TABLE OF CONTENTS

FIGURES

## TABLES



## PLATES



## ATTACHMENTS

# D6 HYDROLOGY

This appendix addresses surface water drainage characteristics and use (**Sections D6.1.1 and D6.1.2**), surface water quality (**Section D6.1.3**), regional and site hydrogeology (**Sections D6.2.1** and **D6.2.2**), groundwater use (**Section D6.3**), regional and site groundwater quality (**Sections D6.4.1** and **D6.4.2**), and the regional and site hydrologic conceptual models (**Sections D6.5.1** and **D6.5.2**). Potential hydrologic impacts, mitigation, and monitoring are presented in the **Operations Plan** and **Reclamation Plan**.

## D6.1 Surface Water

### D6.1.1 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 most runoff quickly infiltrates, recharging shallow groundwater, evaporates, or is consumed by plants through evapotranspiration. Based on the loam and sandy-loam soils found at the site, the steady-state saturated infiltration rate under laboratory conditions is estimated at 0.2 to 0.8 in/hr (Hillel, 1980). However, the practical infiltration rate is likely much higher because saturated conditions are rare, and more macropores are present under field conditions and at large scales. Infiltration-excess (Hortonian) overland flow has not been observed at the site, except on the compacted soils found in existing 2-track roads.

Alluvial deposits, if any, along drainages are not extensive, and the shallow aquifer, Battle Spring, is typically under confined conditions, although locally unconfined conditions exist. The variation from unconfined to confined conditions is due to the interfingering of sands and shales throughout the Battle Spring Formation (see, e.g., Section 5.2.1 (Stratigraphy)). The shallow water table is typically 150 to 200 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.

**Figure D6-2** shows a longitudinal profile of the main channel in each of the primary watersheds within the Permit Area, and the endpoints are shown in **Figure D6-1**. Within the Permit Area, the average slope of the main channel in the Western Draw, West Battle Spring Draw, and East Battle Spring Draw watersheds is 1.4, 1.2, and 1.1 percent, respectively. The sinuosity (channel length divided by valley length) of the main channels in each watershed is 1.24, 1.10, and 1.03, respectively. The drainage density in each watershed is 3.0, 4.2, and 5.0 $mi/mi^2$, respectively.

The existing drainages are incised, and have u-shaped 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 D6-1a**. **Table D6-1b** shows the calculated peak discharge at the downstream boundary of the three principal watersheds, delineated as Points A2, B4, and C2 in **Figure D6-1**. 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 D6-3a**. 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.

### D6.1.2 Surface Water Use

Surface-water permits with legal descriptions inside and within three miles of the Permit Area were queried using the Wyoming State Engineers Office (WSEO) Water Rights Database (WSEO, 2006). **Table D6-2** lists the thirteen surface water permits that exist within the three-mile study area, and **Figure D6-3b** displays the locations of these surface water permits. None of these locations are within one-half mile of the Permit Area. All of the surface water permits, with one exception, are related to mining operations.

As noted in **Section D6.3**, there are four BLM wells within one mile of the Permit Area. These wells have stock ponds associated with them, although with the exception of one pond that is currently in use, it is not clear how recently the ponds have been used. The water-use permits for these ponds are associated with the wells that supply the ponds, i.e., they are not associated with any surface-water-use permits. Also, as noted in the previous section, the Crooked Well Reservoir (**Figure D6-3a**) is located in the Permit Area. However, it is a small off-channel detention pond, less than one-quarter acre in size, and there is no water-use permit associated with it.

### D6.1.3 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 (Shepard 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 D6-3**. 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).

Nalgene Storm Water Samplers (**Figure D6-4**) were installed to collect 0.26 gallon (1 L) grab samples of first flush streamflow during runoff events. These samplers were installed at 12 locations in the Permit Area (**Figure D6-5a**) in April 2006. 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 retrieved on April 17, 2007, and **Figure D6-5b** shows snowmelt discharge in one of the stream channels in the Permit Area on that date. Due to the lag between the first runoff flush and sample retrieval, the wetted perimeter of the channels during first flush is not known. In the absence of wetted perimeter or cross-sectional area, discharge cannot be estimated using typical empirically-based approximations such as Manning’s or Limerino’s equations. When present, surface water discharge at the Lost Creek Permit Area has always been estimated by qualified personnel as less than 0.5 cfs, so it is believed that the discharge was less than 1 cfs when the samples were collected.

The water quality data for the seven surface water samples are summarized in **Table D6-4**. **Attachment D6-1** presents the raw water quality data from the laboratory. Ionic strength was low in all samples, which is 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 radioactive activity, as indicated by the results from the radiological surveys. Still, the levels are well below all Wyoming agricultural and drinking water standards.

## D6.2 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 **Appendix D5** of this report. Regional and site hydrogeology are discussed in **Sections D6.2.1** and **D6.2.2**; groundwater use in **Section D6.3**; regional and site groundwater quality in **Sections D6.4.1** and **D6.4.2**; and the regional and site hydrologic conceptual models in **Sections D6.5.1** and **D6.5.2**.

### D6.2.1 Regional Hydrogeology

The Project is located within the northeastern portion of the Great Divide Basin. The basin is topographically closed with all surface water draining to the interior of the basin (**Figure D6-1**). 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 D6-6**). 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 et al., 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 et al., 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, the top of which is about 14,000 ft bgs in the Permit Area, 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 D6-7** and further described below, from deepest to shallowest:

- Lewis Shale (aquitard between Tertiary and Mesaverde aquifer systems);
- Fox Hills Formation (Cretaceous);
- 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.

### D6.2.1.1 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.

### D6.2.1.2 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.

### D6.2.1.3 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 approximately 3,000 feet thick.

Collentine et al. (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 gallons per minute (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.

### *D6.2.1.4 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 approximately 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 Natftz (1996) that groups the Fort Union aquifer with the Battle Spring/Wasatch aquifers, shows inferred movement of groundwater toward the basin center (**Figure D6-8**).

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 et al. (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 D6.4**.

### *D6.2.1.5 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 and north is abrupt, 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 Formation is over 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 et al. (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 D6-6**) 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 et al. (1981) report that wells completed in the Battle Spring aquifers typically yield 30 to 40 gpm; but yields as high as 150 gpm are possible. Collentine et al. (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 D6.4**.

#### *D6.2.1.6 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 available resources of good quality water are limited.

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.

## D6.2.2 Site Hydrogeology

LC ISR, LLC has been collecting lithologic, water level, water quality, 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. Two recently completed long-term pump tests (**Attachments D6-2a** and **D6-2b**) 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 Lost Creek Fault (Fault) through the Permit Area (**Section D5.2.2).** Results of Permit Area water quality sampling and analysis are presented in **Section D6.4.2**.

Plate D5-3 shows the locations of all the existing monitor wells in the Permit Area. **Table D6-5** provides completion data for the monitor wells currently in use, and **Attachment D6-3** includes well completion logs for those wells. **Figure D6-9** shows the locations of the historic Conoco (or Texasgulf) monitor wells (the M-25-92 series), and it shows the locations of the exising monitor wells that were used for baseline data collection and in the LC16M and LC19M pump tests.

### *D6.2.2.1 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 secondary production zone and also the underlying aquifer to the HJ Horizon. The No Name Shale unit 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 D6-10** depicts the hydrostratigraphic relationship of these units.

A brief description of each hydrostratigraphic unit follows, 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 250 to 300 ft bgs on the north side of the Lost Creek Fault and 275 to 350 ft bgs on the south side of the Lost Creek Fault within the Permit Area (**Section D5.2.2**). The FG Horizon is subdivided into the Upper (UFG), Middle (MFG) and Lower (LFG) Sands. The total thickness of the FG Horizon is approximately 100 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 ten to 25 feet (**Figure D6-10**). 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 D6-10**). 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, at depths ranging from 450 to 550 ft bgs. The Sage Brush Shale is laterally extensive and ranges from five to 75 feet in thickness (**Figure D6-10**). The Sage Brush Shale is the lower confining unit to the HJ Production Zone. The confining characteristics of this unit have been demonstrated through pumping 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 over 75 feet in thickness (**Figure D6-10**). The top of the UKM Sand is usually between 450 and 600 ft bgs within the Permit Area. The decision to proceed with a permit revision 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 would be the lower confining unit to the UKM Sand, if LC ISR, LLC decides to request a permit revision to include the UKM Sand in the Lost Creek Project. Additional drilling is being conducted. The pump test in the fall of 2007 provided additional information on the confining characteristics of this unit, and if LC ISR, LLC proceeds with a revision for production of the UKM Sand, this data will be included in the revision.

**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. The pump test in the fall of 2007 provided additional information on the hydrologic relationship between the UKM and MKM Sands in the fall of 2007.

### *D6.2.2.2 Potentiometric Surface, Groundwater Flow Direction and Hydraulic Gradient*

Potentiometric surfaces for the DE, LFG, HJ, and UKM Horizons are illustrated as contour maps in **Figures D6-11a to D6-11h** and also on cross sections in **Plates D5-1a to D5-1g**. Depiction of these surfaces on the cross sections were generated by tracking the intersection of the plane of the cross section profile with the potentiometric contours for the given horizons.

The LC ISR, LLC hydrologic evaluation of the Project included measurement of water levels in monitor wells completed in the HJ aquifer, the overlying aquifers (DE and LFG) 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 D6-6** lists static water level data recorded in 1982, 2006, 2007, and 2008.

The potentiometric surface for the HJ Horizon in the vicinity of the Lost Creek Fault is shown on **Figure D6-11a**. The water level data were collected in November 2007 well after the completion of all drilling and pump test activity. Water levels from this period represent a comprehensive data set under static conditions around the Lost Creek Fault. From the figure, it is evident that the Lost Creek Fault provides a significant hydraulic barrier to groundwater flow. The potentiometric surface on the north side of the Lost Creek Fault is five to 15 feet higher than on the south side. Wells located approximately 100 feet apart on either side of the Lost Creek Fault (Wells HJT104 and HJMP107) show a difference of 13.6 feet with the higher elevation on the north side of the Fault. The difference in hydraulic head across the Lost Creek Fault becomes less to the northeast.

The steep gradient observed in the potentiometric surface from the north to the south side of the Lost Creek Fault is most likely a manifestation of a lower permeability transition area associated with a fault smear zone and/or secondary faulting and fracturing near the Fault. This is consistent with regional groundwater flow impacted by lower permeability zones studied and modeled by Freeze (1969). Although limited groundwater leakage occurs across the Lost Creek Fault (as demonstrated during the long term pump tests that are described later in this report), the majority of groundwater flow on both sides of the Fault appears to be generally parallel to the Fault, to the west-southwest. Based on the potentiometric surface map, groundwater is inferred to flow to the west-southwest, generally consistent with the regional flow system.

Potentiometric surface data for the overlying (LFG) aquifer for November 2007 is shown on **Figure D6-11b**. The data indicate a similar groundwater flow direction as in the HJ aquifer (toward the west-southwest). The barrier effect of the Lost Creek Fault is also evident within this shallower hydrostratigraphic unit with an observed difference of six to eight feet of hydraulic head across the Fault.

Potentiometric surface data for the underlying (UKM) aquifer for November 2007 is shown on **Figure D6-11c**. The data for this deeper horizon also indicate a generally west-southwest direction of groundwater flow. However, the impacts of the Lost Creek Fault are not as evident in this hydrostratigraphic unit, with little if any difference in hydraulic head across the fault.

HJ Horizon water level data from 1982 and 2006 are shown on **Figure D6-11d**. There are 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 Lost Creek Fault.

Potentiometric surface maps were also developed using data distributed across the entire permit area. Additional monitoring wells were installed in the fall of 2008, enabling better definition of the potentiometric surfaces out to the limits of the permit area. Data collected in December 2008 were used to construct potentiometric surface maps for the DE, LFG, HJ and UKM aquifers (**Figures D6-11e** through **D6-11**h, respectively). The maps show that the hydraulic gradient and groundwater flow direction across the permit area are similar to that seen in the vicinity of the Lost Creek Fault.

The horizontal hydraulic gradient for the HJ aquifer in the vicinity of the Lost Creek Fault, 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). Horizontal hydraulic gradients were also estimated from the December 2008 permit area potentiometic map (**Figure D6-11g**). **Table D6-7a** summarizes the hydraulic gradients determined from the water level data. The horizontal hydraulic gradient across the permit area is similar on both side of the Lost Creek Fault at around 0.005 ft/ft on the north side and 0.006 ft/ft on the south side.

The horizontal hydraulic gradient for the DE sand was initially calculated from only two wells on the south side of the Lost Creek Fault at 0.0064 ft/ft (33.0 ft/mi) (**Table D6-7**). 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 (**Figure D6-11e**).

Horizontal hydraulic gradients for the LFG aquifer in the area of the Lost Creek Fault range from 0.0046 to 0.0058 ft/ft (24.3 to 30.6 ft/mi) (**Table D6-7a**). 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 (**Figure D6-11f**). Horizontal hydraulic gradients calculated for the UKM aquifer near the Lost Creek Fault ranged from 0.0038 to 0.0063 ft/ft (20.1 to 33.3 ft/mi) (**Table D6-7a**). The horizontal hydraulic gradient across the permit area in the UKM sand ranged from 0.005 ft/ft on the north side of the Lost Creek Fault to 0.006 ft/ft on the south side of the Fault (**Figure D6-11h**). The average hydraulic gradient within the HJ, LFG and UKM aquifers is approximately 0.005 ft/ft (26.4 ft/mi).

Vertical hydraulic gradients were determined by measuring water levels in closely grouped wells completed in different hydrostratigraphic units. **Figure D6-12** shows the location of the well groups used for the assessment of vertical hydraulic gradients. **Table D6-7b** summarizes the calculated vertical gradients between the DE, LFG, HJ and UKM aquifers. Vertical hydraulic gradients range from -0.04 to 0.37 ft/ft between the DE, LFG, HJ and UKM aquifers and consistently indicate decreasing hydraulic head with depth. Of the nine well groups evaluated, the only places where a downward potential is not evident between the DE and LFG aquifers is in the west, southwest, and west central portions of the Permit Area. This is consistent with earlier observations that the DE and LFG sands coalesce in places within 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.

### *D6.2.2.3 Aquifer Properties*

Aquifer properties for the Battle Spring aquifers within the Permit Area have been estimated from historic and recent pump tests. Transmissivity, storativity, and hydraulic conductivity were evaluated from short term and long term pump tests. Description of the results and analyses of the pump tests are provided below.

**1982 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 Lost Creek Fault. The locations of the pumping wells and monitor wells are shown in **Figure D6-13**. 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 $5 \times 10^{-4}$. There was no reported response in the HJ aquifer north of the Lost Creek 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 D6-8**.

**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 was conducted in HJ well completions. The locations of the wells included in the pump test program are shown on **Figure D6-13**. Results of the pump test are summarized in **Table D6-8**.

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 Lost Creek Fault in any of the pump tests. Hydro-Engineering concluded that the Lost Creek 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).

**2007 Pump Tests**

Between June to November 2007, two long-term pump tests were conducted by Petrotek Engineering Corp. in the HJ aquifer at Wells LC19M and LC16M (**Attachments D6-2a** and **D6-2b**). Both wells had been previously tested by Hydro-Engineering (2007). LC19M is located on the north side of the Lost Creek Fault and LC16M is located south of the Fault. The objectives of the tests were to further develop aquifer characteristics of the HJ Horizon, to evaluate the hydraulic impacts of the Lost Creek Fault, and to demonstrate confinement of the production zone (HJ Horizon) aquifer. HJ monitor wells on both sides of the Lost Creek Fault and within distances likely to be impacted by the pump tests were included as observation wells. Observation wells in the overlying (LFG) and underlying (UKM) aquifers near the pumping wells and across the Lost Creek Fault were also monitored during the tests. **Tables D6-9a** and **D6-9b** list the data for monitor wells included in the LC19M and LC16M pump tests, respectively. **Figures D6-14a** and **D6-14b** include the locations of the pumping wells and all observation wells included in the LC19M and LC16M tests, respectively. Pre-pumping monitoring was performed several days in advance of the tests to establish baseline conditions and to evaluate barometric effects.

The first pump test was conducted using Well LC19M to evaluate aquifer properties on the north side of the Lost Creek Fault. A step-rate test was performed on pumping Well LC19M June 23, 2007 to determine a suitable pumping rate for the long-term test. The long-term test for LC19M 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 from the LC19M test.

The transmissivity calculated from five wells completed in the HJ aquifer on the north side of the Lost Creek Fault (including the pumping well LC19M) 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 (with the exception of the pumping well) ranged from $6.6 \times 10^{-5}$ to $1.5 \times 10^{-4}$ and averaged $1.1 \times 10^{-4}$. **Table D6-10a** summarizes the analyses of the LC19M pump test. Drawdown at the end of the test in the HJ aquifer is shown on **Figure D6-15**.

Minor responses were observed across the Lost Creek Fault during the LC19M pump test (e.g., approximately 0.3 to 0.7 feet of drawdown in Well HJMP107 and other wells south of the Fault). Responses in observation wells across the Lost Creek Fault were negligible relative to the magnitude of drawdown observed in monitor wells located on the same side of the Fault as the pumping well. The impact of the Lost Creek Fault on groundwater flow can be clearly seen from the responses recorded in a pair of observation wells that were placed on either side of the Fault, within 100 feet of each other. Well HJT104, located on the north side of the Fault and completed in the HJ Horizon, had a maximum drawdown of 40.5 feet at the end of the LC19M 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 LC19M. 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 LC19M 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 Lost Creek 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. At the termination of pumping at LC19M, the water level difference between HJT104 and HJMP107 was 23 feet with the higher head south of the Fault. Minor responses to pumping were observed across the Fault during the LC19M test. Based on the pump test 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 LC19M pump test 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 LC19M 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 Lost Creek 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 drawdown response could be caused by: (1) pumping in the drilling water well (LC1) which is completed in both the DE and FG Horizons; (2) communication across multiple sands due to the scissors nature of the Lost Creek Fault distant from the pumping well location; (3) communication due to juxtapositioning of hydrostratigraphic units across the Fault; or (4) leakage through the confining shale, or any combination of these. While LC ISR, LLC has aggressively pursued re-plugging of historic wells, it is also possible that some of the communication could be related to abandoned wells. Please see **Section D5.2.4.1** for further details on locating and abandoning historic holes. Additional discussion regarding the results of the testing are included in **Attachment D6-2a**.

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 $3.5 \times 10^{-5}$ to $1.4 \times 10^{-4}$ and averaged $7.3 \times 10^{-5}$. Well HJT105 had a calculated storativity of $9.1 \times 10^{-5}$ which appears anomalously high and was not included in the average. Storativity was not, nor could be, calculated from the pumping well. **Table D6-10b** summarizes the analyses of the LC16M pump test. Drawdown near the end of the test in the HJ aquifer is shown on **Figure D6-16**.

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 D6-16**). 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 D6-16**). 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 D6-2b**.

As previously described, hydraulic communication between the HJ aquifer and overlying and underlying aquifers may be through historic boreholes that were improperly abandoned and have not yet been located, leakage through the confining shale units, or contact of sands juxtaposed across the Lost Creek Fault. Additional investigation will be completed prior to production of any mine units to isolate the cause of hydraulic communication between the production zone aquifer and the overlying and underlying aquifers.

It should be noted that although some minor hydraulic communication exists between the hydrostratigraphic units of interest, the hydraulic response only becomes apparent when large stresses (head differences) are applied to the aquifers. Under normal ISR production operations and those proposed for this project, flows are generally balanced so that a net bleed of approximately one percent is maintained within a mine unit/well pattern. Those typical operating conditions will not stress the aquifers to the extent of the recently completed pump tests. Therefore, it is anticipated that any hydraulic response in the overlying and underlying aquifers will be even less than the already negligible responses observed during the LC19M and LC16M pump test.

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 Lost Creek 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 D6-17** summarizes the results of the Hydro-Search, Inc. (1982), Hydro-Engineering (2007), and Petrotek Engineering Corporation pump test results (**Attachments D6-2a** and **D6-2b**). **Table D6-11** summarizes the aquifer characteristics calculated from the pump test data and related field observations.

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 Operations Plan contained with this application);
- 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;
- the hydraulic properties of the Lost Creek Fault have been defined over the test area to an extent such that mine planning can be achieved; and
- test data indicate that the Lost Creek Fault significantly restricts flow in the HJ Horizon.

# D6.3 Groundwater Use

Groundwater permits with legal descriptions inside and within three miles of the Permit Area were queried using the WSEO Water Rights Database (WSEO, 2006). **Tables D6-12a** and **D6-12b** list the permits, including potentially active permits as well as abandoned and cancelled permits, which were issued by WSEO to parties other than LC ISR, LLC or its affiliates. The permit information includes, but is not limited to, location, uses, priority dates, status, yield, total depth, and static water depth. **Table D6-12a** lists permits within one-half mile of the Permit Area; this table correlates with **Plate D6-1a**. **Table D6-12b** lists permits within three miles of the Permit Area; these locations are shown on **Plate D6-1b**.

The majority of the groundwater-use permits filed in the vicinity of the Permit Area is for monitoring or miscellaneous mining-related purposes. Many of those permits are associated with the Kennecott Sweetwater Mine (formerly owned by Minerals Exploration Co.), which is in reclamation. This mine was an open-pit operation, and a number of the permits were for the dewatering and monitoring wells associated with the open pit. These wells were at shallower depths than those proposed for ISR at Lost Creek. Construction of the mine began in 1979, and dewatering in advance of mining was completed in 1983. A number of the permits are for monitoring and remediation of the tailings impoundment at the Sweetwater Mill, adjacent to the mine; and the more recent permits are for monitoring associated with surface facilities at the mine.

**Table D6-12c** is a list of the permits issued by the WSEO to LC ISR, LLC or its affiliates (Ur-E and NFU Wyoming, LLC). At this time, there are three water supply wells and 75 monitor wells permitted and bonded by WDEQ to LC ISR, LLC and its affiliates. Installation of these wells is on-going, and locations of wells currently used for water quality sampling, pump tests, and water supply are shown on figures which are discussed in other sections of **Appendix D6**. Currently, the Project consumes a negligible amount of groundwater for well development, monitoring, testing, and miscellaneous purposes related to uranium exploration. Projected water use once ISR begins and the impacts of that use are discussed in the Operations Plan included with this application.

The groundwater permits within one mile unrelated to mining are those of the BLM. In 1968 and 1980, the BLM Rawlins District was granted three permits by the WSEO (13834, 55112, and 55113). Each of these permits is associated with a well that supplies a stock pond (or tank). These wells and associated stock ponds are located outside of the Permit Area (**Figure D6-18**). In addition, there is a fourth BLM well, supplying a stock pond, for which no water-use permit was found. The permit numbers and names of these four BLM wells are:

SEO Permit 13834 - Battle Spring Draw Well No. 4451;
SEO Permit 55112 - Boundary Well No. 4775;
SEO Permit 55113 - Battle Spring Well No. 4777; and
No SEO Permit - East Eagle Nest Draw Well.

Battle Spring Draw Well No. 4451 pumps water into a stock tank east of the Permit Area (Township 25 North, Range 92 West, Section 21, NW¼, NE¼, NE¼). In 1968, a uranium exploration hole was drilled at this location; when water was encountered, plastic casing was installed and the well was developed. The well depth is 900 feet, with a static water level of 104 feet. A yield of 19 gallons per minute is permitted. The screened interval is unknown, but given the well depth, it may be significantly deeper than the sands targeted by LC ISR, LLC under this permit. In November 2007, this well did not appear to have been used in some time (**Figure D6-19**); however, in April 2009, the well had apparently been recently put back into use, as discussed in **Section D11.3** (**Figure D11-4**). Although Well No. 4451 is outside of the Permit Area, two ground water samples, one pond water sample, one algae sample, and one soil sample were collected and analyzed (**Table D6-13**). The results indicate that the water, algae, and soil all have high levels of radionuclides. In addition, the algae sample had a high selenium concentration.

Boundary Well No. 4775 and Battle Spring Well No. 4777 were drilled as stock wells in 1981 to a depth of approximately 280 feet and 220 feet, respectively. These wells are shallower than the sands targeted by LC ISR, LLC under this permit. A water use of 25 gpm is permitted at each of these wells. According to aerial photographs, Boundary Well No. 4775 is located northeast of the Permit Area, in Township 25 North, Range 92 West, Section 10, SE¼, NE¼, SW¼. Battle Spring Well No. 4777 is situated southeast of the Permit Area, in Township 25 North, Range 92 West, Section 30, SE¼, NW¼. Boundary Well No. 4775 has apparently not been used in some time (**Figure D6-20**), and the windmill on the Battle Spring Well No. 4777 was not in working order in June 2007 (**Figure D6-21**).

In June and July of 2007, LC ISR, LLC contacted BLM to identify the status of these groundwater-use permits. These groundwater-use permits are still considered active (BLM, 2007a). In addition to these wells, BLM identified another active stock well, the East Eagle Nest Draw Well.

The East Eagle Nest Draw Well is located north of the Permit Area, in the NW¼, NW¼, NW¼ of Section 13, Township 25 North and Range 93 West. From mid-May through mid-September, an electric submersible pump in the well is used to pump water into a livestock watering pond at an average rate of five gallons per minute for six to eight hours each day (**Figure D6-22**). The total depth of this well is 370 feet, with a static water level of 269 feet.

Throughout the phases of the Project, LC ISR, LLC will correspond with BLM to ensure that the stock reservoirs and wells are not impacted in a manner that restricts the intended use, and LC ISR, LLC will work with BLM to replace the water source if any wells are rendered unusable due to LC ISR's mining activities.

# D6.4 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.

## D6.4.1 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 et al., 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 U.S. 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 et al., 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.

Water samples collected from a Lance pump test in Section 14, Township 23 North, Range 99 West had reported 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 et al., 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 and Miller, 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 a 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 18 samples included in the Mason and Miller (2005) 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 and Miller, 2005). 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.

## D6.4.2 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.

### *D6.4.2.1 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 Horizon aquifer and the overlying (LFG) and underlying (UKM) aquifers. The fourth group included three wells completed within the HJ Horizon aquifer. The location of the wells is shown on **Figure D6-23**. The Conoco wells were sampled for the parameters listed in **Table D6-14**. These 12 wells were installed as part of a joint venture between Conoco and Texasgulf Inc. The wells, permit numbers P61528W thru P61539W, are shown in **Table D6-12a** as being drilled by Texasgulf Inc. Each of the twelve wells was abandoned as documented in a September 16, 1987 letter from Texasgulf Inc. to the State Engineer's office (**Attachment D5-3**).

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. Four quarters of sampling have been completed for several of the wells that were installed in 2006. Additional wells have been installed in 2007 and are being incorporated into the groundwater monitoring network. The locations of the LC ISR, LLC monitor wells that have been sampled for water quality are indicated on **Figure D6-24**.

In addition to the wells discussed above, per WDEQ-LQD's request, LC ISR, LLC installed ten additional monitor wells to further characterize the regional geochemistry of the potentially effected aquifers. The locations of these wells, designated with an MB prefix, are also shown on **Figure D6-24**.

### *D6.4.2.2 Groundwater Quality Sampling Results*

**Historic 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 Horizon 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 D6-25a**). 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 from that well were not representative of the site aquifers and that the well was 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 and EPA drinking water standards at that time (0.01 mg/l). The WDEQ Class I Standard and the EPA MCL are currently 0.05 mg/L. Radium-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 radium-226 (5.0 pCi/L). **Figure D6-25b** depicts the distribution of Ra-226 from the 1982 sampling round. Elevated Ra-226 groundwater concentrations are common within and around uranium orebodies. 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 D6-25c**).

**Baseline Sampling**

LC ISR, LLC began baseline sampling in September 2006. The baseline sampling round included the following seventeen locations:

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

The second sampling round was conducted in November 2006. The third sampling round was conducted in February and March 2007. The fourth sampling round was conducted in May 2007. All 17 of the wells listed above were included in each sampling event (**Figure D6-26a**). In addition to the baseline sampling program, LC ISR, LLC has also sampled two of the water supply wells, LC1 and LC2. Ten additional baseline monitoring wells were drilled and installed in the fall of 2008 to provide more extensive coverage of the entire Permit Area. The additional wells included the following:

- DE Monitor Wells: MB-1, MB-7, MB-10;
- LFG Monitor Wells: MB-2, MB-5, MB-8;
- HJ Monitor Wells: MB-3B, MB-6, MB-9; and
- UKM Monitor Well: MB-4.

These wells have been sampled for four quarters for the same constituents as the initial baseline wells (listed in **Table D6-14)**. Wells MB-7 and MB-10 had insufficient water to sample throughout the monitoring period.

Results of the LC ISR, LLC baseline monitoring program are summarized in **Table D6-15a**. The raw laboratory data are presented in **Attachment D6-4**. In **Table D6-15a**, those analytical results which exceed specific WDEQ WQD or EPA criteria are highlighted, and the WQD and EPA criteria used for the comparison are included in **Table D6-15b**. The table shows that the WDEQ TDS Class I standard is exceeded at one well in each of the DE, HJ and UKM aquifers, Wells LC31M, LC26M, and LC23M, respectively. Twenty-two out of the 25 wells have TDS levels below the Class I Standard. The distribution of TDS (averaged from the four sampling events) is shown in **Figure D6-26a**. Sulfate exceeds the WDEQ Class I Standard (250 mg/L) in one DE monitor well (LC31M) and one HJ monitor well (LC26M). The distribution of sulfate, averaged from September 2006 to May 2007, is shown in **Figure D6-26b**. As with the Conoco monitoring results, chloride values are low with all but five samples at ten mg/L or lower (**Table D6-15a**).

Piper diagrams have been developed to compare groundwater quality between individual wells (**Figure D6-27a**) and between different aquifers (**Figure D6-27b**). 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 Springs 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.

The trace constituents, boron, cadmium, chromium, copper, mercury, molybdenum, nickel, and vanadium were at or below detection limits for all samples. Zinc was also at or below detection limits for all but two samples. Ammonia exceeded the WDEQ Class I Standard (0.5 mg/L) in one DE monitor well (LC29M) and one UKM monitor well (LC23M). Selenium exceeded the WDEQ Class I Standard and EPA MCL (0.05 mg/L) in one DE monitor well (LC31M). Iron exceeded the WDEQ Class I Standard and EPA MCL (0.3 mg/L) in two DE monitor wells (LC29M and MB-1), three LFG monitor wells (LC18M, LC21M and MB-8), one HJ monitor well (MB-9), and one UKM monitor well (LC24M). Manganese was above the WDEQ Class I Standard and EPA MCL (0.05 mg/L) in seven of the 12 samples collected from DE monitor wells but did not exceed those standards in any other sampled aquifer.

With the exception of four UKM monitor wells (LC17M, LC23M, LC27M, and LC28M), one LFG monitor well (MB-5), and one HJ monitor well (MB-6), every well exceeded the EPA uranium MCL of 0.03 mg/L in at least one quarter. The average uranium concentration of all samples collected in the baseline monitoring program (0.226 mg/L) is almost an order of magnitude greater than the MCL. The average distribution of uranium at individual wells from September 2006 to July 2010 is shown on **Figure D6-28a**.

The average distribution of radium-226+228 is shown on **Figure D6-28b**. The WDEQ Class I Standard and EPA MCL for radium-226+228 is 5.0 pCi/L. **Table D6-16** summarizes the number of wells in each aquifer that exceed the EPA MCL.

A summary of the water quality for each of the four hydrostratigraphic units of interest (DE, LFG, HJ and UKM) is presented below. All metal concentrations are reported as dissolved.

*DE Sand Water Quality*

Six wells completed in the DE Sand were included in the baseline sampling program (LC29M, LC30M, LC31M, MB-1, MB-7, and MB-10). Both MB-7 and MB-10 had insufficient water to sample and therefore were not included in the analyses. Sample results from the existing baseline monitor wells are included in **Table D6-15a**.

Results of the baseline sampling indicate that three of the DE monitor wells (LC29M, LC30M, and MB-1) are calcium bicarbonate water, whereas the third is a calcium sulfate type (LC31M). Both sulfate and TDS levels in LC31M exceed the WDEQ Class I Standards (250 mg/l and 500 mg/l, respectively). Chloride levels in all four wells are low (12 mg/L or less).

Manganese exceeded the WDEQ Class I Standard (0.05 mg/L) in seven of the 16 samples collected from DE monitor wells. The average detectable manganese value was 0.10 mg/L for the DE monitor wells. The average selenium concentration at well LC31M was 0.172 mg/L, exceeding the WDEQ Class I Standard of 0.05 mg/L.

Iron exceeded the WDEQ Class I Standard (0.3 mg/L) in two of the four samples from LC29M and one of the four samples from MB-1. The average values for the four samples from LC29M and MB-1 were below the standard. Similarly, the average ammonia concentration was below the WDEQ Class I Standard (0.5 mg/L) at well LC29M, although two of the four samples exceeded the standard.

Uranium levels exceeded the EPA MCL in every sample collected from the DE monitor wells except one MB-1 sample collected in August 2009. The average uranium concentration for the 16 samples collected was 0.577 mg/L. Radium 226 exceeded the EPA radium 226+228 MCL of 5.0 pCi/L in two samples. Combined radium 226+228 exceeded the standard in four of the samples. However, the average radium 226+228 activity for each of the DE monitor wells was below the WDEQ Class I Standard.

*LFG Sand Water Quality*

Seven wells completed in the LFG Sand were included in the baseline sampling program (LC15M, LC18M, LC21M, LC25M, MB-2, MB-5, and MB-8). Sample results from the existing baseline monitor wells are included in **Table D6-15a**.

Results of the baseline sampling indicate that the LFG monitor wells are calcium-bicarbonate to calcium-sulfate water. TDS and sulfate levels are below the WDEQ Class I Standards (500 mg/L and 250 mg/L, respectively) and chloride levels in all seven wells are low (10 mg/L or less).

Manganese and selenium were below the respective WDEQ Class I Standards in all the LFG samples. Iron exceeded the WDEQ Class I Standard in three out of four samples at LC18M, one out of four samples at LC25M, and in one sample at MB-8 for total iron.

Uranium levels exceeded the EPA MCL in every sample collected from the LFG monitor wells except for samples taken at MB-5. The average uranium concentration for the LFG samples was 0.289 mg/L. Radium levels were widely distributed. At least one sample from all LFG wells exceeded the WDEQ Class I Standard for radium 226+228 except for MB-2.

*HJ Horizon Water Quality*

Seven wells completed in the HJ Horizon were included in the baseline sampling program (LC16M, LC19M, LC22M, LC26M, MB-3B, MB-6, and MB-9). Sample results from the existing baseline monitor wells are included in **Table D6-15a**.

Results of the baseline sampling indicate that the HJ monitor wells are calcium-bicarbonate to calcium-sulfate water. Both sulfate and TDS levels in LC26M exceed the WDEQ Class I Standards (250 mg/L and 500 mg/L, respectively). Chloride levels in all four wells are low (11 mg/L or less).

Manganese and selenium were below the respective WDEQ Class I Standards in all the HJ samples.

Uranium levels exceeded the EPA MCL in every sample collected from LC16M, LC19M, LC22M, LC26M, and MB-3B HJ monitor wells. Only one sample from MB-9 and no samples from MB-6 exceeded the EPA MCL. The average uranium concentration for the HJ samples was 0.160 mg/L.

*UKM Sand Water Quality*

Seven wells completed in the UKM Sand were included in the baseline sampling program (LC17M, LC20M, LC23M, LC24M, LC27M, LC28M, and MB-4). Two of the wells were originally thought to be completed in the HJ Horizon (LC27M and LC28M) but were later reinterpreted as UKM completions. Sample results from the existing baseline monitor wells are included in **Table D6-15a**.

Results of the baseline sampling indicate that the UKM monitor wells are calcium-bicarbonate to calcium-sulfate water. TDS and sulfate levels are below the WDEQ Class I Standards (500 mg/L and 250 mg/L, respectively) in all but one sample and chloride levels in all seven wells are low (32 mg/L or less).

Manganese and selenium were below the respective WDEQ Class I Standards in all the UKM samples.

Uranium levels exceeded the EPA MCL in some samples collected at LC20M, LC24M, and MB-4. LC17M, LC23M, LC27M, and LC28M did not have any samples that exceeded the uranium EPA MCL. The average uranium concentration for the UKM samples was 0.028 mg/L.

Average radium 226+228 levels exceeded the WDEQ Class I Standard in at least one sample for each of the UKM monitor wells except MB-4.

*Summary of Site Groundwater Quality*

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 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 approximately 60 percent of the samples collected and the average uranium concentration is almost an order of magnitude greater than the EPA MCL for that constituent. An elevated concentration of these constituents is consistent with the presence of uranium orebodies.

## D6.5 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.

### D6.5.1 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 Springs 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 (artesian) 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 Springs 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 include waters with elevated radionuclides (uranium, Ra-226 and Ra-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 crops out 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.

## D6.5.2 Site Groundwater Conceptual Model

### *D6.5.2.1 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):
    - zero 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 ft 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 UKM 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 possible 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 possible secondary production zone and first underlying aquifer;
  - UKM Sand is 30 to 60 ft 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.

### *D6.5.2.2 Potentiometric Surface and Hydraulic Gradients*

Potentiometric surfaces for the DE, LFG, HJ, and UKM Horizons are illustrated as contour maps in **Figures D6-11a to D6-11h** and also on Cross Sections in **Plates D5-1a to D5-1g**. Depiction of these surfaces on the cross sections were generated by tracking the intersection of the plane of the cross section profile with the potentiometric contours for the given horizons.

Potentiometric surface of the HJ Horizon indicates that groundwater flow across the permit area is to the west-southwest under a hydraulic gradient of 0.005 to 0.006 ft/ft (15.8 to 31.6 ft/mi), generally consistent with the regional flow system. The Lost Creek 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.

However, the Fault does not appear to strongly affect either the direction of flow or the hydraulic gradient within the HJ Horizon. **Figure D6-11g** shows that the groundwater flow direction across the permit area, based on the potentiometric surface, is toward the west southwest on both sides of the Fault. The reason for the minimal impact of the Fault on groundwater flow direction within the permit area is because the Fault is only present across a small portion of the permit area, dying out to the east-northeast and west-southwest. The hydraulic gradient north of the Fault is approximately 0.005 ft/ft whereas on the south side of the Fault the hydraulic gradient is approximately 0.006 ft/ft. The pump tests indicate minor leakage of groundwater across the Fault when large head differences exist within the HJ aquifer across the Fault.

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. Groundwater flow on both sides of the Lost Creek Fault is toward the west-southwest at hydraulic gradients between 0.005 ft/ft to 0.007 ft/ft as shown in the potentiometric maps for the DE, LFG and UKM Sands (**Figures D6-11e**, **D6-11f** and **D6-11h**, respectively). 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, although some minor hydraulic communication exists between those units. The hydraulic communication only becomes apparent when large stresses (head differences) are applied to the aquifers through pumping. Hydraulic communication between the HJ aquifer and overlying and underlying aquifers may be through historic boreholes that were improperly abandoned, leakage through the confining shale units, or contact of sands juxtaposed across the Lost Creek Fault. Additional investigation will be completed prior to production of any mine units. More detail about abandonment work is provided in **Section D5.4.2.1**. In particular, **Table D5-2** is a summary of efforts to relocate and re-abandon historic holes, and **Attachment D5-3** includes historic memos regarding previous operator's attempts to relocate and re-abandon holes.

Vertical hydraulic gradients range from -0.020 to 0.37 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 predominately 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. An exception to this occurs in the eastern portion of the site where the vertical gradient between the DE and LFG aquifers is 0.28, indicating a strong downward potential.

### D6.5.2.3 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 Lost Creek Fault) is 60 to 80 $ft^2$/d (450 to 600 gpd/ft) on both sides 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. Using the effective transmissivity and an average thickness of 120 feet, the "effective" hydraulic conductivity of the HJ Horizon is in the range of 0.5 to 0.67 ft/d. The actual hydraulic conductivity of the aquifer is probably between one and 1.5 ft/d. Storativity of the HJ Horizon ranges from $5.0 \times 10^{-5}$ 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. As discussed in the previous section, the long-term multi-well pump tests performed in the fall of 2007 (the LC19M and LC16M tests described in Attachments D6-2a and D6-2b, respectively) provided data on the degree of connnection between the overlying and underlying aquifers relative to the HJ Horizon.

### D6.5.2.4 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.

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. The average uranium concentration for all of the hydrostratigraphic units of interest is 0.30 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 Production Zone aquifers than for the FG and DE Horizons. Dissolved radionuclide levels are commonly elevated in groundwater associated with uranium-bearing sandstones.

### *D6.5.2.5 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 Horizon) 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 Lost Creek Fault acts as a hydraulic barrier to flow and will need to be accounted for in mine unit design and operation.