the mass balance on these constituents. Thus, a reasonable mechanism that could supply additional mass of these constituents from the tailings upon pit infilling is required.

A mechanism that could provide the additional mass loading to satisfy the mass balance would be the creation of a secondary tailings-derived source term. It is plausible and even probable that such a secondary source term was created via the prolonged deposition of tailings constituents on the geologic material (e.g., pit walls, backfill) in contact with the tailings solution during active mining and pit dewatering. An explanation and evaluation of this potential mechanism is provided in the following section.

2.1.2.6. Highland Pit Lake Geochemical Model

The geochemical processes described in the Highland CSM (Section 1.3.2) were used to develop a refined geochemical model that quantifies the proposed transport processes and extent of chemical reactions in groundwater. The geochemical code PHREEQC (Parkhurst and Appelo, 1999) was chosen because it is a well-established code with applications to a wide range of geochemical conditions. PHREEQC is capable of performing a variety of aqueous geochemical calculations, such as: (1) speciation and saturation index calculations; (2) reaction-path and advective-transport calculations involving specified irreversible reactions, mixing of solutions, mineral and gas equilibria, surface complexation reactions, and ion exchange reactions; and (3) inverse geochemical modeling calculations. The MINTEQ database (Allison et al., 1991) was used for this study because it contains an extensive thermodynamic compilation that is adequate for addressing a broad range of geochemical conditions involving uranium and other metals. Research contributing to development of the MINTEQ database was supported in part by the Office of Solid Waste at the U.S. Environmental Protection Agency. The current MINTEQ database originated from the well-developed thermodynamic database of the U.S. Geological Survey's WATEQ3 model (Ball et al., 1981).

Tailings neutralization and metals attenuation

In the CSM, acidic fluid (pH =2) from the tailings impoundment migrates into the underlying TDSS where it becomes neutralized by calcite. Calcite dissolution produces gypsum oversaturation, and the increase in pH promotes precipitation and adsorption of dissolved metals. This process was modeled in PHREEQC by simulating the reaction of tailings fluid with an excess of calcite (input file provided in **Appendix D**). The average of three tailings chemistry results from 1982 and 1986 were used as input to the model, and the partial pressure of carbon dioxide gas [$PCO_2(g)$] was adjusted to obtain an equilibrium pH of 7.0 commonly observed in the impacted groundwater. Selected oversaturated mineral phases were allowed to precipitate, including ferrihydrite [$Fe(OH)_3(a)$], aluminum hydroxide [$Al(OH)_3(a)$], basaluminite [$Al_4(OH)_{10}SO_4$], and gypsum [$CaSO_4 \cdot 2H_2O$]. PHREEQC also simulated the attenuation of trace metals and metalloids by surface adsorption processes. The mass of ferrihydrite precipitated in the model (1.5 g/L) was used to calculate the mass of surface adsorbent; the surface area and surface site densities for hydrous ferric oxide were assigned to the adsorbing phase (Dzombak and Morel, 1990). The adsorbing phase was pre-equilibrated with natural background groundwater, using groundwater chemistry from Well 182, at the beginning of the simulation.

The model simulation results for tailings fluid neutralization were consistent with the existing CSM (**Figure 1-36**). Reaction with calcite increased the pH and the concentrations of dissolved calcium and bicarbonate, whereas gypsum precipitation decreased the concentrations of sulfate and total dissolved solids (**Table 2-7**). Aluminum and iron concentrations also decreased due to precipitation of their respective hydroxide phases following the increase in pH. Mineral precipitation and/or surface adsorption resulted in a significant decrease in the concentrations of arsenic, barium, cadmium, chromium, copper, lead, nickel, selenium, uranium, and zinc, while the concentrations of boron, manganese, molybdenum, and silver remained unchanged.

Transport and desorption of hazardous constituents

The geochemical modeling results indicate that mineral precipitation and surface adsorption processes have the potential to remove most dissolved constituents from solution following tailings fluid neutralization. However, a fraction of each constituent will remain in solution and therefore be subject to transport in groundwater. For example, approximately 20% of the uranium and 18% of the selenium are predicted to remain in solution after neutralization (**Table 2-7**). The calculated species distribution for the neutralized tailings indicates that dissolved uranium and selenium remain in solution as mobile constituents. The predicted uranium distribution is dominated by the sulfate complexes in the acidic tailings fluid, whereas the uranium distribution becomes dominated by carbonate complexes in the neutralized tailings (**Table 2-8**). The presence of uranium-carbonate complexes limits the extent of additional uranium adsorption and therefore contributes to uranium mobility (Langmuir, 1997). Similarly, **Table 2-8** shows the predicted distribution of dissolved selenium in the neutralized tailings is dominated by the highly-mobile selenate (SeO_4^{2-}) ion (McNeal and Balistrieri, 1989).

In the CSM, a portion of the mobile uranium and selenium becomes adsorbed to various mineral surfaces as it moves through the TDSS, while the remaining fractions are transported to the pit and to the Southeast Drainage. Recovery of groundwater elevations following cessation of mining and reclamation activities indicates there is an influx of unimpacted groundwater from surrounding areas. Under these conditions, the adsorbed uranium (and selenium) could be released into solution, provided there is an increase in alkalinity or pH of groundwater moving through the aquifer (Langmuir, 1997). Therefore, a second PHREEQC transport simulation was conducted to evaluate the potential for uranium and selenium desorption from the aquifer solids by unimpacted groundwater.

The assemblage of major mineral phases (e.g., calcite, gypsum) in the desorption model was identical to that of the tailings fluid neutralization scenario. The mass of adsorbing phase was estimated by assuming the aquifer solids contain 0.1% ferrihydrite with a surface area and site density consistent with hydrous ferric oxide (Dzombak and Morel, 1990). A cation exchange phase was added to correspond with a montmorillonite clay content of 1% (Dahl and Hagmaier, 1974). In the initial steps of the model, both the adsorbing and exchange phases were pre-equilibrated with the neutralized tailings fluid (**Table 2-7**). Desorption from the solids was then simulated by moving 30 pore volumes of unimpacted groundwater through a single model cell containing the applicable mineral solids and sorbing phases. Sensitivity of the model results to the mass of sorbing phases was evaluated by simulating a wide range in ferrihydrite (0.05 to 0.5%) and clay (0.5% to 5%) content. An example PHREEQC desorption input file is provided in **Appendix D**.

The desorption model results indicate that uranium and selenium, which are initially present in neutralized tailings fluid but which become adsorbed to aquifer solids during transport, have the potential to be subsequently desorbed when contacted by unimpacted groundwater. The predicted concentrations of desorbed uranium (**Figure 2-11**) are approximately 12 mg/L in the first pore volume and decrease to <1 mg/L after five pore volumes of unimpacted water have passed. The predicted concentrations of desorbed selenium (**Figure 2-12**) are approximately 0.30 mg/L in the first pore volume and decrease to <0.05 mg/L after five pore volumes. The model was relatively insensitive to the range in sorbing phases for uranium, but slightly sensitive to the mass of ferrihydrite for selenium. These results are consistent with the CSM, where the desorption of residual uranium and selenium in the TDSS is considered to be an alternate and ongoing source of uranium and selenium to both the Pit Lake and the Southeast Drainage regolith.

2.1.2.7. Summary of Pit Lake Chemistry

The Highland Pit Lake contains several constituents at concentrations that are significantly greater than their corresponding concentration in the local groundwater system. Major ion constituents found at elevated concentrations are chloride and sulfate which were derived from tailings seepage and indicate the presence of co-transported 11e.(2) byproduct material in the Pit Lake. Mass balance calculations indicate that 53% and 30% of the chloride and sulfate, respectively, in the Pit Lake are tailings-derived. The hydrologic model predicts that the Pit Lake will be a groundwater sink and therefore, the concentrations of all constituents in the lake are expected to increase over the next 500 to 1,000 years due to evapoconcentration. The lake will become increasingly saline with TDS rising to greater than 10,000 mg/L over the next 1,000 years.

The average concentrations of uranium and selenium in the Pit Lake are currently 3.19 mg/L and 0.073 mg/L, respectively, and are above the EPA MCL and WDEQ surface water quality standards. The concentrations of these constituents are predicted to increase over time due to the effects of evapoconcentration. Mass balance calculations indicate that as much as 24% and 11% of the uranium and selenium in the Pit Lake, respectively, are tailings-derived, 11e.(2) byproduct material (**Attachment 2**). More recent investigations and data analysis support the previous modeling and indicate the presence of 11e.(2) byproduct material in the Pit Lake and suggest that the percentages of these constituents could be even greater. The supporting hydrological and geochemical data and analyses are summarized below:

- A large flux of tailings seepage (an estimated average of 120 gpm) was known to have entered the open and backfilled pits during active mining (Section 1.2.2.7);
- Mass balance on chloride and sulfate confirm seepage of tailings solution to the Pit Lake, as there are no other likely sources for these constituents (Section 2.1.2.3);

- Mass balance calculations also show the need for additional mass of uranium, radium, and selenium to supplement the mass available from groundwater influx to the Pit Lake (Section 2.1.2.3);
- Wells between the tailings impoundment and the pits/backfilled pits (Wells 117, 178, and 180) and along primary flow paths show elevated concentrations of chloride, sulfate and uranium, consistent with the chemical signature of tailings and the migration of tailings solution to the Pit Lake (Section 2.1.2.5);
- Uranium isotopic data (Section 2.1.2.4) indicate that the uranium contained in the Pit Lake has a U^{234}/U^{238} AR value consistent with tailings solution;
- Historic SPLP data and current isotopic data indicate that the backfill could only be a minor source of uranium and selenium mass loading to the Pit Lake (Section 2.1.2.5); and
- Historic SPLP data also indicate that the OBSS is unlikely to be a significant source for mass loading of selenium and uranium to the Pit Lake (Section 2.1.2.5).

2.2 Transport Assessment

2.2.1 Hydrologic Conditions

Hydrogeologic conditions have been discussed in Sections 1.2.2.5 and 1.2.2.7 and are summarized here in the context of the potential fate and transport of COCs. It is important to note that transport of constituents within tailings seepage to the backfilled pits and the Pit Lake occurred primarily during active mining and milling operations and likely significantly decreased shortly after closure of the tailings impoundment. Similarly, active transport of tailings seepage into the Southeast Drainage occurred primarily during active mining and milling operations and certainly has decreased since closure of the tailings impoundment. As such, current transport is likely minimal in both these areas.

2.2.1.1. Backfilled Pits and Pit Lake

The conceptual model for transport of tailings seepage to the backfilled pits and Pit Lake is as follows:

- Seepage from the tailings impoundment entered the TDSS through outcrops directly underneath the impoundment;
- Seepage entering the TDSS moved preferentially to the northeast and southwest along strike;
- Seepage moving southwest entered the active pits early in the mine life and continued to flow into the pits after backfilling;

- Assessments of seepage into the pits made during and shortly after active mining and milling suggest as much as 660 million gallons entered the pit area during the active mining period;
- Assessment also suggest that an additional 400 million gallons of seepage probably flowed to the pit area after mining had ceased;
- Current seepage from the tailings impoundment to the pit is minimal;
- During mining, significant dewatering occurred to depress water levels in the OBSS units around the pit, which produced a high hydraulic gradient from the tailings impoundment to the open pits;
- Upon cessation of mining, groundwater flowed into the dewatered zone, the backfilled pits, and into the Pit Lake;
- Pit Lake inflows are currently from local groundwater (primarily the OBSS–Units 50SS, 40SS, and 30SS) and surface water within the Pit Lake drainage basin. Outflows from the Pit Lake are due to evaporation from the lake surface; and
- The Pit Lake is currently a groundwater sink, with water flowing toward the lake generally from all directions.

2.2.1.2. Southeast Drainage

The hydrogeologic conceptual model for the Southeast Drainage is as follows:

- The presence of the tailings impoundment has generally isolated a large part of the upper watershed in the Southeast Drainage from providing surface and groundwater flow to the lower watershed;
- Groundwater within the Southeast Drainage is limited to a zone of regolith (weathered in-situ rock material) underneath and adjacent to the channel;
- During active mining, significant seepage from the tailings impoundment was a source of surface flows and recharge to the Southeast Drainage;
- Seepage has significantly diminished since the cessation of mining and the initiation of closure activities. Underflow through the tailings dam is estimated to be approximately 0.13 gpm (see calculation below);
- Groundwater flow in the Southeast Drainage is primarily in response to spring-summer runoff, with flows diminishing during fall and winter months. Groundwater flow at the mouth of the Southeast Drainage has been estimated at approximately 0.24 gpm, or roughly twice the underflow from the dam (see calculation below);
- Groundwater from the drainage discharges into the alluvial groundwater system of North Fork Box Creek. Groundwater through-flow in this system was estimated to be

approximately 18.7 gpm, or 78 times the flow from the Southeast Drainage (see calculation below).

Groundwater flow within the Southeast Drainage represents the primary transport mechanism for 11e.(2) byproduct material. General estimates of groundwater flow have been developed based on available data. Underflow from the tailings dam has been estimated based on conditions observed in Well MFG-1. This well is installed in weathered material in the 50SS, and represents the uppermost groundwater encountered beneath the toe of the dam. Depth to water in MFG-1 is approximately 42 feet, and the well has only 6 feet of saturation above the underlying shale into which it is keyed. Underflow from the tailings impoundment at the toe of the dam was estimated using Darcy's Law, as follows:

$$Q = K \times I \times A,$$

where

Q = groundwater flux (ft^3/day)
K = hydraulic conductivity (ft/day)
I = hydraulic gradient (ft/ft)
A = cross sectional area perpendicular to flow (ft^2)

Long-term groundwater flow under the tailings dam was estimated as follows:

Flow depth = 6 ft based on saturated thickness at MFG-1
Flow width = assume 75 ft based on assumed average drainage width from photos and topographic maps
Flow area = 450 ft^2
Hydraulic gradient = 0.008 ft/ft based on the gradient between MFG-1 and TT-8
Hydraulic conductivity = 7 ft/day based on slug test at TT-8
Groundwater flow under the tailings dam into the Southeast Drainage = 24.9 ft^3/day or 0.13 gpm

This represents a small percentage of the estimated 5 gpm (**Attachment 1**) recharge to the tailings impoundment. As previously noted, the majority of this recharge likely enters the TDSS through outcrops under the impoundment, with a minor amount providing underflow into the Southeast Drainage.

This underflow mixes with seasonal infiltration from surface runoff as it moves downgradient within the regolith. Groundwater flux at the mouth of the Southeast Drainage was also estimated based on Darcy's Law, as follows:

Flow depth = 30 ft based on saturated thickness at BBL-4
Flow width = assume 75 ft
Flow area = 2,250 ft^2

Hydraulic gradient = 0.003 ft/ft based on the gradient between BBL-3 and BBL-4
Hydraulic conductivity = 7 ft/day based on slug test at TT-8
Groundwater flux at bottom of Southeast Drainage = 46.3 ft^3/day or 0.24 gpm

Groundwater flux at the mouth of the Southeast Drainage is thus approximately twice the underflow at the dam. This groundwater flow mixes with groundwater flow within the North Fork Box Creek alluvium in the vicinity of Well TT-7 (**Figure 1-28**). Groundwater flow from upgradient of this area was estimated based on Darcy's Law, as follows:

Flow depth = assume 50 ft for average alluvial thickness
Flow width = 600 ft measured width from topographic maps
Flow area = 30,000 ft^2
Hydraulic gradient = 0.004 ft/ft based on the gradient between TT- 5 and TT-7
Hydraulic conductivity = assume 30 ft/day as representative of alluvium
Groundwater flux at bottom of Southeast Drainage = 3,600 ft^3/day or 18.7 gpm

Based on this estimate, the amount of groundwater flow from the Southeast Drainage (0.24 gpm) is approximately 1.3 % of the estimated flow in North Fork Box Creek (18.7 gpm) in the vicinity of TT-7.

2.2.2 Predicted Long-Term Hydrologic Conditions

Predicted Long-Term Tailings Seepage

The long-term tailings seepage will be derived from ongoing recharge through the tailings impoundment, which is assumed to be similar to natural background recharge. As noted, this recharge has been estimated to range from 3 to 5 gpm. The majority of this recharge is expected to flow into the TDSS, with minor flows moving under the tailings dam to the Southeast Drainage.

Pit Lake Hydrology at Steady State

The water level within the Pit Lake will rise until a general equilibrium is reached between groundwater and surface water inflows and evaporative outflows. Recent numerical modeling using conservative assumptions as to the local availability of groundwater and hydraulic gradients toward the pit predicts a final Pit Lake elevation of approximately 5,060 feet amsl in Year 2054 and that the lake will act as a long-term hydraulic sink (**Attachment 1**). These estimates are considered a reasonable representation of potential long-term conditions.

Southeast Drainage Regolith

Long-term groundwater flow in the Southeast Drainage will be similar to current conditions that are affected by the presence of the tailings impoundment and the small post-mining watershed. Underflow from the dam is currently estimated at 0.13 gpm. Long-term groundwater flow in the Southeast Drainage will continue to be limited to the regolith underneath and adjacent to the channel. Flow will primarily be in response to recharge from surface runoff within the small watershed. Long-term flow from the Southeast Drainage into North Fork Box Creek will likely remain at a low rate (0.24 gpm or less). Long-term flow within the North Fork Box Creek alluvial system also will likely not change from current conditions.

2.2.3 Predicted Contaminant Transport

The degree of contaminant transport is controlled by the rate and direction of groundwater flow, in conjunction with potential geochemical reactions which could retard the migration of COCs in groundwater. In the CSM, as described in Section 1.3.2, oxidizing acidic tailings seepage (pH = 2), containing elevated chloride, sulfate, uranium, selenium and other metals migrates downward where it reacts with calcite ($CaCO_3$) in the TDSS. Dissolution of calcite causes the pH to increase, and in the presence of high sulfate, promotes precipitation of gypsum ($CaSO_4 \cdot 2H_2O$). The relative solubility and mobility of uranium and other tailings-derived constituents following calcite dissolution are controlled by adsorption/desorption reactions and the oxidation-reduction (redox) conditions in the groundwater as illustrated in **Figure 1-36.**

Under oxidizing conditions, precipitation of iron hydroxides is promoted by the increase in pH resulting from calcite dissolution. Iron hydroxides have the potential to limit the migration of uranium (VI) and other COCs through adsorption, and are known to be the most important potential sorbents for uranium (Langmuir, 1997). The actual extent of surface adsorption depends on factors such as: (1) the amount of iron hydroxide precipitated, (2) the concentration and solution speciation of the constituent of interest, (3) the concentrations of potential competing ions (e.g., sulfate), (4) total dissolved solids concentration, and (5) pH. The adsorption behavior of uranium and selenium specifically depends on its solution speciation, which in turn is a function of pH, redox, and the concentrations of potentially complexing ions. Uranium(VI) and selenium(VI) which become adsorbed under oxidizing conditions can be desorbed and released back into solution, provided there is an increase in alkalinity or pH (Langmuir, 1997).

Under reducing conditions (e.g., Eh < 200 mV and near-neutral pH), uranium is found primarily in the reduced uranium (IV) oxidation state, where it precipitates as insoluble uraninite (UO_2) or coffinite ($USiO_4$) (Langmuir, 1997). This scenario is analogous to the original ore-forming process, where uranium transported in oxidizing waters encounters a redox interface containing a reductant such as organic matter or pyrite. Uranium precipitation, rather than adsorption, is more important in this case due to the low solubility of the uranium (IV) minerals and the instability of Fe(III) hydroxides under reducing conditions. Therefore, tailings-impacted groundwater under reducing conditions is expected to contain low to non-detectable uranium concentrations and measurable iron, while the concentrations of sulfate and chloride would remain elevated.

2.2.3.1. Tailings Dam Sandstone (TDSS)

The major ion chemistry of tailings-impacted TDSS groundwater is consistent with the conceptual geochemical model discussed in Sections 1.3.2 and 2.2.3. The neutral pH (above 6) and sulfate concentrations are consistent with calcite dissolution followed by gypsum precipitation, which reduces the concentration of sulfate to 2,000 to 4,000 mg/L.

The geochemical speciation model PHREEQC was used to calculate the distribution of uranium solution species in tailings-impacted Wells 112, 114, 120, and 178. These four wells represent acidic tailings solution which has been neutralized by calcium carbonate, as indicated by neutral pH conditions (pH = 6.0 to 7.1) and equilibrium conditions with respect to gypsum. The solution speciation was calculated using the most recent sample results (2002) that included both uranium and the full suite of major ions. The speciation results were consistent with those in **Table 2-8** and indicate that greater than 99% of the dissolved uranium which is present in tailings-impacted wells exists as uranium-carbonate complexes. The presence of uranium-carbonate complexes limits the extent of uranium adsorption in oxidizing waters and therefore contributes to uranium mobility.

The solution speciation calculations indicate the dissolved uranium would be mobile in groundwater; however, there was a large range in the absolute concentration of uranium (<0.0003 to 0.0363). This large range in uranium concentration indicates the presence of variable redox conditions, and consequently varying degrees of uranium mobility in the TDSS. Under reducing conditions, uranium(IV) becomes insoluble, while dissolved iron(II) concentrations remain measurable. When conditions become oxidizing, iron(III) hydroxides precipitate, dissolved iron concentrations are below detection, but the dissolved uranium(VI) remains mobile because it exists in solution as uranium-carbonate complexes (**Table 2-8**).

The relationship between iron and uranium is shown on **Figure 2-13** and is consistent with variable redox-control of uranium in the TDSS. When measurable iron concentrations are present (>0.05 mg/L), uranium concentrations are consistently below 0.003 mg/L, indicating reducing conditions. The two samples with uranium concentrations equal to or greater than approximately 0.003 mg/L were associated with non-detectable concentrations of iron (<0.05 mg/L), indicating more oxidizing conditions. Relative to the tailings impoundment, these data indicate oxidizing conditions to the south (Well 178) and east (Wells 112, 125), with reducing conditions to the north (Wells 120, 181, 183) and west (Well 114) (**Figure 1-2**).

Well 175, however, presents an exception to the redox control of uranium observed in the majority of monitoring wells. Well 175 contained elevated iron concentrations (247 mg/L) along with measureable uranium (0.0065 mg/L) **(Figure 2-13)**. Uranium concentrations have also been increasing at Well 175, while uranium concentrations in many of the tailing-impacted wells have been decreasing following Site reclamation. The observed chemistry at Well 175 and its location on the western edge of the impoundment suggest that this well may be located on a redox boundary, where a mixture of oxidizing and reducing waters is captured during sampling.

2.2.3.2. *Southeast Drainage Regolith*

A description of COC concentrations and uranium trends in the Southeast Drainage alluvial groundwater was presented in Section 2.1.1. With respect to contaminant transport, groundwater in the Southeast Drainage regolith generally contains high bicarbonate concentrations (200-500 mg/L) and neutral pH values (6.5 to 7.5). In shallow alluvium under these conditions, uranium would also exist as relatively mobile uranium-carbonate complexes (Section 2.2.3.1). Because the source of tailings solutions to the Southeast Drainage has diminished, uranium will continue to move downgradient, but with decreasing concentrations (Section 2.1.1). Therefore, attenuation of uranium between the POC and POE in the Southeast Drainage occurs primarily through dilution with fresh recharge and mixing with downgradient groundwater.

Even though the maximum concentrations of selenium and radium-226+228 exceed MCLs at single wells, their concentrations are expected to be protective at the POE as a result of natural dilution in the Southeast Drainage. For example, the increase in volumetric flux from 0.16 gpm at BBL-2 and BBL-3 to 0.24 gpm at BBL-4 represents a dilution factor of 1.5. Using the maximum selenium concentration of 0.078 mg/L at BBL-2, natural dilution, regardless of natural retardation that would be expected to occur, would reduce the selenium concentration to a protective value of 0.05 mg/L at Well BBL-4. Similarly, the maximum radium-226+228 activity of 7.24 pCi/L at BBL-3 would be reduced to a protective value of 4.83 pCi/L at BBL-4.

The Upper Southeast Drainage contains OBSS monitoring well BBL-1 and regolith monitoring wells TT-8, BBL-2, and BBL-3, while the Lower Southeast Drainage contains regolith monitoring well BBL-4 and alluvial monitoring wells TT-4 through TT-7. In the Site hydrogeochemical conceptual model (Section 1.3), the limited residual seepage from the tailings migrates under the tailings dam and introduces tailings constituents into the limited Southeast Drainage groundwater system. The concentrations of these constituents decrease with increasing distance down the Southeast Drainage toward North Fork Box Creek due to mixing and/or geochemical attenuation. Uranium concentrations in Well BBL-1 have been consistently below detection (<0.0003 mg/L), and together with the low sulfate and chloride concentrations (**Table 2-3**) indicate that the 50SS is not impacted by tailings seepage in the Southeast Drainage.

Well TT-8, the first well encountered downgradient of MFG-1 and completed in the regolith, contains an average uranium concentration of 0.118 mg/L, which is intermediate between the average uranium concentration of 0.336 mg/L in MFG-1 and 0.0526 mg/L in Well BBL-2, the next sequential downgradient regolith well (**Table 2-3**). Uranium concentrations in Well BBL-3 are similar to those measured in BBL-2 (**Figure 2-14**), indicating there is no significant mixing and/or attenuation of uranium due to the relatively short travel distance between the two wells. The limited amount of data for Well TT-8 do not allow for evaluation of long-term trends at that location, but the slightly decreasing trends in uranium concentration observed in Wells BBL-2 and BBL-3 since 2006 (**Figure 2-14**) indicate a decreasing source contribution from MFG-1.

In the Lower Southeast Drainage, the effects of mixing and/or attenuation are apparent as the concentration of uranium in the regolith/alluvium continues to decrease with distance downgradient from the proposed POC Well MFG-1 to Well TT-5 near North Fork Box Creek. Sulfate and chloride concentrations generally follow this same pattern of decreasing concentrations with increasing downgradient distance from the tailings, with a minor deviation observed in Well BBL-3. The concentrations of uranium in Wells TT-4, TT-5, and TT-6, in the vicinity of North Fork Box Creek, are below the MCL of 0.03 mg/L (**Table 2-3** and **Figure 2-15**). However, higher uranium concentrations exist at Well TT-7. Therefore this location was selected as a conservative POE for North Fork Box Creek, which only flows intermittently. The average uranium concentration at TT-7 (0.0466 mg/L) is slightly above the uranium MCL (**Table 2-3** and **Figure 2-15**).

The uranium isotopic data collected in 2009, which are discussed in detail in Section 2.1.2.4, are consistent with dilution of uranium concentrations in the regolith/alluvium with distance from the source. Well MFG-1 has a distinct tailings signature, as indicated by the high uranium concentration and a $^{234}U/^{238}U$ AR near 1.0 (**Figure 2-16**). In contrast, natural groundwater generally contains lower uranium concentrations and higher AR values compared to tailings. Therefore, mixing of tailings water with natural groundwater in varying proportions produces a line of mixing as shown for the Southeast Drainage regolith/alluvium wells on **Figure 2-16.** A general trend of decreasing uranium concentration with increasing AR is evident with distance downgradient from Well TT-8 to Well TT-4. The location of Well TT-7 along the mixing line on **Figure 2-16** indicates that it is in closer hydrologic connection to the Southeast Drainage regolith, and therefore this location provides an appropriate representation of maximum potential uranium concentrations at the POE. Displacement of Wells TT-5 and TT-6 from the isotopic mixing line indicate a distinctly different isotopic signature which is potentially unaffected by tailings and may be influenced by mixing within the North Fork Box Creek alluvial water.

2.2.4 Summary of Transport Assessment

The updated hydrologic and contaminant transport conceptual model at Highland is consistent with certain components of the historical model and modifies other components. Specifically, the updated model recognizes transport of 11e.(2) hazardous constituents down the Southeast Drainage and into the Highland Pit Lake, which modifies the historical CSM that presumed that such transport had not and would not occur. The updated model is based on re-analysis of historical data as well as on analyses presented in this Application.

In keeping with the historical conceptual model, large amounts of tailings fluid seeped into the uppermost aquifer hosted by the TDSS. As much as one billion gallons of impacted groundwater from the TDSS migrated to the Highland Pit Lake, though seepage has greatly diminished since the cessation of mining and completion of surface reclamation. This has allowed uranium to be transported down the Southeast Drainage and toward the Pit Lake but has continued to retard hazardous constituent transport north and west. This has occurred because redox conditions in the TDSS, which largely controls the mobility of uranium and other redox sensitive hazardous constituents, are not uniformly reducing but rather are oxidizing up-dip in the TDSS to the south and east of the tailings impoundment where the TDSS outcrops nearby. Farther down-dip in the TDSS and away from the source of oxidized waters, the groundwater remains reduced. Transport of 11e.(2) byproduct material derived hazardous constituent into the Pit Lake was not part of the historical conceptual model.

The historical groundwater inflow to the Pit Lake from the TDSS has caused the hazardous constituents uranium and selenium to exceed their respective MCLs in the Pit Lake while all constituents remain below their respective MCLs in the POC wells to the north. The Pit Lake is currently, and will remain, a hydrologic sink due to net evaporation exceeding groundwater inflows, thereby containing the hazardous constituents in the Pit Lake. Current and predicted long-term seepage from the tailings and seepage of impacted groundwater from the TDSS into the Pit Lake is minimal and will have negligible additional impact on long-term Pit Lake water quality.

A portion of the historical tailings seepage also migrated under the tailings embankment and discharged into the surface flows and limited groundwater system of the Southeast Drainage. The alluvial groundwater system is limited in lateral extent and receives recharge from tailings seepage from under the tailings embankment and from seasonal surface infiltration. This limited groundwater system discharges into the similar alluvial groundwater system of North Fork Box Creek. Minor tailings fluid seepage and transport of hazardous and non-hazardous constituents down the Southeast Drainage are anticipated to occur in perpetuity.

Though tailings seepage underflow to the Southeast Drainage has diminished since the cessation of mining and completion of surface reclamation, historical and current seepage has resulted in concentrations of the hazardous constituent uranium to be above the MCL throughout the Southeast Drainage. The constituents selenium and radium-226+228 are also above their respective MCLs in single isolated occurrences but not at the head of the Southeast Drainage, nearest the tailings impoundment. Uranium is anticipated to remain above its MCL in the Southeast Drainage groundwater in perpetuity while natural dilution alone will ensure that the isolated occurrences of selenium and radium will be below their respective MCLs at the confluence of the limited Southeast Drainage and North Fork Box Creek groundwater systems.

2.3 Exposure Assessment

The following sections discuss future land and water use at the Site, identify the POEs for hazardous constituents in the Southeast Drainage and Highland Pit Lake, identify potential exposure pathways and receptors for the hazardous constituents in the Southeast Drainage and Highland Pit Lake, summarize the results of an ecological risk assessment of the Highland Pit Lake, and establish risk-based concentrations (RBCs) that are protective of public health, safety and the environment for the POE.

2.3.1 Current and Potential Future Land and Water Use

As discussed in Section 1.2.2.2, primary land uses in the project area have traditionally been open grazing of livestock and dry-land farming. Current land uses are open grazing of livestock and very limited irrigated farming. Oil and gas development occur to the east of the project area and uranium ISR operations occur to the north and west. The Site is 25 miles from any town or housing area with the exception of two ranch houses within 5 miles west and east of the Site. The Site is accessible via a private 5-mile easement across open range.

Projection of future land use is speculative because Wyoming population changes and the associated impact on land use are dramatically affected by regional and national economic issues that do not necessarily follow linear trends through time. In addition, population growth tends to concentrate more around cities, towns, and major transportation corridors and less in remote rural areas traditionally held by family ranches. As a result, using historical short-term population changes as a basis for long-term projections for specific regions is unreliable due to the extremely high uncertainty associated with the assumptions that underlie the projections.

The Highland Site is approximately 25 miles from the two nearest towns, Glenrock and Douglas, Wyoming, and is not near major transportation corridors or other geographic or cultural features that would attract population growth. The U.S. Census Bureau (2005) indicates that there were 493,782 people in Wyoming in 2000 and a projected population of 522,979 for 2030, a projected 5.9 percent population increase. The 2000 census data for Converse County, Wyoming indicate a population of 12,052 with a population density of 2.8 persons per square mile. A population estimate for Converse County for 2009 was 13,578 persons or 3.1 persons per square mile, indicating a 12.6% increase in 9 years (U.S. Census Bureau, 2010). This short period coincided with a period of increased energy development in Wyoming and the growth rate is not likely reflective of long-term sustainable population growth.

Even with the historical and ongoing natural resource development in the area, the Highland Site has not had significant residential population growth or groundwater resource development adjacent to the project area, and minimal future population growth would be expected. The local population density is less than one person per square mile and the long-term area rural population growth since the state of Wyoming was established is less than 0.01% per year. Therefore, there is essentially no projected future change in land use or significant population growth for the project area.

Projected Future Water Use Demand

Projection of future water use demand for the area is as speculative as projection of future population growth and land use. In the case of the Southeast Drainage, the groundwater resources are not irrevocably removed from the hydrologic cycle and all future use. Rather, only access to the limited groundwater resource over a shallow depth and discrete area for domestic consumption would be impacted. All other uses would continue to be protective of public health, safety and the environment, and the water, once it enters the North Fork Box Creek groundwater system, remains available for all appropriate uses. Therefore, projection of future water use demand for the Southeast Drainage groundwater system is focused solely on that specific drainage and not regionally as the availability of the resource to the region is in no way impaired.

The projected change in future water use demand on this small individual drainage directly adjacent to the reclaimed mine is considered to be very low compared to current demand, which is essentially none. This projection is based on the remote location of the Site relative to populated areas, the low population density in the County and project area, and the projected population growth and changes in future land use.

The assessment of future demand for the Highland Pit Lake as a drinking water source is similar to that of the Southeast Drainage groundwater. The Highland Pit Lake is also remote from existing population centers, and is subject to the ubiquitous bacteriological contamination of surface waters and shallow alluvial waters in the western states (e.g., giardia). In addition, the Pit Lake is not highly visible from surrounding areas nor is it easily accessed. As a result of its limited visibility, limited access, and other factors mentioned previously, there is little to no projected change in water use demand for the Pit Lake.

2.3.2 Points of Exposure (POE)

The proposed LTSB illustrated in **Figure 1-37** defines the POE for the Site and the area over which institutional controls will be applied. Hazardous constituents from tailings seepage have accumulated in the Southeast Drainage and the Pit Lake at concentrations above their MCLs, and the sole practicable alternative identified necessitates inclusion of the Pit Lake and the Southeast Drainage within the LTSB (see Section 3.2). The area encompassed by the proposed LTSB ensures control over access to the 11e.(2) byproduct material and associated potential hazards as well as long-term access to environmental monitoring locations at the Site.

Because there are currently engineered controls (site access fences and gates with frequent site inspections) and institutional controls (land title) for the Southeast Drainage and Highland Pit Lake, there is no current potential for human exposure to hazardous constituents from these exposure points. The POE for the hazardous constituent migration down the Southeast Drainage is at the drainage's confluence with North Fork Box Creek. This location is currently monitored quarterly at Well TT-7.

Though little if any groundwater from the TDSS still flows to the Pit Lake at this time, sufficient hazardous constituents from the tailings seepage historically migrated to the Pit Lake to make it a POE for the hazardous constituents uranium and selenium. Due to its evaporative nature, the Highland Pit Lake is now and will perpetually be a hydrologic sink and will contain and prevent these hazardous constituents from further migration. The pit is currently monitored at three depths from a single, central sampling location, on a semi-annual basis (**Figure 3-1**).

2.3.3 Human Receptors and Exposure Pathways

As mentioned, existing engineered controls (fencing, gates, steep topography, and frequent site inspections) as well as institutional controls (land title) currently preclude human exposure to hazardous constituents in the Pit Lake and Site groundwater.

Southeast Drainage

The hazardous constituents from the tailings have migrated downgradient within the limited groundwater system of the Southeast Drainage and North Fork Box Creek alluvium. The groundwater system is limited to the weathered bedrock materials associated with Southeast Drainage and the alluvium of North Fork Box Creek.

Access to these limited water resources is solely through the floodplain and channel materials, which are relatively shallow with thin saturated thicknesses, as described in Section 1.2.2.7. Further, the regolith/alluvial floodplain and channel deposits do not extend under the terraces formed by un-weathered bedrock. The alluvial floodplain of North Fork Box Creek is regularly inundated by seasonal rains and the resulting overbank flow from the primary flow channels. Further, the alluvial floodplain and primary flow channels of North Fork Box Creek have poor access due to the steep topography resulting from the channel incision into the lithologic formations. In addition, the ephemeral surface water is subject to biological fouling (giardia and fecal coliform bacteria) by wildlife and livestock.

Based on the remote nature of the Site, the establishment of a domestic drinking water supply from surface water or groundwater at the Southeast Drainage POE and subsequent infrequent acute human exposure through ingestion are unlikely exposure scenarios. Therefore, no additional assessment of human exposure is considered at the POE for the Southeast Drainage.

Pit Lake

The Pit Lake could be a potential source for human consumption without appropriate controls. MCLs are the appropriate RBCs for the Pit Lake to assess the risk of exposure to these hazardous constituents through the drinking water pathway. The concentrations of selenium and uranium in the Pit Lake are greater than the drinking water MCLs.

As described previously, the Pit Lake is a groundwater sink and barrier to migration of tailings seepage to the west of the tailings impoundment. The Pit Lake represents the POE west of the tailings and is the western boundary of the LTSB (**Figure 1-37**). It is currently secured from human access, however, without institutional controls it could be used as a source of drinking water. Additionally, the Pit Lake is available to ecological receptors and hazardous constituents could accumulate through the food chain.

2.3.4 Ecological Receptors and Exposure Pathways

Southeast Drainage

North Fork Box Creek and the Southeast Drainage are classified as a Class 3B surface water bodies as defined in Section 4(c)(ii) of Chapter 1 of the Wyoming Water Quality Standards and as identified in the Wyoming Surface Water Classification List (WDEQ, 2001). Class 3B waters are tributary waters including adjacent wetlands that are not known to support fish populations or drinking water supplies and where those uses are not attainable. Class 3B waters are intermittent and ephemeral streams with sufficient hydrology to normally support and sustain communities of aquatic life including invertebrates, amphibians, or other flora and fauna that inhabit water at some stage of their life cycles. Based upon this classification and the nature of this portion of North Fork Box Creek, the ephemeral surface waters are a potential drinking water source for livestock and wildlife. These waters also create sporadic and isolated habitat for aquatic biota and terrestrial plants but are not a reasonable human domestic drinking water source. Livestock consist primarily of cows and sheep, while the large mammalian wildlife consists primarily of deer and pronghorn antelope.

Although no survey of wildlife was conducted for the Southeast Drainage area, smaller mammalian wildlife receptors are assumed to be similar to those identified in the ecological risk assessment of the Highland Pit Lake (see Tetra Tech and Redente Ecological Consultants, 2011 included as **Attachment 3**). These mammals include muskrats, meadow voles, deer mice, and predators such as the coyote, red fox, skunk, badger, and raccoon. Avian species are also assumed to be similar to those identified in the Pit Lake ecological risk assessment although the populations would be expected to much lower due to limited nesting habitat and the smaller amount of available surface water. Additional pathways for potential exposure include avian species ingestion of terrestrial plants and aquatic biota and larger mammals grazing on terrestrial plants.

Pit Lake

As described in the ecological risk assessment of the Pit Lake (**Attachment 3**), a simplified CSM of the Pit Lake ecosystem was developed to visually represent some of the biological components of the Pit Lake potentially at risk from COCs. The CSM schematically presents the relationship between chemical sources and classes of receptors at the Site and identifies potentially complete and significant pathways through which ecological receptors may be exposed to the identified constituents of potential ecological concern.

The aquatic and terrestrial receptors evaluated in the ecological risk assessment and the relevant exposure pathways considered are summarized below.

Aquatic Receptors:

- Aquatic plants (e.g., cattails and algae) – direct contact with surface water and sediment;
- Benthic (i.e., sediment) invertebrates – direct contact with surface water and sediment;

- Zooplankton – direct contact with surface water;
- Aquatic-feeding birds and mammals – direct contact with surface water and ingestion of biota; and
- Herbivore mammals (e.g., deer) – direct contact with surface water.

Terrestrial Receptors:

- Terrestrial plants – direct contact with soil;
- Invertebrates – direct contact with soil;
- Herbivores (e.g., mule deer and meadow vole) – ingestion of surface water and biota (e.g., grass), also ingestion of soil for meadow vole; and
- Carnivores (e.g., red-tailed hawk) – ingestion of biota (e.g, meadow vole).

There are no fish known in the Pit Lake. A total of about 45,000 rainbow, cutthroat, and hybrids of the two species were planted in the Pit Lake on two occasions in the 1990s in an attempt to establish a fishery in the lake. The results from the investigations conducted for the ecological risk assessment determined that the lake cannot support a fish population primarily due to the general configuration of the lake which has a very small shallow water zone conducive to establishment of an aquatic biological community.

While no listed species were recorded in Wyoming Natural Diversity Database (as of 1/23/06) as occurring in the township containing the Pit Lake, two of the listed species were observed in the general area of the Pit Lake. The short-eared owl (*Asio flammeus*) and golden eagle (*Aquila chrysaetos*) were both observed on several occasions in the general area of the Pit Lake. The short-eared owl, a ground nester, was assumed to have nested in the area based on repeated observations of the birds in the same general area.

2.3.5 Summary of Risk Assessment and Protective Concentrations of COCs at the POE

Southeast Drainage

As identified in the previous section, there is no reasonable human pathway for exposure through a surface water or groundwater ingestion pathway for the Southeast Drainage at the POE. Therefore, the protective RBCs should be protective of the beneficial uses supported by the water, which are the support of aquatic life and watering for wildlife and livestock.

Neither EPA nor Wyoming have promulgated standards for uranium for these receptors (wildlife or livestock). Wyoming previously had a uranium standard of 5 mg/L for livestock and 1.4 mg/L for aquatic life (WDEQ, 2005), however, these standards were recently rescinded. Colorado has the following uranium standards for support of aquatic life (CDPHE, 2009).

Acute = e(1.1021[ln(hardness)] + 2.7088)
Chronic = e(1.1021[ln(hardness)] + 2.2382)

These equations are valid for hardness (as mg/L $CaCO_3$) of 400 mg/L or below. The hardness of North Fork Box Creek exceeds 400 mg/L. Using a hardness value of 400 mg/L in the equations above, the protective acute exposure uranium concentration is 11.1 mg/L and the chronic protective chronic exposure uranium concentration is 6.9 mg/L. The Wyoming rescinded uranium aquatic standard of 1.4 mg/L is considered a conservative RBC and protective for ecological exposures. This is supported by the information and analysis presented in the Highland Pit Lake Ecological Risk Assessment (**Attachment 3**).

The hazardous constituents selenium and radium-226+228 are slightly above their respective MCLs at one well each. As discussed in Section 2.2.3.2, Site characterization data and conservative assessment of their transport indicates that these hazardous constituents currently do not and will not exceed their respective MCLs at the Southeast Drainage POE. Therefore there is no current or potential future hazard from selenium or radium-226 +228 at the POE for the Southeast Drainage.

Pit Lake

The Highland Pit Lake Ecological Risk Assessment is included as **Attachment 3**. In this assessment a phased approach was used to assess risks from selenium and uranium to Pit Lake biota via several exposure pathways. Terrestrial plants, aquatic biota, birds, and mammals were assessed as potential receptors.

In the risk analysis, measured selenium and uranium concentrations were compared with toxicity reference values (TRVs). TRVs represent known levels of effects for specific exposure ranges based upon dose-response studies conducted primarily in the laboratory. Both conservative and less conservative no observed adverse effects level (NOAEL) TRVs were used to evaluate the potential risk. NOAELs for a given exposure pathway encompass a range of concentrations at which no toxic effects are expected and are generally understood to be safe to individual organisms. In some cases, low observed adverse effects level (LOAEL) TRVs were used to represent conditions that were protective of populations of organisms instead of individuals as is inferred from the use of NOAELs.

Estimating effects based on exposure involves comparing measured selenium and uranium concentrations with the media specific TRVs. Results are expressed as a Hazard Quotient (HQ) (EPA, 1997) where:

Hazard Quotient (HQ) = Exposure Point Concentration (EPC) ÷ TRV

If the HQ is less than 1.0 (indicating the exposure concentration or dose is less than the TRV), the occurrence of adverse effects is very unlikely. If the HQ is equal to or greater than 1.0 (indicating the exposure is equal to or greater than the TRV), there is some potential for adverse effects to occur (EPA, 1997). In practice, the general guidelines below are followed (**Attachment 3**):

- HQ < 1: No Significant Risk;
- 1<HQ<10: Small Potential for Adverse Effects;
- 10<HQ<100: Significant Potential for Adverse Effects;
- >100: Expected Adverse Effects.

The risk analysis was conducted in a phased approach beginning with a very conservative analysis, designated as a screening level assessment, and ending with a less conservative analysis, designated as a baseline assessment. In both cases, the underlying criteria for judging whether risks to biota were acceptable were the choice of TRVs used in the assessments.

For the screening level assessment, a highly-conservative approach was used including the use of the maximum detected concentrations in Pit Lake samples as exposure point concentrations and the most conservative (i.e., lowest reported effect) TRV value. If this comparison indicated low potential for adverse effect, the selenium and/or uranium was not considered further. If this was not the case, a more realistic evaluation of exposure and effects were conducted using 95th percentile upper confidence limits (UCLs) as the exposure point concentration and the less conservative TRV that is still protective of individual receptors or, in all cases, receptor populations.

Based on the conservative screening analysis, about half of the exposure scenarios for selenium and uranium exceeded applicable TRVs. However, the less conservative baseline analysis showed that the 95th percentile UCLs concentrations of selenium and uranium in Pit Lake biota were generally below NOAEL or LOAEL concentrations. After the baseline assessment, the following four selenium and one uranium exposure pathways yielded HQs >1.5:

- Benthic invertebrates – Shorebirds (HQ = 7.8) (selenium);
- Benthic invertebrates – Waterfowl (HQ = 7.8) (selenium);
- Grass – Rodent (HQ = 1.9) (selenium);
- Meadow vole – Red-tailed hawk (HQ = 1.7) (selenium);
- Benthic invertebrate tissue (HQ = 1.6) (uranium).

All of the remaining aquatic and terrestrial exposure pathways for the baseline assessment had HQs less than 1.5.

While a risk analysis may indicate a potential for adverse effects based on numerical comparisons, it is important to interpret the significance of the risk analysis within the context of the physical and biological characteristics of the Pit Lake. This final step in the assessment evaluates the significance of selenium and uranium concentrations in biota with respect to the type and amounts of habitat, biological productivity, and recorded use of the Pit Lake by wildlife. These physical and biological attributes of the Pit Lake determine the potential magnitude and significance of food chain transport of selenium and uranium to aquatic and terrestrial consumers.

Highland Pit Lake provides little habitat and primary and secondary biological productivity to maintain a significant permanent aquatic plant and animal community or to host migrant species that frequent the lake primarily during summer months. This is primarily due to the general configuration of the lake which has very steep banks with a very small shallow water zone conducive to establishment of an aquatic biological community.

The conclusion resulting from the chemical assessment alone was that risks to most receptors were below accepted safe level criteria. The few pathways that resulted in HQs exceeding 1.5 after the final TRV screening were either not complete (i.e., benthics to avifauna), were not observed during frequent visits to the Site, or were less than full time exposures, as is assumed in the published TRVs.

Integrating habitat and biomass estimates into the interpretation of the chemical data, including food availability and frequency of use of the lake by migratory species, leads to the conclusion that risks to resident and migratory biota at Highland Pit Lake are very low.

3.0 CORRECTIVE ACTION ASSESSMENT

This section summarizes the previous corrective actions undertaken at the Site and assesses alternative corrective actions for protecting human health and the environment. **Appendix E** presents the detailed analysis of corrective action alternatives.

3.1 Results of Corrective Action Program

Several actions have been undertaken to mitigate groundwater impacts from tailings seepage since operations ceased in 1984. These actions include operational actions to reduce seepage, reclamation actions to reduce seepage, and the 1989 CAP.

3.1.1 Operational Actions to Reduce Tailings Seepage

Prior to 1987 when Criterion 5 of Appendix A to 10 CFR Part 40 became effective, the only tailings seepage control requirement at Highland was to return seepage that came to the surface to the tailings impoundment. However, Exxon took steps before 1987 to reduce seepage. These steps included operating an evaporation system (1970s), recycling tailings liquid to the mill, and operation of a uranium recovery system at the tailings (1970s to mill shut-down in 1984). These efforts reduced the hydrostatic head in the tailings, which resulted in reduced seepage rates, reduced uranium and sulfate mass in the tailings pore water, and lower total acid content in the seepage. Section 3 of the 1998 ACL Application (ECMC, 1998) discusses these actions and their effects in greater detail.

3.1.2 Reclamation Actions to Reduce Tailings Seepage

From 1984 until 1988, Exxon accelerated the removal of water from the tailings and reduced tailings seepage by operating an evaporative spray system and evaporation lagoons in concert with preparations for final reclamation. After the water was removed from the tailings surface, the tailings were re-contoured and a thin interim cover of clayey fill was placed to prevent wind migration of tailings. In addition, recovered windblown tailings were placed in the tailings impoundment in 1989. By the end of 1989, no water remained on the tailings surface and most of the tailings had been covered with soil.

All the tailings were subsequently covered with a low permeability radon barrier consisting of compacted clay. The final vegetated soil cover was constructed over the radon barrier on the entire tailings surface except for a 20-acre area in the middle of the impoundment where the seepage mitigation pond was located. By the end of 1990, the topsoiled areas were planted with permanent vegetation. The radon barrier in the final tailings cover provides effective control over infiltration of rain and snowmelt. The vegetated cover further reduces infiltration by evapotranspiration. Between the radon barrier and the vegetation, the water infiltration has been reduced to about three to five gallons per minute for the entire tailings impoundment.

3.1.3 1989 Corrective Action Program

On August 15, 1989, Exxon submitted a revised groundwater CAP to the NRC (ECMC, 1989b). The CAP approved by NRC on August 18, 1989 via License Amendment No. 32, consisted of pumping the five existing wells (Wells 114, 117, 175, 177 and 178) which were completed in the TDSS in the area of highest COC concentrations, and evaporating the recovered water in lined ponds on a non-reclaimed portion of the tailings impoundment.

Exxon began operating the NRC approved CAP in November of 1989. NRC approved discontinuing pumping from Well 114 in 1990 since the well was unproductive. Suspension of winter operation was approved in 1994 (License Amendment No. 44). The system recovered 15.0 million gallons through 1997. This recovered groundwater contained about 300 metric tons of dissolved solids including 54 kilograms of non-radioactive, potentially hazardous constituents and 1.3 millicurie of radioactive constituents. The potentially hazardous constituents were precipitated with the non-hazardous solids that were deposited at the bottom of the evaporation pond.

In 1998, Exxon submitted an ACL application for POC Wells 125, 175 and 177 with a demonstration that continued pumping was no longer practicable. In May 1999, via License Amendment No. 49, NRC approved the proposed ACLs and cessation of CAP pumping. The remaining evaporites were buried under the final reclamation cover.

Via License Amendment 49, the NRC concurred that there remained no practicable corrective actions for mitigating groundwater impacts from 11e.(2) byproduct material in the TDSS, that the current ACLs present no significant hazard to public health, safety and the environment, and that the limits are as low as reasonably achievable. Based on new Site data described in Section 2 of this application, it has been determined that additional groundwater impacts from 11e.(2) byproduct material are present in concentrations above the license standards (Condition 33B) in the limited Southeast Drainage groundwater system and in the Highland Pit Lake.

3.2 Alternative Corrective Actions

A range of practicable alternative corrective actions have been assessed to comply with the requirements of 10 CFR Part 40, Appendix A, Criterion 5B(4) and 5B(6) (NRC, 1996; 2000). The corrective action alternatives address contaminant source control by removing groundwater hazardous constituents at the POC or treating them in place. The alternatives also address removing and treating any hazardous constituents that exceed MCLs in the Highland Pit Lake and in the groundwater between the POC and the downgradient property boundary of the Southeast Drainage. Corrective action alternatives considered both active and passive methods as well as in-situ and ex-situ treatment technologies.

3.2.1 Alternative Corrective Action Assessment Criteria

Each of the corrective action alternatives has been evaluated for practicability and costs. The evaluation of practicability for each alternative was performed using the following criteria.

- Engineering Feasibility: This criterion assesses the degree of engineering or technical practicability by considering whether the technologies are proven or experimental and whether it is possible to apply the technology to the site specific conditions.
- Effectiveness: This criterion assesses to what degree the alternative can reduce impacts to groundwater or Pit Lake water quality.
- Durability: This criterion assesses how long the remedy will maintain protective conditions that are ALARA and the capital life of the equipment.
- Degree of Active Maintenance: This criterion assesses the number of times the capital life of the equipment will be exceeded within the design performance period and the amount of maintenance the alternative would require to maintain the efficacy of the alternative.

Each practicability criterion is given a relative ranking of excellent, moderate, or poor for each alternative, with excellent being the most desirable ranking. Further, the costs for each alternative were also evaluated, specifically:

- Capital Costs: These costs comprise the cost of designing, purchasing, and installing all capital equipment and infrastructure for each alternative; and
- Operating Costs: These costs comprise the labor, utilities, and supplies necessary for operating each alternative.

3.2.2 Description and Assessment of Alternative Corrective Actions

The following sections describe the developed alternatives and assess the practicability and costs. **Appendix E** presents a detailed basis for the design, operation, costs, and assessment of the following alternatives:

- No Action;
- Southeast Drainage Alternative Corrective Actions;
  - Source Control
    - Interception Cut-Off Wall
    - Permeable Reactive Barrier
  - Downgradient Corrective Action
    - Groundwater Extraction with Pumping Wells

    - In-Situ Redox Manipulation with Injection Wells
  - Management of Collected Water
    - Direct Disposal in the Highland Pit Lake
    - Evaporative Treatment in Lined Ponds
    - Ion Exchange and Discharge
    - Reverse Osmosis
- Highland Pit Lake Alternative Corrective Actions;
  - In-Situ Redox Manipulation
    - Land Mixing (reductant mixing on the Pit Lake margins)
    - Floating Platform (reductant mixing on the Pit Lake surface)
  - Ex-Situ Treatment using Ion Exchange
  - Backfill of Pit Lake
    - Surface Drainage to North Fork Box Creek
    - Closed Surface Drainage
- Institutional Controls with Alternate Concentration Limits.

3.2.3 Benefits of Corrective Action

As per Section 3.3.3.2 of the NRC ACL Guidance (NRC, 1996), the benefits of implementing the identified corrective actions are weighted against the costs of performing (or not performing) such measures. The benefits of implementing the identified corrective action alternatives are evaluated considering:

> *"...the avoidance of adverse health effects, value of pre-contaminated ground-water resources, prevention of land-value depreciation, and benefits accrued from performing the corrective action."*

Table 3-1 summarizes the assessment of the corrective action alternatives; the detailed analysis is presented in **Appendix E**. Assessment of the avoided adverse health effects derived from implementing the corrective actions is summarized in **Table 3-2** and presented in detail in **Appendix E.** The health effects analysis indicates that the radiological and non-radiological doses avoided through remediation of the Southeast Drainage groundwater system and the Pit Lake are sufficiently low that no specific adverse health effects can reliably be associated with these exposures. In addition, the cost of implementing the range of corrective actions considered (**Table 3-3** and **Appendix E**) exceeds the estimated value of the water resources by roughly one to three orders of magnitude. The incremental potential for depreciation of land value due to the relatively small increase in the long-term control area from its current size would likely be minimal and is not considered significant.

In general, successful implementation of a corrective action for the Southeast Drainage groundwater system would have the primary benefit of allowing the groundwater in Southeast Drainage system be used as a potential future domestic drinking water supply. However, due to the limited nature of the Southeast Drainage groundwater system, remote nature of the Site, the lack of current and likely future use of this or similar groundwater systems for drinking water in the region, and the widespread biological contamination of surface waters (e.g., giardia), this exposure scenario is extremely unlikely.

The benefits of successful implementation of a corrective action for the Highland Pit Lake would vary depending on the selected alternative. Backfilling the pit to an elevation above the long-term groundwater level would have the primary benefit of eliminating the surface water and removing any exposure pathway. This would remove the potential human exposure pathway but would also remove a water resource for ecological receptors for which it is protective. Alternatively, treating the Pit Lake without backfilling would have the primary benefit of temporarily improving the water quality such that it would be protective as a potential human drinking water source for approximately 200 years until evapoconcentration once again degraded the water quality to the point where high TDS concentrations would render the water unsuitable for drinking water (>1,000 mg/L).

3.2.4 Corrective Action Assessment Summary and Conclusions

The corrective action alternatives evaluated include proven technologies that represent the state of practice for remediation of water quality impacts and considered active and passive as well as in-situ and ex-situ treatment technologies.

3.2.4.1. Corrective Action Assessment Summary

Tables 3-1 through **3-4** summarize and compare the corrective action alternatives assessments.

<u>*Engineering Feasibility:*</u> The engineering feasibility of all assessed corrective actions alternatives for both the limited Southeast Drainage groundwater system and the Highland Pit Lake were uniformly considered moderate to excellent as they relied on relatively proven and conventional technologies. Similarly, the efficacy of the corrective action alternatives were ranked from moderate to excellent, with the moderate ratings only due to the uncertainty of applying the technologies on a site specific basis without additional detailed testing and design, uncertainty of the local hydrogeology, or the uncertainty of how the alternative would affect the groundwater concentrations.

<u>*Durability:*</u> The durability of the alternatives were generally poor to moderate due to the reliance on mechanical and electrical systems with limited capital lives, and due to the limited period over which some alternatives could maintain protective conditions without wholesale replacement of capital equipment and/or re-application of the corrective action. The exceptions to this were the backfilling of the Highland Pit, which included pretreatment of the Pit Lake waters, essentially returning the groundwater to pre-mining conditions and removing any surface-water exposure pathways, and the alternative consisting of institutional controls and ACLs with the associated proposed LTSB. Both of these alternatives had a high degree of durability in maintaining protective conditions for the requisite compliance period of at least 200 years, and 1,000 years to the extent practicable.

<u>*Long-Term Maintenance*</u>: The degree of active maintenance for all the Southeast Drainage corrective action alternatives were ranked poor, with the exception of the institutional controls with ACLs alternative. The ranking of poor for source control active maintenance for the limited Southeast Drainage groundwater system is due primarily to long-term tailings seepage in the Southeast Drainage which would require perpetual active control and management. The ranking of poor for water management activities for the Southeast Drainage is due to the need for ongoing monitoring and maintenance. The Pit Lake treatment alternatives were ranked excellent with respect to degree of active maintenance with the exception of the ex-situ treatment. All the Pit Lake treatment options, except ex-situ treatment, require one time implementation with no perpetual obligation.

The general goal in design decisions for long-term isolation of the tailings and associated contaminants of 11e.(2) byproduct material is to minimize disturbance without ongoing maintenance (10 CFR Part 40, Appendix A, Criterion 1, Criterion 12). In addition, the U.S. Department of Energy, Office of Legacy Management guidance (DOE, 2009) states:

"Transition from a private licensee to LM [Legacy Management] *invokes a process to ensure that LM concurs in regulatory findings that*

- *The site was constructed in accordance with approved plans and specifications;*
- *The remedies are sound and are implemented to standards that ensure the site is and will remain protective of human health and the environment;*
- *LM obtains a defensible and protective real property position to control land uses that may result in unacceptable risk; and*
- ***Post-closure maintenance needs are of a routine nature, and no major interventions are forecast that transfer health or cost risk to LM*** [emphasis added]."

Major active maintenance of long-term corrective actions that would become the obligation of the long-term custodian are open ended and are unacceptable to the U.S. Department of Energy, Office of Legacy Management, the likely long-term custodian. Therefore, all alternatives that require significant and perpetual (>200 years) active operation and maintenance and replacement of capital equipment during the initial 200 years of ownership by the long-term custodian are rejected from further consideration.

Costs: The comprehensive alternatives for the Southeast Drainage had net present values (NPV) that ranged from $15,530,000 for source control, downgradient groundwater corrective action and water treatment (cut off wall, pumping wells, in-pit disposal) to $26,510,000 for in-situ approaches for both source control and downgradient groundwater corrective action (permeable reactive barrier (PRB) with in situ redox manipulation (ISRM) and injection wells with no ex-situ water management) (**Table 3-4**). Treatment alternatives for the Pit Lake had NPVs ranging from $6,119,000 for in-situ treatment with ISRM and floating platform based additive mixing to $20,340,000 for ex-situ treatment using ion exchange. Pit backfill alternatives, which would also require treatment of the hazardous constituents in the Pit Lake prior to fill placement, had NPVs ranging from almost $69,000,000 to over $80,000,000. The alternative implementing institutional controls with a new POC well and ACLs for the Southeast Drainage had a NPV of slightly less than $5,140,000.

3.2.4.2. Corrective Action Assessment Conclusion and Proposed Alternative

Table 3.4 compares the estimated cost range for corrective actions in the Southeast Drainage and the Pit Lake, the estimated range of values for the pre-contaminated water resources, the ratio of the corrective action costs with respect to the estimated value of the water resource, and the cost range for avoided dose achieved by successful implementation of corrective actions. These data indicate that the cost of the alternatives requiring active maintenance significantly exceed the value of the water resources and the benefits of the corrective actions. Specifically, the ratio of the alternatives net present value to the estimated value of the water resources range from 526 to 16; that is, costs range from 16 times to several hundred times greater than the resource values. Similarly, even Pit Lake alternatives that did not require active maintenance have ratios of the alternatives net present value to the estimated value of the water resources from 1,380 to 9, indicating the costs exceed the resource value by at least 9 times and as much as 1,000 times.

Therefore, based on the assessment provided above, the only practicable action that provides the requisite reasonable assurance of protection of public health, safety and the environment for at least 200 years, and to the extent practicable, 1,000 years with the most reasonable cost-benefit ratio is the implementation of institutional controls over the land within the proposed LTSB (**Figure 3-1**), adoption of the new Southeast Drainage POC Well MFG-1 and performance monitoring well TT-7 in conjunction with the proposed uranium ACL for MFG-1 of 0.7 mg/L and the proposed ACL for uranium in Well 175 of 3 mg/L. This alternative is further addressed in Section 4.

3.3 ALARA Demonstration

The proposed alternative ensures durable control of access to the contaminated water resources in the Pit Lake and the Southeast Drainage to prevent long-term consumption of the water as a drinking water source. Exposure to these water resources by all other receptors remains protective. Per the NRC (NRC, 2000; 2003), if the cost per person-rem averted dose is greater than $2,000, then the proposed action, which provides the reasonable assurance of protection of public health, safety and the environment, is considered to be ALARA. As presented in **Table 3-4**, the proposed action has a cost per person-rem averted dose almost 400 times greater than this threshold. Though the cost per person-rem averted dose was not calculated in a manner entirely consistent with the methods presented in Appendix D of NUREG 1727 (NRC, 2000), the method used is a reasonable alternative allowed under the regulations and the results overwhelmingly demonstrate that the proposed action exceeds the threshold value. Therefore, the proposed action is ALARA.

4.0 Proposed Alternate Concentration Limits

Previous submittals to the NRC including the 1998 ACL application (ECMC, 1998) did not contemplate or address the recently identified 11e.(2) byproduct material above the license condition standards (Condition 33B) in the Highland Pit Lake (uranium and selenium), in the limited groundwater system associated with the Southeast Drainage (uranium, selenium and radium-226+228), and POC Well 175 (uranium). The Hazard Assessment developed in Section 2 of this application has demonstrated that the source of the contaminants in these waters is primarily the uranium mill tailings.

Specifically, recent Pit Lake modeling and geochemical studies have indicated that sufficient amounts of uranium and selenium from tailings seepage have migrated into the Highland Pit Lake to cause Pit Lake uranium and selenium concentrations to exceed their respective MCLs, as discussed in detail in Section 2.1.2. Analysis of historical hydrologic conditions indicates that as much as 660 million gallons of tailings seepage has entered the Pit Lake via the TDSS due to seepage rates that were as high as approximately 200 gpm, though much of this transport occurred before groundwater monitoring wells were installed. These tailings seepage rates through the unlined impoundment are predicted to be nearing their long-term steady state rates of approximately 3 gpm (Section 1.2.2.7).

The results of the Pit Lake mass balance evaluation indicated that 53% of the chloride and 30% of the sulfate in the Pit Lake were derived from tailings solution influx. In addition, the mass balance calculations and modeling indicate that up to 27% and 11% of the uranium and selenium in the Pit Lake were derived from tailings solution influx to the Pit Lake, respectively (Section 2.1.2.2).

The source of uranium in the Pit Lake was further assessed though evaluation of uranium radioisotope activity ratios (AR) ($^{234}U/^{238}U$). The AR in natural groundwater is typically >1 due to enrichment of ^{234}U through natural weathering of ores in oxidizing conditions while tailings fluids typically retain the characteristic U isotopic composition of the original ore (AR = 1.0 ± 0.1). Sampling and analysis of the Pit Lake and selected groundwater monitoring wells for U isotopic composition conducted in December 2009 identified very low AR values for the Pit Lake ranging from 1.02 to just below 1.12, which is strongly indicative of tailings solution while higher AR values (1.4 to >2.0) were identified for groundwater in the TDSS and pit backfill. This indicates an additional source of U from tailings must be present to produce the low AR values and high uranium concentrations observed in the Pit Lake (Section 2.1.2.4; **Figure 2-6** and **Table 2-6**).

Further, SPLP testing conducted on OBSS and waste rock samples yielded results that are inconsistent with a working hypothesis that provides for a large mass of uranium being derived by weathering of the OBSS or meteoric waters moving through weathered waste rock or pit backfill material (Section 2.1.2.5). Therefore, the preponderance of evidence clearly indicates that large amounts of tailings seepage has entered the Pit Lake and that this seepage is the primary source of uranium and selenium responsible for these constituents exceeding their respective MCL values.

Similarly, assessment of the limited groundwater system associated with the Southeast Drainage, which was observed to have received historical tailings seepage from under the tailings embankment, demonstrates the Southeast Drainage continues to receive minor seepage from the tailings (Sections 1.2.2.7 and 2.2.1.2). Uranium values range from 0.3 mg/L at the head of the drainage at the toe of the tailings embankment (Well MFG-1) to between 0.05 and less than 0.03 mg/L in the other downgradient Southeast Drainage wells (**Table 2-3**). Uranium is predicted to remain elevated in the Southeast Drainage due to perpetual tailings seepage from the unlined impoundment (Section 2.2.2).

Though selenium and radium-226+228 exceed their respective MCLs each in different single Southeast Drainage wells, they are below their respective MCLs at the head of the drainage near the tailings impoundment (MFG-1) and at the confluence of the Southeast Drainage and North Fork Box Creek. These two constituents are predicted to remain below their respective MCLs at the confluence of the Southeast Drainage and North Fork Box Creek in perpetuity due dilution and natural attenuation (Section 2.2.3.2).

The exposure assessment developed in Section 2 of this application identifies that unrestricted future access to the Pit Lake water and to the limited groundwater system of the Southeast Drainage as a human drinking water sources is not protective of public health. The hazard assessment also indicates that risks to resident and migratory biota at Highland Pit Lake are very low.

In order to mitigate the conditions that would not be protective of public health and safety, a robust range of corrective action alternatives were evaluated. The alternatives were evaluated with respect to engineering practicability, durability, maintenance requirements, costs, and direct and indirect benefits. The analysis is presented in Section 3 and **Appendix E**.

For the Pit Lake, the corrective action assessment evaluated treatment of the entire Pit Lake volume as a sole remedy as well as backfilling the Pit Lake with mine spoils to remove the exposure surface pathway in perpetuity. Backfilling the Pit Lake considered prior treatment of the Pit Lake water before backfilling a necessity in order to keep the pit waters from rising into areas needed for backfill borrow and to keep from forcing impacted waters into formations and away from the pit. These alternatives were considered to have unreasonably high NPV costs ($8.1MM for treatment alone to $88MM for treatment and backfilling) relative to the estimated value of the water resource (**Table 3-4**).

For the limited groundwater system associated with the Southeast Drainage, Section 3 assessed source control actions to manage long-term seepage down the Southeast Drainage as well as corrective actions to remediate impacted waters already beyond the toe of the tailings embankment. Both active and passive technologies were evaluated. Source control was considered a necessity in conjunction with corrective action of the Southeast Drainage groundwater to prevent re-contamination of the drainage groundwater system from long-term seepage from the tailings. All active actions considered had NPV costs roughly one to three orders of magnitude greater than the estimated water resource value. In addition, these actions all had significant long-term active maintenance obligations, which are incompatible with the 10 CFR Part 40 Appendix A, Criterion 1 and Criterion 12 requirement that ongoing active maintenance not be necessary (**Table 3-4**).

Regarding the recent increase in uranium concentrations in Well 175 on the western side of the tailings impoundment (Section 2.1.1.1), NRC has already concurred (via approval of the 1998 ACL application and approval of License Amendment 49 that approved ceasing the historical groundwater corrective action) that there remain no reasonable corrective actions for mitigating groundwater impacts in the TDSS in the vicinity of the tailings impoundment. The maximum potential concentrations and volumetric flux from the tailings are so low as to not appreciably affect the concentration, total volume of the Pit Lake, or total mass of uranium in the Pit Lake. Consequently, restricted access to the groundwater system between the tailings and the Pit Lake as well as in the Pit Lake itself as drinking water sources is necessary to remove this potential future exposure pathway and protect public health and safety.

Therefore, the only practicable action that provides the requisite reasonable assurance of protection of public health, safety and the environment for at least 200 years, and to the extent practicable, 1,000 years with a reasonable cost-benefit ratio, is the implementation of institutional controls with ACLs. This alternative meets the requirement to reduce exposure concentrations to ALARA (Section 3.3). Consequently, new POEs are identified and modifications to the existing ACLs and the current groundwater monitoring program in License Condition 33 are proposed.

4.1 Point of Compliance and Point of Exposure

Institutional controls are proposed for the lands within the identified LTSB (**Figure 3-1**). Title to the surface and subsurface estates, restrictive covenants regarding access to groundwater, and access easements would be provided to the Federal government upon license termination as per Criterion 11C of 10 CFR Part 40, Appendix A. As an additional but not required measure to provide access control to the lands and waters within the LTSB, fencing would be installed prior to license termination and additional funding included in the long-term surveillance fund to provide for care and maintenance of these engineered access controls.

4.1.1 Southeast Drainage

It is proposed that Well MFG-1 be the POC for the Southeast Drainage and be added to the groundwater monitoring requirements in License Condition 33. Well MFG-1 is completed in the uppermost aquifer at the toe of the tailings embankment. This well representatively monitors the groundwater quality entering the Southeast Drainage limited groundwater system from the tailings area. The groundwater monitored by this well currently has a uranium concentration of approximately 0.32 mg/L.

Well TT-7 is proposed as a POE performance monitoring well. Well TT-7 is located where the Southeast Drainage meets North Fork Box Creek (**Figure 3-1**). Monitoring this location provides verification of protective groundwater conditions.

4.1.2 Highland Pit Lake

POE performance monitoring of the Highland Pit Lake water quality is also proposed. Pit Lake water quality has been monitored for many years and has predictable and relatively stable trends. Long-term water quality is predicted to change slowly due to evapoconcentration. Annual sampling and analysis of a single location in the Pit Lake at a single shallow depth is proposed (see Section 4.3). Sampling of the Pit Lake has indicated that the water quality does not vary substantially with depth (**Table 2-2**) and it is the shallow depths that afford the greatest potential for ecological exposure.

4.2 Proposed ACLs

ACLs for uranium are proposed for the proposed new POC well for the Southeast Drainage (MFG-1) and the existing POC Well 175.

An ACL of 0.7 mg/L for uranium is proposed for Well MFG-1 (**Table 4-1**). This proposed ACL is equal to one half the risk-based concentration of 1.4 mg/L, which is protective of human health and the environment at the POE (Section 2.3.5). This value is conservatively below the exposure point concentration but twice the concentration previously observed in Well MFG-1. Groundwater uranium concentrations at Well MFG-1 have ranged from 0.133 to 0.388 mg/L and are not anticipated to increase as tailings seepage rates continue to decline (Section 2.2.3.2). The low concentrations of uranium (0.04 to 0.05 mg/L) at Well TT-7, just inside the proposed LTSB, and high baseline uranium concentrations in the upgradient surface waters of North Fork Box Creek (0.07 mg/L to 0.09 mg/L) (**Table 2-4**) indicate that the current and long-term impact to surface water quality at the POE from the Southeast Drainage is minimal. The current conditions are protective, the traditional uses of these waters are not impaired, and the long-term conditions will remain protective at the POE.

An ACL of 3 mg/L for uranium in Well 175 is proposed (**Table 4-1**). This concentration is roughly the modeled equilibrium concentration of uranium in the neutralized tailings seepage within the TDSS (Section 2.1.2.7 and **Table 2-7**) and represents a maximum potential future concentration at this location. Groundwater uranium concentrations at Well 175 are currently 0.0325 mg/L (**Table 2-2**). As summarized in Section 1.2.2.7, water levels in the TDSS have dropped significantly as the formation drains and seepage rates have declined to near their predicted steady state condition of between 3 and 5 gpm. Only a portion of this minimal seepage may migrate into the Pit Lake while other portions flow north and down the Southeast Drainage. This minimal amount of seepage into the 3.9 billion gallon Pit Lake will have negligible contribution to the Pit Lake volume or total uranium mass and will have concentrations less than the current Pit Lake uranium concentration (3.19 mg/L; **Table 2-2**). Consequently, an ACL for uranium at this location could be significantly higher than proposed and still maintain protective conditions in the Pit Lake. This ACL will maintain protective conditions in the Pit Lake and would have essentially no potential for future exceedance due to the geochemical controls within the TDSS.

No ACLs for selenium or radium-226+228 are proposed. Exceedances of MCLs for these constituents have been at single locations and with single occurrences. Selenium (Well BBL-2) and radium-226+228 (Well BBL-3) exceeded MCLs in the Southeast Drainage, but their mean and maximum concentrations in the source (as represented by Well MFG-1) and all other Southeast Drainage wells are currently below MCLs. Site characterization data and conservative assessment of their transport demonstrates that these hazardous constituents currently do not and will not exceed their respective MCLS at the POEs. Therefore, no ACLs are needed or proposed for selenium or radium-226+228.

No other ACLs for any other POC wells are needed or proposed.

4.3 Proposed Change to the Approved Monitoring Program and Long-Term Surveillance Boundary

ExxonMobil requests that NRC confirm its determination that there is sufficient 11e.(2) byproduct material in the Pit Lake to warrant its inclusion in the LTSB. In addition, the following modifications to the existing groundwater monitoring program identified in License Condition 33 are proposed (see bold text below). It is also proposed that requirements for monitoring well 177 be removed and the well not replaced as this well has gone dry and this portion of the uppermost aquifer has become fully drained.

33. The licensee shall implement a compliance monitoring program containing the following:

A. Sample wells 015, 112, 114, 117, 120, 125, 127, 128, 129, 134, 148, 171, 172, 173, 174, 175, 176, 177, 178, 179, 180, 181, 182, 183, TT-7 and MFG-1 on a quarterly frequency as well as a single location in the Highland Pit lake on an annual frequency for chloride, nitrate, sodium, sulfate, pH, TDS and water level, and on a semiannual frequency for arsenic, cadmium, chromium, gross alpha, lead, nickel, radium-226 and 228, selenium, thorium-230 and uranium.

B. Comply with the following ground-water protection standards at point of compliance well Nos. 125, 175, 176, ~~177,~~ **and MFG-1** with background being recognized in well No. 182: arsenic = 0.05 mg/L, cadmium = 0.01 mg/L, chromium = 0.1 mg/L, gross alpha = 15.0 pCi/L, lead = 0.05 mg/L, nickel = 0.1 mg/L, radium-226 and 228 = 5.0 pCi/L, selenium = 0.05 mg/L, thorium-230 = 0.55 pCi/L and uranium = 0.03 mg/L with the exceptions of: well 125 uranium = 0.089 mg/L; well 175 nickel = 1.8 mg/L and radium 226 and 228 = 25 pCi/L **and**

uranium = 3 mg/L; ~~**well 177 uranium = 0.11 mg/L**~~; **and well MFG-1 uranium = 0.7 mg/L.**

No specific stability monitoring period is proposed as the proposed new monitoring points have been sampled for over three years and will be sampled a few more years prior to license termination.

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Tables

Table 1-1 Precipitation Statistics for Weather Stations near the Site (Inches)

Month	Casper		Dull Center		Glenrock	
	Mean	Median	Mean	Median	Mean	Median
Jan	0.58	0.53	0.24	0.20	0.35	0.29
Feb	0.64	0.59	0.42	0.29	0.44	0.39
Mar	0.90	0.66	0.74	0.68	0.76	0.57
Apr	1.52	1.39	1.67	1.39	1.79	1.54
May	2.38	2.02	2.33	2.00	2.40	1.90
Jun	1.43	1.08	2.10	1.37	1.34	1.12
Jul	1.29	1.24	1.68	1.41	1.11	0.82
Aug	0.73	0.63	1.28	1.19	0.72	0.66
Sep	0.98	0.71	1.04	0.77	1.13	0.78
Oct	1.14	0.86	1.00	0.77	1.06	1.00
Nov	0.82	0.75	0.58	0.59	0.70	0.65
Dec	0.62	0.47	0.36	0.31	0.39	0.32
Annual	13.03	12.48	13.44	13.39	12.19	11.88

Based on climate normal from 1971 through 2000.

(NOAA, 2004)

Table 1-2 Temperature Statistics for Weather Stations near the Site (°F)

Month	Casper			Dull Center			Glenrock		
	Daily Max	Daily Min	Mean	Daily Max	Daily Min	Mean	Daily Max	Daily Min	Mean
Jan	32.3	12.2	22.3	34.8	10.8	22.8	37.0	15.7	26.4
Feb	37.0	16.4	26.7	40.5	15.9	28.2	41.5	19.8	30.7
Mar	46.9	23.1	35.0	49.4	22.8	36.1	49.6	25.6	37.6
Apr	56.1	29.3	42.7	58.7	30.9	44.8	58.6	32.1	45.4
May	66.4	37.9	52.1	69.0	40.4	54.7	68.8	41.0	54.9
Jun	78.8	46.6	62.7	80.8	48.8	64.8	80.8	49.7	65.3
Jul	86.8	53.2	70.0	89.3	54.6	72.0	88.8	55.8	72.3
Aug	85.3	51.8	68.6	88.4	53.5	71.0	86.8	54.3	70.6
Sep	73.4	41.7	57.6	77.0	42.9	60.0	76.1	43.8	60.0
Oct	59.5	31.8	45.7	63.1	32.1	47.6	62.5	33.6	48.1
Nov	42.6	21.3	32.0	45.3	20.9	33.1	45.8	23.9	34.9
Dec	33.6	14.0	23.8	36.4	12.2	24.3	38.0	17.7	27.9
Average Annual	58.2	31.6	44.9	61.1	32.2	46.6	61.2	34.4	47.8

Based on climate normal from 1971 through 2000.

(NOAA, 2004)

Table 1-3 Monthly Average Precipitation for the Highland Site (Inches)

Month	Highland Mine Site
January	0.39
February	0.50
March	0.80
April	1.66
May	2.37
June	1.62
July	1.36
August	0.91
September	1.05
October	1.07
November	0.70
December	0.46
Annual	12.89

Highland Mine Site data represents averages from Casper, Glenrock, and Dull Center.

(NOAA, 2004)

Table 1-4 Summary of Well Completion Details for the Southeast Drainage and Nearby Drainage Monitoring Wells

Well Name	Northing	Easting	Ground Elevation (ft)	Total Depth Drilled (ft)	Depth of Completed Well (ft bgs)	Screen top (ft bgs)	Screen bottom (ft bgs)	Gravel pack top (ft bgs)	Gravel pack bottom (ft bgs)	Casing diameter (inch)	Screen diameter (inch)	Casing Material
BBL-1	873723.4	415383.1	5092.40	136.5	126.2	85.8	126.2	79.5	136.5	4	4	PVC
BBL-2	873510.6	415471.2	5091.03	36.5	36.5	20.7	36.1	16.0	36.5	4	4	PVC
BBL-3	873158.7	415961.4	5085.56	44.5	42.0	24.8	40.2	15.5	41.8	4	4	PVC
BBL-4	871969.4	417072.4	5066.64	39.6	39.6	14.2	39.6	10.3	39.6	4	4	PVC
MFG-1	874029.5	414525.5	5115.83	51.5	51.5	20.5	50.9	14.5	51.5	4	4	PVC
MFG-2	874038.3	414543.5	5114.74	96.0	93.0	76.6	92.0	72.7	93.0	4	4	PVC
MFG-3	874047.3	414561.7	5113.08	151.5	140.6	130.2	140.6	127.0	140.6	4	4	PVC
TT-1	875807.4	416510.5	5164.42	100.0	93.5	87.5	92.8	77.6	93.5	4	4	PVC
TT-2	875304.2	415185.3	5140.11	85.0	77.0	70.6	75.9	53.5	77.0	4	4	PVC
TT-3	873953.9	416639.9	5100.41	75.5	67.3	47.0	67.3	34.0	67.3	4	4	PVC
TT-4	871562.8	417191.5	5061.65	35.5	33.5	18.0	33.3	7.1	33.5	4	4	PVC
TT-5	871238.1	417247.1	5057.95	29.0	25.0	13.5	23.8	4.0	25.0	4	4	PVC
TT-6	871325.9	417583.7	5056.22	26.0	23.5	13.0	23.3	5.0	23.5	4	4	PVC
TT-7	871699.6	417642.0	5055.22	31.5	27.0	16.7	27.0	3.8	27.0	4	4	PVC
TT-8	873673.8	415434.6	5091.81	60.5	60.5	38.5	58.8	20.5	58.8	4	4	PVC

Table 1-5 Summary of Hydraulic Conductivity Testing Results for the Southeast Drainage and Nearby Drainage Monitoring Wells

Well Name	Test Type	Solution Method	Estimated Hydraulic Conductivity (ft/day)
TT-2	Open Slug	Bouwer-Rice	5.4
TT-3	Pneumatic Slug	Butler-Zhan	7.9
TT-8	Pneumatic Slug	Hvorslev	6.9
Geometric Mean			6.7

All tests conducted on March 10, 2009

Table 1-6 Compliance Standards for Existing Site POC Wells

Constituent	Point of Compliance (POC) Well			
	125	**175**	**176**	**177**
Arsenic (mg/L)	0.05	0.05	0.05	0.05
Cadmium (mg/L)	0.01	0.01	0.01	0.01
Chromium (mg/L)	0.1	0.1	0.1	0.1
Gross Alpha (pCi/L)	15	15	15	15
Lead (mg/L)	0.05	0.05	0.05	0.05
Nickel (mg/L)	0.1	**1.8**	0.1	0.1
Radium-226+228 (pCi/L)	5	**25**	5	5
Selenium (mg/L)	0.05	0.05	0.05	0.05
Thorium-230 (pCi/L)	0.55	0.55	0.55	0.55
Uranium (mg/L)	**0.089**	0.03	0.03	**0.11**

Bold = compliance standard is exception as listed in License Condition 33B.

Table 2-1 Highland Tailings Water Composition (mg/L except as noted)

Parameter	EPRCO (1982)	7/17/1986 (NRC, 1986)	10/22/1986 (NRC, 1986)
Aluminum	261	721	715
Ammonia-N	NR	205	255
Arsenic	0.078	0.181	0.224
Barium	NR	<0.1	<0.1
Boron	NR	0.61	0.79
Calcium	584	320	400
Cadmium	0.03	0.096	0.122
Chloride	217.5	557	685
Cobalt	NR	1.9	7.96
Chromium	1.2	5.15	3.8
Copper	1.1	1.88	1.97
Iron	775	NR	NR
Lead	NR	0.34	0.3
Lead-210 (pCi/L)	NR	4.3	9.1
Magnesium	375	1,122	1,659
Manganese	45	NR	NR
Mercury	NR	<0.0002	0.0004
Molybdenum	NR	<0.1	0.13
Nickel	1.4	NR	NR
Nitrate-N	NR	3.46	1.83
Nitrite-N	NR	0.667	0.123
pH (pH units)	2.4	2.0	2.1
Polonium-210 (pCi/L)	NR	8.5	10.7
Potassium	42	NR	NR
Radium-226 (pCi/L)	NR	7.4	5.6
Selenium	0.126	0.099	0.13
Silver	NR	0.02	0.03
Sodium	262	NR	NR
Strontium	0.5	NR	NR
Sulfate	7,580	13,050	13,900
Thorium	0.82	NR	NR
Thorium-230 (pCi/L)	NR	1,742	3,230
Total Dissolved Solids	NR	20,759	19,040
Uranium	9.1	13.6	19.2
Vanadium	NR	8.15	8.92
Zinc	NR	11.5	11.5

NR = not reported.

Table 2-2 2009 and 2010 Highland Groundwater Data and Summary Statistics[1]

Well Number	Well Name	Sample Date	As (mg/L)	Cd (mg/L)	Cl (mg/L)	Cr (mg/L)	Gross Alpha (pCi/L)	Pb (mg/L)	Ni (mg/L)	NO2 +NO3 (mg/L)	pH-Field (s.u.)	Ra-226 (pCi/L)	Ra-228 (pCi/L)	Ra-226+228 (pCi/L)	Se (mg/L)	Na (mg/L)	SO4 (mg/L)	TDS (mg/L)	Th-230 (pCi/L)	U (mg/L)
U.S. NRC Site GPL			0.05	0.01	-----	0.1	15	0.05	0.1	-----	-----	-----	-----	5	0.05	-----	-----	-----	0.55	0.03
U.S. EPA MCL			0.01	0.005		0.1	-----	0.015	-----	10	6.5 - 8.5 2	-----	-----	5	0.05	-----			-----	0.03
Backfill Monitor																				
170		3/6/2009			39.9		8.7				7.73	7.8	2.0	**9.80**	<0.00099	104	475	855	0.2	**0.526**
		8/13/2009			79.1		9.8				7.47	8.2	<0.9	**9.10**	<0.00099	107	511	831	<0.2	**0.561**
		11/9/2009									7.06									
		2/11/2010			47.8		9.7				7.37	7.8	3.6	**11.4**	<0.00099	113	527	853	<0.2	**0.595**
		8/16/2010			46.6		8.6				7.23	6.9	1.6	**8.50**	<0.00025	100	460	855	<0.1	**0.584**
mean/*median*					53.4		9.2				7.37	7.7	2.0	**9.70**	<0.00099	106	493	849	0.175	**0.567**
171	TDM XXXVIII	3/2/2009	<0.00095	<0.00021	30.5	<0.00068	<0.8	0.00031	0.0022	<0.04	6.58	0.46	1.4	1.86	<0.00099	106	484	857	<0.2	0.001
		5/18/2009			63.9					<0.04	6.28					99.1	559	854		
		8/13/2009	<0.00095	<0.0002	33.9	<0.0006	0.9	0.000072	0.0012	0.064	6.24	0.34	<1.2	<1.54	<0.00099	107	598	860	<0.2	0.0011
		11/9/2009			34.1					<0.04	6.48					105	497	858		
		2/12/2010	<0.00095	<0.0002	60.5	<0.0006	1.1	<0.00005	0.00062	<0.04	6.46	<0.2	2.0	<2.2	<0.00099	108	544	833	<0.2	0.0011
		5/14/2010			33.7					<0.04	6.96					105	494	885		
		8/18/2010	<0.00095	<0.0002	37	<0.0006	<0.3	0.0024	0.0012	0.058	6.88	<0.22	<1.2	<1.42	<0.00025	98	552	869	<0.1	0.0012
		11/1/2010			34.7					<0.04	6.71					99.9	477	850		
mean/*median*			<0.00095	<0.0002	*39.5*	<0.0006	*0.9*	0.00071	0.0013	*<0.04*	*6.53*	0.31	1.5	1.76	<0.00099	104	*521*	858	<0.2	0.001
173	TDM XXXIX	2/23/2009	<0.00095	<0.00021	92.4	<0.00068	2.3	0.00018	<0.0005	<0.04	7.09	0.81	1.5	2.30	<0.00099	90.3	406	884	<0.2	0.0029
		5/18/2009			114					<0.04	7.55					91.7	462	891		
		8/10/2009	<0.00095	<0.0002	126	<0.0006	0.8	0.000064	<0.0005	<0.04	7.61	0.49	<1.2	<1.69	<0.00099	90.2	438	890	<0.2	0.0029
		11/11/2009			98.1					<0.04	7.63					97.7	419	883		
		2/12/2010	<0.00095	<0.0002	93.7	<0.0006	1.1	<0.00005	<0.0005	<0.04	7.31	0.42	2.2	2.62	<0.00099	91.5	452	869	<0.1	0.0031
		5/10/2010			109					<0.04	7.36					94.2	410	901		
		8/18/2010	<0.00095	<0.0002	102	<0.0006	0.8	<0.001	<0.0005	<0.04	7.01	0.47	1.3	1.77	<0.00025	85.1	454	884	<0.1	0.0032
		11/3/2010			83.4					<0.04	7.39					85.9	392	870		
mean/*median*			<0.00095	<0.0002	*100*	<0.0006	1.1	0.00032	<0.0005	*<0.04*	*7.38*	0.55	1.6	2.10	<0.00099	*90.7*	429	884	<0.2	0.0030
OBSS Monitor																				
116	TDM XI	2/18/2009	<0.00095	<0.00021	81.9	<0.00068	1.4	<0.00005	<0.0005	<0.04	7.22	0.97	5.3	**6.27**	<0.00099	109	731	1470	<0.2	0.0137
		5/19/2009			78.1					<0.04	7.21					98.7	840	1510		
		8/31/2009	<0.00095	<0.0002	78.1	<0.0006	2.1	<0.00005	<0.0005	<0.04	7.15	1.4	4.7	**6.10**	<0.00099	106	720	1530	<0.1	0.015
		11/3/2009			68.1					<0.04	7.13					106	723	1510		
		2/6/2010	<0.00095	<0.0002	75.6	<0.0006	2.4	<0.00005	<0.0005	<0.04	7.01	1.9	4.2	**6.10**	<0.00099	106	860	1500	<0.1	0.0148
		4/29/2010			66.6					<0.04	7.22					109	733	1490		
		7/30/2010	<0.00095	<0.0002	69.6	<0.0006	1.7	<0.000052	<0.0005	<0.04	7.32	0.91	2.8	3.71	<0.00025	113	739	1550	0.2	0.0156
		10/30/2010			85.3					<0.04	7.24					97.2	751	1560		
mean/*median*			<0.00095	<0.0002	*76.9*	<0.0006	1.9	<0.00005	<0.0005	*<0.04*	*7.22*	1.3	4.3	**5.55**	<0.00099	*106*	*736*	1515	<0.1	0.015
128	TDM XXIX	4/1/2009	<0.00095	<0.00021	2.3	<0.00068	1.4	0.00025	0.003	<0.04		<0.25	<1.4	<1.65	<0.00099	102	36	463	<0.1	0.0048
		6/17/2009			6.6					<0.04	7.27					104	179	469		
		8/25/2009	<0.00095	<0.0002	9.3	<0.0006	<0.7	0.00023	0.0027	<0.04	6.90	<0.18	<1.1	<1.28	<0.00099	93.3	150	466	<0.2	0.0042

Table 2-2 2009 and 2010 Highland Groundwater Data and Summary Statistics[1]

Well Number	Well Name	Sample Date	As (mg/L)	Cd (mg/L)	Cl (mg/L)	Cr (mg/L)	Gross Alpha (pCi/L)	Pb (mg/L)	Ni (mg/L)	NO2 +NO3 (mg/L)	pH-Field (s.u.)	Ra-226 (pCi/L)	Ra-228 (pCi/L)	Ra-226+228 (pCi/L)	Se (mg/L)	Na (mg/L)	SO4 (mg/L)	TDS (mg/L)	Th-230 (pCi/L)	U (mg/L)
U.S. NRC Site GPL			0.05	0.01	-----	0.1	15	0.05	0.1	-----	-----	-----	-----	5	0.05	-----	-----	-----	0.55	0.03
U.S. EPA MCL			0.01	0.005		0.1	-----	0.015	-----	10	6.5 - 8.5 2	-----	-----	5	0.05	-----			-----	0.03
		11/6/2009			7.5					<0.04	7.10					106	177	462		
		2/8/2010	<0.00095	<0.0002	7	<0.0006	0.8	0.0019	0.0043	<0.04	7.09	0.42	<1.2	<1.62	<0.00099	103	161	462	<0.2	0.005
		5/3/2010			6.8					0.049	7.47					95.9	123	434		
		8/2/2010	<0.00095	<0.0002	7.1	<0.0006	<0.7	0.002	0.0044	<0.04	7.14	<0.17	<1	<1.17	<0.00025	99.7	134	453	<0.2	0.0041
		11/1/2010			6.8					<0.04	7.55					91.3	128	444		
mean/*median*			<0.00095	<0.0002	*6.9*	<0.0006	*0.8*	0.00110	0.0036	*<0.04*	*7.14*	<0.18	<1.4	<1.28	<0.00099	*99*	*142*	*462*	<0.2	0.0045
129	TDM XXX	2/19/2009	<0.00095	<0.00021	52	<0.00068	1.5	0.000056	0.0059	<0.04	7.11	<0.17	1.7	<1.87	0.0017	166	597	1140	<0.2	0.0012
		5/21/2009			35.1					14.5	7.12					187	1160	1880		
		9/1/2009	<0.00095	<0.0002	61.7	0.0007	<0.7	0.000076	0.0118	2.8	6.92	<0.17	<1.1	<1.27	**0.272**	183	964	1670	<0.2	0.0024
		11/9/2009			65.1					0.5	7.30					168	737	1420		
		2/10/2010	0.0012	<0.0002	64	<0.0006	0.8	0.00009	0.003	0.047	6.96	0.45	<1.1	<1.55	0.0016	164	547	967	<0.2	0.0011
		5/3/2010			42.8					4.3	7.29					166	491	1090		
		8/2/2010	<0.00095	<0.0002	20	<0.0006	<0.7	0.00013	0.0216	5.2	6.79	0.23	<0.96	<1.19	**0.864**	195	1200	1880	<0.1	0.0044
		11/1/2010			42.8					0.38	7.10					174	946	1710		
mean/*median*			<0.00095	<0.0002	*47.4*	*<0.0006*	*0.8*	0.00009	0.0106	*1.7*	*7.11*	0.26	<1.1	<1.27	**0.285**	*175*	830	1470	<0.2	0.0023
TDSS Background																				
	RM-4	3/2/2009	<0.00095	<0.00021	16.2	<0.00068	<0.8	<0.00005	<0.0005	<0.04	7.49	<0.17	<0.96	<1.13	<0.00099	219	581	1150	<0.2	0.0009
134		5/18/2009			20.5					<0.04	7.41					197	675	1160		
		8/10/2009	<0.00095	<0.0002	18.6	<0.0006	<0.7	<0.00005	<0.0005	<0.04	7.55	0.43	<1.2	<1.63	<0.00099	191	648	1130	<0.1	0.001
		11/6/2009			19.5					<0.04	7.54					213	611	1170		
		2/11/2010	<0.00095	<0.0002	16.8	<0.0006	1.3	<0.00005	<0.0005	<0.04	7.32	<0.2	2.1	<2.3	<0.00099	218	653	1130	<0.1	0.001
		5/4/2010			17.7					<0.04	7.30					217	551	1130		
		8/16/2010	<0.00095	<0.0002	18.1	<0.0006	<0.7	<0.001	<0.0005	<0.04	7.56	0.41	1	1.41	<0.00025	199	521	1180	<0.1	0.0013
		11/1/2010			20.6					<0.04	7.39					197	576	1150		
mean/*median*			<0.00095	<0.0002	*18.4*	<0.0006	<0.7	<0.00005	<0.0005	*<0.04*	7.45	0.30	<1.2	<1.63	<0.00099	*206*	*596*	*1150*	<0.1	0.001
172	EM-5	2/18/2009	<0.00095	<0.00021	8.2	<0.00068	1.3	<0.00005	<0.0005	<0.04	7.77	0.98	1.5	2.48	<0.00099	110	296	575	<0.1	<0.0003
		5/19/2009			10.2					<0.04	7.79					112	326	582		
		8/12/2009	<0.00095	<0.0002	175	<0.0006	1.6	<0.00005	<0.0005	<0.04	7.82	0.67	1.6	2.27	<0.00099	123	386	564	<0.2	<0.0003
		11/11/2009			6.1					<0.04	7.62					118	292	572		
		2/15/2010	<0.00095	<0.0002	7	<0.0006	1.1	<0.00005	<0.0005	<0.04	7.59	0.6	2	2.60	<0.00099	118	327	574	<0.09	<0.0003
		5/10/2010			8.7					<0.04	7.55					119	287	596		
		8/13/2010	<0.00095	<0.0002	9.1	<0.0006	1.3	<0.000052	<0.0005	<0.04	7.89	0.92	<1.2	<2.12	<0.00025	118	315	604	<0.1	0.0003
		11/2/2010			8.2					<0.04	7.54					109	284	577		
mean/*median*			<0.00095	<0.0002	*8.5*	<0.0006	1.3	<0.00005	<0.0005	*<0.04*	*7.70*	0.79	1.6	2.37	<0.00099	116	*306*	*576*	<0.1	<0.0003
174	TDM XL	2/18/2009	<0.00095	<0.00021	5.4	<0.00068	1	<0.00005	<0.0005	<0.04	7.86	0.29	1.2	1.49	<0.00099	76.4	100	306	<0.2	<0.0003
		5/19/2009			6.3					<0.04	7.81					71.2	106	311		
		9/2/2009	<0.00095	<0.0002	5.3	<0.0006	1	0.000066	<0.0005	<0.04	7.82	<0.17	<1.3	<1.47	<0.00099	64	108	311	<0.2	<0.0003

Table 2-2 2009 and 2010 Highland Groundwater Data and Summary Statistics[1]

Well Number	Well Name	Sample Date	As (mg/L)	Cd (mg/L)	Cl (mg/L)	Cr (mg/L)	Gross Alpha (pCi/L)	Pb (mg/L)	Ni (mg/L)	NO2 +NO3 (mg/L)	pH-Field (s.u.)	Ra-226 (pCi/L)	Ra-228 (pCi/L)	Ra-226+228 (pCi/L)	Se (mg/L)	Na (mg/L)	SO4 (mg/L)	TDS (mg/L)	Th-230 (pCi/L)	U (mg/L)
U.S. NRC Site GPL			0.05	0.01	-----	0.1	15	0.05	0.1	-----	-----	-----	-----	5	0.05	-----	-----	-----	0.55	0.03
U.S. EPA MCL			0.01	0.005		0.1	-----	0.015	-----	10	6.5 - 8.5 2	-----	-----	5	0.05	-----			-----	0.03
		11/12/2009			5					<0.04	7.75					73.5	105	311		
		2/15/2010	<0.00095	<0.0002	4.6	<0.0006	0.9	<0.00005	<0.0005	<0.04	7.51	0.29	<1.2	<1.49	<0.00099	68	91.5	309	<0.2	<0.0003
		4/30/2010			4.6					<0.04	7.62					65.9	94.2	307		
		8/13/2010	<0.00095	<0.0002	5.8	<0.0006	<0.6	<0.000052	<0.0005	<0.04	8.08	<0.16	<0.9	<1.06	<0.00025	73.6	106	318	<0.1	<0.0003
		11/2/2010			5.3					<0.04	7.83					67.2	94.8	312		
mean/*median*			<0.00095	<0.0002	*5.3*	<0.0006	*1.0*	<0.00005	<0.0005	*<0.04*	*7.82*	0.23	1.2	<1.49	<0.00099	*70*	*103*	*311*	<0.2	<0.0003
182	TDM XLVIII	3/5/2009	<0.00095	<0.00021	11.1	<0.00068	1	<0.00005	<0.0005	<0.04	8.11	<0.21	<1.1	<1.31	<0.00099	112	188	418	<0.2	<0.0003
		5/21/2009			12					<0.04	7.94					117	203	426		
		8/11/2009	<0.00095	<0.0002	97.3	<0.0006	<0.7	0.000091	<0.0005	<0.04	8.11	0.23	<1.3	<1.53	<0.00099	129	203	426	<0.2	<0.0003
		11/5/2009			12.2					<0.04	7.93					114	206	437		
		2/16/2010	<0.00095	<0.0002	8.9	<0.0006	0.6	0.000093	<0.0005	<0.04	7.93	0.46	1.7	2.16	<0.00099	121	189	426	<0.1	<0.0003
		5/4/2010			13.1					<0.04	7.79					114	176	422		
		8/13/2010	<0.00095	<0.0002	12.6	<0.0006	<0.6	0.000094	0.00084	<0.04	7.71	0.39	<1.4	<1.79	<0.00025	113	204	432	<0.2	<0.0003
		11/4/2010			12.5					<0.04	8.01					90	186	422		
mean/*median*			<0.00095	<0.0002	*12.4*	<0.0006	*0.7*	0.00008	<0.0005	*<0.04*	*7.94*	0.32	<1.3	<1.53	<0.00099	*113*	*196*	426	<0.2	<0.0003
TDSS Compliance Monitor Well																				
125	TDM XXVI	2/19/2009	<0.00095	<0.00021	14.2	0.001	3.7	<0.00005	0.0029	0.31	7.19	<0.17	<0.94	<1.11	0.0038	90.6	630	819	<0.2	0.015
		5/22/2009			13					1.1	7.23					78.3	374	768		
		8/24/2009	<0.00095	<0.0002	12.6	<0.0006	2.1	0.00019	0.0015	1.0	7.03	0.8	2.8	3.60	0.0103	77.2	356	757	**0.7**	0.0173
		11/11/2009			10.2					1.2	7.22					86.8	333	765		
		2/8/2010	<0.00095	<0.0002	12.3	<0.0006	2.8	0.000076	0.002	1.4	7.12	1.2	1.8	3.00	0.0142	81.9	403	754	0.5	0.0167
		5/3/2010			10.8					1.5	7.27					84	322	799		
		8/2/2010	<0.00095	<0.0002	11.7	<0.0006	4.1	<0.00005	0.0015	1.6	7.29	0.77	1.6	2.37	0.0151	82.4	328	803	**0.6**	0.0161
		10/30/2010			13.8					1.6	7.20					82.1	366	812		
mean/*median*			<0.00095	<0.0002	*12.5*	*<0.0006*	3.2	0.00009	0.0020	*1.3*	*7.21*	0.7	1.8	2.52	0.0109	*82.3*	*361*	*784*	0.5	0.016
175	TDM XLI	2/19/2009	<0.00095	<0.00021	280	<0.00068	2.4	0.00055	0.808	<0.4	6.35	1.4	7.4	8.80	<0.00099	307	3090	5100	<0.2	0.0284
		5/20/2009			300					<0.04	6.39					308	3330	3980		
		8/31/2009	<0.00095	<0.0002	296	<0.0006	1.3	0.000054	0.797	0.04	6.37	0.8	9.4	10.2	<0.005	290	2840	5070	<0.2	0.0289
		11/12/2009			295					<0.04	6.39					282	3140	4950		
		2/16/2010	<0.00095	<0.0002	371	<0.0006	2.3	0.00026	0.766	<0.04	6.34	1.5	9.1	10.6	<0.00099	281	2850	4640	<0.5	0.0065
		5/10/2010			275					0.05	6.48					300	2880	4880		
		8/3/2010	<0.00095	<0.0002	281	<0.0006	1	0.00022	0.703	<0.04	6.39	0.6	6.7	7.30	0.00032	290	2720	4780	<0.1	**0.0325**
		11/3/2010			269					<0.04	6.52					266	2820	4740		
mean/*median*			<0.00095	<0.0002	*288*	<0.0006	1.6	0.00027	0.769	*<0.04*	*6.39*	1.1	8.2	9.23	<0.005	*290*	*2865*	*4768*	<0.2	0.024
176	TDM XLII	3/3/2009	<0.00095	<0.00021	231	<0.00068	2.1	<0.00005	<0.0005	<0.04	7.01	0.95	3.3	4.25	<0.00099	246	2310	4150	<0.2	<0.0003
		5/21/2009			241					0.04	6.84					248	2840	4020		
		8/12/2009	<0.00095	<0.0002	217	<0.0006	1.1	0.000056	<0.0005	<0.04	7.02	0.83	4.4	**5.23**	<0.00099	241	1990	4100	<0.2	<0.0003
		11/6/2009			264					<0.04	6.87					212	2180	4100		

Table 2-2 2009 and 2010 Highland Groundwater Data and Summary Statistics[1]

Well Number	Well Name	Sample Date	As (mg/L)	Cd (mg/L)	Cl (mg/L)	Cr (mg/L)	Gross Alpha (pCi/L)	Pb (mg/L)	Ni (mg/L)	NO2 +NO3 (mg/L)	pH-Field (s.u.)	Ra-226 (pCi/L)	Ra-228 (pCi/L)	Ra-226+228 (pCi/L)	Se (mg/L)	Na (mg/L)	SO4 (mg/L)	TDS (mg/L)	Th-230 (pCi/L)	U (mg/L)
U.S. NRC Site GPL			**0.05**	**0.01**	-----	**0.1**	**15**	**0.05**	**0.1**	-----	-----	-----	-----	**5**	**0.05**	-----	-----	-----	**0.55**	**0.03**
U.S. EPA MCL			**0.01**	**0.005**		**0.1**	-----	**0.015**	-----	**10**	**6.5 - 8.5 2**	-----	-----	**5**	**0.05**	-----			-----	**0.03**
		2/23/2010	<0.00095	<0.0002	235	<0.0006	1.2	<0.00005	<0.0005	<0.04	6.81	1.4	5.7	**7.10**	<0.00099	228	2100	3970	<0.2	<0.0003
		5/5/2010			237					<0.04	6.89					224	1990	4040		
		8/3/2010	<0.00095	<0.0002	257	<0.0006	1.1	0.000067	0.0015	<0.04	6.79	0.8	3.8	4.60	<0.00025	230	2020	4060	<0.2	<0.0003
		11/3/2010			254					<0.04	6.87					211	2070	3890		
mean/*median*			<0.00095	<0.0002	*239*	<0.0006	1.3	0.00006	<0.0005	*<0.04*	*6.87*	1.00	4.3	5.30	<0.00099	*230*	2188	*4050*	<0.2	<0.0003
TDSS Monitor																				
112	TDM VII	2/19/2009	<0.00095	<0.00021	121	<0.00068	1.3	0.00018	0.0038	<0.04	7.08	0.56	0.96	1.52	<0.00099	237	1760	3080	<0.1	**0.0358**
		5/22/2009			144					<0.04	7.04					240	1860	3080		
		8/19/2009	<0.00095	<0.0002	156	<0.0006	0.6	0.00011	0.0035	<0.04	7.06	0.29	4.6	4.89	<0.00099	225	1890	2980	<0.2	**0.0365**
		11/3/2009			107					<0.04	7.10					242	1760	3180		
		2/5/2010	<0.00095	<0.0002	108	<0.0006	1.6	<0.00005	0.0031	<0.04	7.12	1.1	2.7	3.80	<0.00099	248	1730	2950	<0.1	**0.0363**
		4/29/2010			103					<0.04	7.11					244	1560	2960		
		7/30/2010	<0.00095	<0.0002	102	<0.0006	0.8	0.00014	0.0031	<0.04	7.20	0.28	2	2.28	<0.00025	243	1460	2870	<0.1	**0.0376**
		10/29/2010			100					<0.04	7.18					214	1550	2840		
mean/*median*			<0.00095	<0.0002	*116*	<0.0006	1.1	0.00012	0.0034	*<0.04*	*7.11*	0.56	2.6	3.12	<0.00099	*241*	*1745*	*2970*	<0.1	**0.0366**
114	TDM IX	2/18/2009	<0.00095	<0.00021	307	<0.00068	<0.8	<0.00005	**0.876**	<0.4	5.83	0.29	1.6	1.89	<0.00099	289	3670	5380	<0.2	<0.0003
		5/20/2009			326					0.18	5.94					320	3970	5530		
		8/31/2009	<0.00095	0.00054	357	<0.0006	0.8	0.0031	**0.984**	<0.04	6.53	0.43	6.6	**7.03**	<0.005	306	3220	5300	<0.1	<0.0003
		11/3/2009			297					0.044	6.24					299	3300	5370		
		2/5/2010	<0.00095	<0.0002	292	<0.0006	7.8	<0.00005	**0.541**	<0.04	6.33	2	3.3	**5.30**	<0.00099	303	3620	5210	<0.2	<0.0003
		4/29/2010			308					<0.04	6.43					295	3230	5220		
		7/29/2010	<0.00095	<0.0002	279	<0.0006	2.8	0.000096	**0.667**	<0.04	5.73	0.19	3.6	3.79	<0.00025	296	3030	5180	0.4	0.0003
		10/29/2010			343					<0.04	6.13					273	3240	5110		
mean/*median*			<0.00095	*<0.0002*	*313*	<0.0006	1.9	0.0008	**0.767**	*<0.04*	6.15	0.73	3.8	4.50	<0.00099	*297*	3410	*5260*	<0.2	<0.0003
120	TDM XXI	2/19/2009	<0.00095	<0.00021	435	<0.00068	1.9	<0.00005	0.0021	<0.4	6.62	0.64	3.3	3.94	<0.00099	298	1930	4160	<0.2	0.0005
		5/21/2009			432					<0.04	6.80					317	2130	4260		
		8/25/2009	<0.0048	<0.001	550	<0.003	1.2	<0.00025	0.0027	<0.04	6.78	<0.16	2.5	<2.66	<0.005	279	1830	4110	<0.2	0.0005
		11/9/2009			475					<0.04	6.78					299	1900	4210		
		2/6/2010	<0.00095	<0.0002	455	<0.0006	2.3	<0.00005	0.0049	<0.04	6.77	0.72	<0.96	<1.68	<0.00099	310	2170	4210	<0.2	0.0005
		5/3/2010			378					<0.04	6.87					325	1670	4190		
		8/2/2010	<0.00095	<0.0002	403	<0.0006	1.1	0.00015	0.0066	<0.04	6.78	<0.28	<1.7	<1.98	0.00029	342	1840	4320	<0.2	0.0006
		10/30/2010			478					<0.04	6.86					290	1970	4220		
mean/*median*			<0.0048	<0.001	*445*	<0.0006	1.6	<0.00015	0.0041	*<0.04*	*6.78*	0.45	2.1	<1.98	<0.00099	*305*	1930	*4210*	<0.2	0.0005
178	TDM XLIV	4/1/2009	<0.00095	0.0018	254	<0.00068	2.3	0.0034	**0.399**	1.4	7.25	0.6	<1.1	<1.7	<0.00099	271	2290	4240	<0.3	0.0026
		6/17/2009			370					1.9	7.48					270	2850	4300		
		9/10/2009	<0.00095	0.0012	277	<0.0006	<0.7	0.0013	**0.221**	1.7	6.75	0.42	<1	<1.42	<0.00099	272	2230	4130	<0.2	0.0021
		11/12/2009			264					1.5	6.99					269	2130	4100		
		2/12/2010	<0.00095	0.0014	303	<0.0006	1.6	0.0024	**0.236**	1.4	6.53	0.6	1.3	1.90	<0.00099	268	2440	4080	<0.1	0.0027

Table 2-2 2009 and 2010 Highland Groundwater Data and Summary Statistics[1]

Well Number	Well Name	Sample Date	As (mg/L)	Cd (mg/L)	Cl (mg/L)	Cr (mg/L)	Gross Alpha (pCi/L)	Pb (mg/L)	Ni (mg/L)	NO2 +NO3 (mg/L)	pH-Field (s.u.)	Ra-226 (pCi/L)	Ra-228 (pCi/L)	Ra-226+228 (pCi/L)	Se (mg/L)	Na (mg/L)	SO4 (mg/L)	TDS (mg/L)	Th-230 (pCi/L)	U (mg/L)
U.S. NRC Site GPL			**0.05**	**0.01**	-----	**0.1**	**15**	**0.05**	**0.1**	-----	-----	-----	-----	**5**	**0.05**	-----	-----	-----	**0.55**	**0.03**
U.S. EPA MCL			**0.01**	**0.005**		**0.1**	-----	**0.015**	-----	**10**	**6.5 - 8.5 2**	-----	-----	**5**	**0.05**	-----			-----	**0.03**
		5/14/2010			237					1.0	6.99					265	2180	4180		
		8/3/2010	<0.00095	0.0013	255	0.0013	NA	0.0078	**0.236**	1.3	6.81	NA	NA		0.002	255	2050	4150	NA	NA
		11/4/2010			253					1.4	7.13					255	2150	3990		
mean/median			<0.00095	0.0014	260	<0.0006	1.4	0.0037	**0.273**	1.4	6.99	0.54	<1.1	<1.7	<0.00099	269	2205	4140	<0.3	0.0025
179	TDM XLV	3/3/2009	<0.00095	<0.00021	159	<0.00068	1.7	<0.00005	0.00077	<0.04	7.31	0.46	1.9	2.36	<0.00099	289	1460	2570	<0.2	<0.0003
		5/20/2009			163					<0.04	7.33					299	1710	2640		
		8/12/2009	<0.00095	<0.0002	203	<0.0006	0.9	<0.00005	<0.0005	<0.04	7.43	0.54	2.9	3.44	<0.00099	323	1710	2680	<0.1	<0.0003
		11/5/2009			203					<0.04	7.25					278	1790	2680		
		2/23/2010	<0.00095	<0.0002	172	<0.0006	0.8	<0.00005	<0.0005	<0.04	7.17	0.84	2.3	3.14	<0.00099	286	1540	2740	<0.2	<0.0003
		5/5/2010			173					<0.04	7.19					284	1510	2690		
		8/13/2010	<0.00095	<0.0002	183	<0.0006	1.8	0.000097	0.00093	<0.04	7.13	1.5	2.3	3.80	<0.00025	287	1590	2740	0.09	0.0007
		11/5/2010			167					<0.04	7.20					278	1560	2670		
mean/median			<0.00095	<0.0002	173	<0.0006	1.2	<0.00005	0.0007	<0.04	7.23	0.84	2.4	3.19	<0.00099	291	1609	2680	<0.2	<0.0003
181	TDM XLVII	3/4/2009	<0.00095	<0.00021	58.4	<0.00068	1.3	<0.00005	<0.0005	<0.04	7.35	0.46	<1.1	<1.56	<0.00099	220	554	1320	<0.3	<0.0003
		5/21/2009			75.2					<0.04	7.29					237	661	1330		
		8/11/2009	<0.00095	<0.0002	72.6	<0.0006	<0.7	<0.00005	<0.0005	<0.04	7.43	0.52	1.8	2.32	<0.00099	241	503	1330	<0.2	<0.0003
		11/5/2009			72.1					<0.04	7.11					215	630	1320		
		2/16/2010	<0.00095	<0.0002	58.8	<0.0006	0.8	<0.00005	<0.0005	<0.04	7.24	0.77	<1.4	<2.17	<0.00099	225	661	1290	<0.2	<0.0003
		5/4/2010			67.5					<0.04	7.09					220	600	1310		
		8/11/2010	<0.00095	<0.0002	73	<0.0006	<0.6	0.000099	0.00082	<0.04	6.94	<0.19	1.8	<1.99	<0.00025	219	673	1340	<0.09	<0.0003
		11/4/2010			70					<0.04	7.22					208	653	1330		
mean/median			<0.00095	<0.0002	71	<0.0006	0.8	<0.00005	<0.0005	<0.04	7.23	0.49	1.5	<1.99	<0.00099	220	617	1325	<0.2	<0.0003
183	TDM XLIX	3/3/2009	<0.00095	<0.00021	137	<0.00068	1.5	<0.00005	<0.0005	<0.04	7.22	0.4	1.6	2.00	<0.00099	229	1080	2020	<0.2	<0.0003
		5/20/2009			137					<0.04	7.28					246	1110	1980		
		8/12/2009	<0.00095	<0.0002	367	<0.0006	0.9	<0.00005	0.00052	<0.04	7.39	<0.14	1.7	<1.84	<0.00099	241	1110	2030	<0.1	<0.0003
		11/6/2009			152					<0.04	7.33					241	1100	2070		
		2/23/2010	<0.00095	<0.0002	131	<0.0006	0.7	<0.00005	<0.0005	<0.04	7.20	1	2	3.00	<0.00099	237	1110	2020	<0.1	<0.0003
		5/5/2010			130					<0.04	7.31					245	1010	2060		
		8/16/2010	<0.00095	<0.0002	148	<0.0006	1.3	<0.001	0.0015	<0.04	6.89	0.68	1.7	2.38	<0.00025	244	1100	2100	<0.2	<0.0003
		11/5/2010			132					<0.04	7.30					222	1090	2070		
mean/median			<0.00095	<0.0002	137	<0.0006	1.1	<0.00005	0.0008	<0.04	7.29	0.56	1.8	2.31	<0.00099	238	1088	2045	<0.2	<0.0003
Pit Lake																				
		7/1/2009			37.2		3.1				8.20	2.2	<1	<3.2	0.0804	154	588	1020	<0.1	3.17
167	Surface	8/17/2009			42		2.6				8.20	2.5	<1.4	<3.9	0.0744	134	577	1030	<0.2	3.23
		11/7/2009									8.25									
		6/7/2010			38.4		2.6				8.27	1.9	2.1	4.00	0.0718	127	575	1050	<0.2	3.22
		8/11/2010			38.1		2.6				8.20	2.3	<1.1	<3.4	0.0725	143	608	1050	<0.1	3.3
mean/median					38.9		2.7				8.20	2.2	<1.4	<3.9	0.0748	140	587	1038	<0.2	3.23

Table 2-2 2009 and 2010 Highland Groundwater Data and Summary Statistics[1]

Well Number	Well Name	Sample Date	As (mg/L)	Cd (mg/L)	Cl (mg/L)	Cr (mg/L)	Gross Alpha (pCi/L)	Pb (mg/L)	Ni (mg/L)	NO2 +NO3 (mg/L)	pH-Field (s.u.)	Ra-226 (pCi/L)	Ra-228 (pCi/L)	Ra-226+228 (pCi/L)	Se (mg/L)	Na (mg/L)	SO4 (mg/L)	TDS (mg/L)	Th-230 (pCi/L)	U (mg/L)
U.S. NRC Site GPL			0.05	0.01	-----	0.1	15	0.05	0.1	-----	-----	-----	-----	5	0.05	-----	-----	-----	0.55	0.03
U.S. EPA MCL			0.01	0.005		0.1	-----	0.015	-----	10	6.5 - 8.5 2	-----	-----	5	0.05	-----			-----	0.03
168	1/3 Depth	7/1/2009			35.5		3.3				8.33	1.8	<1.1	<2.9	0.0759	148	579	1000	<0.2	3.18
		8/17/2009			38.2		3.3				8.31	2.6	1.9	4.50	0.0724	135	650	1000	<0.1	3.18
		11/7/2009									8.33									
		6/7/2010			38.5		3.0				8.27	1.2	2.1	3.30	0.0695	124	567	1040	<0.2	3.18
		8/11/2010			38.3		2.6				8.42	2.4	<1.1	<3.5	0.0717	140	590	1000	<0.1	3.19
mean/*median*					37.6		3.0				*8.33*	2.0	1.6	3.55	0.0724	137	597	1010	<0.2	3.18
169	2/3 Depth	7/1/2009			36.3		3.2				8.20	2	<1	<3	0.0737	156	592	1010	<0.2	3.09
		8/17/2009			39.1		4.3				8.29	2.5	4.4	6.90	0.0712	135	578	988	<0.2	3.03
		11/7/2009									8.45									
		6/7/2010			38.7		2.6				8.29	2.3	<1.5	<3.8	0.071	123	555	1060	<0.2	3.24
		8/11/2010			40.0		2.7				8.31	2.4	<1.1	<3.5	0.072	136	596	1020	<0.2	3.31
mean/*median*					38.5		3.1				8.31	2.3	2.0	4.30	0.0720	138	580	1020	<0.2	3.17

Notes:
Due to the small size of the data sets (4-8), the measure of central tendency (mean or *median*) was based on the distribution of the historical data. For samples with normal or lognormal distributions, the non-detect values were replaced by the detection limit and the means were calculated. For data sets with nether normal or lognormal distributions, the median was used.
Bold = Result exceeds Groundwater Protection Standards.
Alternate Concentration Limits (ACL) apply to:
Well 125: Unat = 0.089 mg/l
Well 175: Ni = 1.8 mg/l; Ra226+228 = 25 pCi/L
Well 177: Unat = 0.11 mg/l

Table 2-3 Summary of Monitoring Well Data for Regulated Constituents (Plus Sulfate and Chloride) in the Southeast Drainage (2004 – 2010)

Well Number	As (mg/l)	Cd (mg/l)	Cl (mg/l)	Cr (mg/l)	Gross Alpha (pCi/L)	Pb (mg/l)	Ni (mg/l)	Ra226 +228 (pCi/L)	Se (mg/l)	SO4 (mg/l)	Th230 (pCi/L)	U (mg/l)
U.S. NRC Site GPL	**0.05**	**0.01**	-----	**0.1**	**15**	**0.05**	**0.1**	**5**	**0.05**	-----	**0.55**	**0.03**
U.S. EPA MCL	**0.01**	**0.005**		**0.1**	-----	**0.015**	-----	**5**	**0.05**		-----	**0.03**
MFG-1												
min	<0.00067	<0.0002	280	<0.0006	<0.6	<0.0010	0.0070	<1.5	<0.0003	1860	<0.1	**0.1330**
max	0.0053	0.0005	443	0.0011	2.5	0.00250	0.0344	4.26	0.0146	2560	0.2	**0.3950**
mean	0.0012	0.0003	344	0.0007	1.3	0.00081	0.0135	2.94	0.0038	2189	0.2	**0.3361**
median	<0.00095	0.0002	337	0.0006	1.2	0.00058	0.0098	2.79	0.0021	2150	<0.2	**0.3600**
n	18	18	25	18	18	18	18	18	18	25	18	18
%ND	83	50	0	78	33	17	0	17	28	0	94	0
BBL-1												
min	<0.00067	<0.000099	2.8	<0.00042	<0.4	<0.000047	<0.0005	<1.2	<0.00025	80.6	<0.1	<0.0003
max	<0.00095	<0.00021	8.3	0.0004	1.4	0.00016	0.0030	2.76	0.0010	101	<0.2	<0.0003
mean	NC	NC	3.8	0.0006	0.9	0.00007	0.0010	1.68	0.0007	90.9	NC	NC
median	<0.00095	<0.0002	3.2	<0.0006	1.0	0.00006	<0.0005	1.44	<0.00054	89.0	<0.2	<0.0003
n	16	16	18	16	18	16	16	17	16	18	17	17
%ND	100	100	0	88	56	38	63	76	81	0	100	100
BBL-2												
min	<0.0007	<0.000099	60.4	<0.00042	<0.4	<0.000047	0.0069	<1	0.0106	941	<0.1	**0.0450**
max	<0.0043	0.0003	145	0.0023	2.1	0.00230	0.0739	1.97	**0.0777**	1740	<0.2	**0.0629**
mean	NC	0.0002	84.6	0.0007	1.0	0.00122	0.0190	1.46	**0.0563**	1245	NC	**0.0526**
median	<0.00095	<0.0002	86.4	<0.0006	<1.0	0.00135	0.0115	<1.4	**0.0546**	1340	<0.2	**0.0529**
n	16	16	18	16	18	16	16	17	16	18	17	17
%ND	75	75	0	81	50	6	0	65	0	0	100	0
BBL-3												
min	<0.0015	<0.000099	196	<0.00042	0.7	<0.000047	0.0020	2.80	<0.00025	1550	<0.1	**0.0473**
max	<0.0034	<0.0005	307	0.0025	3.3	0.00046	0.0533	**8.90**	0.0035	2190	<0.2	**0.0589**
mean	NC	NC	241	0.0007	2.1	0.00014	0.0100	**5.45**	0.0013	1800	NC	**0.0511**
median	<0.0019	<0.0002	231	<0.0006	2.2	0.00011	0.0036	**5.00**	<0.00099	1765	<0.2	**0.0500**
n	16	16	18	16	18	16	16	17	16	18	17	17
%ND	6	100	0	88	0	38	0	0	75	0	100	0
BBL-4												
min	<0.00067	<0.000099	123	<0.00042	<0.4	<0.00005	0.0007	<1	<0.00099	1130	<0.1	**0.0343**
max	<0.0034	<0.0005	283	0.0029	2.1	0.00072	0.0198	1.77	0.0148	1500	0.3	**0.0662**
mean	NC	NC	180	0.0007	1.1	0.00020	0.0075	1.42	0.0023	1305	0.2	**0.0407**
median	<0.00095	<0.0002	172	<0.0006	<1.0	0.00016	0.0083	<1.39	0.0014	1325	<0.2	**0.0394**
n	16	16	18	16	18	16	16	17	16	18	17	17
%ND	100	100	0	88	67	6	0	65	13	0	94	0
TT-4												
min	<0.00095	<0.0002	19.3	<0.0006	<0.5	<0.00005	<0.0005	<1.13	<0.00025	476	<0.1	0.0264

Table 2-3 Summary of Monitoring Well Data for Regulated Constituents (Plus Sulfate and Chloride) in the Southeast Drainage (2004 – 2010)

Well Number	As	Cd	Cl	Cr	Gross Alpha	Pb	Ni	Ra226 +228	Se	SO4	Th230	U
	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(pCi/L)	(mg/l)	(mg/l)	(pCi/L)	(mg/l)	(mg/l)	(pCi/L)	(mg/l)
U.S. NRC Site GPL	0.05	0.01	-----	0.1	15	0.05	0.1	5	0.05	-----	0.55	0.03
U.S. EPA MCL	0.01	0.005		0.1	-----	0.015	-----	5	0.05		-----	0.03
max	<0.00095	<0.00021	66.3	<0.00068	1.5	0.00043	0.0015	<1.69	<0.00099	656	<0.2	**0.0340**
mean	NC	NC	30.2	NC	0.93	0.00015	0.0010	NC	NC	553	NC	0.0299
median	<0.00095	<0.0002	21.4	<0.0006	0.75	0.00009	0.0010	<1.4	<0.00099	542	<0.2	0.0297
n	8	8	8	8	8	8	8	8	8	8	8	8
%ND	100	100	0	100	50	38	13	100	100	0	100	0
TT-5												
min	0.0020	<0.0002	7.50	<0.0006	<0.5	<0.00005	<0.0005	<1.16	<0.00025	281	<0.1	0.0093
max	0.0025	<0.00021	29.9	<0.00068	1.0	0.00029	0.0010	2.01	<0.00099	760	<0.2	**0.0363**
mean	0.0022	NC	16.4	NC	0.7	0.00013	0.0007	1.57	NC	515	NC	0.0198
median	0.0021	<0.0002	14.6	<0.0006	<0.7	0.00009	0.0007	<1.575	<0.00099	468	<0.2	0.0160
n	8	8	8	8	8	8	8	8	8	8	8	8
%ND	0	100	0	100	63	38	38	88	100	0	100	0
TT-6												
min	0.0035	<0.0002	14.7	<0.0006	<0.5	<0.00005	<0.0005	<1.16	<0.00025	498	<0.1	0.0136
max	0.0048	<0.00021	32.8	<0.00068	1.2	0.00010	0.0014	<1.81	<0.00099	984	<0.2	0.0211
mean	0.0040	NC	22.5	NC	0.8	0.00006	0.0010	NC	NC	725	NC	0.0168
median	0.0038	<0.0002	22.3	<0.0006	0.65	0.00005	0.0010	<1.27	<0.00099	716	<0.15	0.0160
n	8	8	8	8	8	8	8	8	8	8	8	8
%ND	0	100	0	100	50	50	13	100	100	0	100	0
TT-7												
min	<0.00095	<0.0002	53.4	<0.0006	<0.6	<0.00005	0.0013	<1.16	<0.00025	770	<0.08	**0.0402**
max	<0.00095	<0.00021	103	<0.001	2.8	0.00110	0.0051	2.35	0.0025	1160	<0.2	**0.0524**
mean	NC	NC	72.7	NC	1.4	0.00041	0.0027	1.56	0.0014	946	NC	**0.0466**
median	<0.00095	<0.0002	67.6	<0.0006	0.85	0.00028	0.0018	1.40	0.0013	978	<0.1	**0.0473**
n	8	8	8	8	8	8	8	8	8	8	8	8
%ND	100	100	0	100	25	13	0	88	25	0	100	0
TT-8												
min	0.0012	<0.0002	217	<0.0006	0.6	0.00006	0.0235	2.48	0.0017	1470	<0.1	**0.1130**
max	0.0017	<0.00021	382	<0.00068	2.6	0.00024	0.0292	4.03	0.0040	1950	<0.2	**0.1270**
mean	0.0015	NC	268	NC	1.5	0.00017	0.0271	3.35	0.0023	1728	NC	**0.1179**
median	0.0015	<0.0002	250	<0.0006	1.2	0.00019	0.0278	3.53	0.0019	1765	<0.2	**0.1170**
n	8	8	8	8	8	8	8	8	8	8	8	8
%ND	0	100	0	100	13	0	0	0	0	0	100	0

Bold = Result exceeds Groundwater Protection Standards

Table 2-4 Summary Statistics for Box Creek Surface Water Data[1]

Sample Location	Bicarbonate (as CaCO3) (mg/L)	Carbonate (as CaCO3) (mg/L)	Ca (mg/L)	Cl (mg/L)	Mg (mg/L)	K (mg/L)	Se (mg/L)	Na (mg/L)	SO4 (mg/L)	TDS (mg/L)	U (mg/L)	Gross alpha (pCi/L)	Ra-226+228 (pCi/L)	Th-230 (pCi/L)	pH (s.u.)	Conductivity (µohms/cm)
Wyoming Class III (Livestock)				2,000			0.05		3,000	5,000		15	5		6.5 - 8.5	
BC-1				8.1												
min	11.4	5.40	43.5	26.8	37	7.48	<0.00025	199	681	976	0.0060	<0.5	<1.14	<0.20	7.11	1418
max	166	51.4	179	16.1	119	16.0	<0.00099	653	2070	3150	0.0367	1.1	<1.74	<2.6	10.2	4130
mean	68.8	25.9	109.1	15.7	75.5	11.3	<0.00070	400	1282	1969	0.0203	0.72	<1.45	<0.70	8.80	2868
median	60.3	26.1	86	5	77	11.2	<0.00099	374	1220	2030	0.0188	0.7	<1.41	<0.20	9.05	2780
n	5	5	5	0	5	5	5	5	5	5	5	5	5	5	5	5
%ND	0	0	0		0	0	100	0	0	0	0	40	100	100	0	0
BC-2																
min	391	<0.46	39.9	11.9	31	3.49	<0.00099	179	141	772	0.0324	<0.9	<1.35	<0.20	7.50	1174
max	468	<0.46	270	86.2	62.6	16.7	0.00052	353	1130	2150	0.0886	1.1	2.60	<0.60	7.83	2730
mean	437	<0.46	147.6	40.4	45.6	10.0	0.00083	253	608	1391	0.0648	0.9	<1.92	<0.30	7.64	1884
median	451	<0.46	133	23.1	43.1	9.94	<0.00099	228	554	1250	0.0735	0.9	<1.80	<0.20	7.58	1747
n	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
%ND	0	100	0	0	0	0	67	0	0	0	0	33	67	100	0	0
BC-3																
min	244	3.70	19.4	24.2	40.3	3.72	<0.00099	327	678	1340	0.0197	<0.5	<1.28	<0.10	8.22	2.08
max	413	117	127	83.8	54.4	17.0	0.00032	425	824	1620	0.0676	2	<2.60	<0.30	9.37	2250
mean	320	59.7	53.6	50.8	47.6	10.8	0.00072	379	740	1480	0.0395	1.2	<1.71	<0.22	8.81	1685
median	293	62.1	29.7	44.5	48.5	13.4	<0.00099	376	725	1470	0.0360	1	<1.53	<0.20	8.83	2110
n	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
%ND	0	0	0	0	0	0	60	0	0	0	0	40	100	100	0	0
BC-4																
min	105	<0.46	128	31.8	60.3	4.74	<0.00025	265	770	1540	0.0040	<0.5	<1.25	<0.10	7.39	2.68
max	387	<0.46	157	98.8	101	9.68	<0.00099	367	1380	2170	0.0627	1.2	<3.10	<0.50	8.08	2630
mean	217	<0.46	140	67.5	78.3	6.86	<0.0007	320	1089	1802	0.0208	0.82	<1.69	<0.24	7.77	1813
median	176	<0.46	139	80.2	75.9	5.64	<0.00099	307	1110	1630	0.0074	0.8	<1.30	<0.20	7.90	2130
n	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
%ND	0	100	0	0	0	0	100	0	0	0	0	40	100	100	0	0
BC-5																
min	260	<0.46	31.3	8	19.2	5.46	<0.0003	146	263	604	0.0044	<0.5	<1.25	<0.20	7.67	920
max	347	<0.46	221	126	88.5	6.67	<0.00099	328	1180	2130	0.0478	1	<1.87	<0.40	8.05	2650
mean	296	<0.46	149	71.9	62.8	6.20	<0.00076	256	818	1528	0.0270	0.8	<1.55	<0.27	7.86	1967
median	281	<0.46	195	81.8	80.6	6.40	<0.00099	293	1010	1850	0.0288	<0.9	<1.52	<0.20	7.85	2330
n	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
%ND	0	100	0	0	0	0	100	0	0	0	0	67	100	100	0	0
BC-6																
min	242	<0.46	45.3	31.6	30	5.68	<0.00025	163	376	792	0.0051	<0.5	<1.14	<0.10	8.17	1155

Table 2-4 Summary Statistics for Box Creek Surface Water Data[1]

Sample Location	Bicarbonate (as CaCO3) (mg/L)	Carbonate (as CaCO3) (mg/L)	Ca (mg/L)	Cl (mg/L)	Mg (mg/L)	K (mg/L)	Se (mg/L)	Na (mg/L)	SO4 (mg/L)	TDS (mg/L)	U (mg/L)	Gross alpha (pCi/L)	Ra-226+228 (pCi/L)	Th-230 (pCi/L)	pH (s.u.)	Conductivity (μohms/cm)
Wyoming Class III (Livestock)				2,000			0.05		3,000	5,000		15	5		6.5 - 8.5	
max	278	8.60	66.3	44.1	42.6	8.74	<0.00099	229	444	1040	0.0163	1.4	<2.59	<1.7	8.38	1589
mean	261	4.65	55.2	39	37.1	7.00	<0.0007	205	422	936	0.0089	0.92	<1.56	<0.48	8.24	1390
median	262	5.60	51.8	40.1	37	7.17	<0.00099	215	430	927	0.0061	<0.9	<1.41	<0.20	8.20	1382
n	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
%ND	0	20	0	0	0	0	100	0	0	0	0	60	100	100	0	0

[1]Data range from 2008 through 2010.

Table 2-5 Concentration Comparison of Various Source Terms

Constituent	Average Groundwater Concentration[1]	Average Pit Lake Concentration[1]	Concentration in Tailings Solution[2]	Model Predicted Pit Lake Concentration[1]
	mg/L			
Chloride	9.8	24	218	23
Sulfate	186	335	7,600	333
Uranium	0.0237	3.335	9.1	0.5063
Selenium	0.0018	0.1750	0.13	0.0093

[1] 1987 values from Tetra Tech 2007.

[2] EPRCO (1982)

Table 2-6 Sampling Location Descriptions and U Isotopic Results

Location	Sample Type	U (ug/L)	^{234}U (pCi/L)	^{238}U (pCi/L)	^{234}U Precision (± pCi/L)	^{238}U Precision (± pCi/L)	$^{234}U/^{238}U$
167	Pit Lake (surface)	3,043	1,030	1,010	160	160	1.02
168	Pit Lake (1/3 depth)	3,087	1,060	1,010	170	160	1.05
169	Pit Lake (2/3 depth)	3,145	1,110	990	170	160	1.12
BBL-2	Regolith	50.5	19.4	14.4	3.1	2.3	1.35
BBL-3	Regolith	58.1	23.4	15.6	3.8	2.5	1.50
BBL-4	Regolith	53.4	22.7	13.2	3.7	2.2	1.72
TT-3	Regolith	5.68	2.31	1.5	0.39	0.26	1.54
TT-2	Regolith	17.2	7.0	4.57	1.2	0.76	1.53
TT-4	Regolith	37.7	16.8	8.6	2.7	1.4	1.95
TT-5	Regolith	16.5	6.9	4.13	1.1	0.68	1.67
TT-6	Regolith	19.2	7.4	5.57	1.2	0.91	1.33
TT-7	Regolith	51.3	21.1	13.3	3.4	2.1	1.59
TT-8	Regolith	125	48.6	35.5	7.8	5.7	1.37
170	Backfill	609	240	169	38	27	1.42
171	Backfill	1.78	0.81	0.398	0.15	0.084	2.04
116	OBSS	21.8	10.1	4.65	1.7	0.77	2.17
128	OBSS	5.47	2.11	1.58	0.36	0.28	1.34
129	OBSS	1.60	0.72	0.354	0.14	0.076	2.03
MFG1	OBSS	347	126	107	20	17	1.18
MFG-2	OBSS	9.87	4.36	2.32	0.72	0.39	1.88
MFG-3	OBSS	8.04	3.85	1.58	0.63	0.27	2.44
112	TDSS	47.5	20.5	11.3	3.3	1.9	1.81
120	TDSS	4.83	2.01	1.26	0.34	0.22	1.60
125	TDSS	18.1	7.4	4.77	1.2	0.78	1.55
134	TDSS	1.53	0.66	0.368	0.13	0.08	1.79
172	TDSS	0.412	0.215	0.059	0.053	0.025	3.64
175	TDSS	30.6	11.9	8.7	2	1.5	1.37
142	TDSS/OSS/SH	20.7	8.7	5.22	1.4	0.86	1.67

Note: Samples collected December 2009

Table 2-7 Comparison of Selected Tailings Constituent Concentrations (mg/L) to those Predicted using PHREEQC for Neutralized Tailings Fluid

Constituent	Tailings Fluid Average	Neutralized Tailings Fluid (PHREEQC)
Major Ions		
Bicarbonate	<0.05	190
Calcium	440	540
Magnesium	1,050	1,070
Sodium	260	260
Potassium	42	42
Sulfate	11,500	5,000
Chloride	490	490
pH	2.2	7.0
Total Dissolved Solids	13,800	7,590
Metals and Metalloids		
Aluminum	566	0.032
Arsenic	0.161	<0.0001
Barium	0.10	0.005
Boron	0.70	0.70
Cadmium	0.083	0.015
Chromium	3.4	0.0023
Copper	1.65	0.0013
Iron	775	0.0013
Lead	0.32	<0.0001
Manganese	45	45
Molybdenum	0.12	0.10
Nickel	1.4	0.55
Selenium	0.12	0.021
Silver	0.025	0.025
Uranium	14	2.7
Zinc	11.5	0.89

Table 2-8 Distribution of Dissolved Uranium and Selenium Species Calculated using PHREEQC

Solution Species	Tailings Fluid Average	Neutralized Tailings Fluid (PHREEQC)
	----------- Percent Distribution of Species -----------	
Uranium		
$UO_2(SO_4)_2^{2-}$	46	<1
$UO_2SO_4^0$	35	<1
UO_2^{2+}	19	<1
$UO_2(CO_3)_2^{2-}$	<1	57
$UO_2(CO_3)_3^{4-}$	<1	41
$UO_2CO_3^0$	<1	2.0
Selenium		
$H_2SeO_3^0$	68	<1
$HSeO_3^-$	32	7.5
SeO_4^{2-}	<1	91
$MnSeO_4^0$	<1	1.3

Table 3-1 Alternative Corrective Action Comparison Summary

Alternative Corrective Actions	Engineering Feasibility	Effectiveness	Durability	Active Maintenance	Capital Costs ($1,000)	Annual O&M Costs ($1,000)	Net Present Value ($1,000)
NO ACTION	**Not Carried Forward**						
SOUTHEAST DRAINAGE							
Source Control							
Interceptor Cut Off Wall	Excellent	Moderate	Poor	Poor	$1,335	$33	$5,110
Interception with Pumping Wells	**Not Carried Forward**						
Permeable Reaction Wall (PRB)	Excellent	Excellent	Poor	Poor	$1,728	$45	$12,140
Downgradient Corrective Action							
Pumping Wells	Excellent	Moderate	Poor	Poor	$943	$93	$9,670
ISRM with Injection Wells	Moderate	Moderate	Poor	Poor	$426	$158	$14,370
Management of Collected Water							
Direct Disposal in Pit Lake	Excellent	Excellent	Moderate	Poor	$185	$3	$750
Evaporative Treatment in Lined Ponds	Excellent	Moderate	Poor	Poor	$2,553	$76	$11,790
Chemical Precipitation and Discharge	**Not Carried Forward**						
Ion Exchange and Discharge	Moderate	Moderate	Poor	Poor	$1,755	$245	$26,320
Reverse Osmosis and Discharge	**Not Carried Forward**						
HIGHLAND PIT LAKE							
ISRM with Land Mixing	Moderate	Moderate	Moderate	Excellent	$8,292	$0	$6,206
ISRM with Floating Platforms	Moderate	Moderate	Moderate	Excellent	$6,119	$0	$6,119
Ex-Situ Treatment with Ion Exchange	Moderate	Moderate	Moderate	Poor	$9,035	$1,478	$20,340
Pit Lake Backfill - Surface Drainage to South	Excellent	Excellent	Excellent	Excellent	$80,032	$0	$80,032
Pit Lake Backfill - Closed Surface Drainage	Excellent	Excellent	Excellent	Excellent	$68,983	$0	$68,983
INSTITUTIONAL CONTROLS & ACLs	Excellent	Excellent	Excellent	Excellent	$1,368	$25	$5,140

Table 3-2 Summary of Corrective Action Benefits – Avoided Radiological Dose and Non-Radiological Adverse Health Effects

	Lifetime Avoided Radiological Dose (person-rem)	Lifetime Avoided Radiological Dose (mrem/yr/person)	Avoided Adverse Health Effects from Remediation of Selenium
Southeast Drainage			
Source Control & GW Corrective Action	0.34 - 1.31	11.5 - 43.7	None
Highland Pit Lake	12.3	409	None

Table 3-3 Summary of Corrective Action Benefits – Value of Pre-Contaminated Groundwater & Land Depreciation

Value of Pre-Contaminated Groundwater (as a drinking water source)	Southeast Drainage	Pit Lake
Projected Future Water Use Demand	Very Low	Very Low
Availability of Alternate Water Supply		
Municipal	None	None
Comparable Private Land w/ Water Rights	High	High
Private Well	High	High
Comparable Private Land w/ Water Rights (per acre) Southeast Drainage (7 acres - 160 acres) Pit Lake (116 Acres)	$2000/acre $14,000 - $320,000	$2000/acre $232,000
Value of Stored Water ($/1,000 gallons) Value of Projected Future Demand for Drinking Water (2,000 gallons/yr) (Value of Pit Lake 3.9Bgal @ $0.015 - $0.23/1,000 gal))	$0.015 - $0.23 $30 - $460	$0.015 - $0.23 $58,500 - $897,000
Cost of Alternative Water Supply		
Municipal	NA	NA
Private Well	$38,800	$38,800
Cost of Supplied Water (4 persons consuming 2 liters/day each)	$91,800	$91,800
PREVENTION OF LAND DEPRECIATION VALUES	Low to negligible incremental depreciation	Low to negligible incremental depreciation

Table 3-4 Comparison of Corrective Action Costs, Resource Value Estimates and Cost of Averted Dose

Alternative Corrective Actions	Corrective Action Net Present Value ($)	Value of Pre-Contaminated Resource ($)	NPV to Resource Value Ratio	Cost/person-rem (NPV$/person-rem)	
SOUTHEAST DRAINAGE CORRECTIVE ACTIONS **Lifetime Avoided Radiological Dose**				**Low: 0.34 person-rem**	**High: 1.31 person-rem**
Source Control & Corrective Action (Source Control/Corrective Action/Treatment)		**$14,000 – $320,000**			
Low: (Interceptor Cut Off Wall/Pumping wells/Pit Lake Disposal)	$15,530,000		1,109 - 49	$45,676,500	$11,855,000
High: (PRB/ISRM w/ Injection Wells/No Treatment)	$26,510,000		1,894 – 83	$77,970,600	$20,236,600
HIGHLAND PIT LAKE CORRECTIVE ACTION **Lifetime Avoided Radiological Dose**				**12.3 person-rem**	
ISRM with Land Mixing	$6,206,000	**$58,000 – $897,000**	107 – 7	$504,553	
ISRM with Floating Platforms	$6,119,000		106 – 7	$497,480	
Ex-Situ Treatment with Ion Exchange	$20,340,000		351 – 23	$1,653,659	
Backfill of Pit Lake - Surface Drainage to Box Creek	$80,030,000		1,380 – 89	$6,506,504	
Backfill of Pit Lake - Closed Surface Drainage	$68,980,000		1,189 – 77	$5,608,130	
INSTITUTIONAL CONTROLS WITH ACLs	$5,140,000		89 – 6	$417,886	

Table 4-1 Proposed Uranium Alternate Concentration Limits

Well	Proposed ACL (mg/L)	Protective Exposure Concentration (mg/L)	Range of Historical Values (mg/L)				
			Date Range	Max	Min	Average	Count
175	3	>3.5	8/17/88 – 8/3/10	0.038	<0.001	0.008	50
MFG-1	0.7	1.4	2/24/05 – 8/19/10	0.395	0.133	0.334	17