# LOST CREEK HYDROLOGIC TEST
# COMPOSITE KLM HORIZON 5-SPOT TESTING
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## LOST CREEK PROJECT

## SWEETWATER COUNTY, WY

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## TABLE OF CONTENTS

**TABLE OF CONTENTS**

## Tables



## Figures

## Appendices

## EXECUTIVE SUMMARY

- Lost Creek ISR, LLC (LC ISR) has a Nuclear Regulatory Commission (NRC) License and a Wyoming DEQ Permit to Mine to extract uranium from the HJ Horizon in Mine Unit 1 (MU1) at the Lost Creek Project. In addition, LC ISR plans to develop and extract uranium by in-situ recovery (ISR) within the composite KLM Horizon of the Battle Spring Formation. Hydrologic investigations were conducted to provide support for an amendment to include Resource Area 3 in current State and Federal permits. During October 2012, 5-Spot Hydrologic Testing was completed in the KM Horizon of the composite KLM Horizon in Resource Area 3, which supplements the regional pump test conducted in October 2011 in the KM Horizon (Petrotek, 2013).

- The purpose of the 5-Spot Hydrologic Testing was to assess the level of hydraulic communication between the KM Horizon (Production Zone), and L Horizon and M Horizon of the composite KLM Horizon, in addition to the overlying HJ Horizon and the deeper N Horizon in a typical commercial scale 5-Spot production pattern.

- Prior to testing activities, LC ISR re-developed all wells utilized in the 5-Spot Hydrologic Testing. During development activities, bentonite grout was produced from well KPW-1A. LC ISR initiated remedial activities on KPW-1A. In addition, a completion assessment of all other KM Horizon wells in the 5-Spot area was performed prior to beginning testing activities.

- Extraction testing conducted in the KM Horizon indicated varying degrees of hydraulic communication between the two underlying L and M Horizons of the composite KLM Horizon, confirming that the entire composite KLM Horizon is hydraulically connected.

- Drawdown responses in the overlying HJ Horizon and deeper N Horizon during the extraction test were minor (an order of magnitude lower than responses observed in the composite KLM Horizon). LC ISR has aggressively pursued the re-plugging and abandonment of historic wells, and therefore cross-horizon communication through improperly abandoned wells is considered to be relatively unlikely.

- Based on hydrologic testing results to date, it is anticipated that the minor communication between the composite KLM Horizon and the overlying and underlying horizons can be managed through operational practices, detailed monitoring, and engineering operations.

- Based on the lack of responses observed in the L and M Horizons and overlying HJ Horizon and deeper N Horizon during the Injection/Extraction portion of testing conducted with no bleed, it is anticipated that commercial scale production operations in Resource Area 3 with typical bleed will have little if any impact on the overlying and underlying horizons.

- The 5-Spot Extraction and Injection testing, as well as the 2011 Regional Pump Test (under separate cover) provides sufficient characterization of the composite KLM Horizon to support Nuclear Regulatory Commission (NRC) license and Wyoming Land Quality Division (LQD) permit amendments.

## 1.0 INTRODUCTION

### 1.1 BACKGROUND

The Lost Creek Project is located in the northeastern portion of the Great Divide Basin of Wyoming, within Sweetwater County (Figure 1-1). It lies within all or parts of Sections 13, 24, and 25 of T25N, R93W, and Sections 16 through 20, and 29 through 31 of T25N, R92W. Figure 1-1 shows the Project location and its relationship to the Great Divide Basin. Figure 1-2 presents the location of the 5-Spot test area in relation to Resource Area 3, and Figure 1-3 presents a smaller-scale depiction of the wells utilized during testing.

LC ISR plans to develop and extract uranium from mine units within the KM Horizon of the Battle Spring Formation via ISR. Initial production from the KM Horizon will occur within an area of the Lost Creek Project currently designated as Resource Area 3. This resource area lies to the east of Mine Unit 1, the first planned production wellfield, and partially underlies Mine Unit 1, which will produce from the HJ Horizon (see Figure 1-2). This report provides a summary of the 5-Spot Hydrologic Test conducted within Resource Area 3 during October 2012. Prior to ISR operations in the KM Horizon, the LC ISR Class III Permit (LQD) and Source Materials License (NRC) will be amended.

With reference to Resource Area 3, significant mineralization has been identified only in the KM Horizon, occurring between depths of approximately 430 to 590 feet below ground surface (ft bgs). Average thickness of the KM Horizon is approximately 115 feet thick and total thickness of the composite KLM ranges from approximately 260 to 330 feet thick. Based on the results of testing and stratigraphic analysis (detailed in *Lost Creek Hydrologic Test, Composite KLM Horizon Regional Pump Test, October 2011* [Petrotek, 2013]), the composite KLM Horizon is composed of three named sand units, the KM, L, and M Horizons, which are in hydraulic communication. The following summarizes the general stratigraphy of the composite KLM Horizon:

Composite KLM Horizon Stratigraphy

| | |
|---|---|
| Composite KLM Horizon | KM Horizon – Mineralized Zone, Upper Sand |
| | L Horizon – Middle Sand |
| | M Horizon – Lower Sand |

### 1.2 5-SPOT HYDROLOGIC TEST OBJECTIVES

The objectives of the 5-spot Hydrologic Test in the composite KLM Horizon are to:

1. Evaluate vertical and horizontal hydraulic control in the composite KLM Horizon;
2. Determine site-specific hydraulics associated with flow during typical ISR operations;

3. Characterize pattern-scale aquifer properties within the composite KLM Horizon Production Zone; and,

4. Evaluate the degree of communication between the overlying HJ Horizon and the deeper N Horizon, as well as evaluate hydraulic communication within the three units of the composite KLM Horizon.

The testing procedures and results are presented and discussed in this report.

## 1.3 REPORT ORGANIZATION

The results of the 2012 Composite KLM Horizon 5-Spot Hydrologic Testing are included within this report. This report includes nine sections, summarized below:

1.0 Introduction
2.0 Site Characterization
3.0 Monitor Well Locations, Installation, and Completion
4.0 5-Spot Hydrologic Test Design and Procedures
5.0 Barometric Pressure Corrections
6.0 Hydrologic Test Results
7.0 Hydrologic Test Analysis
8.0 Summary and Conclusions
9.0 References

Field activities for the hydrologic test were jointly performed by LC ISR and Petrotek Engineering Corporation (Petrotek) personnel. Geologic interpretations were performed by LC ISR geologists. Aquifer test analyses were performed by Petrotek, and the summary report was written by Petrotek, with edits by LC ISR staff.

## 2.0 SITE CHARACTERIZATION

### 2.1 HYDROSTRATIGRAPHY

The Lost Creek Project is underlain by the upper portions of the Eocene-age Battle Spring Formation. The total thickness of the Battle Spring Formation at Lost Creek is approximately 6,000 feet. The Battle Spring Formation regionally interfingers to the southwest with time equivalent units of the Wasatch Formation.

LC ISR utilizes the following nomenclature for the hydrostratigraphic units of interest within the Battle Spring Formation in the Lost Creek area (see Figure 2-1). Isopach maps and a structural contour map are provided in the 2011 Composite KLM Horizon Regional Pump Test Report (Petrotek, 2013), and are not reproduced in this document.

### 2.2 OVERLYING UNITS: HJ HORIZON AND SAGEBRUSH SHALE

The composite KLM Horizon, and more specifically the KM Horizon, is bounded above by the confining unit identified as the Sagebrush Shale. The Sagebrush Shale is continuous throughout the Lost Creek Project, and ranges from 3 to 32 feet thick within the resource study area (see Figure 2-2 [Petrotek, 2013]).

Above the Sagebrush Shale is the HJ Horizon, which represents the overlying aquifer in this study. The HJ Horizon is continuous throughout the Lost Creek Project and ranges from 100 to 151 feet thick, with an average thickness of approximately 120 feet. (Note: the HJ Horizon is also the primary production horizon in Mine Unit 1, which partially overlaps Resource Area 3).

### 2.3 COMPOSITE KLM HORIZON AND KM HORIZON PRODUCTION ZONE

The Production Zone evaluated as part of this investigation is the KM Horizon, which is a component of the composite KLM Horizon. The composite KLM Horizon is continuous throughout the Lost Creek Project with a total thickness ranging from approximately 260 to 330 feet; the average thickness is approximately 305 feet (see Figure 2-3 [Petrotek, 2013]). Within the composite KLM Horizon, the KM is the only Horizon which contains significant mineralization; and, thus is herein considered the Production Zone. The KM Horizon averages approximately 115 feet in thickness in the study area.

Within the composite KLM Horizon, there is no confirmed areally extensive confining unit that isolates the KM, L and M Horizons from each other. Rather, there is a series of interfingered layers of mudstone, siltstone and shales. Some of these have historically been referred to as “No Name Shale”, K-Shale, LM Shale and MN Shale. Previous pump tests have evaluated some of these as potential lower aquitards to the KM Production Zone in the proposed Resource Area 3. These bedding units may show continuity over large areas but regional continuity has not been demonstrated. Thus, they cannot be considered truly confining units on a regional scale. However, due to the interfingering nature and low permeability of these units, they do limit and/or restrict vertical flow in the proposed

production area.

## 2.4 MN SHALE AND N HORIZON

The MN Shale is a zone of interfingered layers of mudstone, siltstone, and shale that separates the M Horizon from the deeper N Horizon (Figure 2-1). Based on geologic data, the MN Shale is not considered a true regional confining unit, as continuity is not observed over a regional scale. The MN Shale does limit and/or restrict vertical flow due to the interfingering of finer grained and lower permeability units. It ranges from approximately 10 to 40 feet thick, with a typical thickness of about 10 to 20 feet. As mentioned above, regional continuity of the MN Shale is not certain. An isopach map of the MN Shale is presented on Figure 2-4 of Petrotek (2013).

Beneath the MN Shale is the N Horizon and based on limited data, the total thickness of the N Horizon is approximately 100 feet. No isopach was constructed for this aquifer due to the limited number of borings that have penetrated through the entire N Horizon.

## 2.5 STRUCTURE

In the Lost Creek Project area, the Battle Spring Formation dips to the west at approximately three degrees. The Lost Creek Fault is oriented in a west-southwest to east-northeast direction that spans the length of Resource Area 3. A structural contour map from the top of the composite KLM Horizon is presented in Figure 2-5 of Petrotek (2013), and is not reproduced in this report. The main fault bisects the northwestern portion of the study area, and is downthrown to the south. A subsidiary splay fault splits from the main fault to the south for a limited distance in the central portions of Resource Area 3 (see Figure 1-2).

## 2.6 PREVIOUS TESTING

As part of the historic characterization activities for the NRC License and LQD Permit to Mine applications, LC ISR and Petrotek previously performed multiple in-house pump tests including the 2011 Composite KLM Horizon Regional Pump Test (Petrotek, 2013). A complete summary of testing to date is provided in Petrotek (2013).

# 3.0 MONITOR WELL LOCATIONS, INSTALLATION, AND COMPLETION

## 3.1 WELL LOCATIONS

All wells utilized during testing are located in the 5-spot test area of Resource Area 3 (Figure 1-2). A small scale illustration of the wells in the 5-spot test area is presented on Figure 1-3. All wells were instrumented and monitored by In-Situ LevelTROLL® datalogging transducers.

## 3.2 WELL INSTALLATION AND COMPLETION

All wells used for this test were constructed with 4.5-inch nominal diameter casing. The wells were developed using standard water well techniques, including air lifting, pumping, swabbing, and/or surging. Specific data related to well location, construction, completion interval, and initial water levels are provided in Table 3-1.

## 4.0 5-SPOT HYDROLOGIC TEST DESIGN AND PROCEDURES

The following section details the test design and procedures of the 5-Spot Test conducted at pumping well 5S-KM3. Details of testing are summarized below.

### 4.1 TEST DESIGN

The 5-Spot Hydrologic Test was conducted in the KM Horizon of the composite KLM Horizon, with additional monitoring in the L and M Horizons of the composite KLM Horizon, and in the HJ and N Horizons. Testing was conducted to meet the objectives outlined in Section 1.2.

The general testing procedures were as follows:

1. Install In-Situ LevelTROLL® data-logging transducers (vented) in wells to record changes in water levels during tests. Verify setting depths and head readings with manual water level measurements;

2. Measure and record pre-test background water levels and barometric pressure for a minimum of 72 hours prior to testing;

3. Run the pumping well and/or injection wells at a constant rate (or as close as practical); and,

4. Record water levels and barometric pressure throughout pre-test background, pumping, and recovery periods.

The 5-Spot Test consisted of four phases of testing described below:

1. <u>Extraction Test</u> – A constant rate pump test was conducted at the central extraction well 5S-KM3 (KM Horizon completion) while monitoring water levels in the five KM Horizon observation wells, and the single wells completed in the L and M Horizons of the composite KLM Horizon, and the HJ and N Horizons. The constant rate pump test was conducted to: 1) evaluate aquifer properties (transmissivity [T] and storativity [S]) in the KM Horizon, 2) evaluate the hydraulic communication within the L and M Horizons of the composite KLM Horizon, and 3) evaluate isolation between the composite KLM Horizon and the HJ and N Horizons.

2. <u>Extraction and Injection Test, Four Injectors</u> – A constant rate extraction/injection test was conducted by pumping at the central extraction well 5S-KM3, and pumped water was distributed evenly to the four corner injection wells within a closed-loop manifold system.

3. <u>Extraction and Injection Test, Three Injectors</u> – A constant rate extraction/injection test was conducted by pumping the extraction well 5S-KM3, and evenly distributing the pumped water to three injection wells.

4. Extraction and Injection Test, Two Injectors – A constant rate extraction/injection test was conducted by pumping the extraction well 5S-KM3, and pumped water was re-injected via two injection wells.

## 4.2 PUMP TEST EQUIPMENT, INJECTION MANIFOLD AND MONITORING

Aquifer testing was performed utilizing a Grundfos 40S75-21 (71/2 HP), 460V, 3-phase electrical submersible pump powered by a portable diesel generator. At pumping well 5S-KM3, the pump was set at a depth of 500 feet (approximately 44 feet off the bottom). The static depth to water in 5S-KM3 was approximately 192 feet, providing for approximately 318 feet of head above the pump. Flow from the pump was controlled with a manual gate valve. Surface flow monitoring equipment included two 1.5-inch turbine meters, including a NU FLO MCII (provided by LC ISR) and a Great Plains Industries stainless steel turbine meter (provided by Petrotek). Both meters displayed total flow (in gallons) and instantaneous flow rates (in gallons per minute [gpm]). Per discussions with WDEQ/LQD, no Temporary Discharge Permit was required. Discharge water was land applied approximately 1,500 feet downgradient from KPW-1A via a 2” high-density polyethylene (HDPE) pipeline.

During the injection phase of testing, flow from pumping well 5S-KM3 was conveyed to an injection manifold via 1.5-inch galvanized pipe attached to a 2-inch flexible discharge line. The injection manifold consisted of 2-inch and 1-inch SDR11 HDPE pipe, constructed by LC ISR personnel. The 2-inch flexible discharge line running from the pumping well connected into one 2-inch SDR HDPE tee, with each end connected into two additional 2-inch tees, with reducers to 1” SDR HDPE lines. Each of the four 1-inch lines were fitted with 1-inch poly gate valves for controlling flow to the individual injection wells. The gate valves were positioned downstream of the Turbine Inc. TM Series Turbine Flow Meters.

Water levels were measured and recorded with In-Situ Level TROLL® pressure transducer dataloggers. The pressure rating for the transducers ranged from 30 to 300 psi, and they were programmed to record depth to water at 1 minute intervals (during pre-test background monitoring, and the pumping and recovery periods). During the extraction and injection test, transducers were programmed to record data on a logarithmic scale. A summary of the monitoring equipment used is presented in Table 4-1.

The following is an interval-specific summary of water level monitoring locations by completion interval:

- Overlying HJ Horizon – 1 well (5S-HJ1)
- Composite KLM Horizon – 8 wells, including:
    - KM Horizon – 6 wells, including the central extraction well (5S-KM3), four corner injection wells, and an intermediate observation well located inside the 5-spot pattern.

  - L Horizon – 1 well (KMU-1)
  - M Horizon – 1 well (M-M1)
- N Horizon – 1 well (5S-N1)

LC ISR and Petrotek personnel installed the monitoring equipment prior to testing on October 4, 2012, and verified the datalogger programming and equipment layout. Petrotek and LC ISR personnel collected the daily downloads after instrument installation and transferred the data to Petrotek for review and QA/QC for the duration of pre-test background monitoring and all phases of testing for the 5-Spot Hydrologic Test.

## 4.3 POTENTIOMETRIC SURFACES

A potentiometric surface was not constructed for the small area of the 5-Spot test pattern. A more complete characterization of potentiometric levels in the KM Horizon at Resource Area 3 is provided in Petrotek (2013, Figure 4-2).

## 5.0 BAROMETRIC PRESSURE CORRECTIONS

### 5.1 MONITORING EQUIPMENT

As previously discussed, all of the In-Situ Level TROLLS® used for the pump test were vented. In-Situ has stated that if vented transducers are used, the vent eliminates the impact of barometric pressure on the sensor. However, a change in water levels due to barometric changes will occur whether a vented sensor is used or not. Hence, use of vented equipment eliminates the barometric impact on the sensor, but does not correct the water level measurements for barometric effects on the aquifer. In this regard, the vented Level TROLLS® are barometrically *compensated*, but not *corrected*. If significant variations in water levels or barometric pressure are observed, the data may require correction for fluctuations in water levels associated with changes in barometric pressure. An In-Situ BaroTROLL® was installed prior to testing and used to measure barometric pressure during testing.

### 5.2 BAROMETRIC CORRECTIONS

Based upon the negligible impacts of barometric pressure on water level data observed during the 2011 Composite KLM Horizon Regional Pump Test (Petrotek, 2013), barometric corrections were not applied to the water level data collected during these investigations.

# 6.0 HYDROLOGIC TEST RESULTS

The following section discusses the details and results of the 5-Spot Hydrologic Test. Details regarding pre-test monitoring, extraction/injection rates and test durations, and responses in the composite KLM Horizon and overlying and underlying aquifers are discussed separately for the four phases of testing listed in Section 4.1.

## 6.1 EXTRACTION TEST

### 6.1.1 Pre-Test Re-development Activities and Subsequent Work-over on Well KPW-1A

Petrotek recommended re-developing the KM Horizon well completions based on past experience of performing 5-spot hydrologic testing at other ISR facilities. During swabbing activities on KPW-1A, the development crew produced volclay/bentonite slurry back to surface. Following this discovery, LC ISR initiated a detailed reconnaissance program to review completion records, assess and confirm completion and well screen intervals of KM Horizon completions in the field, and perform any remedial actions deemed necessary.

Review of the completion records indicated that KPW-1A was originally completed with two screened intervals in the KM Horizon. One screen was installed at 520 – 565 ft bgs and the other at 575 – 610 ft bgs. LC ISR personnel indicated that the bottom screen interval was subsequently plugged off with volclay bentonite grout in late 2011. LC ISR re-entered KPW-1A and removed the volclay grout. The bottom under-reamed screen interval was then cemented through the entire lower and part of the upper KM interval. The top of cement was tagged at 544 ft bgs. A new well screen was placed at 519 – 539 ft bgs.

Screen intervals of all KM wells in the immediate 5-spot area were field verified and reset as necessary. Screen intervals in wells 5S-KM1 and M-UKM1 were slightly off and were reset consistent with underream intervals. Following verification and resetting of select well screens, all KM wells in the 5-spot area were tested for and passed mechanical integrity testing prior to conducting the extraction test.

Following the well completion work conducted on the 5-Spot wells and sufficient pre-test background monitoring, the extraction test was conducted during October 5 – 8, 2012.

### 6.1.2 Pre-Test Monitoring

Water level stability data were collected prior to the start of the extraction test at pumping well 5S-KM3. Plots of the pre-test background, pumping, and recovery data for the pumping well and five observation wells completed in the KM Horizon are presented in Figure 6-1. Hydrographs of the L and M Horizon wells (KMU-1 and M-M1, respectively) are presented in Figure 6-2. Hydrographs of the HJ Horizon well (5S-HJ1) and the N Horizon well (5S-N1) are shown on Figures 6-3 and 6-4, respectively.

Prior to conducting the extraction test at 5S-KM3, water levels were stable in all the KM Horizon wells (Figure 6-1). Water levels in the L and M Horizon wells (Figure 6-2) were also stable prior to the start of testing. Water levels in the overlying HJ Horizon well and underlying N Horizon well were also stable prior to the start of testing (Figures 6-3 and 6-4).

### 6.1.3 Pump Duration and Rate

The extraction test was started at 14:00 Hours on October 5, 2012, and was terminated at 16:31 Hours on October 8, 2012. The total duration of pumping was 4,471 minutes (3.10 days), and the average pumping rate was 28.5 gpm (Table 6-1). At approximately 1,439 minutes into the test, the pumping rate was adjusted to a slightly higher rate (seen in the hydrograph of the pumping well in Figure 6-1 to 6-4). The average pumping rate for the first 1,439 minutes was 28.0 gpm, and the average rate from 1,439 to the end of testing was 28.7 gpm.

### 6.1.4 Composite KLM Horizon Response and Drawdown

Table 6-2 presents a summary of drawdown observed in the KM, L, and M Horizons of the composite KLM Horizon at shut-in of pumping well 5S-KM3. Hydrographs of drawdown during the extraction test are presented in Figure 6-1 (KM Horizon) and Figure 6-2 (L and M Horizons). Drawdown in the pumping well was approximately 116 feet; at the intermediate observation well 5S-KM4, drawdown was 30 feet. Observed drawdown in the four equidistant corner wells varied between approximately 23 to 61 feet.

At well 5S-KM1, an anomalous water level rise is observed as the water level in the well rises approximately 0.4 feet over the course of several hours on October 6 (Figure 6-1). The observed drawdown at shut-in was 29.4 feet. It is unclear as to cause of this water level rise, but this phenomenon was not observed at any other monitoring locations.

Observed drawdown in the L and M Horizon wells KMU-1 and M-M1, in comparison with KM Horizon wells, are similar to the ratio of drawdown observed during the 2011 regional testing of the composite KLM Horizon (Petrotek, 2013). Final drawdown values at KMU-1 and M-M1 were 6.1 feet and 1.1 feet, respectively (Table 6-2).

### 6.1.5 HJ Horizon and N Horizon Response

Hydrographs of water levels during the pump test for the HJ Horizon and N Horizon observation wells are presented on Figures 6-3 and 6-4, respectively. Neither well in these horizons was observed to respond to pumping in the KM Horizon. The rise in water level observed in the HJ Horizon is consistent with the “Noordbergum Effect” associated with poroelasticity theory presented in earlier reports.

## 6.2 INJECTION AND EXTRACTION TESTING: PRELIMINARY INJECTION TO FOUR WELLS

### 6.2.1 Pre-Test Background Monitoring

Following the completion of the Extraction Test, transducers continued to collect water level pre-test background data up to the start of the injection and extraction testing conducted on October 18, 2012. Pre-test background monitoring hydrographs are presented on Figures 6-5 (KM Horizon), 6-6 (L and M Horizons), 6-7 (HJ Horizon), and 6-8 (N Horizon).

Prior to the start of testing, water levels in the KM Horizon wells were within approximately one foot or less of static water levels prior to the Extraction Test except at well KPW-1A (approximately 1.4 feet of residual drawdown) and well M-UKM1 (approximately 1.6 feet residual drawdown). Water levels in the L and M Horizons (Figure 6-6) were within approximately 0.5 feet of static water levels prior to injection and extraction testing. Due to the lack of observed response in the overlying HJ Horizon and deeper N Horizon, water levels in these wells were stable prior to testing (Figures 6-7 and 6-8).

### 6.2.2 Test Details and Results

The initial test attempt to pump at well 5S-KM3 and distribute recovered fluid to the four corner injection wells was conducted as a preliminary test of the 5-Spot injection/extraction test network and to gauge the injective capacity at the four injection wells. During much of the test, the extraction and injection rates fluctuated as adjustments were made to individual well flow rates. Due to the fact that the injection well heads were open and unsealed, two wells (KPW-1A and M-UKM-1) became flowing artesian and injection flow rates had to be reduced. Due to the fluctuation in rates and the fact that this portion the test was a preliminary evaluation, data regarding pumping/injection rates are not presented and only a short discussion of results is provided.

Hydrographs of the KM Horizon wells are presented on Figures 6-9 and 6-10. This initial test was conducted for approximately four hours during which several adjustments to the pumping rate and individual well injection rates were made.

Water levels in the injection wells 5S-KM1 and 5S-KM2 stabilized near the end of this initial test, with a total increase of approximately 19 ft and 14 feet, respectively (Figure 6-9). The water level in the intermediate observation well, 5S-KM4, was approximately 3 feet higher at the end of the initial test.

Water levels in the remaining two KM Horizon wells, KPW-1A and M-UKM1 indicate significantly less injective capacity (see Figure 6-10). During the early stages of this initial test, water levels in both wells became flowing artesian. Injection into well KPW-1A was eventually halted, as it was determined to be impractical to continue attempting to inject fluid into this well. It is likely that the plugging of the bottom screen interval with volclay grout (detailed in Section 6.1.1) has significantly impacted the hydraulic response, both in

the inability to inject fluid, as well as the extremely slow recovery response observed at this well relative to the other wells. At well M-UKM1, adjustments were made to the injection rate and water levels eventually stabilized.

Water levels in the L and M Horizons (Figure 6-11), the HJ Horizon (Figure 6-12), and the deeper N Horizon (Figure 6-13) were unaffected during the preliminary injection/extraction test.

## 6.3 INJECTION/EXTRACTION TEST #1: THREE INJECTORS

Based on preliminary test results, it was determined that KPW-1A was not suitable as an injector due to the presumed plugging of the screen interval with volclay grout that likely resulted in the observed minimal injective capacity. Injection/Extraction Test #1 was conducted by pumping at well 5S-KM3, and evenly distributing fluid to the three injection wells utilized for this test (wells 5S-KM1 and 5S-KM2 shown on Figure 6-9, and wells M-UKM1 presented on Figure 6-10).

### 6.3.1 Extraction and Injection Rates and Test Duration

The Injection/Extraction Test #1 involved pumping from the central extraction well, and evenly distributing the extracted fluid between the three injection wells (5S-KM2, 5S-KM2, and M-UKM1). Test #1 began on October 19, 2013 at 11:00 Hours and continued for 24 hours to October 20, 2013 at 11:00 Hours.

Rates for Injection/Extraction Test #1 are provided in Table 6-3. As previously noted, the extraction/injection is a closed-loop system, and the rate of pumping should equal the rate of injection. Due to the level of precision in the totalizers, there was a slight difference between the extraction and injection rates. The measured extraction rate during Injection/Extraction Test #1 was approximately 10.9 gpm at 5S-KM3. The total average injection rate was approximately 11.4 gpm, and average injection rates at wells 5S-KM2, M-UKM1, and 5S-KM1 during Test #1 were 3.8 gpm, 3.7 gpm, and 3.9 gpm, respectively.

In general, rates were relatively constant during Injection/Extraction Test #1. On October 20 at 8:30 Hours, the pumping rate was increased approximately 0.8 to 0.9 gpm, which is reflected in the increased depth to water in the pumping well on Figures 6-9 and 6-10. Correspondingly, the injection rates at the three injectors increased slightly as well, which is reflected in the abrupt water level rises observed near the end of testing (Figures 6-9 and 6-10) at the three injection wells.

### 6.3.2 Injection/Extraction Test #1 Hydraulic Response – Composite KLM Horizon

Drawdown in the pumping well 5S-KM3 at the end of the 24-hour Injection/Extraction Test #1 was approximately 30 feet (28 feet prior to the minor increase in rate on October 20). Figure 6-9 presents the hydraulic response to injection of the two outer injection wells, 5S-KM1 and 5S-KM2, as well as the intermediate observation well 5S-KM4. The hydrograph of the third injection well, M-UKM1, as well as the non-injecting observation well KPW-1A is

shown on Figure 6-10.

The water level responses to injection at approximately 4 gpm were similar in the two injection wells 5S-KM1 and 5S-KM2. At well 5S-KM1, a maximum water level rise of approximately 18 feet was observed within approximately 30-45 minutes, and after that the water level slowly declined approximately 1 foot to the end of the test (Figure 6-9). At well 5S-KM2, a maximum water level rise of approximately 14 feet was observed with a similar slow decline in water level of approximately 1 foot to the end of the test. At the third injection well, well M-UKM1, the injective capacity was significantly lower, and may be attributable to a localized area of lower permeability, well completion issues, or a combination of both. At well M-UKM1, the water level in the well rose approximately 35 feet in the first 10 minutes of testing. Maximum water level rise of almost 150 feet was reached within approximately 2 hours of testing; subsequently, water level gradually fell to approximately 125 feet above initial static water level during testing. Near the end of testing, the slight increase in pumping rate (and corresponding injection rates at the three wells) resulted in a consistent water level rise in this well through the end of testing to approximately 143 feet above initial static water level (Figure 6-10).

The drawdown in the intermediate observation well (5S-KM4, Figure 6-9) reached a maximum level of approximately 3.8 feet early during testing. As the KM Horizon reached a condition closer to equilibrium with the extraction/injection well patterns, the drawdown in this well fell to approximately 3.0 feet for the remainder of the test.

At well KPW-1A, the water level during testing was relatively unaffected. Due to the likely poor completion at this well (detailed in Section 6.1.1), the water level in this well was still recovering from the artesian conditions that were induced during the initial injection and extraction test (Figure 6-9).

The water levels in the L and M Horizons, below the pumped KM Horizon, were unaffected by the Injection/Extraction Test #1 activities as shown on Figure 6-11.

### 6.3.3 Injection/Extraction Test #1 Hydraulic Response – HJ Horizon and N Horizon

Water levels in the overlying HJ Horizon and the deeper N Horizon are shown on Figure 6-12 and 6-13, respectively. Water level fluctuations observed during testing appear to be related to barometric pressure changes. No drawdown or water level rise attributable to pumping or injection during testing was observed in the overlying HJ and deeper N Horizon wells.

## 6.4 INJECTION/EXTRACTION TEST #2: TWO INJECTORS

Following Injection/Extraction Test #1, the decision was made to cease injection at well M-UKM1 due to its limited injection capacity. Injection/Extraction Test #2 involved doubling the 5S-KM3 pumping rate and routing the water evenly between the two wells with the highest

injective capacity, 5S-KM1 and 5S-KM2.

### 6.4.1 Extraction and Injection Rates and Test Duration

Injection/Extraction Test #2 involved pumping from the central extraction well at approximately twice the Test #1 rate, and evenly distributing the extracted fluid between the two injection wells utilized during testing (5S-KM2 and 5S-KM1). Injection/Extraction Test #2 began on October 20, 2013 at 11:00 Hours and continued for just over 72 hours to October 23, 2013 at 11:05 Hours.

Rates for Injection/Extraction Test #2 are provided in Table 6-3. As previously noted, the extraction/injection is a closed-loop system, and therefore the rate of pumping should equal the rate of injection. Due to the totalizers level of imprecision, there was a slight difference between the measured extraction and injection rates. The measured extraction rate during the Injection/Extraction Test #2 was approximately 22.6 gpm at 5S-KM3. The total average injection rate was approximately 24.9 gpm, and individual average injection rates at wells 5S-KM1 and 5S-KM2 were 12.5 gpm and 12.4 gpm, respectively.

In general, the rates were relatively constant during the Injection/Extraction Test #2, and no adjustments were made to the pumping rate after the test was initiated.

### 6.4.2 Injection/Extraction Test #2 Hydraulic Response – Composite KLM Horizon

The increased pumping rate from approximately 11-12 gpm during Injection/Extraction Test #1 to approximately 22.6 gpm during Injection/Extraction Test #2, increased the observed drawdown in the pumping well (5S-KM3) to 67 feet below initial static water level. Within just over an hour, drawdown was near maximum level and the water level remained relatively constant throughout the remainder of the 72 hour test.

Increasing the individual injection rate to approximately 12 gpm at the two active injection wells 5S-KM1 and 5S-KM2 resulted in a continuous water level rise throughout the duration of the 72 hour injection/extraction test (Figure 6-9). At well 5S-KM1, the water level rise due to injection rose from a near constant value of approximately 17 to 18 feet during Injection/Extraction Test #1 to an eventual maximum water level rise of approximately 70 feet. At well 5S-KM2, the water level rise during Test #1 was approximately 13 to 14 feet; during Test #2, the maximum water level rise reached approximately 62 feet at the end of testing. In contrast to the early initial water level rise maximum that was reached during Test #1 (injection rate of ~ 4 gpm to each well) followed by a gradual decline in water level during later stages of testing, the water levels in both injection wells rose sharply as a result of the increased injection rate, and water levels continued to rise approximately 12 feet after the initial steep water level rise throughout the entirety of testing (Figure 6-9).

The drawdown in the intermediate observation well (5S-KM4; see Figure 6-9) increased from approximately 3 feet at the end of Test #1, to a maximum drawdown value of approximately 7 feet, and remained relatively constant until the end of Test #2. At the corner observation well M-UKM1 (see Figure 6-10), the water level rise associated with

injection at this well during Injection/Extraction Test #1 recovered, and a relatively constant drawdown value of approximately 23 to 24 feet below initial static water level was observed within several hours of the start of Injection/Extraction Test #2.

The water level at the assumed damaged well KPW-1A decreased slightly in response to the increased pumping at well 5S-KM3 (Figure 6-10). Based on the final water level elevation at this well after the end of Injection/Extraction Test #2, drawdown in this well was approximately 5 feet.

The water levels in the L and M Horizons, below the pumped KM Horizon, appear unaffected by the extraction/injection test as shown on Figure 6-11. Based on the location of these wells in the southeastern corner of the well pattern near well M-UKM1 (where drawdown during Test #2 was approximately 23 feet) and their distance from the two active injection wells to the north, drawdown in the KM Horizon at the L and M Horizon well locations (KMU-1 and M-M1, respectively) is likely greater than 23 feet. Therefore, the expected response in the L and M Horizons (if there is an observable response) is likely to show drawdown as opposed to a water level rise associated with injection. Based on the hydrographs for well KMU-1 and M-M1 (Figures 6-11), the water level changes in the L and M Horizons reflect fluctuations on the order of several tenths of a foot associated with atmospheric pressure. No discernible drawdown trend was observed in either well during the course of the 72 hour Test #2.

### 6.4.3 Injection/Extraction Test #2 Hydraulic Response – HJ Horizon and N Horizon

Water levels in the HJ Horizon and N Horizon are shown on Figure 6-12 and 6-13, respectively. Water level fluctuations observed during Injection/Extraction Test #2 at those locations appear to be related to barometric pressure. No drawdown attributable to extraction or injection activities was observed in the HJ Horizon well or the N Horizon well during Injection/Extraction Test #2.

## 6.5 DISCUSSION OF 5-SPOT HYDROLOGIC TEST RESULTS

The KM Horizon drawdown observations during the 5-Spot Hydrologic Test indicate the presence of anisotropy within the KM Horizon on a local scale, specifically relative to well M-UKM1. During the extraction test, more than twice the drawdown (61 feet) was observed at well M-UKM1 located approximately twice the distance from pumping well 5S-KM3 relative to 5S-KM4 (30 feet of drawdown). Anisotropy was also observed during the Composite KLM Horizon Regional Pump Test (Petrotek, 2013) conducted during the fall of 2011, but to a lesser degree. Electric logs of all wells associated with the 5-Spot area were reviewed by LC ISR and Petrotek geologists. There was no discernible difference in sand quality noted at well M-UKM1 when compared to other KM Horizon intervals in the 5-Spot Area. Other than aquifer anisotropy, the large drawdown response observed at M-UKM1 remains unexplained at this time.

# 7.0 HYDROLOGIC TEST ANALYSIS

## 7.1 ANALYTICAL METHODS

Drawdown data collected during the Extraction Test from monitor wells in the KM Horizon (instrumented with Level TROLLS®) were graphically analyzed to determine aquifer properties of transmissivity (T) and storativity (S). The analysis method used was the Hantush-Jacob (1955) leaky aquifer solution for partially penetrating wells. The assumption used in this analysis was that the aquifer is confined and has a saturated thickness of 115 feet (average thickness of the KM Horizon, provided by LC ISR geologists). Type curve matches for all analyses are presented in Appendix A, and complete water level data are provided in Appendix B.

As indicated above, the test data were analyzed using the Hantush-Jacob method, which include the following assumptions:

- The aquifer is leaky confined and has apparent infinite extent;
- The aquifer is homogeneous and isotropic, and of uniform effective thickness over the area influenced by pumping;
- The potentiometric surface is horizontal prior to pumping;
- The well is pumped at a constant rate;
- The pumping well is partially penetrating;
- Water is released instantaneously from storage with decline in head;
- Aquitard beds have infinite areal extent, uniform vertical hydraulic conductivity and uniform thickness, and flow is vertical in aquitards; and,
- Well diameter is small, so well storage is negligible.

These assumptions are reasonably satisfied, with the exception of the following: uniform thickness of the aquifer and infinite extent of the aquifer due to the presence of boundary conditions (i.e., Lost Creek Fault), uniform thickness and infinite extent of the aquitards. Locally, the KM Horizon and the bounding aquitard layers are not homogeneous and isotropic; however, over the scale of the extraction test, the aquifer can be treated in this manner.

The software used to graphically analyze the data was Aqtesolv PRO (Version 4.5, HydroSOLVE).

## 7.2 ANALYTICAL RESULTS

Drawdown data collected from monitor wells in the 5-spot pattern were graphically analyzed to determine aquifer properties of transmissivity (T) and storativity (S). Due to the relative insignificance of barometric effects demonstrated from historical testing in the HJ and composite KLM Horizons, barometric corrections were not applied to the drawdown data. The analytical method used was Hantush-Jacob (1955), assuming a leaky confined aquifer with partially penetrating pumping and observation wells and with a saturated thickness of 115 feet. Due to the slight variation in pumping rate at approximately 1,439 minutes into the test (see Table 6-1), an average pumping rate of 28.0 gpm was used for the first 1,439 minutes, and an average rate of 28.7 gpm was used from this time to the end of the test at 4,471 minutes.

Table 7-1 presents a summary of the analytical results from the Extraction Test. KM Horizon transmissivities values computed from the Hantush-Jacob analysis ranged between 80 $ft^2$/day to 132 $ft^2$/day, with an average T value of 111 $ft^2$/day. These values are consistent with the results of analysis from the composite KLM Horizon Regional Pump Test (Petrotek, 2013). Based on an aquifer thickness of 115 feet, calculated hydraulic conductivity (K) values ranged between approximately 0.7 to 1.1 ft/day.

Calculated S values ranged between 4.7 x $10^{-5}$ to 3.5 x $10^{-4}$ from the Hantush-Jacob drawdown analysis, omitting the significantly lower value from well M-UKM1. The calculated storativity value for well M-UKM1 is an order of magnitude lower (1.3 x $10^{-6}$) than expected in this aquifer, and therefore this data is not considered representative and is disregarded. Calculated storativity values are similar in scale to previous testing conducted in the composite KLM Horizon (Petrotek, 2013).

## 8.0 SUMMARY AND CONCLUSIONS

- Extraction and extraction/injection testing on a 5-spot production pattern scale demonstrates that sufficient confinement exists between the composite KLM Horizon and overlying HJ Horizon, which has also been confirmed based on the results of the 2011 Regional Pump Test.

- The testing conducted at the 5-spot pattern further confirms that sufficient confinement exists between the composite KLM Horizon and the N Horizon. As production is proposed in the upper KM Horizon of the composite KLM Horizon, the presence of the L and M Horizons provides an additional buffer between the KM Production Zone and the deeper N Horizon.

- Based on the lack of response observed during the 5-Spot Injection/Extraction Tests conducted (with no bleed) in the L and M Horizons, the overlying HJ Horizon, and the N Horizon, it is anticipated that commercial scale production operation in Resource Area 3 with bleed (likely on the order of 1%) will have little if any impact on the HJ and N Horizons.

- Aquifer properties derived from the 5-Spot Extraction Test are consistent with values obtained from the 2011 Regional Test, and further confirms that the KM Horizon has sufficient transmissivity for in-situ recovery mining operations.

- The 5-Spot Extraction and Injection Testing, and the 2011 Composite KLM Horizon Regional Pump Test (under separate cover) provide sufficient characterization of the composite KLM Horizon to support Nuclear Regulatory Commission (NRC) license and Wyoming Land Quality Division (LQD) permit amendments.

## 9.0 REFERENCES

Hantush, M.S. and C.E. Jacob, 1955. Non-steady radial flow in an infinite leaky aquifer. American Geophysical Union Transactions, vol., 36, pp. 95-100.

Petrotek Engineering Corporation, 2009. Lost Creek Regional Hydrologic Testing – Mine Unit 1, North and South Tests; prepared for Lost Creek ISR, LLC October 2009.

Petrotek Engineering Corporation, 2013. Lost Creek Hydrologic Test, Composite KLM Horizon Regional Pump Test, October, 2011; prepared for LC ISR LLC April 2013.