

Prepared For:

**WESTERN NUCLEAR, INC.  
SPLIT ROCK MILL SITE  
Jeffrey City, Wyoming**

**SITE GROUND WATER CHARACTERIZATION  
AND EVALUATION**

**VOLUME 1 OF 1**

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## ACRONYMS AND ABBREVIATIONS

ACL	alternate concentration limit
AEA	Atomic Energy Act
AEC	Atomic Energy Commission
ALARA	as low as reasonably achievable
ASTM	American Society for Testing and Materials
CAP	Corrective Action Program
cfs	cubic feet per second
COC	constituent of concern
COPC	constituent of potential concern
ENSR	ENSR Consulting and Engineering, Inc.
EPA	U.S. Environmental Protection Agency
°F	degrees Fahrenheit
gpm	gallons per minute
GWPP	Ground Water Protection Plan
HEL	health effect level
HSU	hydrostratigraphic unit
IRIS	Integrated Risk Information System
K <sub>d</sub>	variable partitioning coefficient
MCL	maximum concentration limit
mg/L	milligrams per liter
mph	miles per hour
mrem/yr	millirem per year
NCRP	National Council on Radiation Protection and Measurements
NIRL	negligible individual risk level
NRC	U.S. Nuclear Regulatory Commission
NW Valley	Northwest Valley
pCi/L	picocuries per liter
POC	point of compliance
POE	point of exposure
ppm	parts per million
PQP	Project Quality Plan
PSP	Project Scoping Plan
QA/QC	Quality Assurance/Quality Control
RAGS	Risk Assessment Guidance for Superfund
RBC	Risk-Based Concentration
RCRA	Resource Conservation and Recovery Act
RIP	Resin-in-Pulp
SMI	Shepherd Miller, Inc.
SW Valley	Southwest Valley
TWP	Task Work Plan
TWS	Task Work Scope
UMTRCA	Uranium Mill Tailings Radiation Control Act
UPL	upper prediction limit

## ACRONYMS AND ABBREVIATIONS, CONTINUED

USGS	U.S. Geological Survey
WNI	Western Nuclear, Inc.

## CHEMICAL ABBREVIATIONS

Ag	Silver
Al	Aluminum
As	Arsenic
B	Boron
Ba	Barium
BaSO <sub>4</sub>	Barite
Be	Beryllium
CaCO <sub>3</sub>	Calcite
CaMoO <sub>4</sub>	Calcium Molybdate
Cd	Cadmium
Co	Cobalt
Cr(total)	Chromium
Cu	Copper
F	Fluoride
FeO(OH)	Goethite
FeO(OH) <sub>n</sub> H <sub>2</sub> O	Limonite
Fe <sub>2</sub> O <sub>3</sub>	Hematite
FeS <sub>2</sub>	Marcasite
FeSe <sub>2</sub>	Ferroselite
Hg	Mercury
Mn	Manganese
MnO <sub>2</sub>	Manganese Dioxide
Mo	Molybdenum
MoS <sub>2</sub>	Jordisite
Ni	Nickel
NH <sub>3</sub>	Ammonia
NH <sub>4</sub>	Ammonium
NH <sub>4</sub> <sup>+</sup> -N	Ammonium-N
NO <sub>2</sub>	Nitrite
NO <sub>3</sub>	Nitrate
Pb	Lead
Ra-226+228	Combined Radium
RaSO <sub>4</sub>	Radium Sulfate
Sb	Antimony
Se	Selenium
Th-230	Thorium-230
Th-232	Thorium-232
Tl	Thallium
U	Uranium
Zn	Zinc

## **1.0 GENERAL INFORMATION**

### **1.1 Introduction**

This document summarizes a comprehensive undertaking that includes a characterization and evaluation of the historic and present ground water impacts associated with the Western Nuclear, Inc. (WNI) Split Rock Site. This document presents the information necessary for the selection of a corrective action alternative, which provides the required reasonable assurance of protection of public health, safety and the environment from ground water impacts associated with the uranium milling byproduct material at the WNI Split Rock Site. This effort sometimes has been referred to in accompanying text and attachments as the Ground Water Protection Plan (GWPP). This document presents site data in the format suggested by the U.S. Nuclear Regulatory Commission (NRC) in the Staff Technical Position: Alternate Concentration Limits For Title II Uranium Mills (NRC, 1996). This summary document includes a description of the historical site operations and present site hydrogeologic and geochemical conditions and evaluates potential corrective action alternatives. The potential alternatives are evaluated with respect to their ability to provide the required reasonable assurance of protection of public health, safety and the environment and to satisfy the intervention principle of reducing concentrations to as low as reasonably achievable (ALARA) below protective levels. Based on this evaluation and public comment, a preferred correction action alternative is proposed. This document is supported by numerous technical appendices that provide the detail necessary for independent verification of all presented facts and conclusions. Table 1 summarizes the overall structure of this document and its supporting appendices. Table 2 identifies the specific locations in the summary document and its appendices of key review topics.

## 1.2 Facilities Description

### 1.2.1 Historical Context

Following the promulgation of the Atomic Energy Act (AEA) in 1946, which created the Atomic Energy Commission (AEC) (forerunner to the NRC), private uranium mining and milling operations were developed under negotiated contractual agreements with the AEC. These contracts provided for guaranteed prices which allowed the operators to receive a reasonable profit while allowing the United States to develop domestic uranium mining and milling capabilities, reducing its dependence on foreign sources of uranium ore for strategic military purposes.

The perceived hazards associated with these early milling operations and associated wastes were limited to occupational radiological exposures (primarily airborne particulate exposures) with no consideration of potential environmental impacts. Increased awareness regarding potential health and environmental hazards associated with uranium mill tailings began in the late 1960s when use of these tailings in construction of residential and commercial buildings occurred in the area of Grand Junction, Colorado. To provide for public and environmental protection and to address the ability of the AEC (and subsequently the NRC) to regulate the previously unregulated uranium mill tailings and associated wastes, Congress passed the Uranium Mill Tailings Radiation Control Act of 1978 (UMTRCA). This legislation created a two-part regulatory system to comprehensively handle tailings and wastes from inactive/abandoned sites (Title I) and "active" sites (Title II). This regulatory system provided for the U.S. Environmental Protection Agency (EPA) to develop standards of general applicability for the protection of public health and safety and the environment from potential radiological *and non-radiological hazards* associated with uranium tailings and other uranium milling wastes. To provide this protection, UMTRCA explicitly defined NRC jurisdiction over a new category of AEA-regulated material now known as

"11e.(2) byproduct material" (the tailings or wastes produced by the extraction or concentration of uranium or thorium from any ore processed primarily for its source material content)<sup>1</sup> by implementing and enforcing protection standards that conform with those developed by EPA.

Because of the state of environmental understanding under which industry and the regulatory community worked at the time, the design and operation of uranium mills of the 1950s and 1960s did not incorporate the level of environmental protection measures that would be used today. Consequently, potential environmental impacts created at existing uranium mills, which were designed and operated according to the state-of-the-art practices at the time and in accordance with all applicable regulations and requirements, became subject to more stringent environmental requirements to the extent reasonably achievable. With the decline in world uranium demand and associated price declines beginning in the early 1980s and continuing today, most of the Title II uranium mills are now in the process of final site reclamation. Thus, the potential environmental impacts and challenges facing the Title II sites today are not necessarily a function of neglect or mismanagement by the operators but, rather, likely are more a function of the changes through time in the regulatory requirements and the evolution of understanding regarding the potential environmental consequences of what used to be state-of-the-art milling practices.

#### **1.2.1.1 Mill Operations**

The following sections summarize general aspects of the Split Rock Site mill and tailings disposal history.

By 1956, sufficient uranium reserves had been developed at WNI properties in the Crooks Gap and Gas Hills areas, or committed to WNI by other miners in the area, to

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<sup>1</sup>AEA section 11e.(2), 42 U.S.C. §2014e(2).

justify the installation of an ore processing mill (Quinn, 1961). The location of the mill site was originally selected in conjunction with the AEC and was approved on the basis of: (1) the proximity to U.S. Highway 287, (2) the favorability of the future townsite location, (3) the centralized location of the mill between ore bodies to the north and south of the mill, which minimized ore haulage, and (4) the favorable hydrogeologic conditions, which afforded rapid elimination of water in the tailings through seepage into the underlying aquifer (see Figure 1). The mill was located about 2 miles northeast of the company town of Jeffrey City, Wyoming, at the head of two alluvium filled valleys.

The Split Rock Mill was an acid-leach, ion-exchange, and solvent-extraction uranium-ore processing mill that processed approximately 7.7 million tons of uranium ore from 1957 to 1981. The facility was designed originally to process 400 tons of ore per day; however, in 1961, due to heightened uranium demand, the milling capacity was increased to 845 tons per day. By 1967, milling capacity had increased to approximately 1,200 tons per day to accommodate contracts with both private industry and the AEC. After a series of expansions in the 1970s, the mill was processing 1,700 tons of ore per day. On June 19, 1981, WNI announced that because of diminishing demand and depressed prices for uranium, the mill would be placed on stand-by. The mill remained on stand-by until 1986. In 1986, the license was amended to terminate use of the tailings pond for disposal, and WNI was required to submit a Tailings Reclamation Plan to the NRC. The mill was decontaminated and decommissioned in the summer of 1988. Mill components were dismantled and buried in the areas designated as the mill burial site. The mill burial site is located primarily beneath the former mill site. A more detailed description of the mill process is included in Section 2.1.

#### **1.2.1.2 Tailings Operations**

Process waste in the form of tailings solids and acidic liquids were discharged to the unlined tailings disposal areas which were operated from 1957 until 1981. These ponds

were designed in 1957, when the original AEC license (R-205) was issued. The tailings pond design criteria favored a disposal pond which eliminated process effluent through seepage, maximizing tailings storage while decreasing water storage and handling requirements. At the mill's peak production period, mill estimates indicated a ratio of 5 parts process effluent to 1 part solids were being discharged into the tailings disposal areas.

Three primary tailings disposal areas were used during the operational life of the mill; the original Old Tailings Impoundment, the Alternate Tailings Impoundment, and the "new" Main Tailings Impoundment. A total of approximately 7.7 million tons of tailings were deposited. A more complete description of the tailings impoundments is presented in Section 2.1.

### **1.2.2 Current Land Use**

The Split Rock Site is located in a remote and sparsely populated portion of Wyoming. Land uses prior to the uranium boom included ranching and livestock grazing. After establishment of local mines and the mill facility, the mill town of Jeffrey City was founded and grew to accommodate a population of industrial site workers; maximum population density occurred during the 1970s with about 3,000 local residents. In recent years, since the shut down of the nearby mines and decommissioning of the mill, local population has declined to approximately 75 residents, and activities in the area focus mainly on ranching. The land immediately surrounding Jeffrey City and the Split Rock Site is mostly privately owned. Recreational land uses include fishing on the Sweetwater River and seasonal game hunting.

Most residents of Jeffrey City derive their water supply from the town wells, although several residents near Jeffrey City have private water supply wells (see Figure 2). The Jeffrey City Townsite wells presently supply approximately 100 gallons per minute



(gpm) on an average basis, though pumping to maintain the water storage tanks is periodic.

### 1.3 Extent of Ground Water Constituent Migration

Several site-derived constituents have migrated beyond the edge of the tailing reclamation cover. Specifically, six constituents of concern (COCs) have been identified that currently exist and are expected to continue to migrate past the edge of the tailings reclamation cover:

Constituent	Protective Values (mg/L except as noted)
Ammonia	0.7
Manganese	0.73
Molybdenum	0.18
Nitrate	10
Radium (226+228)	5 pCi/L
Uranium	0.11

These constituents are derived from tailings and either are listed as hazardous constituents in 10 CFR Part 40 or 40 CFR Part 192 or have the potential to be hazardous as defined by EPA (Integrated Risk Information System [IRIS], 1989). A complete description of the COC identification process is provided in Section 2.1.2.

Because of the mobility and relative abundance of uranium in the ground water system, uranium can be used to represent the maximum extent of existing and future contaminant migration. In other words, none of the other COCs will exceed the migration of uranium, and the extent of the uranium contamination defines the maximum extent of migration of any constituent. The current extent of uranium migration is shown on Figure 3.

## 1.4 Current Ground Water Standards

Current ground water standards are listed in Source Material License SUA-56 - License Condition 74 (B). These standards were developed using maximum concentration limits (MCL) and site background determined from well WN-15 (sampled in 1987). The standards are applicable at the point of compliance (POC) wells WN-4 and WN-21. The standards are as follows:

Constituent	Standard (mg/l except as noted)
Beryllium	0.05
Cadmium	0.01
Chromium	0.05
Lead	0.05
Nickel	0.05
Radium (226+228)	5 pCi/l
Selenium	0.013
Thorium-230	0.95 pCi/l
Uranium	0.16

## 1.5 Proposed Standards

The comprehensive evaluation, discussed in Chapters 2 and 3 and detailed in the appendixes to this submittal, identified a total of 17 constituents above the higher of background or the protective standards, determined by MCLs or risk based concentrations (RBCs), in or underlying the reclaimed tailings. Of these 17 constituents, only six constituents identified in Section 1.3 exceed the higher of background or the protective standards at or down gradient of the existing point of compliance (POC) wells. Two alternate approaches, in accordance with 10 CFR, Part 40, Criterion 5, are presented in Chapter 4 that eliminate the potential risks associated with these site constituents.

The first approach follows an ACL format where concentrations that will maintain protective conditions at the points of exposure (POEs) are developed for the POC wells. Standards are proposed for all 17 identified constituents with the standard for 11 of these constituents set at the higher of background or the protective standards (MCL's or RBC's). The proposed standards for the other six constituents are the ACLs developed herein. This approach is consistent with Criterion 5B(6) of 10 CFR Part 40, Appendix A.

The other proposed alternative states that, for reasons of site specific conditions, under Criterion 5B(3) of 10 CFR Part 40, Appendix A, none of the identified constituents pose a significant present or potential future hazard. Therefore, there are no hazardous constituents and there are no applicable or necessary ground water standards and no monitoring is required. This approach is supported by the regulations since, once the proposed alternative is implemented, no site constituents will be "capable of posing a substantial present or potential future hazard to human health or the environment" [10 CFR Part 40, Appendix A, Criterion 5B(3)].

## **2.0 HAZARD ASSESSMENT**

The Hazard Assessment presents a characterization of the source-terms which may potentially supply COPCs to the ground water, an evaluation of the present distribution of the COPC, and an assessment of how the COPC will be transported. These characterization data are used to develop reasonably conservative projections of constituent concentrations in the ground water and surface water to support defensible human and ecological exposure assessments.

### **2.1 Source and Contaminant Characterization**

#### **2.1.1 Facility and Process Description**

The objective of this section is to describe and to summarize the milling history of the Split Rock Site, with emphasis on the aspects of site operations that affected the geochemistry of soils and ground water. A detailed description of the site and milling history and processes is provided in Appendix F.

##### **2.1.1.1 Recovery Process**

The Split Rock Mill was an acid-leach, ion-exchange, and solvent-extraction uranium-ore processing mill. The original mill as constructed in 1957, and as expanded in 1959, utilized the Reciprocating Basket Resin-in-Pulp (RIP) method of ion-exchange for the recovery of uranium oxide. In the spring of 1965, a solvent extraction circuit was added, and the "Eluex" process was used. In October 1966, the "Basket RIP" circuit was removed and replaced with a continuous countercurrent RIP process, but the "Eluex" process was retained. This change was made in order to reduce operating and maintenance costs and to increase recovery and plant capacity (Garbella, 1967).

Simplified schematics of the mill process from 1957 to 1965 and from 1965 to 1981 are shown on Figures 4 and 5.

Prior to 1974, the ore was ground by primary and secondary crushers before being fed into the mill circuit. From 1974 to 1981, the ore went through a semi-autogenous grinder (Canonie, 1989a). The grinding circuit operated 8 hours per day to produce one day's leach feed supply. Total storage capacity was contained in two tanks that held approximately 1,150 tons of ore containing about 6,000 pounds of  $U_3O_8$ . The slurry for leach was stored at 50 to 55 percent solids (WNI, 1976, 1980).

The pulp from the storage tanks was metered to the leaching circuit which consisted of 11 agitated wooden tanks in series. The nominal retention time for the total leaching circuit was 16 hours. Sulfuric acid was added to the first leach tank to an approximate pH of 1.0. Sodium chlorate, an oxidant, was added to the third tank in series to dissolve the uranium. The dissolved uranium formed a uranyl sulfate complex. Gravity passage of the pulp through a series of tanks took approximately 12 hours, with about 95 percent of the uranium being extracted. The total leaching circuit contained about 2,500 pounds of  $U_{nat}$  at any given time as a combination of dissolved uranium and uranium contained in the slurry solids. The pH of the last leaching vessel was adjusted to a value of 1.1 with a lime slurry addition in order to minimize ammonia usage for the final pH adjustment to the RIP circuit (WNI, 1976, 1980).

The RIP system consisted of two separate, independent, parallel ion-exchange systems: the exhaustion circuit and the elution circuit. In the exhaustion circuit, the uranyl sulfate in solution was exchanged for sulfate on the active sites of the resin. This circuit was operated in a countercurrent manner with screens to remove the slurry from the resin downstream. The countercurrent operation allowed the stripped resin to contact the solution with the lowest concentrations, thereby maximizing the total uranium removal as the slurry discharge at this point was pumped to join the washed sands for transfer to the tailings pond.

The loaded resin from the exhaustion circuit was fed into the elution circuit, where the uranium was removed from the resin. Elution of the uranium was conducted with a 10 to 15 percent sulfuric acid solution in a series of 11 beds, with resins moving countercurrent to the liquid. This created a pregnant strip solution loaded with uranium. The stripped resin was washed to remove the strong acid. The exhaustion and elution circuits contained approximately 2,500 pounds of  $U_{nat}$  in solution at any given time in the process (WNI, 1976, 1980).

Pregnant strip solution from the resin elution circuit was fed to the solvent extraction circuit. The solution was mixed with an organic liquid in four stages of mixing and settling. The extracted the uranyl sulfate complex from the aqueous phase by ion-exchange. The raffinate (or stripped solution) was recycled to a holding tank, where the acid concentration was adjusted and the solution reused in the resin elution circuit.

The loaded organic liquid was stripped of uranium by contact with ammonium sulfate solution adjusted to pH 4 with anhydrous ammonia. A sodium carbonate solution was placed into contact with the stripped organic liquid for molybdenum removal. The molybdenum strip solution was then sent to the tailings impoundment and the stripped organic liquid was recycled to the solvent extraction circuit. No organic phases left the milling circuit or were discharged to the tailings impoundment. The solvent extraction circuit contained approximately 2,000 pounds of  $U_{nat}$  in either the aqueous or liquid organic phase (WNI, 1976, 1980).

The aqueous solution containing the purified and concentrated uranium was treated in two agitation tanks in series with anhydrous ammonia to a pH adjustment of 7, which caused the uranium to precipitate as ammonium diuranate. The precipitate was dewatered successively in a thickener and a centrifuge and was then calcined (roasted) in a natural gas-fired roaster. The roaster was operated at temperatures of 1,300 to 1,450 degrees Fahrenheit ( $^{\circ}F$ ). The calcined product (yellowcake), which contained approximately 90 percent  $U_3O_8$ , was run through a small hammermill to break up the

lumps and store it for subsequent packaging. The yellowcake was packaged and shipped in 55-gallon steel drums, each holding about 800 to 900 pounds of product (WNI, 1976, 1980).

#### **2.1.1.2 Reagent and Water Use**

Table 4 summarizes the reagents used in the milling process and their purpose. Table 5 presents estimates of the monthly consumption of the process additives, as well as additional chemicals and reagents used at the mill during peak operations for the period between 1974 and 1981 (Canonie, 1989b). A small uranium assay laboratory was operated at the mill site. Table 6 lists most of the reagents used in that laboratory. Sulfuric acid, used at an approximate rate of 60 to 100 pounds per ton of ore, nitric acid, used at an approximate rate of 15 pounds per ton of ore, calcium oxide (lime), used at an approximate rate of 10 pounds per ton of ore, and manganese dioxide, used at an approximate rate of 10 pounds per ton of ore, comprised the vast majority of reagent mass used in the milling process.

Process mill water initially was furnished by two 180-foot-deep wells located near the mouth of the Northwest (NW) Valley. Initial (1961) mill water consumption was approximately 750 gpm (Quinn, 1961). During subsequent operations, process water was obtained primarily from Well #2, which was pumped at an average rate of 1,400 gpm. The location of industrial Well #2 is shown on Figure 3. Water from the NW Valley pond also was used as part of the process circuit (Canonie, 1989b). At the mill's peak production period, mill estimates indicated a weight ratio of 5:1 water to solids. With a solids throughput of 1,700 tons per day processed, the weight of water would have been 8,500 tons per day, which corresponds to a rate of 1,415 gpm (D'Appolonia, 1977a, b; 1980).

### 2.1.1.3 Ore Characteristics

The Split Rock Mill received ore from two uranium districts: Gas Hills (to the north-northeast of the site) and Crooks Gap (south of Jeffrey City). Mines from the Gas Hills District supplied the mill in the early years of operation, and mines in the Crooks Gap District supplied ore for the later years of operation. The Split Rock Mill also received yellowcake from the Green Mountain ion-exchange (IX) plant located approximately 12 miles south of the Split Rock Mill in the Crooks Gap District. The Green Mountain IX plant was designed to recover soluble natural uranium from mine water (at about 8 to 20 parts per million [ppm], with a maximum flow capacity of about 750 gpm) using one or more ion-exchange columns containing ion-exchange resin. The  $U_3O_8$  was subsequently stripped from the loaded resin with a chloride-sodium carbonate solution, which was then acidified to a pH of 2.0 and subsequently neutralized to a pH of 7.0 to precipitate diuranate. The resulting yellowcake slurry was then thickened and shipped in 55-gallon steel drums via truck to the Split Rock Mill for final processing (WNI, 1980).

Table 7 lists the uranium bearing ore minerals that are located in ore bodies reported to occur in the Crooks Gap District. The primary ore minerals are uraninite and coffinite, which contain uranium in its IV-valent oxidation state. Secondary uranium minerals in the district contain uranium in the VI-valent state.

The Crooks Gap uranium deposits are found in the Battle Springs Formation. Uranium ores are particularly associated with "carbonaceous siltstone beds" (Stephens, 1964). These clayey siltstones contain coarse-grained quartz, feldspar, and rock fragments with micas, chlorite, glauconite, and traces of heavy minerals such as zircon and tourmaline (Klingmuller, 1989). Plant fossils and coaly streaks are common; minor amounts of volcanic glass also are present. Calcite, pyrite, or iron oxides may be present near areas of uranium mineralization.



The uranium ores of the Gas Hills District are contained in the lower Eocene Wind River Formation, also of river and delta origin (Stephens, 1964). Many of the ore minerals of the Gas Hills District (Table 8) are identical to those of the Crooks Gap District, but the Gas Hills deposits apparently contain more selenium and molybdenum (Stephens, 1964; Harshman, 1974). Minerals and elements that are associated with the uranium deposits in the Gas Hills District include pyrite (up to 200,000 ppm, or 20 percent), selenium (up to 500 ppm), vanadium (up to 500 ppm), molybdenum (up to 1,000 ppm), arsenic (up to 10,000 ppm), and small amounts of beryllium (up to 5 ppm) and cobalt (up to 20 ppm) (Harshman, 1974).

According to Harshman (1970), uranium ore roll fronts such as those in Wyoming are typically associated with pyrite or marcasite ( $\text{FeS}_2$ ), jordisite ( $\text{MoS}_2$ ), hematite ( $\text{Fe}_2\text{O}_3$ ), limonite ( $\text{FeO}(\text{OH}) \cdot n\text{H}_2\text{O}$ ), goethite ( $\text{FeO}(\text{OH})$ ), ferroselite ( $\text{FeSe}_2$ ), organic carbon, and calcite ( $\text{CaCO}_3$ ). Various authors disagree as to whether increased copper concentrations are associated with the Wyoming uranium ores (Stephens, 1964; Harshman, 1974). Harshman found copper concentrations of several ppm near uranium ore deposits.

#### **2.1.1.4 Waste Management**

During the period of mill operation, process wastes in the form of tailings solids and acidic liquids were discharged to the tailings disposal area. Non-milling and non-process wastes (e.g., administration and mill building sanitary wastes, paper products, etc.) were disposed of in the Sewage Lagoon or the Waste Trench located in the Southwest (SW) Valley (Canonie, 1989a). Spent sulfuric acid was returned to the site from commercial users and disposed of in the main impoundment. At one time, the Jeffrey City town landfill was sited in the SW Valley. The decommissioned mill is itself buried in the NW Valley (Figure 6). Waste management practices are described in greater detail in Appendix F.

#### **2.1.1.4.1 Tailings Impoundments**

The tailings disposal impoundments were operated from 1958 until 1981 and consisted of three distinct areas referred to as the Main, Old, and Alternate Tailings Impoundments (Figure 6). The mill was placed on standby status from 1981 to 1986. In 1986, the license was amended to terminate the use of the tailings impoundments for tailings disposal.

The tailings disposal areas were located in two alluvial valleys, the NW and SW Valleys, situated between surrounding granite outcrops. In the upper reaches of the valleys where tailings were deposited, the granite is overlain by dune sands and fluvial deposits of the Split Rock Formation, which together vary from 0 feet to 150 feet thick. The thickness of these sediments increases down both valleys to over 500 feet at the mouth of the SW Valley and 330 feet at the mouth of the NW Valley (see Appendix B).

The original tailings disposal area, the Old Impoundment, was operated from 1958 to 1977. This area originally occupied approximately 100 acres prior to construction of the new tailings embankment in 1977 (Figure 6). The Alternate Tailings Impoundment was constructed prior to 1977 and served as an additional tailings storage area. In 1977, the tailings liquid overtopped and breached the Old Tailings Impoundment embankment. Following the breach, the embankment was repaired, all tailings were returned to the impoundment, and a new compacted tailings embankment was constructed upstream of the existing embankment. This embankment created the Main Tailings Impoundment. The Old and Alternate Impoundments were not used after 1977. The new 127.2-acre Main Tailings Impoundment consisted of new tailings (deposited after 1977) overlying portions of the old tailings (deposited before 1977).

By the end of operations, the three tailings disposal areas encompassed approximately 180 acres and contained approximately 7.7 million tons of tailings (Canonie, 1989b). The tailings disposal areas are illustrated on Figure 6. Approximately 7.7 million tons of

waste solids and billions of gallons of process effluent were discharged to the tailings disposal areas over 25 years of operation. Approximately 5.3 million tons of waste solids were discharged prior to 1977 in the Old and Alternate Tailings Impoundments, and the remaining 2.4 million tons of waste solids were discharged to the Main Tailings Impoundment. The maximum thickness of tailings deposited in the impoundments was approximately 80 feet. Included in the discharges of effluent to the tailings pond was the water pumped from the Northwest Valley Seepage Pond. As of 1980, the tailings disposal facility received up to 1,700 tons of solid tailings per day and water at an average rate of approximately 1,000 to 1,400 gpm (D'Appolonia, 1980).

#### **2.1.1.4.2 Waste Trench**

The Waste Trench was located in the southwest portion of the site, south of the Old Tailings Impoundment and east of the Alternate Tailings Impoundment (see Figure 6). The burial trench area covered approximately 7.7 acres. The bottom of the trench was above the maximum level of the ground water table.

In general, four major types of waste were placed in the waste trench, including:

- Carbon and wood fibers cleaned out of the ore pulp after leach
- Waste paper, bottles, rags, and miscellaneous trash
- Worn-out parts, equipment, and other materials
- Trash material in ore segregated on the ore pad and at the mill-feed shoot, which consisted of wood, wire cable, old tools, roof bolts, and so forth.

The trench in which waste was placed was approximately 18 feet wide by 14 feet deep by 100 feet long. Material in the trench was compacted by tracking it with a bulldozer. Following filling, the trench was covered with a minimum of four feet of clean soil. The center of the trench was located approximately 200 feet south and 200 feet east of the

toe of the southwest corner of the Old Tailings Impoundment. The location and nature of materials placed in the Waste Trench are discussed in detail in the "Revised Section 4.3, Application for Burial of Contaminated Material in Soil," dated April 3, 1981. This application is incorporated into Source Material License SUA-56, Amendment No. 44, License Condition 73 (Canonie, 1989b; WNI, 1981). The waste trench has had and will have no impact on the overall ground water conditions at the site.

#### **2.1.1.4.3 Disposal of Spent Acid**

In the late 1960s and the 1970s, WNI sold sulfuric acid produced at the Split Rock Site to several local petroleum refineries and agreed to accept spent acid back from the processes (WNI, 1983).

From 1962 until the mill tailings pond overflow in April 1977, the spent acid was disposed of in the tailings pond. After the overflow, WNI no longer accepted spent acid for disposal. Spent acid was delivered to the site in tanker trucks which drove up onto the Old Tailings Embankment and discharged the spent acid directly into the tailings impoundment. A comprehensive evaluation (section 2.1.2) determined there are no organic constituents that might have been associated with spent acid within the tailings or aquifer. The sulfuric acid from the spent acid disposal was similar to the sulfuric acid used in the milling process. Therefore spent acid disposal has had little or no impact on ground water conditions at the site.

#### **2.1.1.4.4 Sewage Lagoon**

The Sewage Lagoon was located in the southwest portion of the site, immediately west of the Alternate Tailings Impoundment, and covered an area of approximately 3.2 acres (see Figure 6). As of approximately 1980, the mill and office contributed approximately

22 acre-feet per year (14 gpm over a period of one year) of sanitary wastewater and sewage to the sewage pond (NRC, 1980).

Sanitary wastes at the mill site were pumped through a sewer pipe into a lagoon within the fenced-in restricted area south of the Old Tailings Impoundment. During operations, the Sewage Lagoon was approximately 10 feet deep. As of 1989, liquids within the lagoon were about 3 feet deep (NRC, 1980; Canonie, 1989b). The lagoon was decommissioned during surface reclamation activities by filling the dry lagoon with approximately 6 feet of clean dune sand and then covered with coarse tailings sands to grade. This area was then covered under the radon barrier designed for Area 2A under the approved Tailings Reclamation Plan. Since the volume of water discharged to the sewage lagoon was small compared to the tailings discharge rate and, because there is no evidence of any special ground water constituents that exist as a result of the sewage lagoon, there is no impact to ground water from the sewage lagoon.

#### **2.1.1.4.5 Landfills**

The uranium processing mill was decommissioned and demolished during the summer of 1988 (Canonie, 1989b). Components were dismantled and buried in the mill site burial area with the approval of the NRC. The mill site burial area was primarily located beneath the former mill site (WNI, 1987).

Non-hazardous and non-radioactive solid wastes from the mill and the town of Jeffrey City were buried in a sanitary landfill southeast of the former mill building and northwest of the former seepage ponds (Figure 6). The procedures for the sanitary landfill operation were inspected and approved by the appropriate Wyoming state agencies (NRC, 1980). No impact from the mill burial or the sanitary landfill has been identified or is expected.

## 2.1.2 Constituents of Potential Concern (COPC)

Constituents derived from tailings have been identified in ground water and shallow surface soils in the Sweetwater River floodplain at levels above background concentrations at the Split Rock Site. The identification of the constituents for which license conditions must be established is a step-wise process that identifies the constituents that are potentially hazardous to human and ecological health related to former mill site activities and that exist at concentrations above naturally existing (i.e., background) concentrations. The monitoring system, procedures, and Quality Assurance/Quality Control (QA/QC) Program used to characterize constituent distribution and behavior at the Split Rock Site are discussed in detail in Appendix F, Appendix A, and Exhibit B and Appendix J, respectively.

The constituent screening process was applied to the tailings ground water grouping defined by the WNI ground water database as follows:

1. All constituents listed in 10 CFR Part 40, Appendix A and 40 CFR Part 192 were selected for consideration. It should be noted that none of the organic volatile or semi-volatile compounds listed in 10 CFR Part 40, Appendix A or 40 CFR Part 192 were identified in site tailings or ground water (see Appendix F, Section F.5.3.9). Therefore, the list of potential hazardous constituents includes only metals and radionuclides.
2. Additional constituents reasonably assumed to be derived from byproduct material that could adversely impact public health and safety and the environment were included in the list. Only those constituents for which the potential risks to human and ecological receptors could be reasonably estimated were included.
3. Maximum ground water concentrations from the tailings area for the period of January 1, 1996 through December 31, 1997 (see Table 3), were compared to the lowest background concentration of the floodplain alluvium or Split Rock Formation aquifers. Those constituents that were not detected in concentrations greater than the lowest background concentration were discarded and are not considered as COPC for this site.

4. The remaining constituents were further compared to MCLs promulgated by the EPA. Constituents for which there are no promulgated MCLs, EPA Region 3 Risk-Based Concentrations (RBCs) were used as protective concentrations. However, because some of the assumptions regarding the appropriateness of RBCs as protective standards for this site may be in question, site specific health effect levels (HELs) for the constituents without promulgated MCLs were developed to establish that the RBCs are appropriate protective standards. Development of the HELs is presented in Appendix I, Attachment I.a. The higher of background, MCL, and RBC values were considered to be the relevant protective values.
5. Any constituent for which the maximum measured concentration in the tailings area was greater than the larger of either: (a) the lowest ground water background value or (b) its respective MCL or RBC value, was considered a COPC.
6. Existing COPC concentrations beyond the edge of the tailings reclamation cover were compared to the protective standards, considering existing human exposure pathways, to determine if there are any present risks to human health.
7. All COPC concentrations presently above the protective standards beyond the edge of the tailings reclamation cover are classified as constituents of concern (COC) and are considered to be the only constituents with the potential to exceed protective standards in the future. Therefore, these COC would be the focus of development and evaluation of potential of corrective action alternatives.

#### **2.1.2.1 Evaluation of Site Data to Identify Constituent of Potential Concern**

An initial list of 25 constituents was originally identified for consideration (Table 3). The list includes: Ag, Al, As, B, Ba, Be, Cd, Co, Cr(total), Cu, F, Hg, Mn, Mo, Ni, NH<sub>3</sub>, NO<sub>3</sub>, Pb, Ra-226+228, Sb, Se, Th-230, Tl, U, Zn. This list was further evaluated by determining the constituents that are above the protective standards both up gradient and down gradient of the edge of the tailings reclamation cover. All constituents so identified are considered as COPCs. Those COPCs that have values that exceed the protective standards beyond the edge of the tailings reclamation cover are identified as COCs and are the only constituents that could potentially pose a future hazard, should pathways to receptors exist. These COCs are the focus of development and screening of potential corrective action alternatives.

All 25 of the constituents considered were evaluated in three distinct locations:

1. The tailings impoundment and areas above the edge of the tailings reclamation cover
2. The Split Rock Formation aquifer down gradient of the edge of the tailings reclamation cover
3. The shallow floodplain alluvial aquifer.

The floodplain alluvial aquifer and the Split Rock Formation aquifer were considered separately due to the distinctly different baseline ground water qualities of these two aquifers (see Appendix F). The tailings and areas up gradient of the edge of the tailings reclamation cover were considered as the primary source term, which could potentially impact both aquifers and surface water bodies.

Water quality data for the period of January 1, 1996 through December 31, 1997, from the three locations described above were selected according to the following criteria:

- Only data from wells completed to monitoring well quality were included. Screening level data or data rejected for QA/QC reasons were excluded. Exceptions to this condition are discussed below.
- The maximum value for each constituent at each monitoring location for the period of January 1, 1996 through December 31, 1997, was considered. These values are a conservative representation of present conditions. Pre-1996 data is considered to be non-representative of current conditions due to evolution of the ground water flow and geochemical conditions.
- All data qualified as U (non-detected, reported value is quantitation limit), J (estimated value), or UJ (non-detected, reported value is estimated) were retained for evaluation at their full reported value, while data qualified as R (rejected) were rejected from the data set. See Appendix F for discussions of the database and data qualifiers. See Appendix J for a detailed discussion of QA/QC procedures for data quality review.



The wells evaluated for each area are summarized in Table 9, and their locations are shown on Figure 7. Details regarding the construction, sampling, and analysis of samples from each of these monitoring locations are presented in Appendix A.

#### **2.1.2.2 Evaluation of Site Constituents**

The 8 constituents barium, boron, chromium, cobalt, copper, mercury, silver, and zinc were not identified anywhere in the site ground water (within tailings areas or beyond the edge of the tailings reclamation cover) at levels above the larger of background, MCLs, or RBCs. Therefore, these constituents are not considered hazardous or of potential concern and are discarded from further discussion. Table 3 presents the maximum values of all 25 constituents considered from the tailings area, maximum concentrations from locations beyond the edge of the tailings reclamation cover, background concentrations from each aquifer, and the protective standards for each of the 25 constituents initially considered.

The remaining 17 constituents are above the protective standards in the tailings and for some constituents beyond the edge of the tailings reclamation cover. Therefore, these 17 constituents are considered COPC. The list of COPC includes: Al, As, Be, Cd, F, Mn, Mo, Ni, NH<sub>3</sub>, NO<sub>3</sub>, Pb, Ra-226+228, Sb, Se, Th-230, Tl, and U. Three of the constituents are not explicitly referenced in 10 CFR Part 40, Appendix A, Criterion 13 (Al, Mn, and NH<sub>3</sub>). However, Criterion 13 indicates that the list of hazardous constituents is not exhaustive and additional constituents which may pose hazards to public health and safety and the environment may be added to ensure comprehensive protection. These three constituents were added since the EPA has developed parameters by which potential risks can be calculated (IRIS, 1989).

Only those constituents that presently exceed protective standards beyond the edge of the tailings reclamation cover have the potential to pose future hazards. The geochemical characterization presented in Appendix F demonstrates that future concentrations of all constituents from the source areas will not increase in the future

and, therefore, no additional constituents should pose a potential future hazard to human health. In other words, any COPC that does not exceed protective standards beyond the edge of the tailings reclamation cover today will not do so in the future due to decreasing volumetric flow from the tailings and stable long-term geochemical conditions.

The *maximum* COPC concentrations for each well beyond the limits of the tailings reclamation cover were determined for the period of January 1, 1996 through December 31, 1997 (Table 3). The maximum constituent concentration for all these wells were compared to the background concentrations of the Split Rock Formation and the alluvial floodplain aquifer and to the protective values (MCLs or RBCs). If the maximum COPC concentrations for any well beyond the limits of the tailings reclamation cover exceeds the larger of background or protective standards, then the COPC becomes a COC and potential future hazards to public health and safety and the environment could be unacceptable if additional protective measures are not considered.

The maximum concentration of the constituents aluminum, antimony, arsenic, beryllium, cadmium, fluoride, lead, nickel, selenium, thallium and thorium-230 in ground water beyond the edge of the tailings reclamation cover do not exceed the larger of background or their protective standards. These constituents were detected in the tailings area at concentrations above the protective values. However, concentrations of the constituents are not anticipated to exceed these protective values beyond the edge of the tailings reclamation cover in the future.

The concentrations of the COCs, ammonia, manganese, molybdenum, nitrate, combined radium (Ra-226+228), and uranium, were identified to be above the protective standards beyond the edge of the tailings reclamation cover. Although there are no existing domestic uses that are presently impacted by these constituents, the relative abundance and potential future transport of the constituents may cause impacts

in the future if no protective actions are taken. Therefore, corrective action may be required for the future protection of public health and safety and the environment.

These are the six constituents that will be addressed by the various potential corrective action alternatives. Specifically, uranium, which is the most prevalent and mobile constituent of the six COC, with the largest long-term source, will be the principal focus of the corrective action selection process. Any potential alternative that adequately addresses uranium risks will also adequately address concerns relating to all other COCs.

### 2.1.3 Extent of Constituents of Concern

As noted above, the COPCs aluminum, antimony, arsenic, beryllium, cadmium, fluoride, lead, nickel, selenium, thallium, and thorium-230 were detected in the tailings area above the protective standards but are never anticipated to exceed these standards beyond the edge of the tailings reclamation cover in the future. Therefore, they will not be discussed further here. More detail regarding the current distribution, extent, and predicted future behavior of all site-derived constituents is presented in Appendix F.

The COCs ammonia, manganese, molybdenum, nitrate, combined radium (Ra-226+228), and uranium were identified to be above the protective standards beyond the edge of the tailings reclamation cover. Figure 3 and Figures 8 through 13 illustrate the present extent and distribution of these six COCs in ground water. Characterization of the distribution of site COCs is based on the *maximum* concentration of each observed COC in each monitoring well. Details regarding this characterization are presented in greater detail in Appendix F. Details regarding the monitoring system used for the characterization are presented in Appendix F and Appendix A. All documentation regarding sampling, analysis, and QA/QC procedures are included in Appendix A. Results of the QA/QC program are presented in Appendix J.

### **2.1.3.1 Uranium**

#### **2.1.3.1.1 Extent of Uranium**

A mass balance of uranium at the Split Rock Site (Attachment F.m to Appendix F) estimated that approximately 1.67 million pounds of uranium were deposited in the tailings impoundments as the remnant 5 percent of the uranium originally contained in the primary ore, which was not removed by the milling process based on the milling efficiency of 95 percent. Of this estimated 1.67 million pounds of uranium, approximately 36 percent remained in the tailings impoundment while the other 64 percent has migrated out of the tailings impoundment. The flushing of the tailings during the pumpback period from 1983 to 1986 essentially rinsed a significant amount of the uranium from the impoundments. However, as noted above, the majority of this uranium now is associated with the aquifer solids and does not remain dissolved in the ground water. Approximately 40 percent of the original 1.67 million pounds of uranium is now associated with the aquifer solids in the NW and SW Valleys, 20 percent in each valley. Less than 0.25 percent of the original uranium mass is in the ground water below the tailings impoundments, only 2 percent is in the ground water of the NW and SW Valleys, and less than 0.2 percent is in the floodplain alluvial aquifer ground water. Overall, more than 93 percent of the uranium deposited in the tailings impoundments remains associated with solid materials (aquifer materials or tailings solids).

Figure 3, illustrating maximum current uranium concentrations at each ground water sampling point, shows that uranium has migrated from the impoundment area down the NW and SW Valleys. Figure 14 illustrates the locations of cross sections that depict the vertical distribution of uranium in the ground water that are presented in Figures 15 through 22. Concentrations in the upper valleys have decreased over the past 10 years as the seepage flux has diminished, and the portion of runoff from the granite outcrops

that infiltrates to ground water beneath the tailings impoundment to dilute the remaining seepage.

Uranium has migrated out of the impoundment and down both the SW and NW Valleys following the local ground water flow patterns. At the mouth of both valleys are areas where uranium concentrations are higher than in areas directly up gradient and down gradient. As reported in Appendix F (Section F.5.2), higher uranium concentrations at the mouth of the NW Valley (NWEB-1 and the WN-36 well cluster) and SW Valley (WN-B and Well-28) are thought to be historical remnants of ground water with higher uranium concentrations that originated from the Main Tailings Impoundment earlier in the mill's history. This water slowly migrated down the valleys to its current position at the valley mouths.

From the NW Valley, the uranium-bearing seepage turns to the northeast as it enters the floodplain and flows toward the river (Figure 3). Figure 17 shows that the highest uranium concentrations in the floodplain down gradient of FPEB-4 and FPEB-5 are found within the alluvial layer and not in the Split Rock Formation. This is caused by the higher hydraulic conductivity and lateral gradient in the alluvium compared to the Split Rock Aquifer (see Appendix C), which has allowed the site-derived plume to migrate farther in this shallow zone. The alluvium may contain buried channel deposits of coarse-grained material that provide preferred pathways for shallow ground water flow in the floodplain.

Like the NW Valley, the uranium distribution in the SW Valley (Figure 3) also shows an area of uranium concentration at the valley mouth that is higher than locations both up gradient and down gradient. These values are larger than uranium concentrations presently found in the Main Tailings Impoundment. From the SW Valley, the seepage has split into two branches, with the larger branch flowing to the south and southeast and the smaller branch flowing to the north and northwest around the granite outcrop and toward the river.

Variations in uranium concentration with depth are shown on Figures 15 through 22. Uranium distribution with depth is heterogeneous in both valleys. Uranium is found at depth in the valleys but not outside the valley mouths. The pattern of uranium concentrations in ground water in the valleys supports a model of local areas at the valley mouths, with higher uranium concentrations being the historical remnants of ground water that originated from the tailings earlier in the mill's history.

Uranium concentrations that exceed the Split Rock Formation ground water background value of 0.126 mg/L also are found in two areas not affected by site seepage (Figure 3). Elevated concentrations in the Red Mule Subdivision area are due to naturally occurring uranium mineralization in this area, as stable isotopes and other constituents associated with the uranium indicate no link between ground water in this area and site-derived seepage (see Appendix F, Section F.5.3.5.2 and Attachment F.g). Similarly, elevated concentrations in the area of SWAB, approximately 0.5 mile north of Jeffrey City, are also the result of naturally occurring uranium mineralization in this area.

#### **2.1.3.1.2 Behavior of Uranium**

Uranium will continue to be introduced to the ground water system through residual tailings seepage and through slow disassociation of uranium from aquifer solid materials. Because at the present time the majority of uranium in the aquifers at the Split Rock Site is associated with aquifer solids and because tailings seepage rates are declining, future concentrations of uranium in ground water will depend largely on how uranium is released from solids. Factors that affect the way uranium is released include the chemistry of the water that passes through the aquifer, the form of uranium associated with the solids, and the fraction of uranium on the solids that is available for release. Several studies on the aquifer materials were recently conducted to characterize these factors. These test are presented in Appendix F, Section F.6, and include mineralogical analyses, bulk chemical analyses, distribution coefficient testing, batch and column leach testing, and sequential extraction testing.

Based on these test results, an empirical relationship between the concentration of uranium on solids and dissolved in the ground water has been developed. This relationship involves a variable partitioning coefficient ( $K_d$ ) to represent the sum of all chemical interactions under equilibrium conditions. An analytical model based on this variable  $K_d$  was developed and applied using site specific input values of porosity,  $K_d$ , the initial concentration in water, the concentration in inflowing water, and the bulk density of solids (see Appendix F, Section F.6, and Appendix H, Attachment H.c, Supplement H.c.1). The results are shown in Figures 23 through 25. Figure 23 shows that the near steady-state uranium concentrations in ground water are reached within about 20 pore volumes. Given the present and predicted flow rates down the NW and SW Valleys, steady-state uranium concentrations would be reached in 400 years and greater than 1,000 years (Figures 24 and 25), respectively, under natural conditions, though steady state flow conditions are anticipated to occur within the next 30 years.

### **2.1.3.2 Manganese**

#### **2.1.3.2.1 Extent of Manganese**

Figure 12 shows elevated manganese (Mn) concentrations mostly within the NW Valley and within and just outside the SW Valley mouth. The background concentration limit for manganese in the Split Rock Aquifer is 0.53 mg/L. Manganese dioxide ( $MnO_2$ ) was used in the milling process and was consequently discharged to the tailings impoundments. The higher manganese concentrations in the NW Valley may be due to the greater flux of tailings water flowing down the NW Valley. At near-neutral pH values under moderate to oxidizing conditions, manganese forms Mn-oxyhydroxides. Precipitation of these Mn-oxyhydroxides will remove much of the manganese from solution, leaving lesser amounts in solution. Manganese concentrations in the Sweetwater River floodplain alluvium do not exceed the alluvium background concentration limit of 2.39 mg/L.

#### **2.1.3.2.2 Behavior of Manganese**

Manganese in the acidic tailings water exists as the reduced  $Mn^{2+}$  form, which is highly mobile under acidic conditions. As the tailings water mixes with background underflow below the tailings in the aquifer and the pH increases, there is a potential for oxidation of  $Mn^{2+}$  to  $Mn^{4+}$ , with much of the manganese precipitating in the form of manganese hydroxide minerals. However, based on the pH of the ground water and the measured Eh values, it appears that some  $Mn^{2+}$  form will persist in solution.

Overall, much of the manganese deposited in the tailings naturally associated with the ore or added as a component of process chemicals has precipitated onto the aquifer solids. This fraction of the site-derived manganese will essentially remain associated with the aquifer solids, and the small fraction that may re-dissolve in the future will do so in concentrations well below levels of concern to public health and safety and the environment. Nevertheless, some of the manganese remains in solution and transports with limited retardation. The existing mass of dissolved manganese will continue to migrate in a manner similar to the existing uranium dissolved in significant quantities in ground water. However, because manganese on the aquifer solids will not re-mobilize in the future and tailings seepage is rapidly declining, manganese will have no significant long-term source and will never extend beyond the maximum extent of uranium in ground water. Similarly, any corrective action designed to mitigate uranium impacts should be equally effective in mitigating manganese impacts.

#### **2.1.3.3 Ammonia**

Relatively large quantities of anhydrous ammonia ( $NH_3$ ) were used in the milling process. In acidic environments, anhydrous ammonia produces dissolved ammonium ( $NH_4^+$ ). As pH increases, ammonium converts back to ammonia ( $NH_3$ ), some of which remains dissolved in the ground water.



Continued exposure of ammonium to oxidizing conditions (oxygen present), such as in the tailings water or in shallow ground water, results in the oxidation of ammonium to nitrite ( $\text{NO}_2^-$ ) and nitrate ( $\text{NO}_3^-$ ), and these reactions are facilitated by microorganisms (Brock and others, 1994). Therefore, the occurrence and behavior of ammonia, ammonium, and nitrate are closely related

#### **2.1.3.3.1 Extent of Ammonia**

Of the  $\text{NH}_3+\text{NH}_4^+$  nitrogen species, only the ammonia ( $\text{NH}_3$ ) species poses significant toxicologic risks to human or ecological health. The analytical laboratory procedures determined the total amount of  $\text{NH}_3+\text{NH}_4^+$ . Therefore the total amount ammonia had to be calculated from the total  $\text{NH}_3+\text{NH}_4^+$  values to determine the amount of ammonia. Under the ambient ground water pH conditions beyond the edge of the tailings reclamation cover (pH  $\approx$  8), approximately 2.5 percent of the total reduced nitrogen species ( $\text{NH}_3+\text{NH}_4^+$ ) will occur as ammonia ( $\text{NH}_3$ ) (American Public Health Association, 1992). Figure 26 illustrates the calculated  $\text{NH}_3$  distribution. The present distribution of ammonia above a concentration of 0.5 mg/L is limited to small, discrete areas at each valley mouth.

#### **2.1.3.3.2 Behavior of Ammonia**

Ammonia ( $\text{NH}_3$ ) was initially present at the site from the use of anhydrous ammonia in the milling process. Upon reaction with acidic water, however, ammonia rapidly converts to ammonium ( $\text{NH}_4^+$ ). Below a pH of 9.0, the dominant form of reduced nitrogen will be ammonium, with very little ammonia remaining in solution. Under very low pH conditions, such as those existing in the tailings impoundment, ammonium is very mobile. At higher pH conditions in the zone of mixing or down valley, ammonium becomes moderately mobile.

The source of ammonium-N ( $\text{NH}_4^+\text{-N}$ ) from the tailings impoundment, which would supply the reduced nitrogen for conversion to ammonia at the higher pH conditions in the lower valleys and regional aquifer, is diminishing as seepage from the tailings declines to a long-term steady-state value of less than 5 gpm. In addition, there is no long-term source of ammonia or ammonium-N ( $\text{NH}_4^+\text{-N}$ ) from the aquifer solids. Continued exposure of ammonium-N ( $\text{NH}_4^+\text{-N}$ ) to oxidizing conditions, such as in the tailings water or in shallow ground water, results in the oxidation of ammonium to nitrate ( $\text{NO}_3^-$ ), and these reactions are facilitated by microorganisms (Brock and others, 1994). Therefore, while ammonia likely will continue to migrate, it will also decrease in concentration due to dispersion and oxidation to nitrate. The geographic extent of ammonia will never exceed the extent of uranium in ground water, and any corrective action designed to mitigate uranium impacts in ground water should be equally effective in mitigating ammonia impacts.

#### **2.1.3.4 Nitrate**

As stated above, nitrate exists in the system primarily as a degradation product of ammonia/ammonium.

##### **2.1.3.4.1 Extent of Nitrate**

Figure 11 shows the distribution of maximum nitrate ( $\text{NO}_3$ ) plus nitrite ( $\text{NO}_2$ ) concentrations at the site. Nitrite is difficult to analytically separate from nitrate. The laboratory reports these two species as one value although, based on historical data and current site conditions,  $\text{NO}_3$  makes up the vast majority of the total oxidized nitrogen ( $\text{NO}_3+\text{NO}_2$ ).

Due to the relatively high mobility of  $\text{NO}_3$ , contour lines on Figure 11 of elevated  $\text{NO}_3+\text{NO}_2$  concentrations clearly illustrate ground water flow patterns at the site. Nitrate

concentrations in excess of the MCL value of 10 mg/L (the Split Rock Formation background value is 3.99 mg/L) extend into the floodplain area and beyond the mouth of the SW Valley to the north and east. The highest  $\text{NO}_3+\text{NO}_2$  concentrations occur at the mouth of each valley, consistent with the present location of elevated uranium concentrations. This distribution in the NW Valley extends from the WN-35 cluster (362 mg/L), located halfway up the NW Valley, to the WN-42 well cluster (122 mg/L) in the Sweetwater River floodplain. The SW Valley area of elevated nitrate concentrations is bounded by Well-28 (94.5 mg/L) and the WN-32 well cluster (98.5 mg/L) to the north and by SWAB-2 (148 mg/L) to the south. The highest nitrate values are located almost entirely out of the SW Valley in the hydrologically stagnant zone in this area. The shapes of both areas of elevated nitrate concentration show strong influence by local and regional ground water flow regimes.

The occurrence of the highest  $\text{NO}_3+\text{NO}_2$  concentrations is most likely a function of ground water movement down the valleys coupled with decreasing source input. In addition, relatively clean water pumped to the tailings pond during the pumpback period probably diluted up gradient ground water and pushed water with higher concentrations ahead of it. The increase in  $\text{NO}_3+\text{NO}_2$  concentrations at the valley mouths may also be caused by the conversion of  $\text{NH}_3/\text{NH}_4^+$  to  $\text{NO}_3$ . A comparison of Figure 10 ( $\text{NH}_3/\text{NH}_4^+$  map) and Figure 11 ( $\text{NO}_3+\text{NO}_2$  map) shows that the area of increasing  $\text{NO}_2+\text{NO}_3$  concentrations roughly corresponds to the area of decreasing  $\text{NH}_3/\text{NH}_4^+$  concentrations. The total nitrogen concentration decreases along the flow paths, indicating that the nitrogen is either removed from the system by sorption or degradation to  $\text{N}_2$  gas.

There are two other areas where  $\text{NO}_3+\text{NO}_2$  levels exceed background concentrations. One area is at Well SWAB-24 and the other is at Well RM-1. While the source of the  $\text{NO}_3+\text{NO}_2$  in these areas is not well understood, it is possible that nitrogen compounds could be coming from other sources in these areas. SWAB-24 is just north and down gradient of the Jeffrey City Sewage Lagoon, a likely source of nitrogen compounds.

The Red Mule Subdivision contains houses that have local septic systems, which are a potential source of nitrogen compounds in that area. As indicated by stable isotope studies (Section F.5.3.5.2) and hydrogeologic evaluation (Appendix C), no site-derived constituents have migrated as far as the Red Mule Subdivision.

Vertical distribution of  $\text{NO}_3+\text{NO}_2$  is shown on Figures 27 through 29. Nearly the entire profile of ground water in the NW Valley has  $\text{NO}_3+\text{NO}_2$  concentrations greater than 10 mg/L. In the tailings impoundment (well cluster WN-33),  $\text{NO}_3+\text{NO}_2$  concentrations increase with depth. This may be another artifact of the cleaner pumpback water being put "on top of" the more concentrated water from the milling process. At well cluster WN-35,  $\text{NO}_3+\text{NO}_2$  concentrations greater than 300 mg/L have been found from the water table to a depth of approximately 90 feet. Near the granite surface, 200 feet below the top of the water table, a  $\text{NO}_3+\text{NO}_2$  concentration of 147 mg/L was also found at the WN-35 well cluster. These elevated  $\text{NO}_3+\text{NO}_2$  concentrations at depth are most likely the result of  $\text{NO}_3+\text{NO}_2$  being transported to these areas along ground water flow paths instead of being created by microbially mediated in-situ production. The nitrification process is strictly aerobic and therefore should be somewhat limited by water depth (Brock and others, 1994), although site redox data (Section F.5.3.1.4) indicate that oxidizing conditions exist throughout the Split Rock aquifer.

Vertical distribution of  $\text{NO}_3+\text{NO}_2$  in the SW Valley (Figures 28 and 29) is similar to the NW Valley, although  $\text{NO}_3+\text{NO}_2$  concentrations greater than 100 mg/L have not been observed in the SW Valley. Concentrations of  $\text{NO}_3+\text{NO}_2$  greater than 10 mg/L occur in the deeper portions of the SW Valley (39.2 mg/L at SWEB-1, 370 feet below the water table). The concentrations are typically below 50 mg/L except for a limited area near the mouth of the valley.

#### **2.1.3.4.2 Behavior of Nitrate**

Nitrate travels relatively un-retarded in ground water. The present distribution of nitrate is within the present distribution of uranium in the ground water. The nitrate concentrations will continue to decrease through dispersion and biological degradation. The long-term source of nitrate to the ground water system is from tailings seepage and from conversion of  $\text{NH}_4^+$ -N. Because tailings seepage rates are declining and will reach steady-state rates of less than 5 gpm in the next 30 years, there will be no significant long-term source of nitrate to the ground water system. Therefore, the geographic extent of nitrate will never exceed the geographic extent of uranium in ground water, and any corrective action designed to mitigate uranium in ground water should be equally effective in mitigating nitrate concentrations.

#### **2.1.3.5 Molybdenum**

Ore from the Gas Hills District is enriched in molybdenum (up to 1,000 ppm) (Harshman, 1974) that, therefore, deposited at the site in tailings materials. However, during the later stages of milling at the site, molybdenum was recovered from the mill circuit before tailings were discharged to the impoundment.

##### **2.1.3.5.1 Extent of Molybdenum**

Molybdenum (Mo) concentrations exceeded limits slightly at only four discrete places at the site (Figure 13): (1) in the Main Tailings Impoundment (0.55 mg/L), (2) in the middle of the NW Valley around well cluster WN-35 (0.18 mg/L), (3) at the mouth of the NW Valley (0.22 mg/L), and (4) at the mouth of the SW Valley (0.14 mg/L). The background concentration of molybdenum in the Split Rock Formation aquifer and the floodplain alluvial aquifer are both 0.1 mg/L. The RBC for molybdenum is 0.18 mg/L.

#### **2.1.3.5.2 Behavior of Molybdenum**

Molybdenum in natural waters exists as an anion ( $\text{MoO}_4^{2-}$ ), so that it is more mobile as pH increases and does not adsorb well to clays. However, molybdenum solubility is controlled by precipitation at neutral pH by calcium in equilibrium with gypsum or calcite, forming calcium molybdate ( $\text{CaMoO}_4$ ). This process is likely occurring at the Split Rock Site.

Due to the very low concentrations, isolated occurrences of concentrations above the RBC, low concentrations in the tailings, and decreasing tailings seepage rates, molybdenum above applicable limits will not migrate much beyond its present extent.

#### **2.1.3.6 Combined Radium (Ra-226+228)**

Radium-226 (Ra-226) is a product of the U-238 decay series and is thus found associated with uranium ore deposits. Radium-228 (Ra-228) is only indirectly associated with uranium as a product of the thorium-232 (Th-232) decay series; thorium may be associated with uranium ore at trace levels. Radium was not recovered in the uranium mill circuit at the site, so the vast majority present in the ore was discharged to the tailings impoundments. The EPA has published an MCL for combined radium (Ra-226+228) of 5 pCi/L, so the activity of both isotopes has been measured in site ground water.

##### **2.1.3.6.1 Extent of Radium**

Both Ra-226 and Ra-228 are found at activity above background levels in the Main Tailings Impoundment area (Figures 8 and 9), where activity of Ra-226 greater than 2,000 pCi/L (1,000 times higher than the background limit of 2.0 pCi/L) and activity of Ra-228 greater than 41 pCi/L (10 times higher than background limit of 4.1 pCi/L) have

been detected. The discussion of background values determined for the site is presented in Section 2.2.6.

A number of small regions exist outside the Main Tailings Impoundment area where radium activities exceed background limits. One of these areas, near the WN-38 well cluster in the Sweetwater River floodplain, is anomalous because there are no other zones in the NW Valley or the Sweetwater River floodplain with radium activity higher than background. Additionally, the ratio of Ra-226 to Ra-228 activity is out of equilibrium. Higher Ra-228 activity compared to Ra-226 activity also occurs at the mouth of the SW Valley at locations SWAB-2, SWAB-8, SWAB-18, and SWAB-9. The elevated Ra-228 activity likely is due to naturally occurring elevated activities of its parent, thorium-232, in these areas. Thorium-232 is more abundant in nature than U-238, the parent of Ra-226 (Fetter, 1993). Radium is not highly mobile in ground water (see Section F.5.3.3.2), which also suggests that the isolated, above background samples are not due to migration of site-derived radium.

The maximum value from each well is contoured in Figures 8 and 9. However, review of sampling data (see Appendix F, Table F-5-4) shows that SWAB-4, SWAB-8, SWAB-15, and SWAB-18 each had only one sample in which Ra-228 was detected; Ra-228 was not detected in other samples. This results in contours being drawn around locations where Ra-228 is probably not present.

The occurrence of slightly higher than background radium activity at the mouth of the SW Valley without corresponding areas at the mouth of the NW Valley may be a function of the low mobility of radium and the close proximity of tailings materials to the SW Valley mouth. The vertical Ra-226 distribution down and out of the SW Valley is shown on Figures 30 through 32. Although data are limited, Ra-226 has only been detected above background activities at shallow depths, even in the Main Tailings Impoundment area (well cluster WN-33).

### **2.1.3.6.2 Behavior of Radium**

Radium is present in natural waters only as the  $Ra^{2+}$  ion and its complexes. Radium sulfate ( $RaSO_4$ ) is relatively insoluble when accompanied by high concentrations of sulfate, like those found at the Split Rock Site (Landa, 1980). However, equilibrium modeling indicates that, even at the high sulfate concentrations within the impoundment, radium sulfate is still undersaturated and would tend to stay dissolved. Radium is commonly precipitated with barite ( $BaSO_4$ ) in sulfate-rich waters and is also precipitated, to a lesser extent, with other sulfates such as gypsum or anhydrite (Langmuir and Riese, 1985). It can also coprecipitate with iron under oxidizing conditions. Having the smallest hydrated ion in the alkaline earth series, radium is preferentially retained by ion exchange surfaces (Landa, 1980). As a result, its transport is severely limited, and the present distribution of combined radium in ground water beyond the edge of the tailings reclamation cover is anticipated to rapidly decrease with concentrations remaining below background in the long-term.

## **2.2 Hydrogeology and Transport Assessment**

Site characterization studies have added to and modified the understanding of the hydrogeologic and geochemical systems and the overall conceptual model of the Split Rock Site. The additional data supplied by these recent characterization studies have provided a more detailed understanding of the geologic conditions in which the ground water resides, how these conditions influence ground water flow, their interaction with the surface water systems, the baseline ground water quality conditions that exist within the distinct hydrostratigraphic units (HSUs), and how COCs exist and transport through the geologic media. These studies were carried out in accordance with the comprehensive Project Scoping Plan (PSP) and Project Quality Plan (PQP), included as Exhibits A and B, respectively, to this GWPP, and specific Task Work Scopes (TWSs)



and Task Work Plans (TWP) included in Appendix B, Appendix F, and Appendix I. These studies included:

- Drilled, logged and sampled over 100 borings
- Installed over 100 wells and piezometers
- Installed over 100 drive point minipiezometers
- Performed several surface geophysical surveys
- Performed 41 borehole geophysical surveys
- Extensively sampled the Sweetwater River surface water, sediments, flow rates, and biota
- Sampled floodplain sediments and floodplain pond water quality
- Reviewed 29 historical aquifer tests
- Performed 21 single well pumping tests, 25 multiple well pumping tests, and 12 slug tests, as well as laboratory testing of aquifer materials
- Performed geochemical characterization tests on over 245 samples of aquifer materials to characterize their present and potential hydrologic and geochemical behavior
- Performed over 70 tests on tailings samples to characterize the present and potential geochemical, mineralogical, and hydrologic behavior, including: X-ray diffraction, X-ray fluorescence, electron microprobe, bulk chemical analyses and leaching tests
- Collected over 4,720 ground water quality samples
- Identified all local wells and water uses
- Modeled in detail geologic, hydrologic, geochemical, and constituent transport conditions

A detailed discussion of the recent site characterization activities is included in Appendix A. Based on the results and interpretation of all recent and historical data, a comprehensive site conceptual model was been developed.

A detailed discussion of all tasks and methods performed to assist in hydrogeological characterization is presented in Appendix A. A detailed discussion of previous regional and site specific studies is presented in Appendix B. The TWS and TWP for the hydrogeologic characterization are presented as attachments to Appendix B. In addition, a review of State Engineering office records for existing permitted wells was performed. Appendix B presents a detailed discussion of the regional and local hydrogeology of the site, including discussions of the lithology, mineralogy, geometry, and structural features of each HSU. In addition, review of existing site hydrogeologic data and detailed analysis of hydrogeologic data collected as part of the characterization studies is included in Appendix C. Appendix D presents a detailed discussion of the regional and local hydrology.

## **2.2.1 Physical Setting**

The regional and local hydrology of the area is discussed in greater detail in Sections 2.2.3 and 2.2.4, respectively, and Appendix D of this report. The Split Rock Site is situated at approximately 6,000 feet above mean sea level in the arid high plains of central Wyoming. Precipitation averages around 11 inches per year with net evaporation averaging approximately 36 inches per year. The Split Rock Site is located at the head of two gently sloping alluvial valleys surrounded by sparsely vegetated and steeply sloped granite hillsides.

### **2.2.1.1 Climate**

The total mean annual precipitation for the Jeffrey City Station is approximately 11 inches for the period of record from 1964 to 1993 (EarthInfo, Inc., 1996). The precipitation ranges from an average monthly low of 0.37 inches in February to an average monthly high of 2.13 inches in May. The average annual snowfall is 52.03 inches. No snowfall is recorded in the summer months of June, July, and August. The

highest average monthly snowfall rate is 11.26 inches in November (EarthInfo, Inc., 1996).

The mean annual temperature in this region is approximately 42°F. The average monthly temperature varies from 15°F in January to 66°F in July.

Pan evaporation is on the order of 36 to 42 inches per year (D'Appolonia, 1977b; NRC, 1980, respectively). Evapotranspiration exceeds precipitation at the site; which is to be expected given the cold desert climate of the region. Potential evapotranspiration on the plains is estimated to range from 17.8 to 22.7 inches per year (Attachment D.b), based on site specific data for the period 1979 to 1993.

Wind patterns and speeds for the site are estimated to be similar to those of Casper, Wyoming, located approximately 85 miles east of the site. The prevailing wind direction is from the west to southwest, with maximum wind speeds of over 62 miles per hour (mph) and monthly average wind speeds from 10 to 17 mph. The local topography strongly influences the micro-meteorological conditions at the site (NRC, 1980).

### **2.2.2 Geologic History**

The information derived from the recent characterization studies has been synthesized into a three-dimensional geological model of the Split Rock Site. A map showing the local geology is included as Figure 33. A schematic of the stratigraphic section is shown on Figure 34. Contour maps showing the thickness of each stratigraphic unit and the structural elevation of the top of each unit are presented in Attachment B.d to Appendix B. Cross sections showing the structure and stratigraphy in profile are presented in Attachment B.e. The geologic history, resulting stratigraphy, and local geologic structure are discussed in the following paragraphs.

Jeffrey City is located approximately two miles south of the crest of the Granite Mountains in Fremont County. The Granite Mountains are bounded on the north by the Wind River Basin and on the south by the Great Divide Basin. The major structural features in the Split Rock Site area are the Granite Mountains Uplift, the North and South Granite Mountains Fault Systems, and the Split Rock Syncline. The movement of these structures over time controlled depositional environments and the resulting stratigraphy at the Split Rock Site. The Emigrant Trail Thrust Fault is also located within the investigation area, although it has been dormant over the period in which the stratigraphy in the investigation area was developed.

The Granite Mountains are a major anticlinal uplift in south-central Wyoming. The exposed Precambrian core trends west-northwest and is about 85 miles long and 30 miles wide (Love, 1970). The uplift has a gentle north flank and a steep south and west flank. The chief episode of uplift, folding, and faulting occurred in Eocene time. Later structures, including the North and South Granite Mountains Fault Systems and the Split Rock Syncline, were superimposed on and drastically modified the configuration of the mountain arch. Today, the mountains remain partly buried by upper Cenozoic sedimentary deposits. The Split Rock Site is located within narrow valleys near the crest of the uplift.

During Miocene time, the southern portion of the Granite Mountains began to subside into the Split Rock Syncline. Simultaneously, an enormous volume of tuffaceous sandstone was deposited across most of Wyoming. These deposits became what is known as the Split Rock Formation in central Wyoming (Love, 1961). The Granite Mountains were largely buried by the sandstones of the Split Rock Formation; only the highest peaks remained exposed. The sand deposition was largely eolian, or windblown. In the area of the Split Rock Site, the Split Rock Formation lies directly on the Precambrian granite.

During the early to middle Pliocene, the Split Rock Syncline continued to sag forming Moonstone Lake. In and adjacent to the lake, more than 1,000 feet of tuffaceous strata comprising the Moonstone Formation were deposited. Some of the beds in the Moonstone Formation are unusually rich in uranium and thorium and are believed to be source rocks for part of the uranium present in the Gas Hills and Crooks Gap uranium districts. Many zones are locally radioactive and contain more than 0.01 percent uranium. However, only isolated remnants of the Moonstone Formation are found today due to Pliocene erosion.

A regional uplift event began in late Pliocene time, beginning the present cycle of erosion in most of central Wyoming. Only about 1,000 feet of the buried crest of the mountains was exhumed. The easterly course of the Sweetwater River was established along the trough line of the Split Rock Syncline. During this time, the Moonstone Formation was eroded, reducing its thickness and limiting its areal extent. The Sweetwater River became trapped along a superimposed course across the granite knobs and, as the syncline in the south subsided, many northward-flowing tributaries became unable to reach the river.

During Pleistocene time, Crooks Creek was unable to maintain a downhill course on the north side of the syncline and became ponded. The Sweetwater River carried enough flow to transport coarse gravels and pebbles from source areas in the Wind River Mountains. As the climate became more arid, wind erosion increased, scooping out some undrained depressions in the exposed Split Rock Formation and depositing dunes of reworked Split Rock sandstone in and around the protruding granite knobs. The reduced flow and low channel gradient of the Sweetwater River now allows transport and deposition of principally sand, silt, and clay. Crooks Creek is an intermittent stream just north of Crooks Gap and does not contain enough volume to reach the Sweetwater River most of the year.

### 2.2.3 Regional Hydrogeology

Two geologic units within the investigation area yield significant quantities of ground water to wells. These are Quaternary deposits (e.g., Sweetwater River floodplain alluvium) and Miocene rocks (Split Rock Formation). On a regional basis the floodplain alluvial aquifer is a minor component to the overall hydraulic system and is described below.

The Split Rock Formation outcrops in a wedge-shaped pattern that begins west of Sweetwater Station and extends east to the North Platte River, covering an area of about 1,500 square miles. Potentially large supplies of ground water are available from this aquifer. The saturated thickness of the aquifer ranges from about 500 to 3,000 feet in the area south of the Sweetwater River and from about 200 to 600 feet in the area north of the river. The areas of greatest thickness are along the axis of the Split Rock Syncline, directly south of the WNI Split Rock Site. Published values of hydraulic conductivity for the Split Rock Formation near the investigation area range from 0.05 to 5.4 feet per day (Borchert, 1977). Reported discharges from wells completed in the Split Rock aquifer range from 3 to 1,100 gpm.

The movement of ground water in the Sweetwater Basin is controlled by the location of recharge and discharge areas, by the thickness and hydraulic conductivity of the geologic units, and by the location of impermeable and relatively impermeable units. Important recharge mechanisms for any aquifer include precipitation, infiltration of surface water, infiltration of irrigation water, and leakage from bounding geologic units. Important discharge mechanisms include springs, evapotranspiration, leakage to bounding geologic units, and discharge to lakes, streams, and drains. Recent river gain and loss studies (Borchert, 1977; Plafcan and others, 1995) indicate that the Sweetwater River gains about 17 cubic feet per second between the gaging station near Sweetwater Station (approximately 11 miles upstream of the Split Rock Site) and the gaging station near Alcova (approximately 40 miles downstream of the Split Rock Site).

Discharge measurements indicate that the Sweetwater River loses water in the middle stretch below Alkali Creek to near Jeffrey City and begins to gain water in the lower reach from Jeffrey City to Alcova.

The general direction of ground water movement in the Sweetwater Basin is to the east and northeast, toward and in the direction of flow of the Sweetwater River. Uplifts along the southern boundary of the basin, including the Green Mountains and Ferris Mountains, serve as recharge areas. Near Jeffrey City, the ground water flow direction is nearly due east (Borchert, 1987).

## **2.2.4 Local Hydrogeology**

### **2.2.4.1 Hydrostratigraphy**

The overall stratigraphy left by this dynamic geologic history, illustrated in Figure 34, consists of the sandstones, conglomerates, and siltstones of the Split Rock Formation overlying the Precambrian granite. A thin covering of windblown sands form dunes from 10 to 40 feet thick over the Split Rock Formation. Where the Sweetwater River has meandered through the valleys has left intricate deposits of sand, silt, and clay river sediments 15 to 30 feet thick over the Split Rock Formation.

The geologic and man-made materials in the immediate area of the Split Rock Site have been divided into the following nine hydrostratigraphic units (HSUs):

- Precambrian Granite (GR)
- White River Formation (WR)
- Lower Split Rock Unit (LSR)
- Upper Spit Rock Unit (USR)

- Alluvium (AS)
- Eolian Deposits (DS)
- Sweetwater River Alluvium (FP)
- Tailings (TA)
- Fill (F)

The ground water and transport of site-derived constituents primarily involves the Upper and Lower Split Rock HSUs, collectively called the Split Rock Formation aquifer, and the Sweetwater River Alluvium HSU, called the floodplain alluvial aquifer. This is a shallow aquifer (15 to 30 feet thick) of river sediments that overlies the Split Rock Formation. This aquifer is hydrologically connected to the underlying Split Rock Formation. This shallow and highly permeable floodplain alluvial aquifer was formed where the river cut and meandered across the Split Rock Formation which fills the alluvial basins between the Green Mountains to the south and the Granite Hills.

A thin covering of windblown sand forms a layer of alluvium above the Split Rock Formation over much of the region. Though a small portion of the ground water and site-derived constituents do move through fill materials near the tailings impoundments and eolian dune sands overlying the Split Rock units, these HSUs have no significant influence on the bulk transport or chemistry of the site-derived constituents.

Two aquifers (Split Rock and floodplain alluvium) with distinct baseline ground water quality characteristics have been identified at the Split Rock Site. First, the Split Rock Formation covers the majority of the site and directly overlies the granite bedrock. This formation consists primarily of sandstone and conglomerates with some silty sands (see Appendix B for a detailed discussion). This formation has been divided into two HSUs due to distinct lithologic and geologic characteristics, though they form a single aquifer and are hydraulically similar. This formation varies in thickness from up to several thousand feet thick in the Sweetwater Syncline south of the site to essentially zero



where it laps onto the granite outcrops. In the site NW and SW Valleys, the Split Rock Formation varies from 0 to 150 feet thick in the upper valleys to over 500 feet thick at the valley mouths. The hydrogeologic characteristics of these two HSUs have been determined through field and laboratory testing as well as evaluation through numerical flow model calibration (See Appendix B, Appendix C, and Appendix E).

#### **2.2.4.2 Local Ground Water Flow**

The local hydrologic boundaries are formed by the Green Mountains to the south, which provide the primary recharge to the regional ground water system, and the Sweetwater River to the west and north, which acts as the primary hydrologic sink for the regional ground water system (see Figure 35). The granitic basement is the lower hydrologic boundary to the ground water system. Regional and local ground water flow, when forced up against the granite basement, move upward creating upward vertical gradients. Ground water flow from the north to the Sweetwater River is inhibited by granite outcrops, and some soda lakes form where ground water discharges to the surface. In the vicinity of the Split Rock Site, the regional flow gradient is approximately 0.003 to the east (Borchert, 1987).

Local ground water in the Split Rock Site area is recharged from direct precipitation on the valley floor and from precipitation run-off from the surrounding granite hillsides. Approximately 0.6 inches per year of precipitation infiltrates the valley floor to deep recharge, while approximately 6 inches per year of runoff from the surrounding granite hillsides recharge the alluvial aquifer (see Appendix D). In addition, drainage of the tailings has historically input up to 1,400 gpm to the upper valley ground water system. Since tailings and water disposal in the tailings impoundments ceased in 1986, tailings drainage and consolidation have greatly diminished, and the elevated ground water levels beneath the tailings caused by tailings drainage have largely dissipated. Tailings seepage rates are presently estimated to be approximately 150 gpm and are expected to reach long-term, steady-state rates of less than 5 gpm in the next 30 years.

At the Split Rock Site, ground water flows from areas high in elevation surrounding the Main Tailings Impoundment, down the NW and SW Valleys, and then merges with regional flow. Ground water flows northwest out of the NW Valley and merges with northeastward regional flow. Ground water flows southwest out of the SW Valley, meets regional flow, and diverges into two flow paths around the granite outcrops, one to the north and one to the east. Lateral areas with structurally high granite beneath the Sweetwater River floodplain causes ground water to discharge from the Upper Split Rock unit into the Sweetwater River alluvium. A significant lateral constriction in the Split Rock units and the Sweetwater River alluvium occurs near well WN-19 and at the point where the river passes through the granite outcrop at the Three Crossings Diversion Dam. This constriction enhances ground water discharge from the Sweetwater River alluvium into the Sweetwater River.

The Sweetwater River forms the northern hydrologic boundary to the Split Rock Site. The regional flow of the Sweetwater River is roughly west to east. The river flows past the Split Rock Site to Pathfinder Reservoir, approximately 40 miles downstream of the Split Rock Site. The Sweetwater River is the primary discharge point for the regional ground water flow, though it acts as a recharge mechanism to the shallow floodplain alluvial aquifer along its reach during periods of seasonal high flow, typically from May to August. The Sweetwater River in the Split Rock Site area is classified as Class II waters in the State of Wyoming and provides recreational fishing and wildlife habitat. Water from the river is used primarily for flood irrigation and supports recreational game fishing.

### **2.2.5 Site Hydrogeologic Conceptual Model**

This conceptual model of the hydrologic flow system at the Split Rock Site serves as a summary and synthesis of the hydrologic information developed from the comprehensive site characterization. The conceptual model begins by summarizing climatic conditions and the historical hydrologic conditions in the impoundment area (at

the up gradient edge of the site ground water flow path). The conceptual model then describes the present hydrologic conditions and how they change along the ground water flow path down the NW and SW Valleys. Appendix A presents the details regarding the scope and procedures used for the hydrogeologic characterization. Appendix C presents details regarding aquifer properties characterization. Appendix D presents details regarding the site hydrologic characterization including the hydrology of the surface water system. Appendix E presents results of the site flow modeling. Appendix G presents calibration of the transport model, while predictive flow and transport modeling is presented in Appendix H. A history of the site monitoring program is provided in Appendix F.

#### **2.2.5.1 History and Evolution of Site Conceptual Model**

The Main Tailings Impoundment has been draining since it began operation. Seepage rates have decreased since 1986, when disposal of water in the impoundment was stopped and the ground water table under the impoundment is now below the base of the tailings. The impoundment areas are now covered with a compacted clay reclamation cover designed primarily to attenuate radon emissions. The annual infiltration and percolation rate through the cover and the tailings is anticipated to be at a very low rate of approximately 0.6 inches per year.

Current estimates place the residual tailings seepage at 130 gpm to 150 gpm, decreasing to an average of 30 gpm over the next 30 years. Eventually, the seepage from the tailings is expected to reach equilibrium with the reclaimed tailings area steady-state infiltration rate (0.6 inches per year), causing tailings seepage to reach a long-term, steady-state seepage rate of less than 5 gpm.

Ground water in the NW and SW Valleys is derived from both tailings seepage and recharge from precipitation. Precipitation recharges the ground water system in two ways: (1) by aerial recharge (infiltration through the relatively flat floors of the valleys,

including the tailings reclamation cover) and (2) by runoff from the granite outcrops via shallow surface joints and cracks, which funnel the runoff to the aquifer and reduce the amount of loss to evaporation. Steady-state aerial recharge (infiltration) through the reclaimed tailings areas is estimated to be approximately 0.6 inches per year, while runoff from the granite outcrops is estimated to be 6 inches per year.

Presently, the Old Tailings and the Alternate Tailings Impoundments in the SW Valley have completely drained and are contributing little or no seepage to the ground water flow of the SW Valley. The Main Tailings Impoundment in the uppermost NW Valley continues to contribute flow to the ground water system (approximately 150 gpm), though in greatly diminished quantities from peak conditions (approximately 1,200 gpm). Due to the presence of a sub-surface granite high, or saddle, present at the head of the SW Valley, ground water from the uppermost NW Valley (Main Tailings Impoundment area) is directed primarily down the NW Valley. At present, approximately 90 percent of the tailings seepage and ground water underflow from the uppermost NW Valley under the Main Tailings Impoundment flow down the NW Valley, while the remainder flows down the SW Valley. In the long term, these percentages are expected to be 100 percent and 0 percent, respectively, as the water table in the uppermost NW Valley falls below the lowest point in the bedrock saddle. However, sufficient basin area exists in the SW Valley below the bedrock saddle for ground water flow to continue in perpetuity due to precipitation and resulting aerial recharge.

#### **2.2.5.1.1 Peak Main Tailings Impoundment Flow Conditions**

In 1986, a peak of approximately 900 gpm was seeping from the Main Tailings Impoundment in the uppermost NW Valley, and approximately 55 gpm was entering the uppermost NW Valley as recharge (underflow). Additionally, approximately 25 gpm was entering the system in the NW Valley below the Main Tailings Impoundment area, and 32 gpm was entering the system in the SW Valley below the Main Tailings Impoundment. This water is from aerial infiltration and granite runoff. A total of

approximately 885 gpm flows to the NW Valley and the remaining 127 gpm flows to the SW Valley. Prior to August 1986, all of the water flowing from the NW Valley was returned to the main impoundment by pumping water that accumulated in the NW Valley Seepage Pond (approximately 450 gpm) with the remainder intercepted by Well #2. Well #2 was shut down in August 1986. The NW Valley Seepage Pond was pumped at rates from 350 to 450 gpm until 1990, at which time the water levels in the NW Valley had dropped so low that the pond became dry. Wells A, B, and C were pumped at a combined rate of 150 to 195 gpm, which effectively intercepted the approximately 127 gpm flowing from the SW Valley. These pumps were also shut down in 1986.

#### **2.2.5.1.2 Migration of Water beyond the SW Valley**

Prior to 1983, there were no extraction wells present in the SW Valley. From 1983 to 1986, essentially all flow down the SW Valley was captured by wells WN-A, WN-B, and WN-C and returned to the tailings impoundment. From 1986 to December 1989, water was not extracted from the SW Valley wells. In January 1990, the NRC Corrective Action Program (CAP) was initiated in both the NW and SW Valleys. The CAP system was designed to reduce the mass of constituents in the ground water system by capturing the annual pumping volume objective of 47.3 to 66 million gallons per year (average pumping rate of approximately 90 gpm to 125 gpm). Initially, the wells operated year-round, but in February 1992, pumping was reduced to approximately 6 months per year (April through October). In the SW Valley, the CAP consisted of Well 9E and WN-B until April 1995, when Well 9E was removed from the CAP to facilitate surface reclamation. In 1997, the CAP was further modified by changing the annual pumping volume objective from 47.3 to 66 million gallons per year to 6 to 15 million gallons per year because of the loss of area for evaporation of CAP water due to surface reclamation. Approximately one-half of the total pumping is from the SW Valley, which equates to an annual rate of approximately 10 gpm. In the SW Valley, at the current CAP pumping rate and duration, the remaining well (WN-B) is removing only a

fraction of the present annual ground water flow and is, therefore, of limited usefulness. Additionally, the CAP is ineffective in remediating contaminants that migrated past the mouth of the valley. Although constituent mass has been removed from the ground water, the CAP was not intended to and therefore has been ineffective at reducing the source of constituents to the ground water system.

As ground water flows to the southwest out of the SW Valley, it encounters regional ground water that is flowing to the northeast. As the two flow systems converge, a ground water divide forms and site-derived ground water flows both to the northwest and southeast around the granite outcrops. The town of Jeffrey City is located on the western side of the ground water divide and is isolated from site-derived flow. Ground water from the SW Valley mixes with flow in the aquifer beneath the South Plain Area and also with the Sweetwater River alluvial aquifer to the north. Estimates indicate that in 1996 approximately 12 gpm of the 52 gpm exiting the SW Valley flows to the north and rejoins ground water flow in the floodplain area.

#### **2.2.5.1.3 Migration of Water beyond the NW Valley**

Until 1986, all site-derived ground water flowing down the NW Valley was captured by pumping at Well #2. Prior to 1977, pumping rates at Well #2 were as high as 1,400 to 1,450 gpm (Canonie, 1989a; D'Appolonia, 1977b). During 1981 to 1986, the pumping rate at Well #2 was reduced to 650 gpm. After the NRC approved the cessation of pumping from Well #2 in 1986, ground water began to migrate from the NW Valley into the Sweetwater River floodplain. In January 1990, the NRC CAP was initiated. In the NW Valley, the CAP consisted of pumping Wells 4E and 5E. Initially the wells operated year-round. In February 1992, pumping in the NW Valley was reduced to approximately 6 months per year (April through October). In May 1997, pumping of Well 5E in the NW Valley was discontinued due to reduced evaporative capacity of the CAP system and low constituent recovery efficiency from this well. In 1997, the total of the CAP annual volume was reduced from 47.3 to 66 million gallons per year to 6 to 15 million gallons

per year because of the loss of area for evaporation of CAP water due to surface reclamation. Approximately one-half of the CAP pumping is from the NW Valley, which equates to approximately 10 gpm on an annual basis. In the NW Valley, at the current pumping rate and duration, the remaining well (Well 4E) is removing a very small fraction of the annual ground water flow from the NW Valley and, therefore, is of limited usefulness. Additionally, the CAP is ineffective in remediating contaminants that have all ready migrated past the mouth of the valley beyond the area of CAP pumping influence.

#### **2.2.5.2 Recent Conditions**

In 1996, approximately 150 gpm was seeping from the Main Tailings Impoundment in the uppermost NW Valley, and approximately 55 gpm was entering the uppermost NW Valley as recharge. Of this 205 gpm, approximately 20 gpm flowed into the SW Valley (10 percent of uppermost valley flow), and approximately 185 gpm continued to flow down the NW Valley. The Northwest Valley Seepage Pond pumping was discontinued in 1990 because the pond had become dry. Recharge to the NW Valley and SW Valley (below the uppermost valley) from aerial infiltration and granite runoff remained constant at approximately 25 gpm and 32 gpm to each valley, respectively. Approximately 210 gpm flowed to the mouth of the NW Valley. This flow joined the regional flow in the Sweetwater River floodplain because Well #2 pumping was discontinued in August of 1986 in order to accommodate tailings reclamation. The remainder of the uppermost valley flow (approximately 20 gpm) was joined by the SW Valley recharge (approximately 32 gpm) and flowed at a rate of approximately 52 gpm to the mouth of the SW Valley. Ground water flowing out of the SW Valley splits into two flow paths where it meets the regional ground water flowing to the northeast. Approximately 80 percent of the SW Valley ground water flows to the south and east around the granite outcrops, while the remaining 20 percent flows to the north where it joins the regional flow in the Sweetwater River floodplain.

#### **2.2.5.2.1 Sweetwater River Floodplain Area**

Water flowing from the mouth of the NW Valley mixes with water in the Sweetwater River floodplain and flows toward the Sweetwater River. A sub-surface granite high located outside the NW Valley constricts the flow in this area, resulting in minor upward gradients. East of the Ore Haul Road, approaching the Narrows (Figure 35), the granite basement rises, constricting the flow area in the Lower and Upper Split Rock units. At this point, essentially all ground water from the NW Valley and regional ground water in the floodplain alluvium and Split Rock Formation (a total of approximately 600 gpm or 1.3 cubic feet per second [cfs]) flows into the floodplain alluvium and Sweetwater River. At the Narrows, the granite bedrock outcrops and essentially all ground water flows into the Sweetwater River.

#### **2.2.5.2.2 Ground Water/Surface Water Interaction**

In the floodplain, approximately 250 gpm of water flows past the mouth of the NW Valley as regional ground water flow. Ground water north and south of the Sweetwater River channel flows from the aquifer to the Sweetwater River. Interaction between the river and the local floodplain aquifer is dynamic as evidenced by the large, seasonal water level changes in the floodplain alluvium in response to changes in river stage. River flow values reported for the U.S. Geological Survey (USGS) gauging station located at Sweetwater Station are similar to those that would be expected near the site. Streamflows at Sweetwater Station vary seasonally with high flows occurring in April, May, and June (with historical averages of 390, 542, and 398 cfs, respectively) and low flows occurring in December, January, and February (with historical averages of 36, 27, and 35 cfs, respectively), as well as August and September (with historical averages of 36 and 22 cfs, respectively) (Table 10). An evaluation of the data shows that the lowest 7-day running average flow on record at the Sweetwater Station is 2.1 cfs. Annually, the average flow for Sweetwater Station is 185 cfs.



### **2.2.5.3 Long-term Conditions**

Estimates of future flow conditions indicate that the existing tailings seepage will decrease from 1996 rates to an average of approximately 30 gpm over the next 30 years. The long-term, steady-state tailings seepage rates will equilibrate with the reclaimed tailings area recharge (infiltration) rate (0.6 inches per year) resulting in tailings seepage rates of less than 5 gpm. No flow from the uppermost NW Valley will enter the SW Valley. However, areal recharge to the SW Valley will maintain long-term ground water flow out of this valley of approximately 32 gpm. The ground water flow from the NW Valley will equilibrate to approximately 85 gpm in the long term.

### **2.2.6 Background Water and Shallow Floodplain Soil Concentrations**

A limited evaluation of background ground water quality was performed in 1987 and was incorporated into the current ground water license compliance standards. These background values were developed from Well-15, the previously designated background well near the mouth of the SW Valley. Results of the recent site characterization studies indicate that this well was probably already impacted by 1987 and, therefore, not representative of background conditions. In addition, these previous background values were developed from a single well over 2 consecutive quarters and do not encompass the natural variability of background ground water quality. Further, these background values were developed from a well in the Split Rock Formation aquifer and do not relate in any way to the water quality of the floodplain alluvium, which is now known to be distinctly different. Therefore, as part of the recent comprehensive site characterization studies, a more complete background characterization study was performed. This background characterization for ground water quality, surface water quality, and shallow soils, is presented in greater detail in Appendix F.

The methodology and approach used for background determination at the Split Rock Site is functionally equivalent to that used at Resource Conservation and Recovery Act (RCRA) facilities and follows the general approach outlined in recent EPA guidance on background statistics (EPA, 1989a, 1992). The methodology is based on the approach defined by the American Society for Testing and Materials (ASTM) (1996) draft standard for background statistics and on Gibbons (1994). Development of background values is discussed in greater detail in Appendix F.

Because the Split Rock Site started operations in 1957, there are no locations on or immediately down gradient of the site that can be assumed to represent background conditions today. Many historical wells not impacted by site activities allow mixing of alluvial and Split Rock Formation ground water or potentially have been impacted in recent years. Therefore, none of the historical data from these wells are used for background determinations.

An inter-well approach was used for ground water in which background water samples were collected from up gradient or distantly cross-gradient areas near the Split Rock Site. The underlying assumption of the inter-well approach is that the variability and distribution of the offsite background concentrations represent those that existed at the site prior to human activities. The areas from which data were deemed to be appropriate for inclusion in the background data set were assumed not to have been affected by site seepage or any site operations.

The background data are described by a set of statistics, most important of which are prediction limits. Upper prediction limits (UPLs) were computed from the background data, and these limits may be used in the future for comparisons with down gradient compliance monitoring data. UPLs represent statistical estimates of the maximum concentration that will include the next series of k measurements at a specified level of confidence based on a sample of "n" background measurements. UPLs of a minimum

confidence level of 95 percent were computed for all constituents except pH, for which both upper and lower limits are appropriate.

Background ground water quality samples were collected and analyzed in accordance with procedures described in the Geochemistry Task Work Plan (Appendix F, Attachment F.b), and data collection activities are also described in the Site Investigation Report (Appendix A). Attachment F.i to Appendix F lists the data used to compute the background statistics for river water and ground water.

Outliers, either anomalously large or small, in a data set can bias most of the statistics commonly used to describe a data set. If outliers are the result of errors, they should be corrected; otherwise, the EPA (1989) has taken the philosophy that outliers should generally be retained in a data set. In the present work, outlier testing was performed using the Rosner (1983) multiple outlier test for up to ten outliers per constituent. Numerous potential outliers were identified by Rosner's test. However, most of these were found to conform with the data trends or were sometimes the result of multiple reporting limits. No data errors were identified among the outliers.

#### **2.2.6.1 Split Rock Formation Background Ground Water Quality**

The set of wells selected to represent background Split Rock Formation water quality is listed on Table 11 and illustrated on Figure 36. These wells include site drinking water wells, Well #22, Well #27; four private wells that are PVC-screened; and recently installed wells. Ground water data used in the background calculations were collected between November 1995 and December 1997, with the exception of Well #22 and Well #27, from which WNI data collected since 1981 have been used.

The UPL for one future prediction ( $k=1$ ) for each of the 25 constituents considered (see Section 2.1.3) is presented in Table 12.

### **2.2.6.2 Sweetwater River Floodplain Alluvium Background Ground Water Quality**

The set of sampling locations selected to represent background Split Rock Formation water quality is listed on Table 11 and illustrated on Figure 36. These locations include private domestic drinking water wells in the immediate area, wells completed especially for the purposes of baseline ground water quality characterization, and stainless steel drive-point sampling installations placed in the shallow floodplain alluvial soils. All these locations are completed in the floodplain alluvium and are located up gradient or distantly cross gradient from the flow path of site-derived constituents.. Although all of the background wells were constructed of PVC, the minipiezometers were constructed with stainless steel screens and galvanized steel riser pipes because their primary uses were to obtain water level data and to map the distribution of potentially site-derived constituents such as uranium. However, water quality data from the minipiezometers were included in the background program to enable comparisons of shallow alluvial ground water with Split Rock Formation ground water.

The UPL for one future prediction ( $k=1$ ) for each of the 25 constituents considered (see Section 2.1.3) is presented in Table 13.

### **2.2.6.3 Sweetwater River Background Water Quality**

Background concentrations of dissolved constituents in the Sweetwater River up gradient of the site were computed. The background statistics provide a basis for comparison for water quality in the Sweetwater River as it flows past the site and receives ground water discharge.

Background statistics for Sweetwater River water were calculated using data from WNI station S-7 near McIntosh Ranch, approximately 3 miles west of the site (Figure 36). Water quality samples have been collected there since 1963, but because data

collected prior to 1982 exhibited greater variability than the later data, the former data were not used in the background calculations. One sample collected from station ENSR-S-1 in October 1995 was also included in the background surface water data set. The water data used in calculating background statistics are presented in Attachment F.i to Appendix F. The same approach used to calculate background concentrations and associated statistics for ground water was used for calculating surface water background values. Cohen (1959) adjustments to mean and standard deviation were made when Cohen's method was applicable. Cohen's method compensates for the influence of nondetected values in a censored data set.

The UPL for one future prediction ( $k=1$ ) for each of the 25 constituents considered (see Section 2.1.3) is presented in Table 14.

#### **2.2.6.4 Shallow Floodplain Soils Background**

A multi-phase study was undertaken between the fall of 1995 and spring of 1997 to evaluate concentrations of constituents of interest in shallow soils (less than 3 feet deep) of the NW, SW, and Northeast Valleys and the Sweetwater River floodplain near the Split Rock Site. The study was conducted in three phases: (1) a preliminary evaluation was conducted in October 1995 by ENSR Consulting and Engineering, Inc. (ENSR) and Shepherd Miller, Inc. (SMI) as part of the environmental site assessment (see Appendix I), (2) a screening-level characterization of constituents in shallow background floodplain soils and shallow floodplain soils potentially affected by site-derived ground water was conducted in November 1996, and (3) an additional shallow floodplain soil sampling program was conducted in April 1997 to augment the 1996 findings. The primary objective of this study was to characterize the vertical and lateral distribution of constituents of interest in shallow soils near the Split Rock Site. In addition, data collected during this study will be useful when evaluating factors that may control the fate and transport of these constituents.

Twenty shallow floodplain soil samples were collected from an area up gradient of past or present plume migration in November 1996 (see Figure 37). To provide additional background concentration information, another round of shallow floodplain soil samples was collected in April 1997 from 20 additional background locations north of the Sweetwater River (Figure 37). These areas are assumed to exhibit background conditions and provide background comparison data from samples that were compositionally and diagenetically similar to the shallow non-background floodplain soil samples (discussed in Section 2.1.3.1). Samples at all locations were collected from above the water table at depths ranging from 0 to 6, 12 to 18, and 24 to 30 inches. Samples were collected as discrete, non-composited samples at each depth range. Details of the SMI 1996 soil sampling procedures can be found in SOP No. 23, "Floodplain Shallow Soil Sampling" (Appendix A, Attachment e).

All background samples from all depth ranges for the November 1996 sampling event were analyzed for the non-radiometric constituents silver, arsenic, calcium, cadmium, chlorine, copper, iron, potassium, percent lime ( $\text{CaCO}_3$ ), magnesium, manganese, molybdenum, sodium, ammonium as nitrogen ( $\text{NH}_4\text{-N}$ ), nickel, nitrate plus nitrite as nitrogen ( $\text{NO}_2+\text{NO}_3\text{-N}$ ), lead, pH, selenium, sulfate, and zinc; the radionuclides Ra-226, Th-230, U-234, U-235, U-238 (by complete hydrofluoric acid digestion and alpha spectrometry per Yankee Atomic Environmental Laboratory procedure No. 389), and  $\text{U}_{\text{nat}}$  (by partial digestion using EPA Method 3050 [ $\text{HNO}_3/\text{H}_2\text{O}_2$ ] and fluorimetry); additional carbon species of  $\text{CO}_3\text{-C}$ , TOC, and total carbon; as well as CEC and grain size analysis for percent sand (2 to 0.05 mm), silt (0.05 to 0.002 mm), and clay (<0.002 mm). All background samples from the April 1997 sampling event were analyzed for the radionuclides Ra-226, Th-230, U-234, U-235, U-238 (by complete hydrofluoric acid digestion and alpha spectrometry per Yankee Atomic Environmental Laboratory Procedure No. 389) and for the same carbon species and physical parameters as the 1996 samples.

Background statistical analysis of shallow floodplain soils data was identical to that used in determining background concentrations of dissolved constituents in ground and surface water. Sample results from the two sampling events in 1996 and 1997 were combined, for a total of 40 samples, to determine background UPLs for each sample depth range and for the physical parameters. Because the 1997 samples were not analyzed for the non-radiometric constituents, only the 1996 data set was used to determine UPLs for these constituents.

Results of the statistical analysis for shallow background soil constituents are given in Appendix F, Section F.7.

### **2.2.7 Other Potential Sources**

Overall, evaluation of the site ground water data has not identified impacts from any of the other waste management facilities on the Split Rock Site, other than the tailings impoundments, as contributing unique or identifiably different COPCs to the ground water system. One possible exception to this overall observation is the possible contribution of nitrogen species (e.g.,  $\text{NO}_3$ ) to ground water in the SW Valley from the Sewage Lagoon. However, this potential contribution is minor and does not significantly alter the interpretation of site ground water chemistry of potential corrective action alternatives.

However, two discrete off-site locations unimpacted by byproduct materials or site operations but with ground water quality in excess of background have been identified. These two locations are the Red Mule area east of the SW Valley and the area near SWAB-36 and SWAB-24 along the haul road north of Jeffrey City (see Figure 3).

The Red Mule area is approximately 1.5 to 2 miles east of the SW Valley and has several residents. Ground water samples from this area show concentrations of uranium and nitrate slightly above background values. Extensive characterization,

including evaluation of overall water quality characteristics, isotopic fingerprinting of water quality, down hole geophysical logging of the geologic profile, and hydrologic analyses (see Appendix F) establish that the slightly elevated uranium concentrations at the Red Mule area are not site-derived and are most likely the result of natural localized uranium mineralization. The elevated nitrate levels (4.93 mg/L dissolved  $\text{NO}_2+\text{NO}_3\text{-N}$  versus a background value of 3.99 mg/L) are minor. The Red Mule subdivision contains houses that have local septic systems, which are a potential source of nitrogen compounds in that area. No other site-derived constituents are above background in this area.

The area near SWAB-24 and SWAB-36 is and has always been up gradient of the site. In addition, only one COC has been identified at each of these two wells above background. Only uranium has been identified above background at SWAB-36, which is probably the result of localized mineralization as discussed above for the Red Mule area. Only nitrate has been detected above background levels at SWAB-24 (7.46 mg/L dissolved  $\text{NO}_2+\text{NO}_3\text{-N}$  versus a background value of 3.99 mg/L). The well SWAB-24 is located just north and down gradient of the Jeffrey City Sewage Lagoon, a likely source of nitrogen compounds.

## **2.2.8 Transport Modeling**

The future transport of COCs was evaluated using numerical models to support evaluation of potential future risks from COCs and to support evaluation of a range of practicable potential corrective action alternatives.

### **2.2.8.1 Technical Approach**

Uranium was used in the transport modeling evaluation as the most conservative and extensive COC whose transport would encompass the transport of all other COCs.



In addition, sulfate was initially modeled to confirm that its transport was indeed encompassed within the predictions of potential future uranium transport. The model RAND3D was used to simulate uranium transport, a random-walk computer code that can simulate three-dimensional solute transport in heterogeneous media (Koch, 1994; Prickett and others, 1981). RAND3D is a public-domain solute transport model that is validated, benchmarked, and generally accepted by regulatory agencies.

The spatial distribution of ground water velocities throughout the region of interest was required input to the transport model. The velocity distribution was obtained from the results of a series of steady-state MODFLOW (McDonald and Harbaugh, 1988) three-dimensional numerical ground water flow models (see Appendix E). The numerical flow models were calibrated against: (1) measured ground water levels throughout the site area at specific points in time and (2) estimated long-term average ground water discharge rates into the Sweetwater River.

The transport modeling effort included: (1) solute transport simulations of uranium and sulfate from 1986 to 1996, (2) transport model calibration, and (3) validation of the transport model. A detailed evaluation of the proposed alternatives, based in part on predictive runs of the transport model, is provided in Appendix H.

The solute transport model domain extends from the mouths of the valleys northward to the Sweetwater River and south and east through the South Plain area (Figure 38). The model was used to simulate transport of uranium and sulfate from 1986 to 1996, the period when constituent migration first took place outside the valleys. Uranium and sulfate were chosen as modeling constituents since they are conservative transport constituents and represent the limit of contaminant migration. Using measured 1986 uranium and sulfate concentration distributions as initial conditions, the model was calibrated to measured 1996 concentration distributions.

## 2.2.8.2 Flow Modeling

Flow velocity distributions input into the transport model were obtained from the numerical ground water flow model of the site and surrounding area. The hydraulic conductivity distribution used in the model was based on: (1) extensive borehole permeability testing across the site (Appendix C) and (2) a series of steady-state model calibrations based on comparisons of model-predicted hydraulic heads with measured water levels in monitoring wells for several distinct time periods (Appendix E).

Ground water flow conditions in the NW Valley and SW Valley changed appreciably during the 1986 to 1996 simulation period (see Appendix D). From 1986 to 1990, ground water flow rates within and immediately outside the valleys were relatively large as a result of high seepage rates from the Main Tailings Impoundment related to the draining of the waters from the 1983 to 1986 pumpback system. From 1990 to 1996, ground water flow rates decreased due to a reduction in tailings drainage and remedial pumping conducted by the CAP. The change in hydrologic conditions was reflected by a lowering of ground water levels below the Main Tailings Impoundment between 1986 and 1996. During this period, monitoring wells located along the Main Tailings Dam indicate that ground water levels fell by several tens of feet.

Development of the ground water flow model is described in detail in Appendix E. Model development entailed the following steps:

- Development of a conceptual site model based on existing data and literature information, field observations, and new data collected in conjunction with the recent site characterization studies (see Figure 39)
- Design and development of a preliminary steady-state numerical flow model using the USGS MODFLOW code (McDonald and Harbaugh, 1988) and available site data and literature values
- Refinement and calibration of the steady-state numerical model to match head and flux targets at two different time periods (1986 and 1996)

- Verification of the model by comparing simulated and measured heads/fluxes for a third time period (1977)
- Development of two versions of the calibrated steady-state model to simulate average stress conditions during 1986 to 1990 and 1990 to 1996.

The active model area is bounded on the north by the Sweetwater River (a head-dependent flux boundary) and on the south by a streamline (no-flow) boundary. The western and eastern boundaries are prescribed-head boundaries with linearly varying hydraulic heads (Figure 40). The southern, western, and eastern boundaries are sufficiently distant from the site that modeled stresses in the site area do not significantly affect fluxes or heads at these boundaries. Thus, the southern, western, and eastern portions of the flow model can be considered "seemingly infinite" in lateral extent.

Due to its overall impermeability, granite within the upland (outcrop) areas is incorporated into the flow model as a no-flow or prescribed-flux boundary. The granite outcrop margins have prescribed fluxes which account for recharge in the upland areas that is conveyed laterally to the Split Rock Formation (commonly referred to as mountain front recharge). A detailed discussion of fluxes prescribed along these boundaries is provided in Appendix E.

The model contains three layers that correspond to grouped HSUs. Model Layer 1 consists of the Sweetwater River Alluvium (HSU-1), Alluvium and Dune Sands (HSU-2), and Tailings and Fill Material (HSU-3). Model Layer 2 represents the Upper Split Rock Unit (HSU-4), and Model Layer 3 represents the Lower Split Rock Unit (HSU-5) and White River Formation (HSU-6). The base of the model (bottom of Layer 3) corresponds with the top of granitic bedrock surface. The top of granite is treated by the model as a no-flow boundary.

Initial input parameters to the flow model were obtained from field data and literature values. The initial hydraulic conductivity distribution, within and between layers, was

based mainly on the results of site aquifer pumping tests which are described in detail in Appendix C. Justification for other input parameters is provided in Appendix E.

The initial parameter values were refined through a calibration process that compared model-simulated fluxes and hydraulic heads with measured or interpreted field values (referred to as modeling targets). The target flux used in the calibration process was ground water discharge to the Sweetwater River, which had been independently measured by stream gauging during 1996 (Appendix D). Head targets consisted of water levels measured in monitoring wells. The primary focus of model calibration was to refine the hydraulic conductivity distribution within and between the model layers. The flow model was calibrated for two time periods; 1986 and 1996. For each period, associated average stresses, such as pumping rates and tailings pond water levels, were input into the model; and simulated heads and fluxes were compared to measured values for that period. The final calibrated model contained a hydraulic conductivity distribution that adequately simulated both time periods.

As a verification, the calibrated model was used to simulate 1977 hydrologic conditions. The predicted hydraulic heads for this simulation were in good agreement with measured 1977 heads. At the end of the calibration/verification process, the flow model was judged to be an adequate simulation tool for generating the ground water velocity distributions required as input to the transport model.

### **2.2.8.3 Transport modeling**

RAND3D is a random-walk model that simulates advection by moving particles along a flow path at prescribed velocities and dispersion by statistically moving (i.e., random-walking) particles. A particle is a discrete element that represents a fixed chemical mass distribution of the dissolved constituent in ground water. Plume migration is simulated by introducing prescribed numbers of particles at source areas or boundaries during each time step and evaluating the dispersed particle "cloud" that develops in the

down gradient flow system over time. At any point in the flow system, the chemical concentration is directly related to the density of particles within a representative volume about the point.

The transport model covers only a portion of the flow model area (Figure 41). Since the purpose of the transport model is to simulate constituent migration outside the valleys, it has prescribed concentration boundaries at the mouths of the NW Valley and SW Valley, and the model does not extend into the valleys or impoundment (source) areas. This model configuration was used to better simulate uranium transport without involving the complex geochemical conditions taking place in the upper valleys. The remaining boundaries of the transport model include zero chemical flux boundaries along the granite outcrops and at the southern edge of the model, and a zero concentration boundary at the western edge where non-impacted ground water enters the model domain. At the eastern and southern edges of the model and along the Sweetwater River are passive boundaries where the transport model computes fluxes based on the characteristics of transport towards those boundaries. RAND3D accounts for particles passing across these boundaries and exiting the model domain. The vertical extent of the transport model is identical to that of the flow model. The base of the transport model (top of granite) is treated as a zero chemical flux boundary.

The prescribed concentration boundaries at the mouths of the NW Valley and SW Valley are essentially vertical planes with spatially varying chemical concentrations. The source concentrations at each boundary were developed in the following step-wise manner:

- Because there were no vertically measured concentration data in 1986, it was assumed that the 1996 measured distribution at the mouth of each valley was the same in 1986 (that is, the absolute concentrations were different, but the distribution of concentration across the mouths of the valleys were equivalent).

- Individual concentrations at each boundary were modified (raised or lowered) until the simulated mass in the floodplain and South Plain areas matched measured data.
- For the NW Valley, the concentration distribution was modified to better match the location of the simulated center of mass to that of the one based on the measured data. Because of the heterogeneity of the floodplain and the inability to account for patterns in mass transport during the flow model calibration, the change from the 1996 measured distribution in the NW Valley was significant. This step was not necessary for the SW Valley, because of the low flow velocities.

Figure 42 shows a cross-section of the 1996 measured uranium in the NW Valley interpreted from data gathered at discrete depths at numerous locations near the boundary. Figure 43 displays interpreted uranium concentration distributions for the SW Valley.

There are no chemical sources or sinks within the transport model domain where chemical mass enters or leaves the flow system. Chemical mass enters the model domain only at the prescribed concentration boundaries crossing the NW Valley and SW Valley (discussed in the previous section). Chemical mass leaves the model domain only at passive boundaries such as the Sweetwater River.

Because the transport model evaluates transient or changing conditions, initial chemical concentrations are required at each cell. Figure 44 shows the interpreted 1986 distribution of uranium concentrations. These distributions are depth-averaged throughout the entire saturated thickness and are based on interpretation of measured field data. The 1986 chemical concentration at the center of each cell within this layer was determined by interpolation of the concentration contours. The number of particles input into RAND3D for that cell was then computed. For uranium, a specified mass per particle of 4.8 kilograms (10.6 pounds) was used and the specified value of 3,267.7 kilograms (7,189 pounds) per particle of sulfate was used to maintain the total number of particles below the model maximum of 5,300.

The uranium transport parameters used in the calibrated model are as follows:

R	= Retardation factor	= 1.0
$\lambda$	= Decay constant	= 0.0 year (no decay)
$n_e$	= Effective porosity	= 0.15
$\sigma_x$	= Longitudinal dispersivity	= 200 feet
$\sigma_y$	= Lateral dispersivity	= 20 feet
$\sigma_z$	= Vertical dispersivity	= 0 feet

Due to the lack of vertically distributed solute concentration data between 1986 and 1996, the quantitative criteria used to judge the calibrations was the location of the overall center of mass and total mass outside the valley mouths in 1996. Figures 45 through 47 show plume comparisons for uranium in Layers 1, 2, and all layers combined, respectively.

These transport parameter values provide a good match between predicted and measured concentrations of uranium and sulfate. The model simulates the centers of mass (uranium and sulfate) moving, on average, approximately 150 feet further (linear distance) from the NW Valley source than the measured centers of mass move in the floodplain. However, the South Plain area shows the opposite trend, with the simulated centers of mass moving approximately 300 feet less than the measured centers of mass. The low gradients in the South Plain area limit the distance that a simulated center of mass can move, while the high permeabilities in the floodplain result in simulated high velocities that tend to send the simulated center of mass out further than measured.

Comparisons were also made of total chemical mass in the measured and predicted plumes. The mass of a chemical constituent in a measured plume within a model layer was evaluated using the associated interpreted concentration contour map for that layer. The model simulations show good comparison to total measured masses of uranium and sulfate. In most cases, the differences between simulated and measured total masses are a few percent. The exception is sulfate in the South Plain area, where

the model over-predicts the mass by 8 percent. Because this results in environmentally conservative predictions (that is, higher simulated concentrations), the calibration was deemed acceptable.

Use of the transport model for predicting future extent and concentrations of COCs for the range of potential practicable corrective action alternatives is presented in Section 3.0.

## **2.3 Exposure Assessment**

A Baseline Risk Assessment (BRA) was performed for the Split Rock Site to support evaluation of corrective action alternatives that provide the required reasonable assurance of protection to public health and safety and the environment. The BRA (see Appendix I) presents the baseline determination of potential risk to humans and environmental receptors associated with exposure to COCs. As part of this determination, the BRA:

- Identifies the COPCs and COCs discussed in Section 2.1.2 and 2.1.3 of this GWPP
- Identifies the appropriate protective values for each COPC
- Evaluates the existing and potential future risks to humans and ecological receptors.

This assessment considers all relevant exposure pathways. The results of this assessment will serve as the primary means of documenting the current impacts at the Split Rock Site. Both radionuclide and chemical impacts on or near the site that occurred as a result of ground water migration from the Split Rock Site were examined. An evaluation of COC concentrations presently beyond the edge of the tailings reclamation cover (see Section 2.1.3), considering existing pathways of exposure, are compared to protective values to determine if any potentially significant risks exist under



present conditions. In addition, anticipated future concentrations, based on results from modeling of alternatives presented in Section 3.0, and exposure pathways are evaluated with respect to the protective standards to determine if potential future risks are acceptable. The risk evaluation considered ground water, surface water, and shallow floodplain soils to be the three media to pose potential hazards to public health and safety and the environment.

### **2.3.1 Technical Approach and Methods**

All site ground water and shallow surface soil data for the period of January 1, 1996 through December 31, 1997, from the recent site characterization (Appendix F), were evaluated to identify the maximum COPC concentrations present at the site as described in Section 2.1.2 and 2.1.3 of this GWPP.

Risk based concentrations (RBCs), that are protective of human receptors, were identified for each constituent for which no MCL exists. It was assumed that RBCs and MCLs are appropriate standards for the protection of human health. However, because some of the assumptions regarding the applicability of RBCs as protective standards may be questioned, HELs were also calculated (see Attachment I.a to Appendix I) using standard risk assessment practices described in the EPA *Risk Assessment Guidance for Superfund (RAGS)* (EPA, 1989b) and affiliated guidance. The HEL values are constituent concentrations that are determined to provide protection of human health at the potential points of exposure.

Potential impacts from current site conditions to terrestrial, avian, and aquatic organisms were evaluated in an Environmental Assessment (EA) conducted by ENSR in 1995 (Attachment I.b to Appendix I). Predicted river concentrations are compared with aquatic criteria to determine whether a potential threat to wildlife and aquatic organisms may exist in the future.

### **2.3.2 Ecological Exposure Assessment**

A comprehensive evaluation of the existing ecological exposures was conducted in 1995 (See Appendix I). This evaluation determined the impact of site-derived constituents on the environmental receptors near the site. Principally, these receptors included plants, wildlife, aquatic life, and livestock that could come in contact with ground water as it enters surface water in either shallow ponded areas in the floodplain northwest of the tailings or as ground water entering the Sweetwater River.

This evaluation was conducted during the period when the maximum volumes and concentrations of site-derived ground water constituents entered the floodplain and Sweetwater River. Transport modeling (see Section 3.0) shows that the concentrations of site-derived ground water constituents declines rapidly after this time period (Appendix H, Attachment H.c). Therefore, the evaluation was conducted under maximum loading conditions, and future loading conditions will decrease.

#### **2.3.2.1 Sweetwater River**

The evaluation showed that there is no adverse impact from the ground water seepage from the tailings impoundment on the Sweetwater River. Aquatic organisms are not impacted by ground water seepage under acute or chronic conditions. There will be no impact to people consuming fish from the river. In fact, under all Sweetwater river flow conditions, except minimum low flow conditions, there will be no measurable changes in water quality concentration in the river above and below the area where ground water seepage enters the river. Under these minimum low flow conditions, the small differences in water quality in the river caused by the ground water seepage are well below any concentrations of concern.

Because the chemicals in the ground water that are entering the river are dissolved and the chemical environment of the surface waters is similar to the near surface ground water, the chemicals will remain dissolved as they enter the surface water system. This means that there is no potential for chemical concentrations to accumulate or increase in the aquatic environment. Therefore, no cumulative future impacts to the Sweetwater river are anticipated.

### **2.3.2.2 Floodplain Surface Ponds**

Many shallow ponds exist in the floodplain of the Sweetwater River north of the site. These ponds are recharged with ground water during portions of the year. During these times, ponds are also used by livestock and wildlife. An evaluation was performed to determine if there was any impact to animals or to people eating the animals. This evaluation is described in detail in Appendix I. The evaluation shows that there will be no impact to animals or people eating animals that live and drink in the floodplain. Additionally, ground water modeling indicates that constituent concentrations will decrease over time from the values observed in the 1995 study. In fact, recent water quality analyses presented in Appendix F show that water quality concentrations in these surface ponds and from ground water in nearby wells is improving significantly over levels observed only a few years ago.

### **2.3.2.3 Vegetation**

Vegetation in the floodplain comes in contact with ground water seepage because of the shallow depth to ground water in many areas between the site and the Sweetwater River. This area is used for grazing and for hay production.

An evaluation of the impact of the seepage water on the health of the grass hay and on the animals that eat grass was conducted. Additionally, the impact of people eating

cattle or wildlife consuming the grass was evaluated. This evaluation is presented in Appendix I and shows that there is no impact to the vegetation, to the animals consuming the grass, or to any human who might eat the animals grazing in the area. Additionally, the concentrations of COCs in the ground water will continue to decline with time.

#### **2.3.2.4 Soils**

Ground water levels in the floodplain between the site and the Sweetwater River fluctuate significantly from the spring to the fall. During the spring, the water table in the floodplain is at or very near the surface. As the level of the river subsides in the summer and fall, the floodplain dries out and the water table is a few feet below the surface. This fluctuation of near surface water levels and capillary action as near surface water evaporates in the summer causes chemicals in the ground water to precipitate and become concentrated on the ground surface. This phenomenon is evident along the Sweetwater River in many places, both upstream and downstream of the site where salt or alkali deposits are clearly visible in the summer and fall. These soils are leached of the salts as the spring flood occurs and then reappear in the summer and fall as the water table recedes.

Between the site and the river, this phenomenon has caused the concentration of some site-derived constituents to be deposited in the shallow floodplain soils. The potential impact of these COCs was evaluated relative to its impact on vegetation, wildlife, and grazing. As shown in Appendix I, there is no impact to humans, vegetation, wildlife, or livestock.

The major COC that was observed at elevated levels (levels above background) in the near surface soil was uranium. While the evaluation showed no impact to vegetation, wildlife, or livestock, the uranium concentrations in the soil were greater than values that were targeted for cleanup in the mill area. Therefore a more thorough evaluation of the

impacts of uranium in the soil was performed with additional characterization sampling in 1996 and 1997.

The potential impact to human receptors from these elevated uranium concentrations in soil was evaluated and found to be insignificant. The results are discussed below in Section 2.3.3.

### **2.3.3 Evaluation of the Human Health Risks Associated With Current and Potential Future Exposure**

Only six COCs (ammonia, manganese, molybdenum, nitrate, combined radium, and uranium) exceed, and may exceed in the future, the protective standards (background, MCLs, or RBCs) beyond the edge of the tailings reclamation cover. As described in Section 2.2, uranium is the controlling parameter since it will travel the farthest and the most rapidly of all COCs. Since COC concentrations beyond the limits of the reclaimed tailings will exceed the protective values in the future and since future pathways may develop, potential future hazards to public health and safety and the environment could be unacceptable and additional protective measures could be necessary. Therefore, evaluation of potential corrective action alternatives is required for the future protection of public health and safety and the environment.

#### **2.3.3.1 Exposure Pathways**

The existing ground water in the site area is used for domestic drinking water, stock watering, and household uses by a small number of area residents. Existing stock watering wells and drinking water wells are identified from a review of the State Engineer's Office records and through field reconnaissance (see Attachment D.i of Appendix D). The maximum extent of uranium in ground water and identified non-monitoring wells are shown on Figure 48. As can be seen, there are no current drinking water wells that are within the existing distribution of site-derived constituents.

The nearest down gradient wells are in the Red Mule area east of the SW Valley. Predictive modeling (see Section 3.0) indicates that wells in this area could become impacted in approximately 100 years. It should be noted that the Red Mule area has anomalous background concentrations for uranium caused by localized mineralization. Local homeowners were notified of the results of the ground water analyses and that uranium concentrations were naturally occurring background. In addition, the municipal wells located in Jeffrey City are up gradient of the site and, therefore, could not be impacted by seepage from the tailings. An evaluation of the potential for previous impacts to the Jeffrey City municipal wells during periods of higher population and water use (see Attachment D.h to Appendix D) indicates that the wells could not have been impacted in the past. The existing ground water use is assumed to be the primary water uses in the future.

Assessment of both current and future human exposure to site-derived hazardous constituents was performed. The two media impacted by hazardous constituents to which humans may be reasonably exposed are ground water and floodplain soils (see Section 2.1.2, Section 2.3.2, and Appendix F). Two exposure scenarios were considered: (1) that of a resident farmer who drinks 2 liters of water per day, 350 days per year for 30 years, and (2) a transient exposure to shallow floodplain soils by a rancher working in the floodplain for 1 week per year. The transient rancher exposure scenario includes the pathways of direct irradiation, ingestion of impacted soils, and inhalation of dust from impacted floodplain soils.

### **2.3.3.2 Current Human Exposure and Risk**

Assessment of the existing distribution of site-derived hazardous constituents indicates that there are no human receptors presently using the ground water within the maximum contaminant distribution. Therefore, there are no current risks to human health from COCs in ground water.

The floodplain is used for agricultural purposes, floods seasonally, and could not reasonably support a residential use exposure scenario. However, more restricted use of this area is possible. Therefore, an exposure scenario has been assumed that consists of a rancher that would spend up to 1 week per year on the floodplain. For the transient rancher, direct irradiation from uranium in shallow floodplain soils, as well as ingestion and inhalation of the floodplain soil particulate material, are not likely to contribute significantly to the total risk, since the potential exposure is only 1 week each year. However, for completeness, all of these pathways were included in the evaluated scenario.

The potential risks to human health from the shallow floodplain soils was calculated using the RESRAD computer code developed by the NRC to evaluate residual radioactive contamination. Dose conversion factors assumed in the RESRAD modeling are adapted from the EPA Federal Guidance #11.

While uranium is the only hazardous constituent above protective standards in the floodplain soils (see Appendix F), the maximum reported values for  $^{234}\text{U}$ ,  $^{235}\text{U}$ ,  $^{238}\text{U}$ ,  $^{226}\text{Ra}$ , and  $^{230}\text{Th}$ , were conservatively used to represent total exposure risk to the floodplain soils. Input soil data (depth = 30 inches) were obtained from the shallow floodplain soil sampling events of 1996 and 1997.

The maximum dose for the transient rancher is 0.5 millirem per year (mrem/yr). This dose is well below the NRC acceptable annual dose level for the general public from residual radioactivity at decommissioned sites of 25 mrem/yr (10 CFR Part 20.1402). It is also below the negligible individual risk level (NIRL) identified by the National Council on Radiation Protection and Measurements (NCRP) of 1 mrem/yr. The NIRL is regarded as trivial compared to the risk of fatality associated with normal societal activities and can, therefore, be dismissed from consideration (NCRP No. 91, 1987). Therefore, there are no current risks to human health from impacted floodplain soils.

It should be noted that removal of the soils with elevated uranium concentrations is not possible. First, the mechanism that causes the elevated levels (i.e., near surface ground water with elevated uranium concentrations) still exists and will remain. Therefore, if the soils with elevated uranium were removed, elevated uranium concentrations would reappear next year, in the same way that they do now. Additionally, any earthmoving activities in the floodplain in areas with shallow ground water conditions and soft soils would be technically very difficult and environmentally, very destructive.

### **2.3.3.3 Potential Future Human Exposure and Risk**

Only those COCs that presently exceed protective standards beyond the edge of the tailings reclamation cover (ammonia, manganese, molybdenum, nitrate, combined radium, and uranium) have the potential to pose future hazards (see Section 2.1.3). If the maximum future COC concentrations for any well beyond the limits of the reclaimed tailings exceeded the larger of background or protective standards (RBCs or MCLs), then the potential future hazards to public health and safety and the environment could be unacceptable and additional protective measures could be necessary.

Results of predictive ground water transport modeling of uranium for a range of practicable potential corrective action alternatives (see Section 3.0) were evaluated for potential risk to human health. These modeling results indicate that human exposure pathways could develop with concentrations of COCs greater than the protective levels in the future due to continued migration of COCs. Therefore, additional measures may be required to provide the required reasonable assurance of protection of public health and safety and the environment.



### 3.0 CORRECTIVE ACTION ASSESSMENT

It is required of all potential corrective action alternatives that they provide for the protection of public health and safety and the environment for all pathways beyond the points of exposure (POEs) over the compliance period (200 years to 1,000 years). In addition, it must be demonstrated that any proposed alternate concentration limits (ACLs), because proposed "alternatives" to existing NRC or EPA regulatory requirements or some combination thereof are as low as reasonably achievable (ALARA) after considering practicable potential corrective actions. The practicability of the alternatives is evaluated on a technical basis, while the reasonableness of the alternatives is evaluated on a relative cost and benefit basis.

Historically, several corrective actions have been performed throughout the operational and reclamation history of the Split Rock Site. These actions include the installation of a toe drain below the impoundment embankment to collect seepage and pumpback of ground water and seepage pond water to the impoundment. In addition, a formal Corrective Action Program (CAP) was implemented in 1990, as required by Source Materials License SUA-56 Condition No. 74, Amendment No. 74, which continues to operate at present as modified (see Section 3.1 of this report). An evaluation of the effectiveness of the historic and existing corrective actions is presented in Section 3.1 of this application.

The selection process for potential corrective action alternatives involves a phased approach in which a suite of technologies and specific areas of application (e.g., NW Valley Aquifer, Southwest Valley Aquifer, Tailings, etc.) are identified, engineering objectives are developed for each area of application (e.g., reduction of COCs in the aquifer, reduction of ground water flow, etc.), and the technologies are grouped to the areas of application. These groupings form a range of potentially practicable corrective action alternatives that will provide the required reasonable assurance of protection to public health and safety and the environment. The suite of alternatives are screened for

practicability based on the criteria of effectiveness, implementability, the certainty of a given technology's application (technology classification), and relative costs of each technology as applied to each area. Once screened, the remaining alternatives are considered to be the practicable potential corrective action alternatives. These practicable alternatives are evaluated for reasonableness by considering the relative costs and benefits of each alternative.

The costs of the practicable alternatives are considered to be the monetary capital costs of implementing the alternative, the long-term costs of operating and maintaining the alternative, decommissioning, as well as the non-monetary costs associated with the environmental and potential health impacts of implementing the alternatives. Because each alternative has been designed to provide essentially equal levels of protection, the benefits of the respective alternatives are evaluated considering current and projected values of the pre-impact resource, the availability of alternative water supplies, and current and projected water use. The reasonableness of each practicable potential corrective action alternatives is assessed based on the relative differences between these costs and benefits. The entire package will be subject to comment by potentially affected or interested parties (stakeholders). All such comments will be addressed by WNi on the record and, ultimately, a preferred alternative will be submitted to the NRC for regulatory approval.

### **3.1 Results of the Corrective Action Program**

The existing Corrective Action Program (CAP) was initiated in 1990 as required by License SUA-56, Condition No. 74. Ground water was pumped from four wells located in areas of elevated uranium concentrations (Canonie, 1989c, 1989d). In the NW Valley, the CAP wells were Wells 4E and 5E; in the SW Valley, the CAP wells were WN-B and Well 9E. Initially, pumping was also performed from the Northwest Valley Seepage Pond. However, by early 1990, the Northwest Valley Seepage Pond was nearly dry, and pumping from the pond was decreased to 40 gpm. Pumping from the

Northwest Valley Seepage Pond ceased entirely in August 1990 (WNI, 1993). Seepage did not reappear in the pond area after this time.

The CAP well system was designed to capture the annual pumping volume objective of 47.3 to 66 million gallons of water per year (average flow rate of 90 to 125 gpm; WNI, 1993). Beginning in January 1990, the wells operated year-round at combined flow rates of 59 to 217 gpm (WNI, 1993, 1994, 1995). In February 1992, the pumping duration was reduced to about 6 months per year (April through October), although the system was still required to pump the same volume of water annually (WNI, 1993). Pumping rates at the CAP wells were increased to meet the annual pumping volume objective (WNI, 1993). Recovered water from the wells was sent to an evaporation pond and to an evaporation misting system that operated over the unreclaimed portion of the tailings impoundment (WNI, 1993). The misting system, originally located on the Main Tailings Impoundment, was moved to the area of the Old and Alternate Tailings Impoundments in 1991 to facilitate surface reclamation.

Well 9E was abandoned in 1995 to allow for completion of the reclamation cover in the SW Valley. The remaining wells continued to be operated at a combined flow rate of 200 gpm during April through October of each year. In May 1997, the NRC approved cessation of pumping from Well 5E. Pumping from this well, located at the mouth of the NW Valley, drew a large amount of clean water from the regional aquifer and was deemed inefficient for the CAP. At this time, final reclamation of the tailings eliminated the surface area over which the CAP pumping was spray evaporated. Therefore, the NRC approved a temporary reduction in the CAP pumping rate to that which could be evaporated using the available surface area of the CAP ponds, approximately 6 to 15 million gallons per year. Today, WN- B (SW Valley) and Well 4E (NW Valley) continue to remove the required pumping volume of 6 to 15 million gallons during the April through October pumping season (WNI, 1997).

Conservative evaluation of the effectiveness of the existing CAP (see Attachment H.g) indicates that CAP pumping in the NW Valley captures approximately 5% of the annual ground water flow down the NW Valley while SW Valley CAP pumping captures approximately 19% of the annual SW Valley ground water flow. In addition, existing CAP pumping from either valley is not capable of capturing ground water that has already passed the CAP pumping wells.

### **3.2 Feasibility of Alternative Corrective Actions**

A comprehensive alternative development process was conducted in order to optimize the alternatives that were subsequently evaluated to determine the best potential alternative to provide the required ground water protection at the site. This process started with a thorough determination of all possible technologies that might be applicable for the site. These technologies were grouped relative to the specific objects, such as reduction of constituent mobility or reduction of source. The best technology for each objective was then selected. The various technologies were then combined to form four site-wide potential corrective action alternatives which provide increments of environmental benefit.

#### **3.2.1 Potential Corrective Action Alternatives Development**

Potential corrective action alternatives have been assembled from the suite of retained process options to provide a baseline alternative, which provide the required reasonable assurance of protection of public health and safety and the environment with minimal cost and action, and three additional alternatives which provide the same level of protection with greater levels of benefit. After public comments and evaluation and responses thereto, these potential alternatives will be refined to the level necessary to select a preferred alternative. The suite of potential alternatives will be evaluated with respect to several criteria against the baseline alternative to determine which potential;

alternative reduces concentrations below protective levels to concentrations that are ALARA. This section develops and describes the key elements of each potential corrective action alternative as well as the compliance strategy and water quality standards for each alternative. A complete description of the alternative development process and details of each of the four potential alternatives is provided in Appendix H.

### **3.2.1.1 Alternative No. 1 - Institutional Control**

The Institutional Control Alternative allows natural flushing to attenuate, disperse, and dilute site-derived constituents to meet protective standards at the points of exposure (POEs) with no active treatment or mitigation measures. The compliance strategy of this alternative consists of removing the drinking water pathway for exposure via institutional control(s) including providing a replacement drinking water supply, when and if it becomes necessary, for existing residents within the area requiring control.

The POEs consist of the boundary of controlled area, small ephemeral surface water ponds or seeps in the Sweetwater River floodplain, and the Sweetwater River for ecological and human exposures. Institutional controls are employed to restrict access to ground water for drinking water. If necessary in the future, an alternative drinking water supply for residents within the controlled area, who are presently drawing drinking water from the Split Rock Formation aquifer, will remove them from the drinking water pathway. No residents are presently at risk from any site-derived constituents and are not anticipated to need an alternate drinking water source for over 100 years. The alternative water supply would be operated in perpetuity. This alternative is illustrated in Figure 49.

### 3.2.1.2 Alternative No. 2 - Hydraulic Diversion With Institutional Control

The Hydraulic Diversion Alternative incorporates a perpetual hydraulic control of flow to prevent eastward constituent migration from the SW Valley and alternate compliance standards with institutional controls to meet protective standards at the POEs with no active treatment measures. The compliance strategy of the Hydraulic Diversion Alternative consists of limiting the area potentially impacted by site-derived constituents through perpetual hydraulic control and removing future drinking water pathways for exposure via institutional control(s). The natural dilution and attenuation characteristics of the ground water and surface water systems allow this alternative to meet protective levels at the POEs. No treatment is assumed or needed for this alternative. The POEs consist of the boundary of controlled area, small ephemeral surface water ponds or seeps in the Sweetwater River floodplain, and the Sweetwater River for ecological and human exposures.

The hydraulic diversion would consist of approximately 16 injection wells located near the mouth of the SW Valley which would create a region of elevated hydraulic head, forcing ground water flow and constituent transport back around to the north and towards the Sweetwater River floodplain. Half of the water from the hydraulic diversion would flow towards and mix with the plume of site-derived constituents, forcing the plume movement to the north around the granite outcrop at the SW Valley mouth. The other half of the injected water would flow away from the hydraulic diversion to rejoin the regional ground water flow with no contact with site-derived constituents. The injection water for the hydraulic diversion, requiring slightly more than 500 gpm, would be drawn from a new supply well installed approximately 1 mile south (up gradient) of the control area (see Figure 50). This diversion system would operate in perpetuity and require periodic replacement (i.e., institutional control(s) and ongoing maintenance). Figure 50 illustrates the configuration of the corrective action alternative design.

### **3.2.1.3      Alternative No. 3 - SW Valley Focused Pumping With Institutional Control**

Alternative No. 3 incorporates active treatment and targeted pumping of a selected area in the SW Valley and institutional controls to meet protective standards at the POEs. The compliance strategy of Alternative No. 3 consists of removing the dissolved and sorbed constituents in the SW Valley focused pumping area by controlled flushing of the aquifer using injection and pumping wells. This will reduce the amount of site-derived constituents in the ground water system, control the short-term and intermediate-term amount of uranium flowing from the SW Valley through interim hydraulic control, and reduce the long-term concentration and distribution of site-derived constituents relative to the baseline alternative. The future drinking water pathway for exposure will be eliminated via institutional control(s). No active treatment of the NW Valley or floodplain are proposed as part of this alternative. Natural flushing will occur in the NW Valley and reduce concentrations over time. The maximum extent of ground water contamination out the NW Valley has all ready occurred and is protective; therefore, additional action is not proposed for this alternative.

The SW Valley focused pumping would consist of pumping 1,876 gpm from 29 wells and injecting 1,700 gpm of un-impacted ground water from an up gradient area into 34 wells located in the focused pumping area of the SW Valley (see Figure 51). Pumped water would be evaporated from lined evaporation ponds. Approximately 1,000 acres of evaporation ponds would be required.

To accelerate the cleanup of the aquifer, fresh water would be required at a rate of approximately 1,700 gpm. The water for fresh water injection would be drawn from a new supply well installed approximately 1 mile south (up gradient) of the control area (see Figure 51).

SW Valley focused pumping would be terminated once ground water concentrations in the area were reduced to within 20 percent of the anticipated long-term steady-state

uranium concentrations from the upper valley. Following termination of focused pumping, all corrective action facilities (wells, evaporation ponds, etc.) would be reclaimed and long-term steady-state flow and ground water quality conditions would equilibrate with steady-state seepage from the tailings. Figure 51 illustrates the configuration of the corrective action alternative design.

An alternate water supply for residents within the controlled area, who are presently drawing drinking water from the Split Rock Formation aquifer, is assumed to remove them from the drinking water pathway while providing them with a drinking water resource. This water supply would be constructed when and if it becomes necessary.

#### **3.2.1.4 Alternative No. 4 - Perpetual Containment Pumping With Institutional Control**

Alternative No. 4 incorporates immediate and perpetual containment pumping of the NW Valley and cleanup of an area outside the SW Valley beyond the area influenced by containment pumping (see Figure 51). Following cleanup outside the SW Valley, cleanup pumping in this area would be discontinued and perpetual containment pumping at a lower pumping rate would be initiated. The compliance strategy of Alternative No. 4 consists of removing the dissolved and sorbed constituents in the SW Valley aquifer area by controlled flushing of the aquifer with injection and pumping wells. This will reduce the amount of site-derived constituents in the ground water system and control the short-term and intermediate-term amount of uranium flowing from the SW Valley through interim hydraulic control. Perpetual containment pumping of both valleys, at relatively low pumping rates following cleanup outside the SW Valley, would prevent all future migration of site-derived constituents from the valleys. The drinking water pathway for exposure in the floodplain area and areas directly outside the valley mouths, which are presently impacted, will be eliminated via institutional control. Figure 52 illustrates the configuration of the corrective action alternative design.



NW Valley containment is implemented immediately and is designed to limit any future migration of site-derived constituents from the valley, while allowing natural flushing to disperse the existing site-derived constituents outside the valley that are presently in the floodplain area. Dispersion and natural flushing of constituents in the floodplain area will decrease the concentrations of site-derived constituents to near background concentrations within a few decades.

The initial SW Valley pumping would consist of pumping 960 gpm from 19 wells and injecting 800 gpm into 16 wells located in areas of elevated concentration in the SW Valley (see Figure 52). Containment pumping in the NW Valley would consist of pumping 5 wells at a combined rate of 100 gpm. Pumped water would be processed through a conventional water treatment plant using pH adjustment and reverse osmosis membrane technology.

Initial SW Valley pumping would be terminated after approximately 25 years, once ground water concentrations in the area were reduced to within 20 percent of the anticipated long-term steady-state uranium concentrations from the upper valley. After SW Valley focused pumping cleanup is completed, the 19 SW Valley extraction wells and all 16 injection wells in the SW Valley will be abandoned. Three SW Valley pumping wells in the valley mouth would then be pumped at a combined rate of 40 gpm, while the 5 NW Valley wells would continue to be pumped at a combined rate of 100 gpm to provide perpetual containment of both valleys. At that time, the treatment facility capacity requirements would decrease resulting in decommissioning and reclamation of a large portion of the treatment facility. Figure 52 illustrates the configuration of the corrective action alternative design.

Evaporation of treatment brines for the initial pumping period (25 years) would require approximately 143 acres of evaporation ponds. Approximately 23 acres of sludge disposal cells would be required to handle the treatment sludge from the water treatment plant (see Attachment H.d to Appendix H). The clean effluent from the water

treatment plant would be re-injected to the aquifer as part of the fresh water injection system. However, additional fresh water would be required (approximately 160 gpm) to meet the fresh water injection water requirements (800 gpm). The water to supplement the fresh water injection would be drawn from a new supply well installed approximately 1 mile south (up gradient) of the control area (see Figure 52).

An estimated 20 acres of evaporation ponds would be required to evaporate the brine from the treatment facility given the long-term containment pumping rates. An estimated 140 acres of sludge disposal cells would be required to accommodate the solid treatment waste generated over the 1,000-year design life although, conceptually, treatment and disposal would be required in perpetuity.

### **3.2.2 Alternatives Evaluation Criteria**

There are two very basic evaluation criteria that were used in the development and in the evaluation of the potential corrective action alternatives. The first criterion is the reasonable assurance of the required protection of public health and safety and the environment for the 1,000 year regulatory horizon. The second criterion is that the chosen alternative must lead to concentrations that are as low as reasonably achievable (ALARA). A discussion of the protection of public health and safety and the environment is provided here. The ALARA concept is developed in Section 3.3, 3.4, and 3.5.

The most basic requirement for the GWPP is that the chosen alternative must provide the required reasonable assurance of protection of public health and safety and the environment. Therefore, a major focus of the GWPP was determining current conditions relative to protective limits and predicting future conditions under various scenarios to ensure that protection of public health and safety and the environment would be provided for the next 200 to 1,000 years.