TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ATTACHMENTS

2.7 Hydrology

NUREG-1569 Section 2.7 states that, "characterization of the hydrology at in situ leach uranium extraction facilities must be sufficient to establish the potential effects of in situ operations on the adjacent surface-water and groundwater resources and the potential effects of surface-water flooding on the in situ leach facility" (NRC, 2003). To meet these requirements, this section addresses surface water features (**Section 2.7.1**), groundwater characteristics (**Section 2.7.2**), surface water and groundwater quality (**Section 2.7.3**), water use information (**Section 2.7.4**), and the overall hydrologic conceptual model (**Section 2.7.5**) based on the geology and hydrology of the Permit Area. Water use, which is limited in the vicinity of the Permit Area, is addressed in **Section 2.2.2.**

2.7.1 Surface Water

2.7.1.1 Drainage Characteristics

The Permit Area is located in the Great Divide Basin, a topographically closed system which drains internally, due to a divergence in the Continental Divide. Most of the surface water is runoff from precipitation or snowmelt, and it quickly infiltrates, recharging shallow groundwater, evaporates, or is consumed by plants through evapotranspiration. Alluvial deposits, if any, along drainages are not extensive, and the shallow aquifer, Battle Spring, underlying the Permit Area is unconfined, unconsolidated, and poorly stratified. The shallow water table is typically 80 to 150 feet below ground surface (ft bgs).

There are no perennial or intermittent streams within the Permit Area or on adjacent lands. The only officially named drainage within the Permit Area is Battle Spring Draw, which is dry for the majority of the year (**Figure D6-1**). A 1:24,000 USGS topographic map was imported into GIS, and used to conduct the drainage network analyses described in this section. Three primary watersheds drain ninety-nine percent of the Permit Area. These watersheds have been named Western Draw, West Battle Spring Draw, and East Battle Spring Draw for the purposes of this application. The Western Draw watershed covers 2.9 mi^2, of which 2.4 mi^2 are within the Permit Area; the West Battle Spring Draw watershed cover 7.0 mi^2, of which 3.1 mi^2 are within the Permit Area; the East Battle Spring Draw watershed covers 5.1 mi^2, of which 1.0 mi^2 is within the Permit Area. The entire Permit Area drains into the Battle Spring Flat, approximately nine miles southwest of the Permit Area. Much of the water conveyed through the ephemeral channels does not reach Battle Spring Flat. Instead, it infiltrates into the alluvium and recharges the Battle Spring aquifer.

The average slope of the Battle Spring Draw (northeastern) drainage in the Permit Area is 1.2 percent, the central drainage has an average slope of 1.5 percent, and the southwestern drainage has an average slope of 1.7 percent. The sinuosity (length of the channel divided by the length of valley) was calculated for the major channel in each basin. The sinuosity values for the northeastern Battle Spring Draw, central, and southwestern basins are 1.02, 1.15, and 1.16, respectively. The drainage densities range from 3.3 miles per square mile in the southwestern basin to 4.6 miles per square mile and 4.5 miles per square mile in the central and northeastern basins, respectively. A longitudinal profile of the northeastern Battle Spring Draw within the Permit Area is shown in **Figure 2.7-2**.

The existing drainages are incised, wide u-shaped and trapezoidal cross-sectional morphologies. Vertical and slumping banks exist where active erosion is occurring. The channels near the downstream boundary of the Permit Area are incised three to six feet and are ten to 15 feet wide. The channel side-slopes range in slope from 1:1 to approximately 2.5:1. The bed material in the larger draws is sandy textured and non-cohesive. Draws around the Permit Area are typically vegetated with sagebrush.

Annual runoff in the Permit Area is very low due to the high infiltration capacity and low annual precipitation. The channels are dry for the majority of the year. Drainages in the Permit Area are naturally ephemeral and primarily flow during spring snowmelt as saturated overland flow when soil moisture is at a maximum. The quantity of spring runoff is variable, depending on the amount of winter snowfall accumulation. Peak runoff from high intensity rain events can be significant; but surface flow is generally short-lived. Storm-water runoff after high intensity rain events is very rare because surface water infiltrates very rapidly or evaporates. Some intermittent and localized flow can occur near a small number of springs; but no surface runoff has been observed from springs within the Permit Area.

Runoff data are limited for the ephemeral and intermittent streams in the Great Divide Basin. There are two USGS streamflow gaging stations within 40 miles of the Permit Area; but they are on perennial streams and are not representative of drainages in the Permit Area. On April 6, 1976, the USGS measured the instantaneous discharge of Lost Soldier Creek, approximately 14.5 miles northeast of the Permit Area. The measurement of 0.2 cubic feet per second was taken during spring runoff so the source of water was predominantly snowmelt (USGS, 2006).

A method for estimating peak stream discharge in ungaged watersheds in response to storms with recurrence intervals from two to 100 years has been developed by Miller

(2003). Miller analyzed streamflow data for hundreds of gaged watersheds in Wyoming ranging from one to 1,200 square miles, and developed regional regression relationships based upon basin characteristics (drainage area, geographic factors, elevation, etc.). The most significant independent variables in Sweetwater County were drainage area and latitude. The equations used for each calculation as well as the associated percent errors are summarized in **Table 2.7-1**. **Table 2.7-2** shows the calculated peak discharge at the downstream boundary of the three principal watersheds, delineated as Points A2, B4, and C2 in **Figure 2.7-1**. Due to the incised nature and the width of the channels, flows from the 100-year flood would likely remain mostly within the channels.

One small (less than one-quarter acre) detention pond exists in the Permit Area, which acts as an off-channel storage area for stock watering. This is Crooked Well Reservoir which is shown in **Figure 2.7-3**. This pond is dry for the majority of the year and typically fills from spring snowmelt during the months of March and April. Wetland vegetation has not been observed around this impoundment. This detention pond is not included in the active surface water rights in the area.

2.7.1.2 Surface Water Quality

Under the WDEQ Water Quality Division (WQD) Classification, Battle Spring Draw is listed as a Class 3B water body. Beneficial uses for Class 3B waters can include recreation, wildlife, "other aquatic life," agriculture, industry, and scenic value, but do not include drinking water, game fish, non-game fish, and fish consumption.

Background historic surface water quality within the study area was characterized using water quality data from 1974 and 1975 that were collected as part of the environmental report for the Sweetwater Uranium permit application (Shephard Miller Inc., 1994). Samples were collected at Battle Spring, which is seven miles southwest of the Permit Area. The historic dataset is small, and more representative of groundwater quality than surface water quality so are not directly comparable to expected surface water conditions within the Permit Area. The water-quality data for the historic sampling at Battle Spring are summarized in **Table 2.7-3**. Historic sampling of Battle Spring in July 1974 showed that pH was highly alkaline at 9.5. Uranium concentrations ranged from 0.006 to 0.95 milligrams per liter (mg/L).

In April 2006, storm-water samplers were installed at 12 locations in the Permit Area (**Figures 2.7-4** and **2.7-5**). In April 2007, an additional sampler was added to represent an area in the southeastern corner that was added to the Permit Area in the summer of 2006. Three samplers were installed to capture runoff as it enters the Permit Area from the upstream side, and the others capture runoff within the Permit Area or at the downstream boundary. The water samples were collected to characterize the quality of ephemeral surface runoff. The sampling locations were selected based on their topographic potential to concentrate ephemeral surface flow.

Seven samplers collected full, one-liter samples from snowmelt runoff in March and April 2007. These samples were collected on April 17, 2007. The water quality data for these seven samples are summarized in **Table 2.7-4**.

Ionic strength was low in all samples, probably due to the majority of the sample being snowmelt water that did not come into contact with the underlying soil. For all samples, the dissolved and total concentrations of trace metals were near or below the detection limit. Radiometric parameters, including uranium, lead-210, polonium-210, and thorium-230, were generally below detection with the exception of dissolved uranium, which was detected at very low concentrations (0.0003 to 0.0004 mg/L) in two samples, suspended uranium (0.0003 to 0.0009 mg/L) in two samples, and total uranium (0.0003 to 0.0009 mg/L) in four samples. Total radium-226 was detected at a low concentration (0.5 picoCuries per liter [pCi/L]) in one sample. This was the LC2 location in the center of the Permit Area in one of the larger channels. Gross alpha was also detected in small amounts (1.1 to 3.6 pCi/L) in six samples. The highest concentration of 3.6 pCi/L was again from the LC2 location. The pH of the sites was slightly acidic to neutral ranging from 6.39 to 7.12. Conductivity was low with less than 100 microSiemens per centimeter for all samples.

In general, the quality of water was very good for all samples. The radiometric parameters detected in the LC2 correlate well with the radiological scans of the Permit Area. This central area has the highest radioactivity, as indicated by the results from the radiological surveys. Still, the levels are well below all Wyoming agricultural and drinking water standards.

2.7.2 Groundwater Occurrence

This section describes the regional and local groundwater hydrology including hydrostratigraphy, groundwater flow patterns, hydraulic gradient, and aquifer parameters. The discussion is based on information from investigations performed within the Great Divide Basin, data presented in previous applications/reports for the Permit Area, and the geologic information presented in **Section 2.6**. Regional and site baseline groundwater quality conditions are discussed in **Sections 2.7.3**, and the conceptual site hydrologic model is summarized in **Section 2.7.4** of this application.

2.7.2.1 Regional Hydrogeology

The Project is located within the northeastern portion of the Great Divide Basin. The basin is topographically closed with all surface water drainage being to the interior of the basin (**Figure 2.7-1**). Available data suggest that groundwater flow within the basin is predominately toward the interior of the basin (Collentine, 1981; Welder, 1966; and Mason, 2005). A generalized potentiometric surface map of the Battle Spring/Wasatch Formations, prepared by Welder and McGreevey (1966), indicates groundwater movement toward the center of the basin (**Figure 2.7-6**). Fisk (1967) suggests that aquifers within the Great Divide Basin may be in communication with aquifers in the Washakie Basin to the south and that groundwater may potentially move across the Wamsutter Arch between the basins.

The topographically elevated area known as the Green Mountains (Townships 26 and 27 North, between Ranges 90 to 94 West) was identified by Fisk as a major recharge area to aquifers within the northeastern portion of the Great Divide Basin (1967). The Rawlins Uplift, Rock Springs Uplift, and Creston Junction, located east, southwest, and southeast, respectively, from the Permit Area, were also identified as major recharge areas for aquifers within the Great Divide Basin (Fisk, 1967). The main discharge area for the Battle Spring/Wasatch aquifer system is to a series of lakes, springs and playa lakes beds near the center of the basin. Groundwater potentiometric elevations within the Tertiary aquifer system in the central portion of the basin are generally close to the land surface.

The Battle Spring Formation crops out over most of the northeastern portion of the Great Divide Basin, including much of the Permit Area. The Battle Spring Formation is considered part of the Tertiary aquifer system by Collentine et al. (1981). The Tertiary aquifer system is identified as "the most important and most extensively distributed and accessible groundwater source in the study area" (Collentine, 1981). This aquifer system includes the laterally equivalent Wasatch Formation (to the west and south) and the underlying Fort Union and Lance Formations. The base of the Tertiary aquifer system is marked by the occurrence of the Lewis Shale. The Lewis Shale is generally considered a regional aquitard, although this unit does produce limited amounts of water from sandstone lenses at various locations within the Great Divide Basin and to the south in the Washakie Basin.

Shallower aquifer systems that can be significant water supply aquifers within the Great Divide Basin include the Quaternary and Upper Tertiary aquifer systems. However, as previously stated, the Battle Spring Formation of the Tertiary aquifer system crops out over most of the northeast part of the basin; and the Quaternary and Upper Tertiary aquifer systems are absent or minimal in extent. The shallower aquifer systems are only important sources of groundwater in localized areas, typically along the margin of the basin where the Battle Spring Formation is absent. Aquifer systems beneath the Tertiary include the Mesaverde, Frontier, Cloverly, Sundance-Nugget and Paleozoic aquifer systems (Collentine, 1981). In the northeast Great Divide Basin, these aquifer systems are only important sources of water in the vicinity of outcrops near structural highs such as the Rawlins Uplift.

For purposes of this application, only hydrogeologic units younger than and including the Lewis Shale (Upper Cretaceous age) are described, with respect to general hydrologic properties and potential for groundwater supply. The Lewis Shale is an aquitard and is considered the base of the hydrogeologic sequence of interest within the Great Divide Basin. Units deeper than the Lewis Shale are generally too deep to economically develop for water supply or have elevated total dissolved solid (TDS) concentration that renders them unusable for human consumption. Exceptions to this can be found along the very eastern edge of the basin, tens of miles from the Permit Area, where some Lower Cretaceous and older units provide relatively good quality water from shallow depths. Hydrologic units of interest within the northeast Great Divide Basin are shown on the stratigraphic column in **Figure 2.7-7** and further described below, from deepest to shallowest:

- Lewis Shale (aquitard between Tertiary and Mesaverde aquifer systems);
- Fox Hills Formation
- Lance Formation (Tertiary aquifer system);
- Fort Union Formation (Tertiary aquifer system);
- Battle Spring Formation-Wasatch Formation (Tertiary aquifer system);
- Undifferentiated Tertiary Formations (Upper Tertiary aquifer system, including Bridger, Uinta, Bishop Conglomerate, Browns Park, and South Pass); and
- Undifferentiated Quaternary Deposits (Quaternary aquifer system).

Discussion of the regional characteristics for each of these hydrostratigraphic units is provided below.

Lewis Shale

The Lewis Shale underlies the Fox Hills Formation and is generally considered an aquitard in the Great Divide Basin. This unit is described by Welder and McGreevey (1966) as light to dark gray, carbonaceous shale with beds of siltstone and very fine-grained sandstone. The Lewis Shale is up to 2,700 feet thick, generally increasing in thickness toward the east side of the basin. In the Permit Area, the Lewis Shale is 1,200 feet thick. Small quantities of water may be available from the thin sandstone beds within this unit near the margins of the basin. The Lewis Shale acts as the confining unit between the Tertiary and Mesaverde aquifer systems.

Fox Hills Formation

Fox Hills Formation overlies the Lewis Shale and consists of very fine-grained sandstone, siltstone and coal beds. It is not considered to be an important aquifer in the Permit Area.

Lance Formation

Overlying the Fox Hills Formation is the Lance Formation, consisting, predominately, of very fine-to fine-grained lenticular, clayey, calcareous sandstone. Shale, coal, and lignite beds are present within the formation, which reaches a maximum thickness of approximately 4,500 feet (Welder, 1966). In the Permit Area, the Lance Formation is 2,950 feet thick.

Collentine and others (1981) include the Lance Formation (Aquifer) as the lower-most aquifer within the Tertiary aquifer system. However, the Lance Aquifer is included as part of the Mesaverde aquifer system by Freethey and Cordy (1991). Several stock wells, located along the eastern outcrop area of the basin, are completed in the Lance Aquifer. The stock wells have estimated yields of five to 30 gpm. Hydraulic conductivity for the Mesaverde aquifer system reported by Freethey and Cordy (1991) (which, by the authors' designation, includes the Fox Hills Sandstone, Lewis Shale, and Mesaverde Group, in addition to the Lance Aquifer) is reported to range from 0.0003 to 2.2 feet per day (ft/d). Because of the limited number of wells completed within the Lance Aquifer in the Great Divide Basin, there are insufficient data to develop representative potentiometric surface maps for this hydrologic unit. However the potentiometric surface is most likely similar in orientation to that seen in the overlying Fort Union and Battle Spring/Wasatch aquifers, with inferred groundwater movement generally toward the center of the basin. No regionally extensive aquitards between the Fort Union and Lance Formation were identified or reported in the hydrologic studies, investigations, and reports reviewed for this permit application.

Fort Union Formation

The Paleocene-age Fort Union Formation is between the Lance Formation and the overlying Wasatch and Battle Spring Formations, reaching a maximum thickness of approximately 6,000 feet within the Great Divide/Washakie Basin area. In the Permit Area, it is 4,650 feet thick. The Fort Union Formation is present at or near land surface in a band around the Rock Springs Uplift and in the northeastern corner of the Great Divide Basin (Mason, 2005). The Fort Union Formation is described as a fine- to coarse-grained sandstone with coal and carbonaceous shale. Siltstone and claystone are present in the upper part of the formation (Welder, 1966).

A potentiometric surface map prepared by Naftz (1996) that groups the Fort Union aquifer with the Battle Spring/Wasatch aquifers, shows inferred movement of groundwater toward the basin center (**Figure 2.7-8**).

The Fort Union aquifer is largely undeveloped and unknown as a source of groundwater supply except in areas where it occurs at shallow depths along the margins of the basin. Well yields from the Fort Union aquifer within the Great Divide and Washakie Basins range from three to 300 gpm. Estimates of transmissivity for the Fort Union aquifer are highly variable. Ahern (1981) estimated transmissivity of less than three square feet per day (ft^2/d) for ten Fort Union Formation oil fields in the Green River Basin. Collentine and others (1981) reported transmissivity of the Fort Union aquifer as characteristically less than 325 ft^2/d from oil well data.

Water quality for the Fort Union aquifer is described in **Section 2.7.3**.

Battle Spring Formation- Wasatch Formation

The most important water-bearing aquifers within the Great Divide Basin are in the Wasatch Formation and the Battle Spring Formation. The Wasatch and Green River Formations grade into the Battle Spring Formation in the northeastern portion of the basin. The Battle Spring Formation is absent along the eastern margin of the Great Divide Basin near the county line between Sweetwater and Carbon Counties. The termination of the Battle Spring Formation to the east is controlled, largely, by structural features, including the Rawlins Uplift to the east and the Green Mountains to the north. A dry oil test in Section 14, Township 24 North, Range 90 West, located within a few miles of the eastern limit of the Battle Spring Formation, had a reported thickness of over 6,000 feet of fine- to coarse-grained sandstone that was interpreted by the American Stratigraphic Company as the Battle Spring Formation. Within the Permit Area, the Battle Spring/Wasatch Formations are 6,200 feet thick.

The Battle Spring Formation is described as an arkosic, fine- to coarse-grained sandstone with claystone and minor conglomerates. There are typically several water-bearing sands within the Battle Spring Formation. The Battle Spring aquifers are included in the Tertiary aquifer system, as defined by Collentine (1981).

Groundwater within the Battle Spring aquifers is typically under confined conditions, although locally unconfined conditions exist. The potentiometric surface within the Battle Spring aquifers is usually within 200 feet of the ground surface (Welder, 1966). Most wells drilled for water supply in this unit are less than 1,000 feet deep. The potentiometric surface map of Wasatch and Battle Spring aquifers (**Figure 2.7-6**) indicates groundwater movement toward the center of the basin (Welder, 1966). From the Permit Area, the potentiometric surface dips to the southwest at approximately 50 feet per mile (ft/mi) (a hydraulic gradient of 0.01 foot per foot [ft/ft]). The hydraulic gradient becomes steeper near the margins of the basin, where recharge to the aquifer is occurring.

Collentine and others (1981) report that wells completed in the Battle Spring aquifers typically yield 30 to 40 gpm; but that yields as high as 150 gpm are possible. Collentine and others (1981) also reported that pump tests conducted on 26 wells completed within the Battle Spring aquifers resulted in transmissivity values ranging from 3.9 to 423 ft^2/d, although most wells were less than 67 ft^2/d. Specific capacity was less than one gallon per minute per foot for 23 of 26 wells tested.

Water quality for the Wasatch/Battle Spring aquifers is described in **Section 2.7.3**.

Undifferentiated Tertiary and Quaternary Sediments

Undifferentiated Tertiary and Quaternary units above the Battle Spring/Wasatch Formations can be sources of water supply; but wells in the northeastern part of the Great Divide Basin are rare and generally limited to the margins of the basin where the Battle Spring Formation is not present. Commonly, along the margins of the basin, hydrostratigraphic units younger than the Battle Spring/Wasatch have been deposited on rocks of Cretaceous age or older. Water supply wells along the margins of the basin are often completed in both the older hydrostratigraphic units and Tertiary and Quaternary sediments. Water quality within these units tends to be variable and of limited quantity.

The undifferentiated Tertiary units consist of interbedded claystone, sandstone and conglomerate with the coarser grained facies providing suitable groundwater resources where present. The undifferentiated Tertiary units are absent within the Permit Area and are not discussed further.

The undifferentiated Quaternary units consist of clay, silt, sand, gravel and conglomerates that are poorly consolidated to unconsolidated (Welder, 1966). These units represent windblown, alluvial and lake deposits. Where present, these deposits can provide acceptable yields of groundwater of relatively good quality. Thin deposits of Quaternary sediments are present within surface drainages in the Permit Area but are usually above the water table and unsaturated. Therefore, Quaternary sediments are not an important groundwater source in the vicinity of the Project and are not described further.

2.7.2.2 Site Hydrogeology

LC ISR, LLC has been collecting lithologic, water level, and pump test data as part of its ongoing evaluation of hydrologic conditions at the Project. In addition to recent data acquisition, historic data collected for Conoco (Hydro-Search, Inc., 1982) were used to support this evaluation. Drilling and installation of borings and monitor wells is ongoing to provide additional data to further refine the site hydrologic conceptual model. Water level measurements, both historic and recent, provide data to assess potentiometric surface, hydraulic gradients and inferred groundwater flow directions for the aquifers of interest at the Project. A recently completed long-term pump test (Petrotek Engineering Corporation, 2007) and several shorter-term pump tests (Hydro-Engineering, 2007), as well as the pump tests conducted for Conoco (Hydro-Search, Inc., 1982), were used to evaluate hydrologic properties of the aquifers of interest, to assess hydraulic characteristics of the confining units, and to evaluate impacts to the hydrologic system of the Fault through the Permit Area (**Section 2.6.2.2**).

Figure 2.7-9 shows the monitor wells, current and historic, that were used in the site hydrologic evaluation. **Table 2.7-5** provides data for those wells to the extent available.

Hydrostratigraphic Units

LC ISR, LLC has employed the following nomenclature for the hydrostratigraphic units of interest within the Project. The primary uranium production zone is identified as the HJ Horizon. The HJ Horizon is subdivided into the Upper (UHJ), Middle (MHJ) and Lower (LHJ) Sands. The HJ Horizon is bounded above and below by aerially extensive confining units identified as the Lost Creek Shale and the Sage Brush Shale, respectively. Overlying the Lost Creek Shale is the FG Horizon. The deepest sand in the FG Horizon, the Lower FG (LFG) Sand, is the overlying aquifer to the HJ Horizon. Beneath the Sage Brush Shale is the KM Horizon. The uppermost sand within the KM Horizon, designated the Upper KM (UKM) Sand, is a potential secondary production zone and also the underlying aquifer to the HJ Horizon. The No Name Shale separates the UKM and Middle KM (MKM) Sand. The MKM Sand is the underlying aquifer to the UKM Sand. The shallowest occurrence of groundwater within the Permit Area occurs within the DE Horizon, which is above the FG Horizon. **Figure 2.7-10** depicts the hydrostratigraphic relationship of these units.

A brief description of each hydrostratigraphic unit follows, going from shallowest to deepest.

DE Horizon

The DE Horizon is the shallowest occurrence of groundwater within the Permit Area, although the horizon is not saturated in all portions of the Permit Area. The DE Horizon consists of a sequence of sands and discontinuous clay/shale units. In the southern part of the Permit Area, sands of the DE Horizon coalesce with sands of the FG Horizon. The top of the unit ranges from 100 to 200 ft bgs.

FG Horizon

The top of the FG Horizon occurs at depths of approximately 200 to 250 ft bgs on the north side of the Fault and 300 to 350 ft bgs on the south side of the fault within the Permit Area (**Section 2.6.2.2**). The FG Horizon is subdivided into the Upper (UFG), Middle (MFG) and Lower (LFG) Sands. The total thickness of the FG Horizon is approximately 160 feet. The basal unit in the FG Horizon, the LFG Sand, ranges from 20 to 50 feet thick within the Permit Area. The LFG Sand is designated as the overlying aquifer for the HJ Horizon.

Lost Creek Shale

Underlying the FG Sands is the Lost Creek Shale. The Lost Creek Shale appears continuous across the Permit Area, ranging from five to 45 feet in thickness. Typically, this unit has a thickness of 10 to 25 feet (**Figure 2.7-10**). The Lost Creek Shale is the confining unit between the overlying aquifer (LFG Sand) and the HJ Horizon. The confining characteristics of the Lost Creek Shale have been demonstrated with a pump test, as described later in this application.

HJ Horizon

The HJ Horizon is the primary target for uranium production at the Lost Creek Project. For purposes of uranium ISR operations, the HJ Horizon has been subdivided into three Sands: the Upper HJ (UHJ), Middle HJ (MHJ) and the Lower (LHJ) Sand. These sands are generally composed of coarse-grained arkosic sands with thin lenticular intervals of fine sand, mudstone and siltstone. The bulk of the uranium mineralization is present in the MHJ Sand. The total thickness of the HJ Horizon ranges from 100 to 160 feet, averaging approximately 120 feet (**Figure 2.7-10**). The top of the HJ Horizon ranges from approximately 300 to 450 ft bgs within the Permit Area. The three sands are generally separated by thin clayey units that are not laterally extensive and, based on pump test results, do not act as confining units to prevent groundwater movement vertically between the HJ Sands. The underlying aquifer to the HJ Horizon is the UKM Sand, which is also a potential uranium production zone. Therefore, the deepest sand within the HJ Horizon, the LHJ Sand, is also designated as the overlying aquifer to the UKM Sand.

Sage Brush Shale

Beneath the HJ Horizon is the Sage Brush Shale, with the top of the shale ranging from 450 to 550 ft bgs. The Sage Brush Shale is laterally extensive and ranges from five to 75 feet in thickness (**Figure 2.7-10**). The Sage Brush Shale is the lower confining unit to the HJ Horizon. The confining characteristics of this unit have been demonstrated through pump tests, as described in later sections of this application.

UKM Sand

The UKM Sand is present beneath the Sage Brush Shale. The UKM Sand is the upper member of the KM Horizon and is generally a massive coarse sandstone with lenticular fine sandstone intervals. The UKM Sand is the underlying aquifer to the HJ Horizon but is also a potential production zone within the Permit Area. The UKM Sand is typically 30 to 60 feet thick but can reach to over 75 feet in thickness (**Figure 2.7-10**). The top of the UKM Sand is usually between 450 and 600 ft bgs within the Permit Area. The decision to proceed with a license amendment for production of the UKM Sand will depend on the results of additional delineation drilling and characterization of the lower confining unit and underlying aquifer that are described below.

No Name Shale

The No Name Shale at the base of the UKM Sand has not yet been fully characterized. The top of the unit is approximately 480 to 650 ft bgs. This unit is generally ten to 30 feet thick. This shale will be the lower confining unit to the UKM Sand. Additional drilling is being conducted and a pump test is planned for the fall of 2007 to assess the confining characteristics of this unit.

MKM Sand

The MKM Sand is the underlying aquifer to the UKM Sand. Information on the MKM Sand is limited at this time. Additional borings are being drilled to evaluate the geologic and hydrologic characteristics of this sand. A pump test is planned to assess the hydrologic relationship between the UKM and MKM Sands in the fall of 2007.

Potentiometric Surface, Groundwater Flow Direction and Hydraulic Gradient

The LC ISR, LLC hydrologic evaluation of the Project included measurement of water levels in monitor wells completed in the overlying aquifers (DE and LFG), the HJ Horizon, and the underlying aquifer (UKM) to assess the potentiometric surface, groundwater flow direction and hydraulic gradient of those units. Additional historic water level data were available from the Conoco hydrologic evaluation of the site (Hydro-Search Inc., 1982). **Table 2.7-6** lists static water level data recorded in 1982, 2006 and 2007.

The potentiometric surface determined in December 2008 for the DE Horizon is shown in **Figure 2.7-11a**. The groundwater flow direction is to the southwest. In 2006, the horizontal hydraulic gradient calculated from only two wells completed in the DE Sand on the south side of the Fault was 0.0064 ft/ft (33.0 ft/mi) (**Table 2.7-7**). Additional DE monitor wells were installed in the fall of 2008. Based on water levels collected in 2008, the horizontal hydraulic gradient across the permit area in the DE aquifer is approximately 0.007 ft/ft on both sides of the Lost Creek Fault.

Water levels collected from the overlying aquifer (LFG Sand) in 2008, 2006, and 1982 indicate a southwesterly groundwater flow direction (**Figure 2.7-11b** and **Figure 2.7-11c**). Data from 1982 and 2006 indicate horizontal hydraulic gradients for the LFG aquifer range from 0.0046 to 0.0058 ft/ft (24.3 to 30.6 ft/mi). Based on the 2008 data across the permit area, the horizontal hydraulic gradient ranged from 0.005 ft/ft north of the Lost Creek Fault to 0.007 ft/ft south of the Fault.

The potentiometric surface for the HJ Horizon is shown on **Figure 2.7-11d** and **Figure 2.7-11e**. The water level data were collected in December 2008 and just prior to beginning a long-term pump test in June 2007 respectively. From the figures, it is evident that the Fault provides a significant hydraulic barrier to groundwater flow. In 2007, the potentiometric surface on the north side of the Fault is 15 feet higher than on the south side, based on wells located approximately 100 feet apart on either side of the Fault (Wells HJT104 and HJMP107). During the long-term pump test, the hydraulic barrier effect of the Fault was confirmed, as described more fully in the following section on aquifer properties. Based on the potentiometric surface maps, groundwater is inferred to flow to the west-southwest, generally consistent with the regional flow system. The Fault may redirect groundwater more westward than if the Fault were not present. Data from 1982 and 2006 are shown on **Figure 2.7-11f**. There is an insufficient number of data points to accurately represent the potentiometric surface for those measurement periods. However, the data illustrate the difference in water levels within the HJ Horizon across the Fault.

The horizontal hydraulic gradient for the HJ Sand, determined from water level data from 1982, 2006 and 2007, ranged from 0.0034 to 0.0056 ft/ft (18.0 to 29.6 ft/mi). **Table 2.7-7** summarizes the hydraulic gradients determined from the water level data.

Figure 2.7-11g and **Figure 2.7-11h** show the potentiometric surface of the UKM Sand for data collected in 2008, 2006, and 1982. The difference in hydraulic heads across the Fault does not appear as pronounced for the UKM Sand as for the other shallower sands. Horizontal hydraulic gradients calculated for the UKM Sand from 1982 and 2006 water level data ranged from 0.0053 to 0.0063 ft/ft (28.0 to 33.3 ft/mi) (**Table 2.7-7**). Similar to the overlying horizons, the general flow direction is southwest.

The similarity in hydraulic gradients between the HJ aquifer and the DE, LFG and UKM aquifers suggests that, although there is a difference in potentiometric heads, the orientation of the potentiometric surface is probably similar.

Vertical hydraulic gradients were determined by measuring water levels in closely grouped wells completed in different hydrostratigraphic units. **Figure 2.7-12** shows the location of the well groups used for the assessment of vertical hydraulic gradients. **Table 2.7-8** summarizes the calculated vertical gradients between the DE, LFG, HJ and UKM aquifers. Vertical hydraulic gradients range from 0.05 to 0.34 ft/ft between the LFG, HJ and UKM aquifers and consistently indicate decreasing hydraulic head with depth. The vertical gradient between the DE and LFG aquifers is minimal in the two places measured. This is consistent with earlier observations that the DE and LFG Sands coalesce in places within the Permit Area. Of the six well groups evaluated, the only place where a downward potential is not evident is between the DE and LFG aquifers in the southwest portion of the Permit Area. The vertical gradients indicate the potential for groundwater flow is downward. A downward potential is indicative of an area of recharge, as opposed to an upward potential that is normally indicative of an area of groundwater discharge. A downward gradient is consistent with the structural and stratigraphic location of the Project with regard to Great Divide Basin.

Aquifer Properties

Aquifer properties for the Battle Spring aquifers within the Permit Area have been estimated from historic and recent pump tests. Hydro-Search Inc. performed a hydrologic evaluation in 1982 to determine the feasibility of in situ production of the Conoco uranium orebody at Lost Creek. Hydro-Search Inc conducted two 25-hour tests within the HJ Horizon. Both pump tests were conducted at a rate of 30 gpm and on the south side of the Fault. The locations of the pumping wells and monitor wells are shown in **Figure 2.7-13**. The results of the tests were variable, with one test indicating a transmissivity of approximately 95 ft^2/d (700 gallons per day per foot [gpd/ft]) and the other indicating a value of 270 ft^2/d (2,000 gpd/ft). The storativity calculated from the first test averaged 5×10^{-4}. There was no reported response in the HJ aquifer north of the Fault. Monitor wells in the overlying (LFG) and underlying (UKM) aquifers did not show any effects from the pump test as reported by Hydro-Search Inc. (1982). Results of the pump tests are summarized in **Table 2.7-9**.

2006 Pump Tests

Hydro-Engineering, Inc. (2007) conducted several short-term single well pump tests and three longer multi-well pump tests in October 2006. The single well tests ranged from 30 minutes to five hours in duration at rates from 0.67 to 14 gpm. The long-term tests were from 20 to 45 hours long at rates of 15 to 19 gpm. Each of the long-term tests were conducted in HJ well completions. The locations of the wells included in the pump test program are shown on **Figure 2.7-13**. Results of the pump test are summarized in **Table 2.7-9**.

The range of transmissivity calculated by Hydro-Engineering for the HJ aquifer was from 44 to 400 ft^2/d (330 to 3,000 gpd/ft). None of the HJ tests indicated significant communication with the overlying or underlying aquifers. There was also no indication of hydraulic communication across the fault in any of the pump tests. Hydro-Engineering concluded that the Fault acts as a hydraulic barrier (2007).

The Hydro-Engineering data suggest that the transmissivity of the LFG aquifer, calculated from four tested wells, was generally much lower than the values estimated for the HJ aquifer. The range of transmissivity for the LFG aquifer was 4.4 to 40 ft^2/d (33 to 303 gpd/ft). Transmissivity for the UKM aquifer, estimated from single well tests at four wells, was similar to but lower than the HJ aquifer, ranging from 26 to 115 ft^2/d (195 to 858 gpd/ft). Three DE well completions were tested, with resulting transmissivity of 1.3 to 130 ft^2/d (10 to 1,000 gpd/ft). Additional discussion regarding the results of the testing are included in **Attachment 2.7-1**.

2007 Pump Tests

In June to July 2007, a long-term pump test was conducted in the HJ aquifer at Well LC19M (Petrotek Engineering Corporation, 2007). LC19M had been previously tested by Hydro-Engineering (2007) and is located on the north side of the Fault. The objectives of the test were to further develop aquifer characteristics of the HJ Horizon, to evaluate the hydraulic impacts of the Fault, and to demonstrate confinement of the production zone (HJ Horizon) aquifer. HJ monitor wells, on both sides of the Fault and within distances likely to be impacted by the pump test, were included as observation wells. Observation wells in the overlying (LFG) and underlying (UKM) aquifers near the pumping well and across the Fault were also monitored during the test. **Table 2.7-10** lists the data for monitor wells included in the pump test. **Figure 2.7-14** includes the locations of the pumping well and all observation wells included in the test.

Pre-pumping monitoring was performed several days in advance of the test to establish baseline conditions and to evaluate barometric effects. A step-rate test was performed on June 23, 2007 to determine a suitable pumping rate for the long-term test. The long-term test was started at 17:20 hours on June 27, 2007 and was terminated on July 3, 2007 at 10:51 hours. The total duration of the test was 5.7 days (8,251 minutes). The average pumping rate during the test was 42.9 gpm. Maximum drawdown in the pumping well was 93.3 feet. Monitoring was continued after pump shut-in to record recovery.

The transmissivity calculated from five wells completed in the HJ aquifer on the north side of the Fault (including the pumping well) were similar, ranging from 30.0 to 75.5 ft^2/d and averaging 68.3 ft^2/d. The average hydraulic conductivity calculated for the five wells, assuming an aquifer thickness of 120 feet, was 0.57 ft/d. Storativity calculated from those wells ranged from 6.6×10^{-5} to 1.5×10^{-4} and averaged 1.1×10^{-4}. **Table 2.7-11a** summarizes the analyses of the pump test. Drawdown at the end of the test in the HJ aquifer is shown on **Figure 2.7-15**. **Figure 2.7-16a** shows the water levels in the HJ monitor wells at the end of the test.

A pair of observation wells was placed on either side of the Fault, within 100 feet of each other. Well HJT104, located on the north side of the Fault, had a maximum drawdown of 40.5 feet at the end of the test. Well HJMP107 (south of the Fault) in the HJ Horizon had a net decrease of 1.4 feet from the beginning of the test to the end of pumping. At least a portion of that change is attributable to a declining trend in water levels that was observed in all monitor wells prior to the start of the test. The reason for the background trend observed has not been identified; however, it might be a result of offset pumping (e.g., LC ISR, LLC's first two water supply wells that are screened over multiple sands).

At the beginning of the test, the water level at HJT104 was at 6,770.68 feet above mean sea level (ft amsl) and the water level at HJMP107 was at 6,754.85 ft amsl, a head difference of almost 15 feet with the higher head north of the Fault. At the end of the pump test, the water levels for HJT104 and HJMP107 were 6,730.14 ft amsl and 6753.47 ft amsl, respectively. The drawdown observed in HJT104 (immediately north of the Fault) was greater than 40 feet, and the water level difference between HJT104 and HJMP107 (across the Fault from each other) was 23 feet with the higher head south of the Fault. Minor responses to pumping were observed across the Fault (e.g., approximately 0.3 to 0.7 feet of drawdown related to pumping in HJMP107 and other wells south of the Fault). Based on the results, the Fault, while not entirely sealing, significantly impedes groundwater flow, even under considerable hydraulic stress.

The response of the overlying and underlying aquifers during the pump tests was small (e.g., on the order of 0.2 to 0.5 feet); but the water level responses did correspond to the start and stop of pumping from LCM19 in the HJ Horizon. The underlying/overlying responses appear to be relatively consistent, regardless of distance from the pumping well, the hydrostratigraphic interval monitored, or the location relative to the Fault. These water level changes suggest potential impacts from off-site pumping or background trends that, because of distance from the monitor wells, are manifested at multiple locations at the same or similar times. As previously stated, a declining trend in water level elevations was observed prior to the start of the test. Most of the wells showed an initial inverted response (increase in water level) at the start of the test and then resumed a gradual downward trend during the test. This phenomenon was also observed and noted by Hydro-Engineering during the 2006 pump tests. It is possible that some of the response could be caused by: 1) pumping in the drilling water well (LC-1) which is completed in both the DE and FG Horizons; 2) communication across multiple sands due to the en echelon nature of the Fault distant from the pumping well location; or 3) both. Additional discussion regarding the results of the testing are included in **Attachment 2.7-2**.

A second long term pump test was conducted to evaluate aquifer properties on the south side of the Lost Creek Fault using LC16M as the pumping well. A step-rate test was performed on pumping well LC16M October 7, 2007 to determine a suitable pumping rate for the long-term test. The long-term test for LC16M was started at 14:10 hours on October 22, 2007 and was terminated on October 28, 2007 at 01:00 hours when the generator used in the test failed. However, the HJ aquifer had been sufficiently stressed at that point and the pumping portion of the test was terminated. The total duration of the test was 5.5 days (7,850 minutes). The average pumping rate during the test was 37.4 gpm. Maximum drawdown in the pumping well was 69.3 feet. Monitoring was continued after pump shut-in to record recovery from the LC16M test.

The transmissivity calculated from six wells completed in the HJ aquifer on the south side of the Lost Creek Fault (including the pumping well LC16M) were similar, ranging from 56.7 to 110.0 ft^2/d and averaging 77.7 ft^2/d. The average hydraulic conductivity calculated for the six wells, assuming an aquifer thickness of 120 feet, was 0.65 ft/d. Storativity calculated from four of the monitoring wells ranged from 3.5×10^{-5} to 1.4×10^{-4} and averaged 7.3×10^{-5}. Well HJT105 had a calculated storativity of 9.1×10^{-5} which appears anomalously high and was not included in the average. Storativity was not, nor could be, calculated from the pumping well. **Table 2.7-11b** summarizes the analyses of the LC16M pump test. Drawdown near the end of the test in the HJ aquifer is shown on **Figure 2.7-16b**.

The drawdown resulting from pumping LC16M shows a cone of depression developed around the pumping well that is elongated roughly parallel to the Lost Creek Fault (**Figure 2.7-16b**). There is also drawdown within the HJ aquifer north of the Fault, although it is relatively minor. The same wells located about 100 feet apart and across the Fault from one another, Wells HJMP107 and HJT104, that were evaluated during the LC19M test were evaluated during the LQ16M test. Well HJMP107, located on the same side of the Fault as the pumping well, had nearly 25 feet of drawdown near the end of the test. Well HJT104, located approximately 100 feet north of Well HJMP107 and north of the Fault, had approximately 2.2 feet of drawdown at the end of pumping. The data from the LC16M pump test appear consistent with the LC19M pump test, showing that the Lost Creek Fault, while not impermeable, is a significant barrier to groundwater flow.

As in the LC19M pump test, the response of the overlying and underlying aquifers during the LC16M pump test was small (e.g., less than one foot in the LFG and less than two feet in the UKM); but the water level responses were coincident with the start and stop of pumping from LC16M (**Figure 2.7-16b**). The response was slightly more pronounced in the UKM and occurred on both sides of the Lost Creek Fault. There were no observation points in the LFG aquifer across the Fault in the LC16M test. Similar to the LC19M pump test, results from the LC16M test indicate limited hydraulic communication between the HJ aquifer and the overlying LFG and underlying UKM aquifers. Additional discussion regarding the results of the testing are included in **Attachment 2.7-3**.

It is noted that detailed mine unit pump tests will be conducted during development of each future mine unit. As such, additional investigations will be performed to assess the background trends observed, characteristics of the Fault and potential communication between the sands monitored for the 2007 test. Based on testing results to date, it is anticipated that any minor communication between the HJ Horizon and the overlying and underlying sands can be managed through operational practices, detailed monitoring, and engineering operations. In this regard, the potential communication observed at Lost Creek is much lower (e.g., five to ten times less) than has been observed in other ISR operations where engineering practices were successfully implemented to isolate lixiviant from overlying and underlying aquifers. **Figure 2.7-17** summarizes the results of the Hydro-Search, Inc. (1982), Hydro-Engineering (2007), and Petrotek Engineering Corporation (2007) pump test results.

The 2007 pump test data support the following conclusions:

- the pump test results provide sufficient aquifer characterization of the HJ Horizon;
- the HJ Horizon has sufficient transmissivity such that mining operations can be conducted consistent with the Operations Plan (see **Section 3.0**);
- the HJ Horizon is sufficiently isolated from the overlying and underlying sands by the Lost Creek and Sage Brush Shales;
- hydraulic continuity of the HJ Horizon has been demonstrated over a large scale (e.g., more than 1,000 feet) such that mine planning (e.g., mine unit and monitor well layout) can proceed;
- hydraulic properties of the Fault have been defined over the test area to an extent such that mine planning can be achieved; and
- testing data to date indicate that the Fault significantly restricts flow in the HJ Horizon.

2.7.3 Groundwater Quality

This section describes the regional and local groundwater quality based on information from investigations performed within the Great Divide Basin, data presented in previous applications/reports for the Permit Area, and recent data collected in the Permit Area.

2.7.3.1 Regional Groundwater Quality

Water quality within the Great Divide Basin ranges from very poor to excellent. Groundwater in the near surface, more permeable aquifers is generally of better quality than groundwater in deeper and less permeable aquifers. Groundwater with TDS less than 3,000 mg/L can generally be found at depths less than 1,500 feet within the Tertiary aquifer system, which includes the Battle Spring/Wasatch, Fort Union and Lance aquifers (Collentine, 1981).

Water quality for the Great Divide Basin is available from a large number of sources including the USGS National Water Information System (NWIS) database, the University of Wyoming Water Resources Data System (WRDS) and the USGS Produced Waters Database. Much of these data are tabulated in "Water Resources of Sweetwater County, Wyoming", a USGS Scientific Investigation Report by Mason and Miller (2005). However, the quality and accuracy of much of the data are difficult to assess. This section of the permit application describes general water quality of the Great Divide Basin, primarily by reference to these sources.

Mason and Miller (2005) noted that water quality in Sweetwater County is highly variable within even a single hydrogeologic unit; and that water quality tends to be better near outcrop areas, where recharge occurs. They also noted that groundwater quality samples from the Quaternary and Tertiary aquifers are most likely biased toward better water quality and do not necessarily represent a random sampling, for the following reasons. Wells and springs that do not produce useable water usually are abandoned or not developed. Deeper portions of the aquifers typically are not exploited as a groundwater resource because a shallower water supply may be available. As a result, these water sources do not become part of the sampled network of wells and springs that ultimately make up the available groundwater database. Groundwater quality samples from deeper Mesozoic and Paleozoic hydrostratigraphic units are often available where oil and gas production or exploration has occurred. Therefore, groundwater samples from older geologic units may have less bias in representing ambient groundwater quality than samples collected from Quaternary and Tertiary aquifers.

Water quality within the shallow Tertiary aquifers generally represents sodium-bicarbonate to sodium-sulfate water types. TDS levels within the Wasatch aquifer in the west and south parts of the Great Divide Basin tend to be high relative to the US EPA's Secondary Drinking Water Standard (SDWS) of 500 mg/L, even within the shallow aquifers. TDS levels within the Battle Spring/ Wasatch aquifers are generally below 500 mg/L along the northern flank of the Great Divide Basin (which includes the Permit Area). Elevated TDS levels (greater than 3,000 mg/L) are present within the Wasatch aquifer along the eastern edge of the Washakie Basin and within the Fort Union and Lance aquifers along the east side of the Rock Springs uplift. Elsewhere within the Great Divide and Washakie Basins, TDS levels in the Tertiary aquifer system are typically between 1,000 and 3,000 mg/L (Collentine, 1981).

Low-TDS waters within the Battle Spring aquifer are predominately sodium-bicarbonate type waters. With increasing salinity, the water type tends to become more calcium-sulfate dominated. However, this trend is not exhibited in the Wasatch, Fort Union and Lance aquifers within the Great Divide and Washakie Basins. The Wasatch and Lance aquifers are characterized by predominately sodium-sulfate type waters, particularly near outcrop areas. The Fort Union is more variable in composition.

Water quality data for Tertiary aquifers away from the outcrop areas are sparse, but available data indicate that TDS levels increase rapidly away from the basin margins. A Lance pump test in Section 14, Township 23 North, Range 99 West has TDS levels in excess of 35,000 mg/L. A Fort Union test in Section 25, Township 13 North, Range 95 West had TDS levels in excess of 60,000 mg/L, based on resistivity logs (Collentine, 1981). Water quality samples from produced water in the Wasatch and Fort Union Formations from an average depth of 3,500 feet had TDS values ranging from 1,050 to 153,000 mg/L with a median value of 13,900 mg/L (Mason, 2005). TDS from four wells completed in the Fort Union Formation located along the margins of the basin ranged from 800 to 3,400 mg/L (Welder and McGreevy, 1966).

A graph of TDS versus sampling depth for produced water samples from the Wasatch Formation in Sweetwater County prepared by Mason and Miller (2005) shows that, at depths greater than 3,000 feet, TDS values are typically above 10,000 mg/L. It is noted that the Mason and Miller data set is small for a large area and may be biased by data from the southern part of the Great Divide Basin; few site-specific data directly applicable to the Project are available.

Water quality within the Battle Spring aquifer is generally good in the northeast portion of the basin with TDS levels usually less than 1,000 mg/L and frequently less than 200 mg/L. Water type within the Battle Spring aquifer is typically sodium bicarbonate to sodium sulfate. Mason and Miller (2005) reviewed eighteen groundwater samples, collected from the Battle Spring aquifer, and observed that those samples represented some of the best overall quality of those studied in Sweetwater County. Sulfate levels can be elevated in Tertiary aquifers, but are generally low in the shallow aquifers of the

Battle Spring Formation. Out of eighteen samples included in the Mason study, only one sample exceeded the WDEQ Class I Drinking Water Standard for sulfate of 250 mg/L. Most of the samples were also below the WDEQ TDS Class I Drinking Water Standard of 500 mg/L. Nitrate, fluoride and arsenic levels were below WDEQ and EPA standards for all of the samples.

Notable exceptions to the relatively good water quality included waters with elevated radionuclides. Uranium and radium-226 (Ra-226) concentrations exceeded their respective EPA Maximum Contaminant Levels (MCLs) of 0.03 mg/l and 5 pCi/l in some of the samples; radon-222 (Rn-222) concentrations were also relatively high in some samples (Mason, 2005); and the presence of high levels of uranium in Tertiary sediments and groundwater of the Great Divide Basin has been well documented. The Lost Creek Shroeckingerite deposit, located northwest of the Permit Area, is noted for high uranium levels in groundwater. Uranium-bearing coals are also present in Great Divide Basin. Sediments of the Battle Spring Formation were derived from the Granite Mountains and contain from 0.0005 to 0.001 percent uranium (Masursky, 1962). Based on historical exploration results, certain areas of the Battle Spring Formation (e.g., Lost Creek) contain much higher uranium concentrations.

Water quality for aquifer systems deeper than the Tertiary (such as the Mesaverde aquifer system) are not described in this report; because they are several thousands of feet deep in the vicinity of the Project and are separated from the Tertiary aquifer system by the Lewis Shale, a regional aquitard. The deeper aquifer systems of the Great Divide Basin will not impact nor be impacted by ISR activities at the Project.

2.7.3.2 Site Groundwater Quality

Information regarding site water quality is primarily derived from reconnaissance studies conducted by Conoco (Hydro-Search, Inc., 1982) and ongoing exploration and delineation of the Project by LC ISR, LLC.

Groundwater Monitoring Network and Parameters

Conoco installed 12 wells, separated into four groups, to evaluate aquifer properties and water quality of the uranium ore-bearing sands and overlying and underlying aquifers within the Permit Area. Three of the groups included wells completed within the HJ aquifer and the overlying (LFG) and underlying (UKM) aquifers. The fourth group included three wells completed within the HJ aquifer. The location of the wells is shown on **Figure 2.7-18.** The Conoco wells were sampled for the parameters listed in **Table 2.7-12**.

LC ISR, LLC installed wells in 2006 completed in the DE, LFG, HJ and UKM aquifers and initiated baseline sampling for the same constituents as Conoco, with the addition of alkalinity (as calcium carbonate [$CaCO_3$]), gross alpha, gross beta and radium-228. Additional wells were installed in 2007, and four quarters of sampling have been completed for these wells. Another ten wells were installed in late 2008 and are being incorporated into the groundwater monitoring network, as outlined below. The locations of the LC ISR, LLC monitor wells that have been sampled for water quality are indicated on **Figure 2.7-19**.

Groundwater Quality Sampling Results

Ten of the 12 monitor wells installed by Conoco were sampled in August 1982. Hydro-Search, Inc. reported that there were no major differences in water quality between the HJ aquifer and the overlying and underlying aquifers (1982). The predominant ions were calcium and sulfate. TDS values were all below the WDEQ Class I Standard of 500, ranging from 200 to 490 mg/L (**Figure 2.7-20a**). The pH of the waters ranged from 7.1 to 8.5, indicating slightly alkaline conditions. Chloride levels were very low, ranging from seven to 18 mg/L.

One of the sampled wells had an obstruction in the well and elevated pH (11.1) and potassium (54 mg/L) values. It was determined that the sampling results are not representative of the site aquifers and that the well is possibly contaminated with cement.

Most trace constituents were below the detection limits. Selenium was present in two samples at 0.023 mg/L, which was above the WDEQ standard at that time (0.01 mg/l). The WDEQ Class I Standard and the EPA MCL are currently 0.05 mg/L. Ra-226 was detected in all of the samples, with a range of 2.5 to 300 pCi/L. Only two samples, one collected from the overlying aquifer and one from the underlying aquifer, were below the WDEQ Class I Standard and EPA MCL for Ra-226 (5.0 pCi/L). **Figure 2.7-20b** depicts the distribution of Ra-226 from the 1982 sampling round. Elevated Ra-226 groundwater concentrations are common within and around uranium ore-bodies. Uranium levels ranged from below detection (less than 0.005 mg/L) to 0.48 mg/L. Six of the ten samples exceeded the current EPA MCL for uranium (0.03 mg/L) (**Figure 2.7-20c**).

LC ISR, LLC began baseline sampling in September 2006. Quarterly water level measurements and water quality samples were collected from 17 monitor wells:

- DE Monitor Wells: LC29M, LC30M and LC31M;
- LFG Monitor Wells: LC15M, LC18M, LC21M, and LC25M;
- HJ Monitor Wells: LC16M, LC19M, LC22M, and LC26M; and
- UKM Monitor Wells: LC17M, LC20M, LC23M, LC24M, LC27M, and LC28M.

At the time of the pump tests (and when the original LC ISR NRC TR was submitted), wells LC27M and LC28M were believed to have been completed in the HJ Horizon. However, since the aquifer test analyses report was completed in March 2007, a revised interpretation of the stratigraphy surrounding wells LC27M and LC28M has been conducted based on more recent drill data. The new interpretation of the stratigraphic sequence for wells LC27M and LC28M concludes that the wells are completed in the UKM Sand as opposed to the HJ Horizon.

In October 2008, ten additional wells were installed. Quarterly samples from these monitoring wells began in August 2009, but two wells completed in the DE Sand (MB-7 and MB-10) have insufficient water for sampling. The eight functioning monitor wells are:

- DE Monitor Wells: MB-1;
- LFG Monitor Wells: MB-2, MB-5, and MB-8;
- HJ Monitor Wells: MB-3B, MB-6, and MB-9; and
- UKM Monitor Wells: MB-4

Sampling dates and baseline water quality results for each of the 25 (operational) monitor wells are displayed in **Table 2.7-13**.

Table 2.7-13 shows that the WDEQ TDS Class I standard is exceeded at one well in the DE, HJ and UKM aquifers. Twenty two out of the 25 wells have TDS levels below the Class I Standard. The distribution of TDS is shown in **Figure 2.7-21a**. Sulfate exceeds the WDEQ Class I Standard (250 mg/L) in one DE monitor well (LC31M) and one HJ monitor well (LC26M). The average distribution of sulfate from September 2006 to May 2007 is shown in **Figure 2.7-21b**. As with the Conoco monitoring results, chloride values are low with a maximum of 32 mg/L and all but four samples at ten mg/L or lower (**Table 2.7-13**).

Piper diagrams have been developed to compare groundwater quality between individual wells (**Figure 2.7-22a**) and between different aquifers (**Figure 2.7-22b**). The individual well comparison plots the average value for each of the wells for all of the samples analyzed. The piper diagram comparing different aquifers represents the average water quality for all wells sampled within individual aquifers (DE, LFG, HJ and UKM). Groundwater within the shallow Battle Spring aquifers beneath the Permit Area is a calcium sulfate to calcium bicarbonate type water. There is some variability in water chemistry when the wells are compared individually. However, when the average for the aquifers is plotted, there is no significant difference in major water chemistry between the production zone and overlying and underlying aquifers. As additional water quality from the new MB wells is obtained, it will be compared with other regional water quality data.

The trace constituents, boron, cadmium, chromium, copper, mercury, molybdenum, nickel, and vanadium were at or below detection limits for all samples. Zinc was at or below the reporting limit for all but two samples, both of which were well under the WDEQ and EPA criteria. Ammonia exceeded the WDEQ Class I Standard in two monitor wells. Selenium exceeded the WDEQ Class I Standard and EPA MCL (0.05 mg/L) in one DE monitor well. Dissolved Iron exceeded the WDEQ Class I Standard and EPA Secondary Standard (0.3 mg/L) in two DE monitor wells (LC29M and MB-1), two LFG monitor wells (LC18M and LC21M), and one UKM monitor well (LC24M). Manganese was above the WDEQ Class I Standard and EPA Secondary Standard (0.05 mg/L) in three of the four DE monitor wells, but was either below detection limit or did not exceed those standards in all other sampled aquifers.

With the exception of UKM monitor wells LC17M, LC23M, LC27M, and LC28M; HJ monitor well MB-6; and LFG monitor well MB-5, every monitor well had at least one sample exceed the EPA Uranium MCL of 0.03 mg/L. The average uranium concentration of the monitor wells sampled in the baseline monitoring program (0.227 mg/L) is approximately an order of magnitude greater than the MCL. The average distribution of uranium at individual wells from September 2006 to May 2007 is shown on **Figure 2.7-23a**.

The average distribution of radium-226+228 is shown on **Figure 2.7-23b**. The WDEQ Class I Standard and EPA MCL for radium-226+228 is 5.0 pCi/L. **Table 2.7-14** summarizes the number of wells in each aquifer that exceed the EPA MCL.

In summary, general water quality in the shallow Battle Spring aquifers within the Permit Area tends to be relatively good, with the exception of the presence of radionuclides. TDS and sulfate values are relatively low, with occasional exceedances of WDEQ Class I standards. Manganese is elevated above state and federal secondary standards in the water table aquifer (DE) but is below standards in deeper confined aquifers in the vicinity of the uranium orebodies. Radium-226+228 exceeds the EPA MCL in over two-thirds of the samples collected and the average uranium concentration is approximately an order of magnitude greater than the EPA MCL for that constituent. Elevated concentration of these constituents is consistent with the presence of uranium orebodies.

2.7.4 Hydrologic Conceptual Model

A hydrologic conceptual model of the Project and surrounding area has been developed to provide a framework that allows LC ISR, LLC to make decisions regarding optimal methods for extracting uranium from mineralized zones, and to minimize environmental and safety concerns caused by ISR operations.

LC ISR, LLC will use ISR technology at the Project to extract uranium from permeable uranium-bearing sandstones within the upper portion of the Battle Spring Formation, at depths ranging from 350 to 900 feet. A conceptual hydrologic model of the Project is summarized below.

2.7.4.1 Regional Groundwater Conceptual Model

The Project is located within the northeastern portion of the Great Divide Basin. The Eocene Battle Spring Formation crops out over most of the northeastern portion of the Great Divide Basin, including the Permit Area. The total thickness of the Battle Spring Formation in the vicinity of the Permit Area is approximately 6,200 feet. The Battle Spring Formation contains multiple aquifers that are a part of the Tertiary aquifer system. Groundwater flow within the Battle Spring aquifers is primarily toward the interior of the basin, southwest of the Project. Recharge to the Battle Spring aquifers within the Project area is mostly the result of infiltration of precipitation to the north and northeast in the Green Mountains and Ferris Mountains. Based on available information, discharge from the Battle Spring aquifers is predominately to a series of lakes, springs, and playa lake beds near the center of the basin. Some groundwater from the Battle Spring aquifers is discharged through pumping for stock watering, irrigation, industrial, and domestic use.

The Battle Spring Formation is described as an arkosic fine- to coarse-grained sandstone with claystone and conglomerates. Groundwater within the Battle Spring aquifers is typically under confined conditions, although locally unconfined conditions exist. The potentiometric surface within the Battle Spring aquifers is usually within 200 feet of the ground surface. Most wells drilled for water supply in this unit are less than 1,000 feet deep. Wells completed in the Battle Spring aquifers typically yield 30 to 40 gpm but yields as high as 150 gpm are possible.

Water quality within the shallow Tertiary aquifers generally represents sodium-bicarbonate to sodium-sulfate water types. TDS levels within the Battle Spring aquifers are generally below 500 mg/L along the northern flank of the Great Divide Basin near areas of outcrop. Low TDS waters within the Battle Spring aquifer are predominately sodium-bicarbonate type waters. With increasing salinity, the water type tends to become more calcium-sulfate dominated. Notable exceptions to the relatively good water quality included waters with elevated radionuclides (uranium, radium-226 and radon-228). High levels of uranium are common in Tertiary sediments and groundwater of the Great Divide Basin. The Lost Creek Shroeckingerite deposit located northwest of the Project is noted for high uranium levels in groundwater. Uranium-bearing coals are present in the Wasatch Formation in the central part of the Great Divide Basin.

As described previously, the Battle Spring Formation outcrops over most of the Permit Area. The Battle Spring is the shallowest occurrence of groundwater within the Permit Area. Water-bearing Quaternary and Tertiary units younger than the Battle Spring Formation are present several miles to the north and east and are hydraulically up-gradient of the Permit Area. Therefore, ISR operations conducted at the Project will have no impact on those shallower hydrostratigraphic units.

2.7.4.2 Site Groundwater Conceptual Model

Hydrostratigraphic Units

The hydrostratigraphic units of interest within the Battle Spring Formation, with respect to the Project include, from shallowest to deepest:

- DE Horizon (shallowest occurrence of groundwater):
  - sands and discontinuous clay/shale units, top of unit 100 to 200 ft bgs;
  - coalesces with underlying FG Horizon to the south; and
  - water levels in the DE Sand are typically 140 to 200 ft bgs;
- Upper No Name Shale (upper confining unit to the FG Horizon):
  - 0 to 50 feet thick;
- FG Horizon (includes overlying aquifer to HJ Horizon):
  - subdivided into UFG, MFG and LFG Sands;
  - total thickness of Horizon is 100 feet;
  - top of unit is 200 to 350 ft bgs;
  - LFG Sand the overlying aquifer to HJ Horizon;
  - LFG Sand is 20 to 50 feet thick; and
  - water levels in the LFG Sand are typically 160 to 200 ft bgs;
- Lost Creek Shale (upper confining unit to the HJ Horizon):
  - laterally continuous across Permit Area;
  - five to 45 feet thick; and
  - confining properties demonstrated from water levels and pump test;
- HJ Horizon (contains the primary production zone):
  - subdivided into UHJ, MHJ, and LHJ Sands, although sands are hydraulically connected;
  - coarse-grained arkosic sands with thin lenticular intervals of fine sand, mudstone and siltstone;
  - averages 120 feet thick;
  - top of unit is 300 to 450 feet bgs; and
  - water levels in the HJ Horizon range from 150 to 200 ft bgs;
- Sage Brush Shale (lower confining unit to the HJ Horizon and upper confining unit to the KM Horizon):

  - laterally continuous across Permit Area;
  - five to 75 feet thick;
  - top of unit 450 to 550 ft bgs; and
  - confining properties demonstrated from water levels and pump test;
- KM Horizon (includes secondary production zone, lower confining units, and underlying aquifers):
  - subdivided into UKM, MKM and LKM Sands;
  - massive coarse sandstones with thin lenticular fine sandstone intervals;
  - top of unit is 450 to 600 ft bgs;
  - UKM Sand is a secondary production zone and first underlying aquifer;
  - UKM Sand is 30 to 60 feet thick;
  - water levels in the UKM Sand are generally 185 to 220 ft bgs;
  - No Name Shale is the lower confining unit to the UKM Sand;
  - No Name Shale is ten to 30 feet thick and laterally extensive but will require additional characterization; and
  - MKM is the underlying aquifer to the UKM Sand, but will require additional characterization.

Potentiometric Surface and Hydraulic Gradients

Potentiometric surface of the HJ Horizon indicates that groundwater flow is to the west-southwest under a hydraulic gradient of 0.003 to 0.006 ft/ft (15.8 to 31.6 ft/mi), generally consistent with the regional flow system. The Fault acts as a hydraulic barrier to groundwater flow as demonstrated from water level differences of 15 feet across the Fault within the HJ Horizon and the pump test results. The Fault may redirect groundwater more westward than if it were not present. Groundwater flow direction and hydraulic gradients for the overlying (DE and FG) and underlying aquifers (UKM) are generally similar to that of the HJ Horizon. The potentiometric heads decrease with depth. Differences in water level elevations between the LFG, HJ and UKM aquifers indicate that confining units are present between these hydrostratigraphic units. Pump tests indicate the presence of confining units between the LFG and HJ aquifers and between the HJ and UKM aquifers.

Vertical hydraulic gradients range from 0.050 to 0.34 ft/ft between the LFG, HJ and UKM aquifers and consistently indicate decreasing hydraulic head with depth. The vertical gradients indicate the potential for groundwater flow is downward. The vertical gradients also support the confining nature of the Lost Creek and Sage Brush Shale. The vertical gradient between the DE and LFG aquifers is minimal, consistent with observations that those hydrostratigraphic units coalesce in places within the Permit Area.

Aquifer Properties

Transmissivity for the HJ Horizon ranges from 35 to 400 ft^2/d (260 to 3,000 gpd/ft). Based on long-term pump tests, the estimated "effective" transmissivity (because of the impacts of the Fault) is 60 to 70 ft^2/d (450 to 525 gpd/ft) on the north side of the Fault. Because of the boundary effect of the Fault (e.g., the system is not an infinite-acting aquifer), the actual transmissivity of the aquifer, without impacts from the Fault, would be higher. Storativity of the HJ Horizon ranges from 5.0×10^{-5} to $5.0 \times 10^{-4.}$

Based on more limited testing, the transmissivity of the LFG aquifer is lower than for the HJ Horizon ranging from 4.4 to 40 ft^2/d (30 to 300 gpd/ft). The range of transmissivity of the UKM aquifer is similar to but slightly lower than the HJ aquifer, from 26 to 115 ft^2/d (195 to 860 gpd/ft). Transmissivity of the DE Horizon is variable, ranging from 1.3 to 130 ft^2/d (10 to 1,000 gpd/ft). Storativity values have not been determined for the overlying and underlying aquifers at this time because no multi-well pump tests have been conducted within those aquifers. However, it is expected that storativity values in the FG and KM Horizons will be similar to the range observed in the HJ Horizon. The DE Horizon is at least partially under unconfined conditions and therefore will have a specific yield instead of a storage coefficient. Long-term multi-well pump tests will be performed in the fall of 2007 to collect additional data regarding aquifer properties of the overlying and underlying aquifers.

Water Quality

Water quality within the hydrostratigraphic units of interest (the production zones and overlying and underlying aquifers) is generally good with respect to major chemistry. TDS and sulfate levels are typically below respective WDEQ Class I Standards and EPA SDWS, although occasionally, regulatory standards are exceeded. Chloride levels are low, (typically less than ten mg/L) making this parameter a good indicator for excursion monitoring. There is no significant difference in major water chemistry between the production zone and overlying and underlying aquifers.

Trace metals generally are below WDEQ Class I Standards and EPA MCLs in the production zone, overlying and underlying aquifers. Ammonia, arsenic, iron, and selenium occasionally exceed the respective standards. Manganese is present above the regulatory standards in over half of the samples collected from the DE Horizon. Manganese was below the WDEQ Class I Standards and EPA MCL in all samples from other hydrostratigraphic units.

Uranium is present in nearly all of the wells at levels exceeding the EPA MCL of 0.03 mg/L. For example, the average uranium concentration for all of the hydrostratigraphic units of interest is 0.31 mg/L, an order of magnitude greater than the EPA MCL.

Radium-226+228 levels exceed the EPA MCL and WDEQ Class I Standard (five pCi/L) in two-thirds of the samples collected. The percentage of wells that exceed radium-226+228 standards is greater for the HJ and UKM aquifers than for the FG and DE Horizons. Dissolved radionuclide levels are commonly elevated in groundwater associated with uranium-bearing sandstones.

Summary

The uranium bearing sandstones within the upper Battle Spring Formation appear to be suitable targets for ISR operations. The primary production zone aquifer (HJ Sand) is bounded by laterally extensive upper and lower confining units, as demonstrated by static water level differences and responses to pump tests. Aquifer properties (transmissivity, hydraulic conductivity and storativity) are within the ranges observed at other ISR operations that have successfully extracted uranium reserves. Water quality is generally consistent throughout the hydrostratigraphic units of interest. Elevated radionuclides are present in the groundwater, but this is consistent with the presence of uranium ore deposits within the sandstones. The Fault acts as a hydraulic barrier to flow and will need to be accounted for in mine unit design and operation.