ESHID-602595

Los Alamos
NATIONAL LABORATORY
EST. 1943

Associate Directorate for Environmental Management
P.O. Box 1663, MS M992
Los Alamos, New Mexico 87545
(505) 606-2337

Environmental Management
P.O. Box 1663, MS M984
Los Alamos, New Mexico 87545
(505) 665-5658/FAX (505) 606-2132

Date: SEP 0 5 2017
Refer To: ADEM-17-0206
LAUR: 17-27466

John Kieling, Bureau Chief
Hazardous Waste Bureau
New Mexico Environment Department
2905 Rodeo Park Drive East, Building 1
Santa Fe, NM 87505-6303

RECEIVED

SEP 5 2017

NMED
Hazardous Waste Bureau

Subject: Completion Report for Groundwater Extraction Well CrEX-2

Dear Mr. Kieling:

Enclosed please find two hard copies with electronic files of the Completion Report for Groundwater Extraction Well CrEX-2.

If you have any questions, please contact Stephani Swickley at (505) 606-1628 (sfuller@lanl.gov) or Cheryl Rodriguez at (505) 665-5330 (cheryl.rodriguez@em.doe.gov).

Sincerely,

Bruce Robinson, Program Director
Environmental Remediation Program
Los Alamos National Laboratory

Sincerely,

David S. Rhodes, Director
Office of Quality and Regulatory Compliance
Los Alamos Environmental Management
Field Office

BR/DR/SS:sm

Enclosures: Two hard copies with electronic files – Completion Report for Groundwater Extraction Well CrEX-2 (EP2017-0104)

Cy: (w/enc.)
Cheryl Rodriguez, DOE-EM-LA
Stephani Swickley, ADEM ER Program

Cy: (w/electronic enc.)
Laurie King, EPA Region 6, Dallas, TX
Raymond Martinez, San Ildefonso Pueblo
Dino Chavarria, Santa Clara Pueblo
Steve Yanicak, NMED-DOE-OB, MS M894
emla.docs@em.doe.gov
Steve White, ADEM ER Program
Danny Katzman, ADEM ER Program
Public Reading Room (EPRR)
ADESH Records
PRS Database

Cy: (w/o enc./date-stamped letter emailed)
lasomailbox@nnsa.doe.gov
Peter Maggiore, DOE-NA-LA
Kimberly Davis Lebak, DOE-NA-LA
David Rhodes, DOE-EM-LA
Bruce Robinson, ADEM ER Program
Randy Erickson, ADEM
Jocelyn Buckley, ADESH-EPC-CP
John Bretzke, ADESH-EPC-DO
Michael Brandt, ADESH
William Mairson, PADOPS
Craig Leasure, PADOPS

LA-UR-17-27466
September 2017
EP2017-0104

Completion Report for Groundwater Extraction Well CrEX-2

Los Alamos
NATIONAL LABORATORY
EST. 1943

Prepared by the Associate Directorate for Environmental Management

Los Alamos National Laboratory, operated by Los Alamos National Security, LLC, for the U.S. Department of Energy (DOE) under Contract No. DE-AC52-06NA253 and under DOE Office of Environmental Management Contract No. DE-EM0003528, has prepared this document pursuant to the Compliance Order on Consent, signed June 24, 2016. The Compliance Order on Consent contains requirements for the investigation and cleanup, including corrective action, of contamination at Los Alamos National Laboratory. The U.S. government has rights to use, reproduce, and distribute this document. The public may copy and use this document without charge, provided that this notice and any statement of authorship are reproduced on all copies.

Completion Report for Groundwater Extraction Well CrEX-2

September 2017

Responsible project manager:

Stephani Swickley		Project Manager	Environmental Remediation Program	8/23/17
Printed Name	Signature	Title	Organization	Date

Responsible LANS representative:

Randall Erickson		Associate Director	Associate Directorate for Environmental Management	8/28/17
Printed Name	Signature	Title	Organization	Date

Responsible DOE-EM-LA representative:

David S. Rhodes		Office Director	Quality and Regulatory Compliance	8-31-2017
Printed Name	Signature	Title	Organization	Date

EXECUTIVE SUMMARY

This well completion report describes the drilling, sampling, well construction, development, aquifer testing, and dedicated pumping system installation for groundwater extraction well CrEX-2, located within Los Alamos National Laboratory (LANL or the Laboratory) in Los Alamos, New Mexico. The CrEX-2 extraction well is intended to remove hexavalent chromium–contaminated groundwater from within the regional aquifer in Mortandad Canyon at the Laboratory. The well was drilled and constructed in accordance with the New Mexico Environment Department's (NMED's) approval of the "Drilling Work Plan for Groundwater Extraction Well CrEX-2."

The CrEX-2 borehole was drilled using dual-rotary air-drilling methods to a total depth of 1240 ft below ground surface (bgs). Fluid additives used included potable water, foam, and polymer. Foam-assisted drilling was used to total depth.

The following geologic formations were encountered at CrEX-2: Unit 2 of the Tshirege Member, Unit 1v of the Tshirege Member, Unit 1g of the Tshirege Member, Cerro Toledo Formation, Otowi Member of the Bandelier Tuff, Guaje Pumice Bed of the Otowi Member, the Cerros del Rio basalt, and the Puye Formation.

Well CrEX-2 was completed as a single-screen well within the regional aquifer. The screened interval is set between 1129.9 and 1179.9 ft below ground surface (bgs) within Puye Formation sediments. The static depth to water after well installation was measured at 1113.7 ft bgs.

The well was completed in accordance with an NMED-approved well design. The well was developed and the regional aquifer groundwater met target water-quality parameters. Aquifer testing indicates regional groundwater extraction well CrEX-2 will perform effectively in meeting the planned objectives. A pumping system and transducer were installed in the well.

CONTENTS

Figures

Tables

Appendixes

Plates

Acronyms and Abbreviations

ADEM	Associate Directorate for Environmental Management
Amsl	above mean sea level
bgs	below ground surface
Consent Order	Compliance Order on Consent
DTW	depth to water
EES	Earth and Environmental Sciences (Laboratory group)
GGRL	Geochemistry and Geomaterials Research Laboratory
gpd	gallons per day
gpm	gallons per minute
hp	horsepower
I.D.	inside diameter
JWGS	Jet West Geophysical Services, LLC
LANL	Los Alamos National Laboratory
NAD	North American Datum
NC	not collected
NMED	New Mexico Environment Department
NTU	nephelometric turbidity unit
O.D.	outside diameter
PVC	polyvinyl chloride
TD	total depth
VOC	volatile organic compound

1.0 INTRODUCTION

This completion report summarizes borehole drilling, well construction, well development, aquifer testing, and dedicated pumping system installation for groundwater extraction well CrEX-2. The report is prepared in accordance with the guidance in Appendix F, Section II, of the June 2016 Compliance Order on Consent (the Consent Order). The CrEX-2 groundwater extraction borehole was drilled between March 5 and April 12, 2017, and was completed between April 13 and May 1, 2017, at Los Alamos National Laboratory (LANL or the Laboratory) for the Associate Directorate for Environmental Management (ADEM).

Well CrEX-2 is located on the south mesa above Mortandad Canyon (Figure 1.0-1), just south of the centroid of hexavalent chromium contamination in groundwater beneath the canyon. The objective of the extraction well is to remove chromium-contaminated groundwater at the top of the regional aquifer for treatment.

The CrEX-2 borehole was drilled to a total depth (TD) of 1240 ft below ground surface (bgs). During drilling, cuttings samples were collected at 10-ft intervals from ground surface to TD. Discrete groundwater samples were collected from the upper 100 ft of the regional aquifer and analyzed to optimize the placement of the well screen. An extraction well was installed with a screened interval between 1129.9 ft and 1179.9 ft bgs within Puye Formation volcaniclastic sediments. The depth to water (DTW) of 1113.7 ft bgs was recorded on May 6 after well installation.

Post-installation activities included well development, aquifer testing, surface completion, geodetic surveying, and pumping system installation. Future activities will include site restoration and waste management.

The information presented in this report was compiled from field reports and daily activity summaries. Records, including field reports, field logs, and survey information are on file at the ADEM Records Processing Facility. This report contains brief descriptions of activities and supporting figures, tables, and appendixes associated with the CrEX-2 project.

2.0 ADMINISTRATIVE PLANNING

The following documents were prepared to guide activities associated with the drilling, installation, and development of extraction well CrEX-2:

- “Drilling Work Plan for Groundwater Extraction Well CrEX-2” (LANL 2017, 602160);
- “Storm Water Pollution Prevention Plan, CrEX-2 Well Pad and Construction Support Activities” (LANL 2017, 602534);
- “IDW [Integrated Work Document] for Drilling CrEX-2 and CrEX-4” (Holt Services Inc. 2017, 602533);
- “Spill Prevention Control and Countermeasures Plan for the ADEP Groundwater Monitoring Well Drilling Operations, Los Alamos National Laboratory, Revision 6” (North Wind Inc. 2011, 213292); and
- “Waste Characterization Strategy Form for Chromium Well CrEX-1” and amendments (LANL 2014, 600344; LANL 2014, 600345; LANL 2015, 600346; LANL 2015, 600965; LANL 2016, 601208; LANL 2016, 601423).

3.0 DRILLING ACTIVITIES

This section describes the drilling approach and provides a chronological summary of field activities conducted at extraction well CrEX-2.

3.1 Drilling Approach

The drilling method, approach, equipment, and drill casing were selected to drill CrEX-2 to the required depth and to ensure that a sufficiently sized drill casing was used to meet the required 3-in.-minimum annular thickness of the filter pack around an 8.62-in.–outside-diameter (-O.D.) well screen.

Dual-rotary drilling methods using a Foremost DR-24HD drill rig were employed to drill the CrEX-2 borehole. The drill rig was equipped with conventional drilling rods, tricone bits, downhole hammer bits, deck-mounted air compressor, auxiliary compressors, and general drilling equipment. Three sizes of A53 grade B flush-welded mild carbon-steel casing (18-in.-O.D., 14-in. and 10-in.–inside diameter [-I.D.]) were used for drilling CrEX-2.

The dual-rotary drilling technique at CrEX-2 used filtered compressed air and fluid-assisted air to evacuate cuttings from the borehole during drilling. Drilling fluids, other than air, used in the borehole included potable water and a mixture of potable water with Baroid Quik Foam foaming agent and Baroid EZ-Mud polymer emulsion. The fluids were used to cool the bit and help lift cuttings from the borehole.

3.2 Chronological Drilling Activities for the CrEX-2 Well

The Foremost DR-24HD drill rig, drilling equipment, and supplies were mobilized to the CrEX-2 drill site from March 3 to 5, 2017. The equipment and tooling were decontaminated before equipment was mobilized to the site. Drilling started on March 5 by advancing a temporary 18.0-in. surface conductor casing to 55 ft bgs.

From March 6 to 7, a 17.0-in. open hole was advanced from 55 ft to 920 ft bgs through the Cerros del Rio basalt and into the top of the Puye Formation. Open-hole video and natural gamma and neutron logs were collected to depth by Laboratory personnel on March 8. From March 8 to 10, 14-in. casing was installed in the open borehole. The borehole was advanced to 1120 ft bgs with 14-in. casing-advance and dual-rotary methods using a 15-in. underreaming hammer bit on March 11 and 12.

Between March 12 and 15, 10-in. casing was installed and advanced to 1220 ft bgs to sample water. Natural gamma and neutron logs were collected at TD by Jet West Geophysical Services, LLC (JWGS) on March 16. No drilling work occurred between March 18 and 24 while the field crew was on days off. From March 25 to April 10, discrete groundwater samples were collected from a temporary well constructed in the CrEX-2 borehole (see section 4.2). Water sampling involved building a temporary well in the borehole at five evenly spaced zones (depths) and retracting the 10-in. casing to expose the well to the formation. Originally, the plan was to retract the 10-in. casing with the drive shoe still attached to the bottom of the casing string. This approach proved impossible, and ultimately, the 10-in. casing was advanced to 1240 ft bgs to cut off the drive shoe at a depth great enough to keep the shoe below final well construction activities.

Following water sampling activities, the temporary well and the entire string of 10-in. casing were removed from the borehole and 14-in. casing advance drilling resumed from 1120 ft bgs. The borehole was advanced to a TD of 1201.5 ft bgs with 14-in. casing and a 15-in. underreaming hammer bit on April 11 and 12. The drive shoe was cut off the 14-in. casing at 1198.6 ft bgs on the April 12 night shift, thereby concluding drilling activities.

4.0 SAMPLING ACTIVITIES

This section describes the cuttings and groundwater sampling activities for extraction well CrEX-2. All sampling activities were conducted in accordance with applicable quality procedures.

4.1 Cuttings Sampling

Cuttings samples were collected from the CrEX-2 extraction well borehole at 10.0-ft intervals from ground surface to the TD of 1240 ft bgs. At each interval, the drillers collected approximately 500 mL of bulk cuttings from the discharge cyclone, placed them in plastic bags, labeled them, and stored them on-site. Radiological control technicians screened the cuttings before they were removed from the site. All screening measurements were within the range of background values. The cuttings samples were delivered to the Laboratory's archive facility at the conclusion of drilling activities.

Section 5.1 of this report summarizes the stratigraphy encountered at well CrEX-2.

4.2 Groundwater Sampling

To optimize the final extraction well design, a better understanding chromium concentrations at depth was necessary. Relying on air-lifted samples from the drill tooling while underreaming 14-in. drill casing was considered inadequate because of the amount of mixing of both formation water and drilling water. The approach outlined below utilized a temporary well constructed in the borehole and a submersible pump.

The advancement of the 14-in. casing was stopped at the top of the aquifer at 1120 ft bgs. Ten-inch casing was then installed and advanced with conventional dual-rotary techniques to the anticipated total depth of the borehole at 1220 ft bgs. The drill bit was a 9 7/8-in. tricone bit and was smaller than the I.D. of the 10-in. casing to reduce the annular space/volume between the casing and borehole wall. A temporary 5-in. well with an 8-ft stainless-steel, pipe-based screen interval was constructed in the 10-in. borehole. The annular space around the well screen was sand-packed with 10/20 filter-grade silica sand (adjacent to screen slots) extending 1 ft to 2 ft above and below the screen slot interval and with 20/40 transition sand emplaced 5 ft above and below the primary filter interval. The 10-in. drill casing was retracted to expose the screen interval to the native formation while the temporary well was constructed. Bentonite was not used for any annular backfilling during the temporary well constructions. This method relied on the very small annular space between the 10-in. casing and native formation, the low permeability of 20/40 sand, and pumping at a relatively low rate to obtain discrete samples.

A 4-in. submersible pump was installed in the temporary well on stainless-steel drop pipe to purge and sample. The pump was capable of producing approximately 8 gallons per minute (gpm) but was held to 5 gpm for sampling. The purge volumes for each sampling interval were calculated as follows: 20 casing volumes for 10-in. casing at a (nominal) length of 10 ft plus introduced water volume for the 20-ft drilling interval being sampled + 10%. [For example: 1 casing volume: (4.1 gal./ft)(10 ft) = 41 gal.; (41 gal.)(20) = 820 gal.; 820 gal. + introduced volume = X; (X)(1.1) = purge volume.]

The well construction and purging/sampling procedure were repeated for five equally spaced intervals throughout the bottom 100 ft of saturated borehole in an upward fashion. The well screen intervals for the sampling were as follows: 1207.3 ft to1215.0 ft bgs, 1187.2 ft to1194.9 ft bgs, 1167.3 ft 1175.0 ft bgs, 1147.3 ft to1155.0 ft bgs, and 1127.3 ft to1135.0 ft bgs. Samples were collected and analyzed at the Laboratory's Geochemistry and Geomaterials Research Laboratory for anions and metals. The New Mexico Environment Department (NMED) also analyzed samples for chromium in the field using HACH kits. The results of chromium sampling are presented in Table 4.2-1.

Groundwater sampling results indicate that chromium contamination does not extend below approximately 1175 ft bgs at the CrEX-2 location. The two lowermost sampling intervals were within the range of background for chromium and did not change with purge duration. The three uppermost sampling intervals all indicated elevated chromium concentrations that were increasing as the purge duration increased. The groundwater sampling results were used to prepare the well design.

Upon completion of water sampling, the pumping system, temporary well, and 10-in.casing were removed from the borehole. Drilling with 14-in. casing resumed to a TD of 1201.5 ft bgs.

5.0 GEOLOGY AND HYDROGEOLOGY

A brief description of the geologic and hydrogeologic features encountered at CrEX-2 is presented below. The Laboratory's geology task leader and geologists examined the cuttings to determine the geologic contacts and hydrogeologic conditions. Drilling observations, video logging, geophysics, and water-level measurements were used to characterize groundwater occurrences.

5.1 Stratigraphy

Rock units for the CrEX-2 borehole are presented below in order of youngest to oldest in stratigraphic occurrence. Lithologic descriptions are based on binocular microscope analysis of drill cuttings collected from the discharge hose. Figure 5.1-1 illustrates the stratigraphy at CrEX-2.

Tshirege Member, Unit Qbt 2 (0–60 ft bgs)

Cuttings from the near-surface consist of weathered light brown tuff fragments mixed with abundant crystals and minor lava clasts in a light brownish-gray matrix. Fragments are poorly sorted, clast-supported, and massive. Lava fragments are generally sparse, light to dark gray, porphyritic, and angular to subrounded. With depth, the cuttings appear less weathered, light pinkish-gray, nonwelded, consolidated, and massive. Tuff fragments are crystal-rich and lightly coated with devitrified tuffaceous matrix. Few devitrified pumice clasts containing aggregates of microcrystalline crystals were noted.

Tshirege Member, Unit Qbt 1v (60–170 ft bgs)

The contact with the overlying Unit Qbt 2 is defined by distinct color and lithologic transitions. The Qbt 1v unit is mostly pulverized, light to medium gray, nonwelded, crystal-rich, devitrified, and massive. The crystals are mostly quartz and feldspars with few dark minerals and are lightly coated with white devitrified tuffaceous matrix. Tuff and pumice fragments are nonwelded, massive, devitrified, and partially coated with devitrified matrix as well. The pulverized matrix is devitrified and grayish to white. Devitrified pumice clasts commonly contain microcrystalline mineral aggregates in vesicles. Felsic lava fragments are sparse throughout the unit and are mostly coated with white, devitrified tuffaceous silt. The Qbt 1v cuttings show no lithologic variation with depth except for few devitrified light orange devitrified pumice clasts and an obsidian or perlite fragment near the base of the unit.

Tshirege Member, Unit Qbt 1g (170–220 ft bgs)

The contact is defined by abundant poorly sorted, matrix-supported, unconsolidated, and subrounded to rounded glassy pumices mixed with minor devtrified tuff and felsic lava clasts in a crystal-rich pulverized glassy matrix. A few obsidian fragments and mafic minerals were also noted. Pumices are mostly light pinkish-gray, but a few medium-gray fragments were also noted. The felsic lavas consist of light gray and pale red fragments. All fragments are lightly coated with glassy tuffaceous silt. The amounts of pumice and felsic lava fragments increase with depth.

Cerro Toledo Formation, Qct (220–260 ft bgs)

The contact between Qbt 1g and Qct is poorly defined because of similar pumice-rich lithology and color. However, the Neutron (API) log for CrEX-2 and the gamma log spectrum for CH-1 aided in the placement of the upper and lower contacts of Qct in CrEX-2. The Qct cuttings along the contact with Qbt 1g consists of poorly sorted, matrix-supported, and subrounded to rounded pumices in a light pinkish-gray silty matrix mixed with abundant fine- to coarse-grained clear quartz and feldspar grains and a few mafic minerals. Most of the pumices are lightly coated with light pinkish-gray glassy matrix. Minor light to dark gray and pale red felsic lava fragments and a few obsidian fragments were also noted.

Otowi Member of the Bandelier Tuff, Qbo (260–580 ft bgs)

Cuttings are mostly poorly sorted, subrounded to rounded, matrix-supported, and crystal-rich. The amounts of gray pumice and light gray felsic lava clasts with minor dark gray and pale red lava fragments are comparable unlike the overlying Qct samples. Quartz and feldspar grains represent a significant fraction of the cuttings. A few mafic minerals and obsidian fragments are also present. Moreover, the pumices, lava fragments, and coarse minerals are not coated with tuffaceous silt. In some cases, the amounts of medium gray and pale red lava fragments, which are subrounded to rounded and generally poorly sorted, are significantly more abundant than the pumice fraction (e.g., 310–440-ft depth). In other cases, the amount of crystals dropped drastically (e.g., 370–390-ft depth). The clast size of the fragments also varied randomly with depth from moderately to poorly sorted fine to gravelly sand and does not appear to be an artifact of drilling. For example, a fine sand-dominated fraction (460–480-ft depth) occurs in the lower half of the Otowi Member deposit. More lithologic variations were noted in the lower part of the Otowi Member ash-flow tuff sequence. The 480–530-ft depth interval contains comparable amounts of poorly sorted and matrix-supported subrounded white pumices and subangular to subrounded dark gray and pale red lava fragments. The matrix contains abundant fine-to coarse grained crystals. The amounts of pumice and lava fragments continued to vary with depth and in some cases, crystal-dominated fractions were noted (e.g., 530–550-ft depth bgs).

Guaje Pumice Bed of the Otowi Member of the Bandelier Tuff, Qbog (580–600 ft bgs)

The unit consists of moderately sorted and clast-supported dense white pumice mixed with abundant medium to dark gray lava fragments. The lava and white pumice fragments are lightly dusted with white tuffaceous silt. Crystals are abundant.

Upper Puye Formation, Tpf (600–620 ft bgs)

The upper Puye Formation sediments consist of a mixture of poorly sorted, matrix supported, and unconsolidated light gray and angular felsic lava fragments and minor sandstone clasts in a crystal-rich light brownish-gray tuffaceous silty sand matrix. The lithic-rich sediments are contaminated with abundant reworked pumice from the overlying Guaje Pumice Bed. Although the upper Puye sediments are dominated by light gray dacite lava fragments, the amount of silty sandstone fragments increased with depth. A few Rendija Canyon lava fragments containing abundant tiny prismatic bronze-like weathered mafic minerals were also noted.

Cerros del Rio Basalt, Tb4 (620–920 ft bgs)

At least two types of basaltic lava flows were noted within the CrEX-2 well. The uppermost flow is dark gray, fresh-looking vesicular lava flow that is sparsely porphyritic with phenocrysts of plagioclase, olivine, and fractured and partially altered coarse pyroxene crystals. Vesicle walls are coated with vapor phase microcrystalline minerals. Basaltic fragments are lightly coated with grayish tuffaceous silt. Some of the basaltic fragments are scoriaceous and partially weathered. The amount of scoria increased with depth. Few fragments of felsic lava fragments, light brownish-gray sandstone, and pumice were also noted as contaminants.

The dark gray vesicular basalt appears to be confined to the uppermost part of the basaltic sequence. With increasing depth, the basaltic cuttings are dominated by medium gray, vesicular, and porphyritic basaltic lava fragments, starting at the 670–680-ft depth interval. The medium gray basalt fragments commonly contain coarse grains of partially weathered and fractured pyroxene, olivine, and plagioclase. Some of the basalt clasts are palagonitized and oxidized. In the middle section of the basaltic lava sequence, more scoriaceous and medium gray lava fragments were noted. The vesicles within the scoriaceous clasts are coated or partially filled with brown alteration products. Pumice and felsic lava fragments are commonly present within the cuttings. More mixed medium and dark gray porphyritic and vesicular basaltic lava fragments were encountered within the lower half of the lava sequence, probably representing discrete lava flows, which is consistent with the spectra from the induction and neutron logging. However, porphyritic medium gray basaltic lava is the dominant flow in the lowermost part of the volcanic sequence (i.e., 830–920-ft depth bgs).

Puye Formation, Tpf (920–1150 ft bgs)

The cuttings are mostly unconsolidated, poorly sorted, and clast-supported with sparse free crystals and no matrix material. Abundant light to dark gray and minor pale red felsic lava fragments that are subrounded to rounded and lightly coated with tuffaceous sediments are common. A few Rendija Canyon lava fragments were also noted. Crystals are sparse. With increasing depth (e.g., 1000–1010-ft depth bgs), the light to dark gray felsic lavas became sparse and more subrounded to rounded light brownish-gray lava fragments are more abundant. More Redija Canyon clasts were also noted. Poorly sorted, clast-supported, and crystal-poor light brownish-gray felsic lava fragments, up to 2.5 cm (~1 in.) in size, persisted for most of the Puye Formation sequence (i.e., 920–1120-ft depth bgs).

In the lowermost part of the Puye Formation sequence (e.g., 1125–1130 ft bgs), the cuttings are poorly sorted but matrix-supported and are dominated by subangular to subrounded light brownish-gray clasts with minor medium to dark gray lava fragments embedded in significant amounts of fine- to medium-sandy matrix. However, the matrix content decreased significantly (1130–1140 ft bgs) and became an important component again (1140–1150 ft bgs). The basal Puye Formation is sandy gravel, moderately sorted, and contains a mixture of subangular to subrounded light brownish-gray and medium gray lava fragments. The fragments are lightly coated with tuffaceous silty sand matrix. Rendija Canyon lava fragments are common, but the crystal content is sparse.

Pumiceous Puye Formation (1150–1240 ft bgs)

Starting at the 1150–1155-ft depth interval, light brownish-gray pumice clasts mixed with minor medium gray felsic lava fragments lightly coated with tuffaceous silt define the transition from the usual type of dacite lava fragment–dominated Puye Formation to a reworked pumice deposit similar to the Miocene pumiceous. The pumice deposit is designated as transitional because it is interbedded within a sequence of dacite lava–dominated Puye Formation, which contains variable amounts of Rendija Canyon lava fragments. The Rendija Canyon lava fragments are similar in age to the Puye Formation. The pumice fragments are moderately sorted, subangular to subrounded, and matrix-supported. Most of the pumice-rich deposits are gravelly sand, consisting of more fine- to medium-grained silty sand fraction (<1.4 mm) that is more abundant than the coarser fragments. The coarser clast are up to 2.5 cm in size. With increasing depth, abundant poorly to moderately sorted and matrix-dominated white and light brownish-gray pumice fragments were noted. Crystals, Rendija Canyon clasts, and dacite lava fragments are sparse.

The cuttings from the 1200–1205-ft depth interval consist of poorly sorted and matrix-dominated gravelly sand containing comparable amounts of light to dark gray felsic lava and pumice fragments. The fragments are lightly coated with light brownish-gray tuffaceous silt and are subangular to subrounded. Crystal are generally sparse but more abundant in the fine- to medium-grained silty sand fraction (<1.4 mm). A few grains of Rendija Canyon clasts were also identified. In the lowermost part of the CrEX-2 well, beds of poorly sorted and matrix-supported medium to dark gray and pale red felsic lava fragments that are similar to the Puye Formation alternate with pumiceous deposits. For example, the cuttings from the 1210–1215-ft and 1220–1230-ft depth intervals contain abundant felsic lava fragments and sparse pumice clasts. Rendija Canyon lava fragments are common. Moreover, the cuttings are contaminated by abundant well-sorted, light yellowish-gray quartz sand added during well completion activities. In contrast, the basal deposits (1230–1240-ft depth) are pumiceous, consisting of poorly sorted and matrix-supported light brownish-gray and subangular to subrounded pumice clasts. The rock fragments are lightly coated with tuffaceous silt and the fine- to medium-grained fraction (<1.4 mm) is more abundant than the coarse fragments that are up to 2 cm in size. More crystals are present in the finer fraction. The amounts of light to medium gray dacite lava and Rendija Canyon fragments are insignificant in the pumiceous deposits.

5.2 Groundwater

Drilling at CrEX-2 proceeded without any indications of groundwater while the 14-in. casing was advanced to 1120 ft bgs. The field crew detected water production from the borehole while the 10-in. casing was advanced at approximately 1140 ft bgs. The water level was 1112.6 ft bgs on April 11, 2017, before well installation. The DTW in the completed well was 1113.7 ft bgs on May 6.

6.0 BOREHOLE LOGGING

On March 8, 2017, Laboratory video and gamma and induction logs were run in the open borehole (Table-6.0-1). Video was run from the surface to 848 ft bgs because of drilling foam standing in the bottom of the borehole. The video log is included in Appendix B (on DVD included with this report). The gamma and induction logs were run by Laboratory personnel from 920 ft bgs to surface. The borehole was logged by JWGS upon reaching a drilling depth of 1220 ft bgs with the 10-in. casing on March 16. Logging consisted of cased-hole gamma ray and neutron density. The gamma and neutron logs are included in Appendix C (on CD included with this report).

On May 23, 2017, a video log was run to document the condition of the completed well.

7.0 WELL INSTALLATION CREX-2 EXTRACTION WELL

The CrEX-2 well was installed between April 13 and May 1, 2017.

7.1 Well Design

The CrEX-2 well was designed in accordance with the objectives outlined in the "Drilling Work Plan for Groundwater Extraction Well CrEX-2" (LANL 2017, 602160). The results from the borehole groundwater sampling, drill cuttings, downhole geophysics, and DTW were reviewed and considered for the final design. The objectives in setting the screen within the contaminated portion of the aquifer were to optimize capture of chromium-contaminated water and therefore optimize the effect of the capture zone that will be established with long-term pumping at CrEX-2.

Extraction well CrEX-2 was designed with a screened interval between 1130.0 ft and 1180.0 ft bgs to optimize chromium removal and hydraulic capture. The well design was submitted to NMED on April 11, 2017, and approved later that day. The final CrEX-2 design and NMED's approval are included in Appendix A.

7.2 Well Construction

The CrEX-2 extraction well was constructed of 8.0-in.-I.D./8.63-in.-O.D. type A304 passivated stainless-steel beveled casing fabricated to American Society for Testing and Materials A312 standards. The screened section utilized two 20.0-ft lengths and one 10.0-ft length of 8.0-in.-I.D. 0.040-in. slot, rod-based wire-wrapped screens to make up the 50.0-ft-long screen interval. Stainless-steel centralizers (two sets of four) were welded to the well casing approximately 5.0 ft above and below the screened interval. A 10.0-ft-long stainless-steel sump was placed below the bottom of the well screen. All individual casing and screen sections were welded together using compatible stainless-steel welding rods. A 2.0-in. steel tremie pipe was used to deliver backfill and annular fill materials downhole during well construction.

The well casing was welded together and installed into the borehole from April 13 to 16, 2017. Backfilling began on April 17 and was completed on May 1.

Figure 7.2-1 presents an as-built schematic showing construction details for the completed well. Table 7.2-1 presents the annular fill materials used in CrEX-2.

The lower bentonite backfill was installed on April 17 from 1198.6 ft to 1185.5 ft bgs using 15.9 ft^3 of 3/8-in. bentonite chips and ¼-in. coated bentonite pellets. The filter pack was installed between April 18 and 20 from 1185.5 ft to 1125.0 ft bgs using 44.7 ft^3 of 10/20 silica sand. The filter pack was surged to promote compaction. The fine-sand collar was installed above the filter pack from 1125.0 ft to 1122.9 ft bgs using 1.3 ft^3 of 20/40 silica sand. From April 20 to May 1, the bentonite seal was installed from 1122.9 ft to 60.1 ft bgs using 1618.3 ft^3 of 3/8-in. bentonite chips. On May 1, a cement seal was installed from 60.1 ft to 10.0 ft bgs. The cement seal used 77.5 ft^3 of Portland Type I/II/V cement.

8.0 POST-INSTALLATION ACTIVITIES

Following well installation at CrEX-2, the well was developed and aquifer pumping tests were conducted. A dedicated pumping system was installed. The wellhead surface completion will be constructed as part of the treatment system piping and infrastructure project in fall 2017. A geodetic survey has been performed. Site-restoration activities have been completed.

8.1 Well Development

The well was developed between May 3 and May 13, 2017. Initially, the screened interval was swabbed and bailed from May 3 to 4 to remove formation fines in the filter pack and well sump. The swabbing tool employed was a 7.5-in.-O.D., 1-in.-thick nylon disc attached to a weighted steel rod. The wireline-conveyed tool was drawn repeatedly across the screened interval, causing a surging action across the screen and filter pack. The bailer was repeatedly lowered by wireline, filled, withdrawn from the well, and emptied into the cuttings pit until the sump was cleaned out. Bailing continued until water clarity visibly improved. Approximately 1200 gal. of groundwater was removed during bailing activities.

From May 4 to May 13, well development was performed with a submersible pump. A 30-horsepower (hp), 6-in. submersible pump was installed in the well for the pumping stage of well development. The screened interval was pumped from bottom to top in 2-ft increments. The pump column did not have check valves installed and the pump was turned off repeatedly during pumping allowing the column of water to backflush into the well screen. Pumping level observations indicated poor production and a low specific capacity. The CrEX-2 well was treated twice with Baroid Aqua Clear to remove formation fines and silt in the filter pack and near-bore formation. Aqua Clear is a phosphate-free dispersant. The solution was mixed with potable water at a concentration of 5 gal. of Aqua Clear to 1500 gal. water and introduced into the screen interval. The solution was surged throughout the screen interval and allowed to sit in the well for approximately 12 h on both occasions. Bailing preceded pumping and a significant amount of formation fines were removed on both occasions. Pump development was completed on May 13. The Aqua Clear treatments resulted in an improvement in specific capacity from approximately 1 gpm/ft to approximately 6.5 gpm/ft.

Approximately 46,070 gal. of groundwater was purged with the submersible pump during well development.

8.1.1 Well Development Field Parameters

The field parameters of turbidity, temperature, and pH were monitored via a flow-through cell at CrEX-2 during well development. The field parameter measurements toward the end of development on May 13, 2017, were pH of 7.56, temperature of 19.73°C, and turbidity of 2.66 nephelometric turbidity units (NTU). Field water-quality parameters for development and aquifer testing are presented in Table 8.1-1.

8.2 Aquifer Testing

Step testing was conducted on May 14, 2017. The well was pumped in three steps at 39 gpm, 55 gpm, and 72.5 gpm in 1-h increments. A total of 9997 gal. of water was removed during the step testing. A 24-h constant rate aquifer test was conducted between May 14 and 15, followed by a 24-h recovery period. The average pumping rate for the 24-h test was approximately 65 gpm. A 30-hp pump was used for the aquifer tests. A total of approximately 92,625 gal. of groundwater was purged during the constant rate aquifer testing. Turbidity, temperature, and pH were measured during the aquifer tests. The CrEX-2 aquifer test results and analysis are presented in Appendix D.

8.3 Pumping System Installation

A dedicated pumping system for CrEX-2 was installed between July 4 and July 6, 2017. The system uses a 6-in. Grundfos submersible pump and 40-hp Franklin Electric motor. The pump control panel includes a variable-frequency drive that will allow for flow control via motor speed manipulation. The pump riser pipe consists of 3.5-in. O.D. American Petroleum Institute threaded and coupled 10-round, N-80 galvanized steel. Two 1.0-in.-I.D. schedule 80 polyvinyl chloride (PVC) tubes are installed along with, and banded to, the pump column. Both PVC tubes are equipped with a 5.0-ft section of 0.010-in. slotted screen and a closed bottom. A dedicated In-Situ Level Troll 500 transducer is installed in one of the tubes, and the second tube will be used for manual water-level measurements.

Pumping system details for CrEX-2 are presented in Figure 8.3-1a. Figure 8.3-1b presents technical notes for the well.

8.4 Wellhead Completion

A reinforced concrete subsurface vault has been installed at the CrEX-2 wellhead. The vault will be slightly elevated above ground surface and will provide long-term structural integrity for the well. A brass monument marker has been embedded in the vault. Six steel bollards, covered by high-visibility plastic sleeves, will be set at the outside edges of the pad to protect the well from accidental vehicle damage. They are designed for easy removal to allow access to the well. Plate 1 shows details of the vault and wellhead completion.

8.5 Geodetic Survey

A licensed professional land surveyor has conducted a geodetic survey of the wellhead and vault. The survey data conforms to Laboratory Information Architecture project standards IA-CB02, “GIS Horizontal Spatial Reference System,” and IA-D802, “Geospatial Positioning Accuracy Standard for A/E/C and Facility Management.” All coordinates are expressed relative to New Mexico State Plane Coordinate System Central Zone 83 (North American Datum [NAD] 83); elevation will be expressed in feet above mean sea level (amsl) using the National Geodetic Vertical Datum of 1929. Survey points include the top of the monument marker in the concrete vault and the top of the stainless-steel well casing. Survey data for CrEX-2 is presented in Table 8.5-1.

8.6 Waste Management and Site Restoration

Waste generated from the CrEX-2 project includes drilling fluids, drill cuttings, and contact waste. A summary of the waste characterization samples collected during drilling, construction, and development of the CrEX-2 well is presented in Table 8.6-1. All waste streams produced during drilling and development activities were sampled in accordance with the “Waste Characterization Strategy Form for Chromium Well CrEX-1” and amendments (LANL 2014, 600344; LANL 2014, 600345; LANL 2015, 600346; LANL 2015, 600965; LANL 2016, 601208; LANL 2016, 601423). Development water was treated and land applied under Discharge Permit 1793 (NMED 2015, 600632).

Cuttings produced during drilling were sampled, and analytical results were evaluated against the land-application criteria found in ENV-RCRA-QP-011.1, “Land Application of Drill Cuttings.” The cuttings met the criteria and were land applied by back-filling the cuttings pit.

Characterization of contact waste will be based upon acceptable knowledge, referencing the analyses of the waste samples collected from the drilling fluids, drill cuttings, and decontamination fluids. A waste profile form will be completed, and the contact wastes will be removed from the site following land application of the pit-contained drill cuttings. The pit liner will be included in the contact waste disposal materials.

Site restoration activities are conducted by Maintenance and Site Services personnel at the Laboratory. Activities include evaporating drilling fluids, removing cuttings from the pit, and managing the development/pump test fluids in accordance with applicable procedures. The polyethylene liner has been removed following land application of the cuttings, and the containment area berms have been removed and leveled. Activities also include backfilling and regrading the containment area, as appropriate.

9.0 DEVIATIONS FROM PLANNED ACTIVITIES

Drilling and well construction at CrEX-2 were performed as specified in "Drilling Work Plan for Groundwater Monitoring Well CrEX-2" (LANL 2017, 602160). Groundwater sampling from the regional aquifer was not part of the drilling work plan but was planned and coordinated with input from NMED.

10.0 ACKNOWLEDGMENTS

Holt Services, Inc., drilled and installed extraction well CrEX-2.

11.0 REFERENCES AND MAP DATA SOURCES

11.1 References

The following reference list includes documents cited in this report. Parenthetical information following each reference provides the author(s), publication date, and ERID or ESHID. This information is also included in text citations. ERIDs were assigned by ADEM's Records Processing Facility (IDs through 599999), and ESHIDs are assigned by the Environment, Safety, and Health Directorate (IDs 600000 and above). IDs are used to locate documents in the Laboratory's Electronic Document Management System and in the Master Reference Set. The NMED Hazardous Waste Bureau and ADEM maintain copies of the Master Reference Set. The set ensures that NMED has the references to review documents. The set is updated when new references are cited in documents.

Holt Services Inc., March 1, 2017. "IWD [Integrated Work Document] for Drilling CrEX-2 and CrEX-4," Los Alamos, New Mexico. (Holt Services, Inc., 2017, 602533)

LANL (Los Alamos National Laboratory), February 28, 2014. "Waste Characterization Strategy Form for Chromium Well CrEX-1," Los Alamos National Laboratory, Los Alamos, New Mexico. (LANL 2014, 600344)

LANL (Los Alamos National Laboratory), August 12, 2014. "Amendment #1 to the Waste Characterization Strategy Form for Chromium Well CrEX-1," Los Alamos National Laboratory, Los Alamos, New Mexico. (LANL 2014, 600345)

LANL (Los Alamos National Laboratory), January 28, 2015. "Amendment #2 to the Waste Characterization Strategy Form for Chromium Well CrEX-1," Los Alamos National Laboratory, Los Alamos, New Mexico. (LANL 2015, 600346)

LANL (Los Alamos National Laboratory), August 10, 2015. "Amendment #3 to the Waste Characterization Strategy Form for Chromium Well CrEX-1," Los Alamos National Laboratory, Los Alamos, New Mexico. (LANL 2015, 600965)

LANL (Los Alamos National Laboratory), February 9, 2016. "Amendment #4 to the Waste Characterization Strategy Form for Chromium Well CrEX-1," Los Alamos National Laboratory, Los Alamos, New Mexico. (LANL 2016, 601208)

LANL (Los Alamos National Laboratory), April 25, 2016. "Amendment #5 to the Waste Characterization Strategy Form for Chromium Well CrEX-1," Los Alamos National Laboratory, Los Alamos, New Mexico. (LANL 2016, 601423)

LANL (Los Alamos National Laboratory), January 25, 2017. "Storm Water Pollution Prevention Plan, CrEX-2 Well Pad and Construction Support Activities, Los Alamos National Laboratory," Los Alamos National Laboratory, Los Alamos, New Mexico. (LANL 2017, 602534)

LANL (Los Alamos National Laboratory), February 13, 2017. “Drilling Work Plan for Groundwater Extraction Well CrEX-2,” Los Alamos National Laboratory letter ADEM-17-0027 to J. Kieling (NMED-HWB) from B. Robinson (LANL) and D. Rhodes (DOE-EM-LA), Los Alamos, New Mexico. (LANL 2017, 602160)

NMED (New Mexico Environment Department), July 27, 2015. “Discharge; Permit, DP-1793, Los Alamos National Laboratory,” New Mexico Environment Department letter to G.E. Turner (DOE) and A. Dorries (LANL) from M. Hunter (NMED-GWQB), Santa Fe, New Mexico. (NMED 2015, 600632)

North Wind Inc., July 2011. “Spill Prevention Control and Countermeasures Plan for the ADEP Groundwater Monitoring Well Drilling Operations, Los Alamos National Laboratory, Revision 6,” plan prepared for Los Alamos National Laboratory, Los Alamos, New Mexico. (North Wind, Inc., 2011, 213292)

11.2 Map Data Sources

Point Feature Locations of the Environmental Restoration Project Database; Los Alamos National Laboratory, Waste and Environmental Services Division, EP2008-0109; 12 April 2010.

Hypsography, 100 and 20 Foot Contour Interval; Los Alamos National Laboratory, ENV Environmental Remediation and Surveillance Program; 1991.

Surface Drainages, 1991; Los Alamos National Laboratory, ENV Environmental Remediation and Surveillance Program, ER2002-0591; 1:24,000 Scale Data; Unknown publication date.

Paved Road Arcs; Los Alamos National Laboratory, KSL Site Support Services, Planning, Locating and Mapping Section; 06 January 2004; as published 28 May 2009.

Dirt Road Arcs; Los Alamos National Laboratory, KSL Site Support Services, Planning, Locating and Mapping Section; 06 January 2004; as published 28 May 2009.

Structures; Los Alamos National Laboratory, KSL Site Support Services, Planning, Locating and Mapping Section; 06 January 2004; as published 28 May 2009.

Technical Area Boundaries; Los Alamos National Laboratory, Site Planning & Project Initiation Group, Infrastructure Planning Division; 4 December 2009.

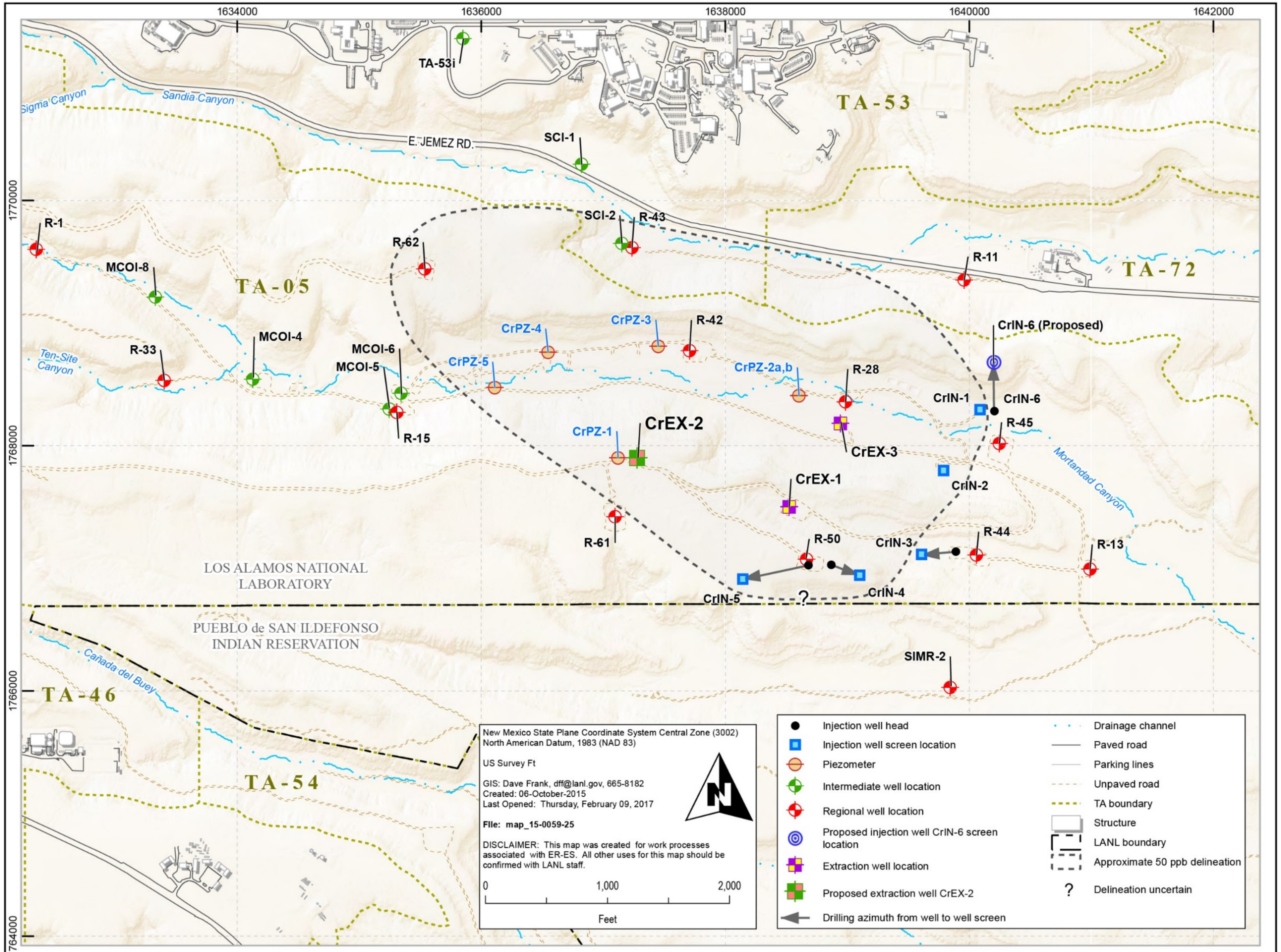


Figure 1.0-1 Location of extraction well CrEX-2

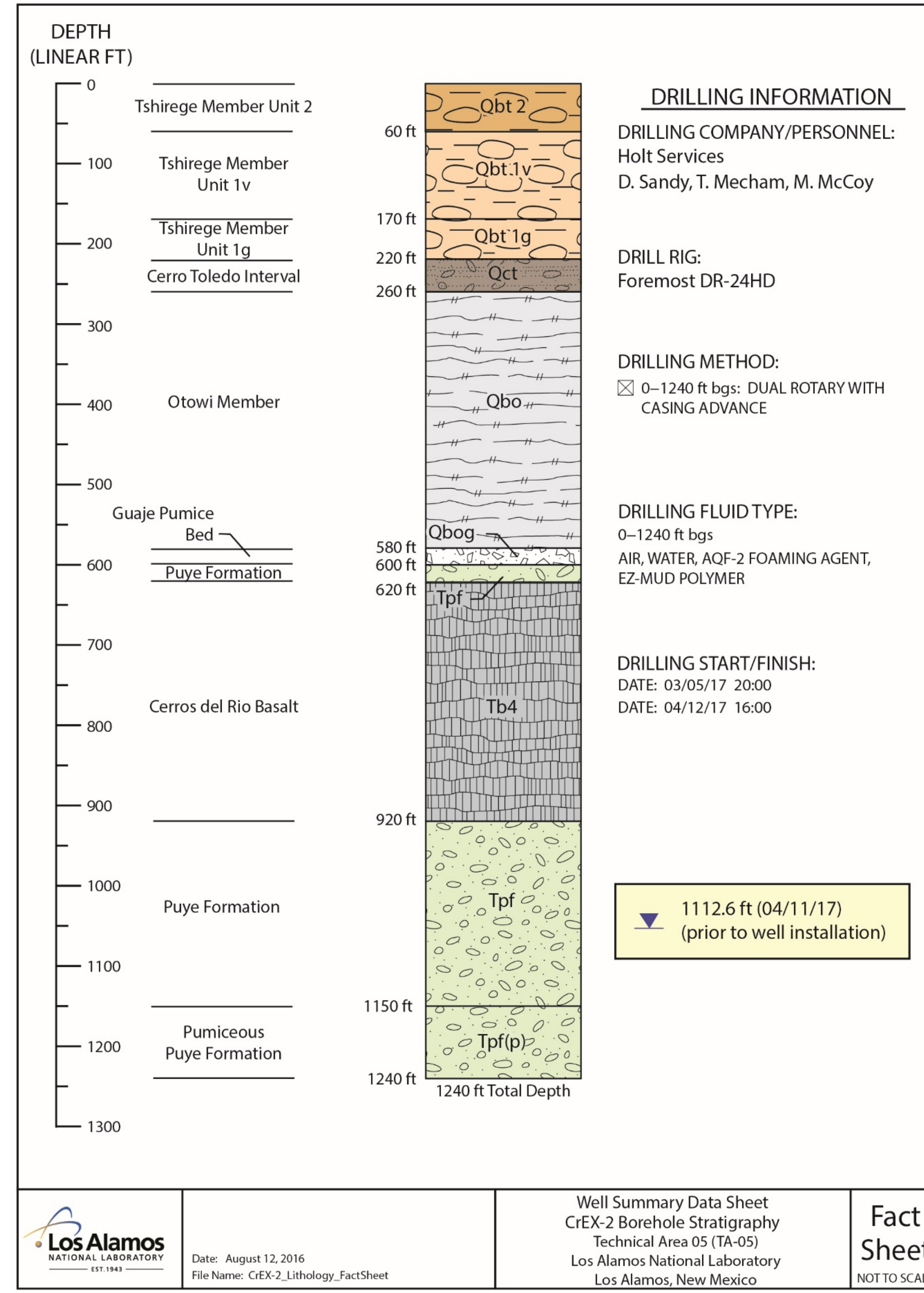


Figure 5.1-1 Extraction well CrEX-2 borehole stratigraphy

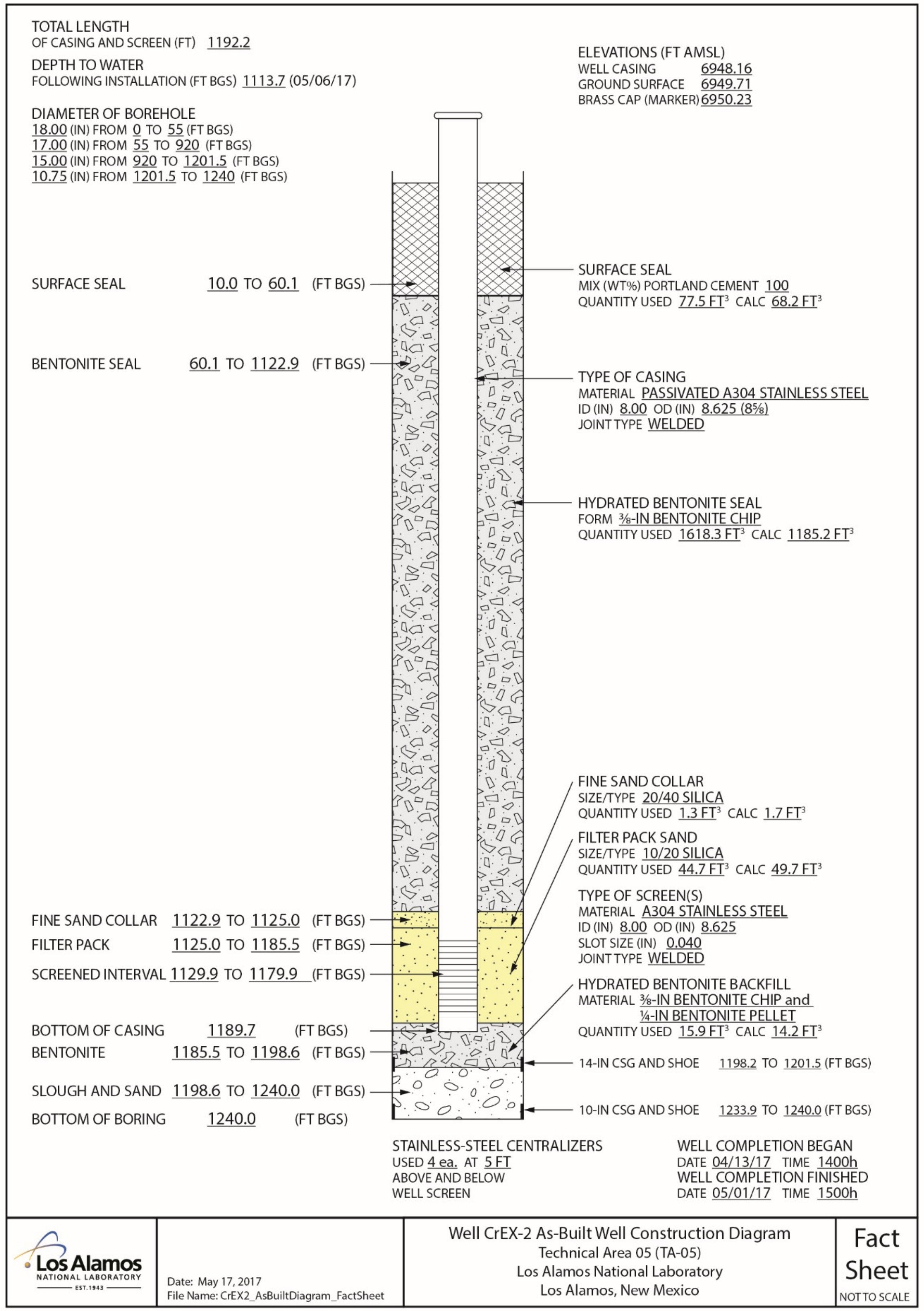


Figure 7.2-1 Extraction well CrEX-2 as-built well construction diagram

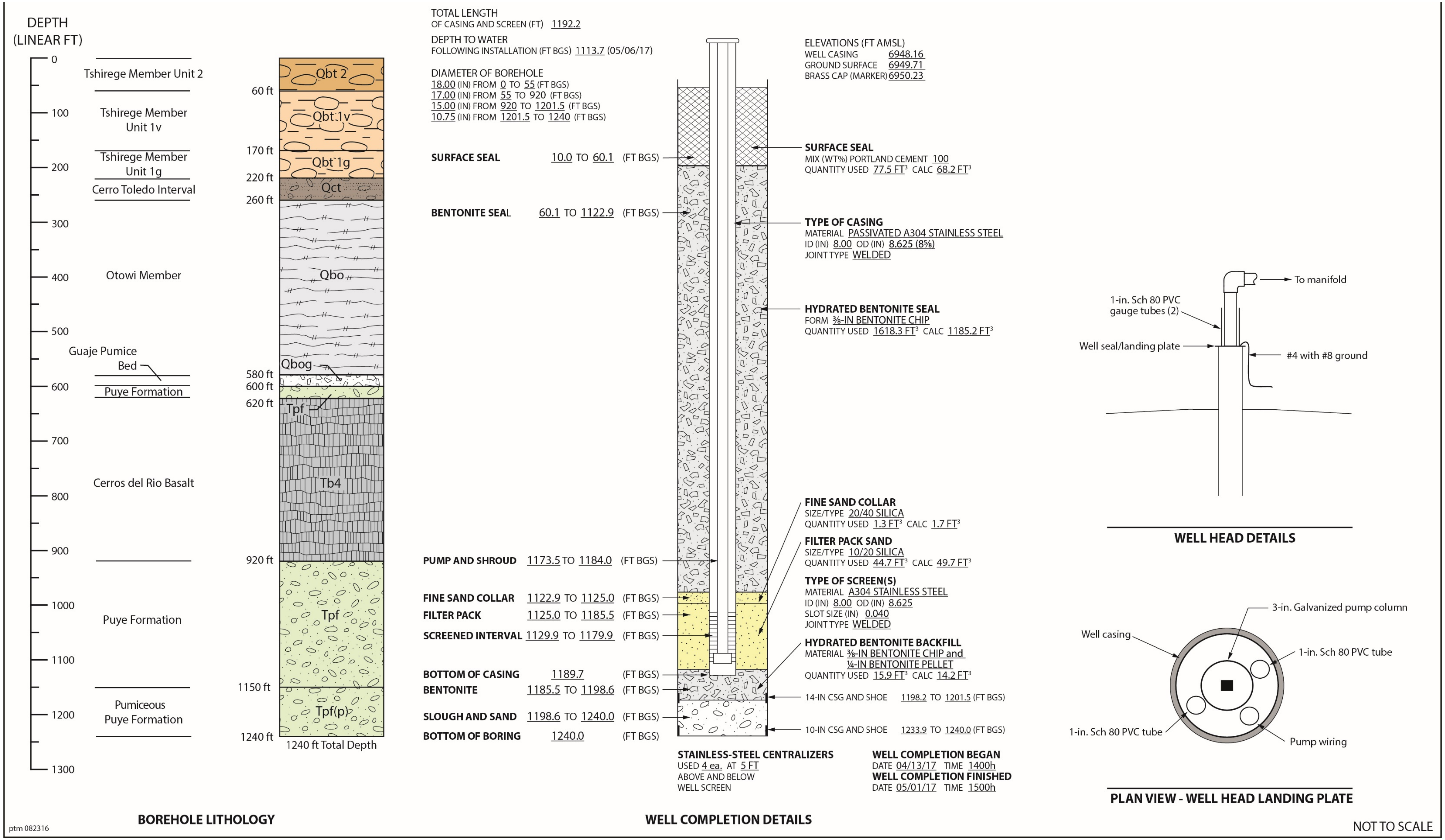


Figure 8.3-1a Extraction well CrEX-2 as-built diagram with borehole lithology and technical well completion details

CrEX-2 TECHNICAL NOTES:

SURVEY INFORMATION*

Brass Marker
Northing: 1767936.344
Easting: 1637235.726
Elevation: 6950.229

Well Casing (top of well seal)
Northing: 1767934.325
Easting: 1637238.798
Elevation: 6948.156

Well Seal Thickness:
0.08 ft.

BOREHOLE GEOPHYSICAL LOGS

Logger: Jet West Geophysical Services
Logs: Natural Gamma Ray, Neutron Density
Date: 08/15/2016

DRILLING INFORMATION

Drilling Company
Holt Services, Inc.

Drill Rig
Foremost DR-24HD

Drilling Methods
Dual rotary fluid-assisted air rotary

Drilling Fluids
Air, potable water, AQF fam, EZ Mud

MILESTONE DATES

Drilling
Start: 03/05/2017
Finished: 04/12/2017

Well Completion
Start: 04/13/2017
Finished: 05/01/2017

Well Development
Start: 05/03/2017
Finished: 05/13/2017

WELL DEVELOPMENT

Development Methods
Swabbing, bailing, and pumping
Aqua-Clear treatment

Parameter Measurements (Final)
pH: 7.56
Temperature: 19.73°C
Turbidity: 2.6 NTU

AQUIFER TESTING

Step Tests
Pumping Rates: 39, 55, 72.5 gpm
Performed on: 05/14/2017

24-h Constant-Rate Pumping Test
Water Produced: 91,650 gal.
Pumping Rate: 65 gpm
Performed on: 05/14/2017–05/15/2017

DEDICATED SAMPLING SYSTEM

Pump
Make: Grundfos
Type: 85S400-30

Motor
Make: Franklin Electric
Model: 2366178125, 40 HP

Pump Column
3.5-inch, N-80, galvanized, API 10-round
NUE couplings

Gauge Tubes
2 X 1.0-in. flush threaded sch. 80 PVC

Transducer
Make: In-Situ Level TROLL
Model: LT 500
Range: 30 psig/69 ft
S/N:

NOTE:
* Coordinates based on New Mexico State Plane Grid Coordinates, Central Zone (NAD83); Elevation expressed in feet amsl using the National Geodetic Vertical Datum of 1929.

Figure 8.3-1b As-built technical notes for extraction well CrEX-2

Table 4.2-1
CrEX-2 Borehole Groundwater Sampling Chromium Results

Sample ID	Sample Date	Filtered	Result (µg/L)	Detected	Sample Time	Screen Top (depth bgs)	Screen Bottom (depth bgs)	Gallons purged
CrEX-2-17-132106	04-05-2017	Y	0.72	Y	13:49	1207.28	1214.98	First interval; 200 gal. purged
CrEX-2-17-132107	04-05-2017	Y	0.84	Y	14:13	1207.28	1214.98	First interval; 400 gal. purged
CrEX-2-17-132108	04-05-2017	Y	1.08	Y	14:37	1207.28	1214.98	First interval; 600 gal. purged
CrEX-2-17-132109	04-05-2017	Y	1.52	Y	15:01	1207.28	1214.98	First interval; 800 gal. purged
CrEX-2-17-132110	04-05-2017	Y	1.67	Y	15:25	1207.28	1214.98	First interval; 1000 gal. purged
CrEX-2-17-132111	04-05-2017	Y	1.49	Y	15:49	1207.28	1214.98	First interval; 1200 gal. purged
CrEX-2-17-132112	04-05-2017	Y	2.11	Y	16:13	1207.28	1214.98	First interval; 1400 gal. purged
CrEX-2-17-132113	04-05-2017	Y	3.01	Y	16:37	1207.28	1214.98	First interval; 1600 gal. purged
CrEX-2-17-132114	04-05-2017	Y	3.72	Y	17:01	1207.28	1214.98	First interval; 1800 gal. purged
CrEX-2-17-132115	04-05-2017	Y	2.36	Y	17:25	1207.28	1214.98	First interval; 2000 gal. purged
CrEX-2-17-132116	04-05-2017	Y	5.91	Y	17:49	1207.28	1214.98	First interval; 2200 gal. purged
CrEX-2-17-132117	04-05-2017	Y	7.81	Y	18:13	1207.28	1214.98	First interval; 2400 gal. purged
CrEX-2-17-132118	04-05-2017	Y	8.56	Y	18:37	1207.28	1214.98	First interval; 2600 gal. purged
CrEX-2-17-132119	04-05-2017	Y	10.03	Y	19:01	1207.28	1214.98	First interval; 2800 gal. purged
CrEX-2-17-132120	04-05-2017	Y	8.42	Y	19:41	1207.28	1214.98	First interval; 3000 gal. purged
CrEX-2-17-132121	04-05-2017	Y	7.80	Y	20:21	1207.28	1214.98	First interval; 3200 gal. purged
CrEX-2-17-132122	04-05-2017	Y	7.34	Y	21:08	1207.28	1214.98	First interval; 3435 gal. purged
CrEX-2-17-132489	04-06-2017	Y	0.76	Y	13:58	1187.21	1194.91	Second interval; 200 gal. purged
CrEX-2-17-132490	04-06-2017	Y	1.21	Y	14:31	1187.21	1194.91	Second interval; 400 gal. purged
CrEX-2-17-132491	04-06-2017	Y	1.67	Y	15:10	1187.21	1194.91	Second interval; 600 gal. purged
CrEX-2-17-132492	04-06-2017	Y	1.29	Y	15:49	1187.21	1194.91	Second interval; 800 gal. purged
CrEX-2-17-132493	04-06-2017	Y	1.60	Y	16:28	1187.21	1194.91	Second interval; 1000 gal. purged
CrEX-2-17-132494	04-06-2017	Y	1.82	Y	17:01	1187.21	1194.91	Second interval; 1172 gal. purged

Table 4.2-1 (continued)

Sample ID	Sample Date	Filtered	Result (µg/L)	Detected	Sample Time	Screen Top (depth bgs)	Screen Bottom (depth bgs)	Gallons purged
CrEX-2-17-132495	04-07-2017	Y	0.47	Y	11:09	1167.28	1174.98	Third interval; 200 gal. purged
CrEX-2-17-132496	04-07-2017	Y	1.62	Y	11:51	1167.28	1174.98	Third interval; 400 gal. purged
CrEX-2-17-132497	04-07-2017	Y	24.12	Y	12:33	1167.28	1174.98	Third interval; 600 gal. purged
CrEX-2-17-132498	04-07-2017	Y	71.35	Y	13:15	1167.28	1174.98	Third interval; 800 gal. purged
CrEX-2-17-132499	04-07-2017	Y	101.80	Y	13:57	1167.28	1174.98	Third interval; 1000 gal. purged
CrEX-2-17-132500	04-07-2017	Y	137.02	Y	14:34	1167.28	1174.98	Third interval; 1177 gal. purged
CrEX-2-17-132501	04-07-2017	Y	156.77	Y	15:16	1167.28	1174.98	Third interval; 1377 gal. purged
CrEX-2-17-132502	04-07-2017	Y	179.37	Y	15:58	1167.28	1174.98	Third interval; 1577 gal. purged
CrEX-2-17-132503	04-07-2017	Y	191.68	Y	16:40	1167.28	1174.98	Third interval; 1777 gal purged
CrEX-2-17-132123	04-08-2017	Y	0.20	N	7:42	1147.28	1154.98	Fourth interval; 200 gal. purged
CrEX-2-17-132124	04-08-2017	Y	1.99	Y	8:21	1147.28	1154.98	Fourth interval; 400 gal. purged
CrEX-2-17-132125	04-08-2017	Y	32.17	Y	9:03	1147.28	1154.98	Fourth interval; 600 gal. purged
CrEX-2-17-132504	04-08-2017	Y	86.24	Y	9:45	1147.28	1154.98	Fourth interval; 800 gal. purged
CrEX-2-17-132505	04-08-2017	Y	119.61	Y	10:27	1147.28	1154.98	Fourth interval; 1000 gal. purged
CrEX-2-17-132506	04-08-2017	Y	135.11	Y	11:03	1147.28	1154.98	Fourth interval; 1177 gal. purged
CrEX-2-17-132507	04-08-2017	Y	161.59	Y	11:45	1147.28	1154.98	Fourth interval; 1377 gal. purged
CrEX-2-17-132508	04-08-2017	Y	177.30	Y	12:27	1147.28	1154.98	Fourth interval; 1577 gal. purged
CrEX-2-17-132537	04-08-2017	Y	195.54	Y	13:09	1147.28	1154.98	Fourth interval; 1777 gal. purged
CrEX-2-17-132538	04-09-2017	Y	0.32	Y	10:00	1127.27	1134.97	Fifth interval; 400 gal. purged
CrEX-2-17-132539	04-09-2017	Y	0.22	Y	10:40	1127.27	1134.97	Fifth interval; 600 gal. purged
CrEX-2-17-132540	04-09-2017	Y	29.20	Y	11:20	1127.27	1134.97	Fifth interval; 800 gal. purged
CrEX-2-17-132541	04-09-2017	Y	60.31	Y	12:00	1127.27	1134.97	Fifth interval; 1000 gal. purged
CrEX-2-17-132542	04-09-2017	Y	100.28	Y	12:40	1127.27	1134.97	Fifth interval; 1200 gal. purged
CrEX-2-17-132543	04-09-2017	Y	131.94	Y	13:20	1127.27	1134.97	Fifth interval; 1400 gal. purged
CrEX-2-17-132544	04-09-2017	Y	158.04	Y	14:00	1127.27	1134.97	Fifth interval; 1600 gal. purged

Table 4.2-1 (continued)

Sample ID	Sample Date	Filtered	Result (µg/L)	Detected	Sample Time	Screen Top (depth bgs)	Screen Bottom (depth bgs)	Gallons purged
CrEX-2-17-132545	04-09-2017	Y	176.01	Y	14:40	1127.27	1134.97	Fifth interval; 1800 gal. purged
CrEX-2-17-132546	04-09-2017	Y	183.00	Y	15:14	1127.27	1134.97	Fifth interval; 1970 gal. purged

Table 6.0-1
Logging Runs

Date(s)	Type of Log	Depth (ft bgs)	Description
03/08/2017	Video	0–848	LANL video from ground surface to 670.0 ft bgs. Observe open-hole interval.
03/08/2017	Gamma log	0–920	LANL gamma log through open-hole section.
03/08/2017	Induction log	0–920	LANL induction log through open-hole section.
03/16/2017	Gamma log	0–1215	JWGS gamma log at drilling TD.
03/16/2017	Neutron log	0–1215	JWGS neutron log at drilling TD.
05/23/2017	Video	0–1195	LANL video to confirm well completion condition.

Table 7.2-1
CrEX-2 Extraction Well Annular Fill Materials

Material	Volume (ft^3)
Upper surface seal: cement slurry	77.5
Upper bentonite seal: bentonite chips	1618.3
Fine sand collar: 20/40 silica sand	1.3
Filter pack: 10/20 silica sand	44.7
Backfill: bentonite chips and pellets	15.9

Table 8.1-1
Field Water-Quality Parameters and Well Performance for Development of Well CrEX-2

Date	Time	Pumping Rate (gpm)	Draw Down (ft)	Depth to Water (ft bgs)	Cumulative Purge Volume (gal.)	pH	Turbidity (NTU)	Temp (Deg C)
Well Development								
5/13/2017	13:34	72.8	NC*	NC	30861.8	6.73	NC	20.33
	13:49	74	NC	NC	31971.8	7.06	NC	20.28
	14:00	75.2	12.22	1125.9	32799	7.19	NC	20.22
	14:30	74	NC	NC	33909	6.74	NC	20.3
	14:45	73	11.97	1125.65	35004	7.13	NC	20.24
	15:00	73	12.4	1126.08	36099	7.29	NC	20.17
	15:15	73.5	NC	NC	37201.5	7.36	NC	20.15
	15:30	74.16	12.62	1126.3	38313.9	7.41	NC	20
	16:21	74	11.52	1125.2	42087.9	7.32	NC	20.93
	16:30	74	11.77	1125.45	42753.9	7.45	3.44	20.08
	16:45	73.8	12.27	1125.95	43860.9	7.52	3.77	19.73
	16:59	73.53	12.44	1126.12	44890.32	7.55	3.8	19.71
	17:15	73.73	12.68	1126.36	46070	7.56	2.66	19.73
Step Test								
5/14/2017	10:05	39	6.516	1120.196	46265	7.2	30.3	17.01
	10:20	39	5.806	1119.486	46850	7.5	1.3	20.49
	10:35	39	5.942	1119.622	47435	7.58	1.2	20.53
	10:45	39	5.977	1119.657	48020	7.61	0.3	20.52
	11:00	39	6.227	1119.907	48605	7.64	3.64	20.5
	11:15	55	8.835	1122.515	49430	7.65	2.8	20.08
	11:30	55.5	9.036	1122.716	50262.5	7.65	2.5	20.04
	11:45	55	9.083	1122.763	51087.5	7.64	2.45	20.05
	12:00	55	9.177	1122.857	51912.5	7.67	2.96	20.13
	12:15	72.5	12.324	1126.004	53000	7.66	2.3	19.9
	12:30	72.5	12.836	1126.516	54087.5	7.65	2.18	19.9
	12:46	72.5	12.921	1126.601	55247.5	7.65	1.89	19.93
	13:00	72.5	12.947	1126.627	56262.5	7.65	1.66	19.91
Constant Rate Test								
5/14/2017	15:25	65	10.561	1124.241	57237.5	7.56	2.88	20.3
	15:40	65	10.932	1124.612	58212.5	7.49	2.29	20.05
	15:55	65	11.144	1124.824	59187.5	7.59	3.8	19.98

Table 8.1-1 (continued)

Date	Time	Pumping Rate (gpm)	Draw Down (ft)	Depth to Water (ft bgs)	Cumulative Purge Volume (gal.)	pH	Turbidity (NTU)	Temp (Deg C)
Constant Rate Test								
5/14/2017	16:10	65	11.234	1124.914	60162.5	7.63	1.18	19.95
	16:25	65	11.271	1124.951	61137.5	7.65	1.72	19.93
	16:40	65	11.305	1124.985	62112.5	7.67	1.12	19.91
	16:55	65	11.339	1125.019	63087.5	7.68	1.24	19.89
	17:10	65	11.348	1125.028	64062.5	7.68	1.13	19.87
	17:25	65	11.315	1124.995	65037.5	7.69	1.2	19.87
	17:40	65	11.357	1125.037	66012.5	7.71	2.07	19.86
	17:57	65	11.353	1125.033	67117.5	7.69	1.09	19.9
	18:11	65	11.346	1125.026	68027.5	7.7	0.99	19.89
	18:25	65	11.366	1125.046	68937.5	7.69	0.94	19.88
	18:40	65	11.355	1125.035	69912.5	7.7	1	19.87
	18:55	65	11.347	1125.027	70887.5	7.69	NC	19.85
	19:10	65	11.325	1125.005	71862.5	7.7	0.85	19.82
	19:25	65	11.326	1125.006	72837.5	7.7	NC	19.83
	19:40	65	11.341	1125.021	73812.5	7.7	1	19.79
	19:55	65	11.331	1125.011	74787.5	7.7	NC	19.78
	20:10	65	11.286	1124.966	75762.5	7.71	0.84	19.76
	20:25	65	11.31	1124.99	76737.5	7.71	NC	19.74
	20:40	65	11.258	1124.938	77712.5	7.71	0.93	19.74
	20:55	65	11.267	1124.947	78687.5	7.71	NC	19.73
	21:10	65	11.248	1124.928	79662.5	7.72	0.93	19.74
	21:25	65	11.226	1124.906	80637.5	7.72	NC	19.73
	21:40	65	11.227	1124.907	81612.5	7.72	0.83	19.72
	21:55	65	11.26	1124.94	82587.5	7.72	NC	19.71
	22:10	65	11.218	1124.898	83562.5	7.71	0.76	19.7
	22:25	65	11.228	1124.908	84537.5	7.72	NC	19.68
	22:40	65	11.239	1124.919	85512.5	7.72	0.78	19.68
	22:55	65	11.214	1124.894	86487.5	7.72	NC	19.67
	23:10	65	11.236	1124.916	87462.5	7.72	0.8	19.67
	23:25	65	11.233	1124.913	88437.5	7.72	NC	19.64
	23:40	65	11.216	1124.896	89412.5	7.73	0.73	19.66
	23:55	65	11.182	1124.862	90387.5	7.72	NC	19.61
5/15/2017	0:10	65	11.178	1124.858	91362.5	7.72	0.69	19.63
	0:25	65	11.162	1124.842	92337.5	7.72	NC	19.6
	0:40	65	11.179	1124.859	93312.5	7.71	0.72	19.58

Table 8.1-1 (continued)

Date	Time	Pumping Rate (gpm)	Draw Down (ft)	Depth to Water (ft bgs)	Cumulative Purge Volume (gal.)	pH	Turbidity (NTU)	Temp (Deg C)
Constant Rate Test								
5/15/2017	0:55	65	11.206	1124.886	94287.5	7.72	NC	19.54
	1:10	65	11.15	1124.83	95262.5	7.72	0.64	19.57
	1:25	65	11.193	1124.873	96237.5	7.72	NC	19.56
	1:40	65	11.158	1124.838	97212.5	7.73	0.63	19.56
	1:55	65	11.186	1124.866	98187.5	7.73	NC	19.58
	2:10	65	11.158	1124.838	99162.5	7.74	0.58	19.57
	2:25	65	11.151	1124.831	100137.5	7.72	NC	19.6
	2:40	65	11.182	1124.862	101112.5	7.73	0.71	19.59
	2:55	65	11.171	1124.851	102087.5	7.73	NC	19.53
	3:10	65	11.178	1124.858	103062.5	7.71	0.7	19.52
	3:25	65	11.147	1124.827	104037.5	7.73	NC	19.56
	3:40	65	11.174	1124.854	105012.5	7.73	0.52	19.55
	3:55	65	11.189	1124.869	105987.5	7.73	NC	19.53
	4:10	65	11.169	1124.849	106962.5	7.75	0.56	19.57
	4:25	65	11.185	1124.865	107937.5	7.73	NC	19.54
	4:40	65	11.163	1124.843	108912.5	7.73	0.56	19.57
	4:55	65	11.132	1124.812	109887.5	7.73	NC	19.6
	5:10	65	11.176	1124.856	110862.5	7.73	0.58	19.58
	5:25	65	11.139	1124.819	111837.5	7.73	NC	19.57
	5:40	65	11.166	1124.846	112812.5	7.73	0.57	19.57
	5:55	65	11.152	1124.832	113787.5	7.73	NC	19.52
	6:10	65	11.183	1124.863	114762.5	7.73	0.9	19.57
	6:25	65	11.175	1124.855	115737.5	7.73	0.71	19.52
	6:40	65	11.168	1124.848	116712.5	7.73	0.44	19.62
	6:55	65	11.153	1124.833	117687.5	7.73	0.69	19.58
	7:10	65	11.14	1124.82	118662.5	7.73	0.73	19.63
	7:25	65	11.138	1124.818	119637.5	7.73	0.41	19.67
	7:40	65	11.166	1124.846	120612.5	7.73	0.43	19.69
	7:55	65	11.149	1124.829	121587.5	7.73	0.45	19.69
	8:10	65	11.163	1124.843	122562.5	7.73	0.4	19.72
	8:25	65	11.138	1124.818	123537.5	7.73	0.69	19.7
	8:40	65	11.137	1124.817	124512.5	7.73	0.51	19.73
	8:55	65	11.156	1124.836	125487.5	7.73	0.55	19.76
	9:10	65	11.181	1124.861	126462.5	7.73	0.61	19.76
	9:25	65	11.142	1124.822	127437.5	7.73	0.45	19.77

Table 8.1-1 (continued)

Date	Time	Pumping Rate (gpm)	Draw Down (ft)	Depth to Water (ft bgs)	Cumulative Purge Volume (gal.)	pH	Turbidity (NTU)	Temp (Deg C)
Constant Rate Test								
5/15/2017	9:40	65	11.158	1124.838	128412.5	7.72	0.41	19.79
	9:55	65	11.194	1124.874	129387.5	7.72	0.41	19.82
	10:10	65	11.196	1124.876	130362.5	7.72	0.45	19.81
	10:25	65	11.18	1124.86	131337.5	7.72	0.46	19.81
	10:40	65	11.177	1124.857	132312.5	7.72	0.42	19.85
	10:55	65	11.163	1124.843	133287.5	7.72	0.5	19.86
	11:10	65	11.211	1124.891	134262.5	7.72	0.49	19.88
	11:25	65	11.169	1124.849	135237.5	7.72	0.97	19.88
	11:40	65	11.161	1124.841	136212.5	7.71	0.39	19.91
	11:55	65	11.149	1124.829	137187.5	7.72	0.4	19.9
	12:10	65	11.164	1124.844	138162.5	7.71	0.41	19.96
	12:25	65	11.15	1124.83	139137.5	7.71	0.38	19.97
	12:41	65	11.192	1124.872	140177.5	7.71	0.51	19.98
	12:55	65	11.116	1124.796	141087.5	7.71	0.4	19.99
	13:10	65	11.134	1124.814	142062.5	7.7	0.42	19.97
	13:25	65	11.127	1124.807	143037.5	7.7	0.43	20
	13:40	65	11.177	1124.857	144012.5	7.7	0.44	19.98
	13:55	65	11.146	1124.826	144987.5	7.7	0.48	20.04
	14:10	65	11.14	1124.82	145962.5	7.7	0.43	20.01
	14:25	65	11.172	1124.852	146937.5	7.7	0.39	20.02
	14:40	65	11.17	1124.85	147912.5	7.7	0.41	19.98
	14:55	65	11.128	1124.808	148887.5	7.7	0.4	20.02

*NC = Not collected.

Table 8.5-1
CrEX-2 Well Survey Coordinates

Identification	Northing	Easting	Elevation
CrEX-2 brass cap embedded in vault	1767936.344	1637235.726	6950.229
CrEX-2 top of well casing	1767934.325	1637238.798	6948.156

Table 8.6-1
Summary of Waste Characterization Samples Collected during Drilling, Construction, and Development of CrEX-2

Event ID	Sample ID	Date Collected	Description	Sample Matrix
11176	WSTMO-17-130771	03/07/2017	CrEx-2 drill cuttings (top) VOC*	Solid
11176	WSTMO-17-130774	03/07/2017	CrEx-2 drill cuttings trip blank VOC	Solid
11176	WSTMO-17-130772	03/08/2017	CrEx-2 drill cuttings(middle) VOC	Solid
11176	WSTMO-17-130775	03/08/2017	CrEx-2 drill cuttings trip blank VOC	Solid
11302	WSTMO-17-136957	05/24/2017	CrEx-2 drill cuttings (comprehensive)	Solid
11177	WSTMO-17-130780	03/07/2017	CrEx-2 drilling fluids (top) VOC	Solid
11177	WSTMO-17-130783	03/07/2017	CrEx-2 drilling field dup. VOC	Solid
11177	WSTMO-17-130786	03/07/217	CrEx-2 drilling fluids trip blank VOC	Liquid
11177	WSTMO-17-130781	03/08/2017	CrEx-2 drilling fluids (top) VOC	Liquid
11177	WSTMO-17-130784	03/08/2017	CrEx-2 drilling field dup. VOC	Liquid
11177	WSTMO-17-130787	03/08/2017	CrEx-2 drilling fluids trip blank VOC	Liquid

*VOC = Volatile organic compound.

Appendix A

Final Well Design and
New Mexico Environment Department Approval

From:	Dale, Michael, NMENV
To:	White, Stephen Spalding
Cc:	Katzman, Danny; Swickley, Stephani Fuller; Rodriguez, Cheryl L; Dhawan, Neelam, NMENV; Murphy, Robert, NMENV
Subject:	RE: CrEX-2 well design proposal
Date:	Tuesday, April 11, 2017 12:00:58 PM

Steve,

New Mexico Environment Department (NMED) hereby approves the installation of the regional-aquifer chromium extraction well CrEX-2 as proposed in your e-mail, with attachment, that was received today, April 11, 2017 at 9:19 AM. This approval is based on information available to NMED at the time of the approval. LANL must provide the results of groundwater sampling, any modifications to the well design as proposed in the above-mentioned e-mail, and any additional information relevant to the installation of the well as soon as such data or information become available. In addition, please provide NMED reasonable-time (e.g., 1 -2 days) notification prior to the initiation of well development, step-drawdown test, and aquifer testing at CrEX-2. Please call if you have any questions concerning this approval.

Thank you,

Michael R. Dale
New Mexico Environment Department
1183 Diamond Drive, Suite B
Los Alamos, NM 87544
LANL MS M894
Cell Phone: (505) 231-5423
Office Phone (505) 476-3078

From: White, Stephen Spalding [mailto:ssw@lanl.gov]
Sent: Tuesday, April 11, 2017 9:19 AM
To: Dale, Michael, NMENV <Michael.Dale@state.nm.us>
Cc: Katzman, Danny <katzman@lanl.gov>; Swickley, Stephani Fuller <sfuller@lanl.gov>; Rodriguez, Cheryl L <cheryl.rodriguez@em.doe.gov>
Subject: CrEX-2 well design proposal

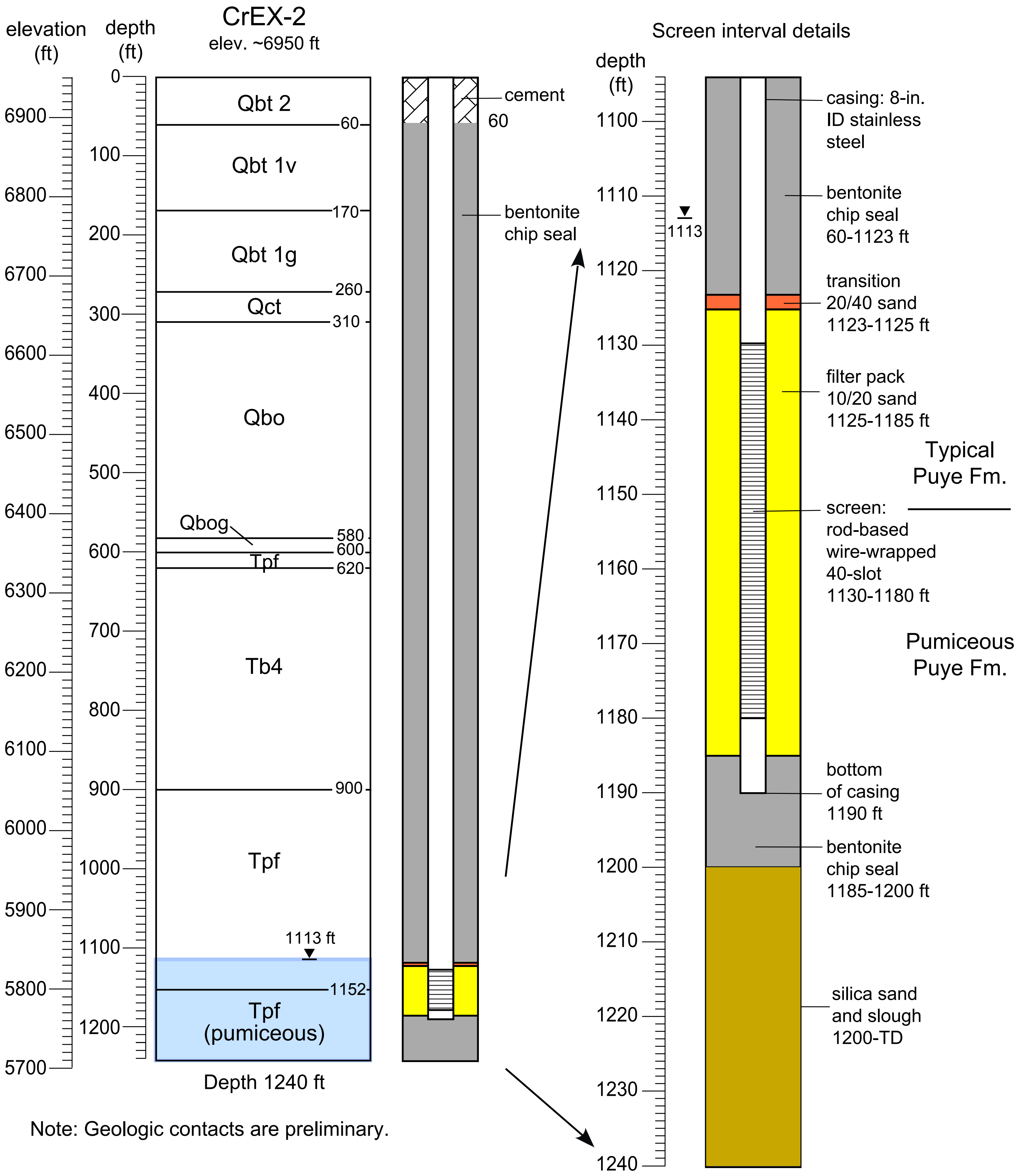
Hi Michael,

Please find attached our CrEX-2 design proposal for your review and approval. Let Danny or I know if you have any questions or want to discuss anything.

Thanks,

SW

Steve White
LANL ER-ES
505-257-8299 (cell)
505-667-9005 (desk)



Note: Geologic contacts are preliminary.

Appendix B

Borehole Video Logging
(on DVD included with this document)

Appendix C

Geophysical Logs
(on CD included with this document)

Appendix D

CrEX-2 Aquifer Testing Report

D-1.0 INTRODUCTION

This appendix describes the hydrogeological analysis of aquifer tests at extraction well CrEX-2 located in Mortandad Canyon within the existing chromium plume at Los Alamos National Laboratory (LANL or the Laboratory). A three-step variable rate and a 24-h constant rate pumping test were performed. The primary objective of the analysis was to determine the hydraulic properties of the aquifer zone screened by CrEX-2.

The CrEX-2 screened interval consists of a 50-ft-long screen from 1129.9 ft below ground surface (bgs) to 1179.9 ft bgs. Before the well was installed, the depth to water was 1112.6 ft bgs, and the distance from the water table to the top of the screen is 17.3 ft.

Conceptual Hydrogeology

The performed aquifer tests provide information about the properties of the regional aquifer in the Puye Formation (Tpf; top surface 920 ft bgs at CrEX-2). Based on previous hydrogeological investigations, aquifer testing, and modeling, the following is known about the regional aquifer below the Pajarito Plateau. It is highly heterogeneous and anisotropic. A complex conceptual model is thought to describe the hydrologic regime, including unconfined (phreatic) behavior near the water table (where CrEX-2 is screened) and confined (or leaky confined) behavior at deeper depths where the nearby municipal water-supply wells are screened (LANL 2007, 098734). Downward vertical head gradients are observed in several multi-screened wells.

The aquifer has unknown total thickness at CrEX-2 but it is thought to be greater than 1000 ft. The effective thickness of the phreatic zone relative to the CrEX-2 well screen for these pumping tests is also not known.

Monitoring well data demonstrate barometric pressure effects on measured head, which may be reflected in aquifer testing that takes place over periods of time longer than typical barometric fluctuations. The regional aquifer is pumped at varying rates by several municipal water supply wells in the area, which may also impact pumping test data, although the effect is small because of the apparent hydraulic separation between the confined and phreatic zones described above. At the nearby well CrPZ-1 (also screened near the regional water-table), model results suggest pumping at PM-2, PM-4, and O-4 may affect drawdowns by a few tenths of meters (LANL 2017, 602333).

Aquifer Testing

CrEX-2 was tested from April 14–16, 2017. Testing consisted of a three-step pumping test beginning at 10:00 a.m. on April 14, and a 24-h constant rate pumping test beginning at 3:10 p.m. on the same day. The pumping rates during the three-step test were 39, 55, and 72.5 gallons per minute (gpm), respectively. The steps were 1 h each with no pump stops between steps. The 24-h test pumping rate was 65 gpm. Water-level and pumping-rate data from CrEX-2 for the duration of the tests are shown in Figure D-1.0-1.

There are no check valves in the pump column, which leads to unusable data in the moments after the pump is activated or shut off, as evident in Figure D-1.0-1. When pumping begins, the pump operates against reduced pressure and produces anomalously high drawdowns (steep drop in depth). When pumping ends, water in the pump returns to the well and a sudden drop in drawdown (increase in depth) is observed. These spikes were removed before analysis, and all subsequent plots show the corrected data with spikes removed. When necessary for parameter estimation using pumping test analysis software, the missing data were replaced with a linear interpolation. Casing storage effects can also be responsible for anomalous early-time behavior when pumping begins but does not explain the drop in drawdown when pumping ends. An overshooting of water levels during recovery after pump shutdown may also be caused by groundwater recharge from the vadose zone. However, in this case, the observed spikes in water levels during changes in well operation are primarily from the lack of check valves.

Pressure data from the well confirmed the reduced heads at the onset of pumping and increased head upon cessation of pumping. The discharge rate of the well against the initial reduced head can be roughly estimated from the magnitude of the drawdown and the specific capacity data. For example, for the 24-h test, the initial spike reached a drawdown of 15.4 ft below the static water level, which corresponds to a discharge rate of 88 gpm according to a linear extrapolation from the step-test drawdown data (section D-3.0).

D-2.0 AQUIFER-TEST INTERPRETATION

Drawdown and recovery data can be analyzed using a variety of methods. The Theis equation (1934-1935, 098241) describes drawdown around a well as follows (Equation D-2.0-1):

$$s = \frac{Q}{4\pi T}\int_u^\infty \frac{e^{-x}}{x}dx = \frac{Q}{4\pi T}W(u) = \frac{Q}{4\pi T}W\left(\frac{r^2}{4at}\right) = \frac{Q}{4\pi T}W\left(\frac{r^2 S}{4Tt}\right)$$ **Equation D-2.0-1**

where *s* is drawdown (in m), *Q* is discharge rate (in m^3/d), *T* is transmissivity (in m^2/d), *a* is hydraulic diffusivity (characterizing the speed of propagation of hydraulic pressures in the subsurface) (in m^2/d), *S* is storage coefficient (dimensionless [−]), *t* is pumping time (in d), and *r* is the distance from the pumping well (in m). Transmissivity is related to hydraulic conductivity, *K* (in m/d), by aquifer thickness *b*: *K* = *T/b*.

The Cooper-Jacob method (1946, 098236) provides a simplification of the Theis equation. The Cooper-Jacob equation describes drawdown around a pumping well as follows (Equation D-2.0-2):

$$s = \frac{2.303Q}{4\pi T} log_{10}\frac{2.25at}{r^2} = \frac{2.303Q}{4\pi T} log_{10}\frac{2.25Tt}{r^2 S}$$ **Equation D-2.0-2**

The Cooper-Jacob equation is valid whenever the *u* value in the Theis equation above is less than 0.05. It can be computed after estimating *S* and *T.* Generally, *u* is small for small radial distance values (e.g., corresponding to borehole radii in the case of a single-well test), and at early pumping times. For the pumped well, the Cooper-Jacob equation usually can be considered a valid approximation of the Theis equation. According to the Cooper-Jacob method, the time-drawdown data are plotted on a semilog plot, with time plotted on the logarithmic scale, after which a straight line of best fit is constructed through the data points and transmissivity is calculated using Equation D-2.0-3:

$$T = \frac{2.303Q}{4\pi\Delta s}$$ **Equation D-2.0-3**

where Δs is the slope of the straight line on the semilog plot (typically estimated as a change over one log cycle of the graph) (in m). The Cooper-Jacob method also allows for estimation of the hydraulic diffusivity *a* (and respectively of the storage coefficient *S*). However, these estimates are typically highly unreliable when drawdown data applied in the pumping-test analyses are observed at the pumping well. The hydraulic diffusivity and the storage coefficient can be estimated reliably only when based on drawdowns observed at an observation well near the pumping well.

The recovery data are analyzed using the Theis recovery method, which is a semilog analysis method similar to the Cooper-Jacob method described above. In this method, the only difference is that the residual drawdown is plotted on a semilog plot versus the ratio *t/t'*, where *t* is the time since pumping began and *t'* is the time since pumping stopped. A straight line of best fit is constructed through the data points, and *T* is calculated from the slope of the straight line as in the Cooper-Jacob method above. The recovery data are particularly useful compared with drawdown data. Because the pump is not running, data responses associated with temporal discharge rate fluctuations are eliminated. The result is that the recovery data set is generally "smoother" and easier to analyze.

Another approach to estimating a lower bound for transmissivity makes use of specific capacities (McLin 2005, 602537). Specific capacity is defined as the pumping rate (*Q*) divided by drawdown, *s*. This approach can also include the effects of partial penetration and well losses. MATLAB code provided by (McLin 2005, 602537) iteratively solves for *T*, which appears on both sides in Equation D-2.0-4:

$$T = \frac{Q}{4\pi(s-s_w)}\left[ln\left(\frac{2.25Tt}{r_wS}\right) + 2s_p\right], \qquad \textbf{Equation D-2.0-4}$$

Where *s* is total drawdown, s_w is well loss, r_w is wellbore radius, and s_p is a correction factor for partial penetration. Well efficiency is required to estimate s_w, but if it is not known, varying values may be used; alternatively, the minimum transmissivity at 100% well efficiency (s_w = 0) may be computed.

All of these analyses assume the aquifer is homogeneous and isotropic. For other fitting models, anisotropy can be investigated as a parameter (K_v/K_h). The thickness of the aquifer affected by the pumping test is not known; while the total thickness of the regional aquifer is greater than 1000 ft because of partial penetration effects and anisotropy, the pumping test does not interrogate the entire aquifer thickness.

More complicated analytical solutions are available to account for drawdown impacts caused by vadose zone flow, partial well penetration, aquifer leakage, etc. Some of these analytical solutions are available in simulation codes such as WELLS (http://wells.lanl.gov) and AQTESOLV (http://www.aqtesolv.com). AQTESOLV is used in this analysis.

D-3.0 DATA ANALYSIS

This section presents the data obtained from the aquifer tests and the results of the analytical interpretations. Data are presented for drawdown and recovery for the three-step test and 24-h constant-rate pumping test.

Three-Step Variable-Rate Aquifer Test

Average values for drawdown at each of the three pumping rates were calculated after drawdown stabilized following the change in pumping rate. Note that these values are approximate because the pumping drawdowns did not reach equilibration during each step.

The specific capacity data obtained from the CrEX-2 three-step pumping test are summarized in Table D-3.0-1. The table also includes specific capacity data obtained during the 24-h constant-rate pumping test. During the step tests, the specific capacity varied between about 101 m^2/d and 118 m^2/d (~5.6 gpm/ft and 6.6 gpm/ft). The step-test data demonstrate a slight decline in specific capacity with pumping rate.

Using the average drawdowns in Table D-3.0-1, time since pumping began, and a storage coefficient *S* of 0.0001 (the results are relatively insensitive to S), the MATLAB code (McLin 2005, 602537) was used to estimate *T* for varying values of uncertain percent aquifer penetration. Figure D-3.0-1 shows the results from each step of the three-step aquifer test. The minimum transmissivities for the three steps, estimated at 100% aquifer penetration, range from 167–183 m^2/d (13,400–14,700 gallons per day [gpd]/ft). The maximum transmissivities, calculated at 10% aquifer penetration, range from 1260–1470 m^2/d (101,000–118,000 gpd/ft).

AQTESOLV was also used to estimate transmissivity using a fit to the data of the Theis solution (1934-1935, 098241). Figure D-3.0-2 shows the best fit curve using automated fitting methods, along with the adjusted data (spikes removed, as described above). The Theis solution does not produce an excellent fit, but this is not surprising given the assumptions of the Theis solution. Estimated parameters are $T = 255$ m^2/d (20,500 gpd/ft) and $S = 5.0 \times 10^{-7}$ (unreliable), with negligible wellbore skin factor and well loss parameters $C = 1$ s^2/ft^5 and $P = 1.562$ (Duffield 2007, 601723).

24-h Constant-Rate Aquifer Test

Figure D-3.0-3 shows a semilog plot of the corrected drawdown data recorded during the 24-h constant-rate pumping test conducted at an average pumping rate of $Q = 353.8$ m^3/d (65 gpm). The removed spike covered the first 330 s (5.5 min) of the data. The corrected data on a semilog plot do not show sustained linear behavior in any portion of the curve.

Nonetheless, the linear Cooper-Jacob approximation to the Theis solution was applied in AQTESOLV for three short segments of the semilog plot (Figure D-3.0-3). The earliest-available time best fit solution resulted in $T = 93$ m^2/d (7500 gpd/ft) and $S = 0.0044$. Fitting the middle segment of the rising drawdown curve resulted in $T = 177$ m^2/d (14,300 gpd/ft) and $S = 6.7 \times 10^{-7}$. The later time curve produces $T = 247$ m^2/d (19,900 gpd/ft) and $S = 2.3 \times 10^{-10}$. These fits are for before $t = 100$ min. Despite the inaccuracy in *S* values, *u* in Equation D-2.0-1 was computed for each of these estimates; all values were less than 2×10^{-5}, so the Cooper-Jacob model is likely valid based on the $u < 0.05$ criterion.

There are several possible reasons why the data do not follow the Theis-type curve and are therefore inappropriate for the Cooper-Jacob estimation of transmissivity. The well is partially penetrating. The aquifer is heterogeneous, it may have dual unconfined/confined behavior with depth, and this well test is likely experiencing three-dimensional flow effects. The well drawdowns might be affected by groundwater flow in the vadose zone causing time-delayed recharge (Tartakovsky and Neuman 2007, 602536). Fluctuations may also occur in nearby municipal water-supply pumping.

The effect of partial aquifer penetration is to modify the direction of flow towards the screen from the horizontal assumed in the more simplistic confined aquifer analyses or Dupuit assumptions of horizontal flow for unconfined aquifers (strong vertical anisotropy in aquifer hydraulic conductivity can diminish the observed effects of partial penetration, however). During a pumping test, the cone of depression expands both vertically and horizontally. The test thus represents increasing thickness of aquifer, leading to typically increased transmissivities in the late-time data. This type of pattern has been observed for the CrEX-2 24-h pumping test, based on the transmissivities estimated above using the Cooper-Jacob method. It hinders attempts to determine hydraulic conductivities because each transmissivity is calculated at an unknown effective aquifer thickness. If the cone of depression reaches an aquitard, drawdown may flatten; in this 24-h test, drawdown reached a peak and then began to decrease with time, which is not expected behavior.

Expected unconfined aquifer behavior during a pumping test includes Theis-type behavior or a slightly slower rise in drawdown compared with the confined aquifer, followed by a flatter mid-time section where drawdown rise is halted as a result of delayed yield of water from the falling water table (Neuman 1974, 085421). At late times, the typical behavior of an unconfined aquifer returns to essentially horizontal flow and the Theis curve may be applicable again. This type of behavior was also observed in the CrEX-1 aquifer test (LANL 2015, 600170), but not at CrEX-2. As a result, typical curves for unconfined aquifers [e.g., from the Neuman (1974, 085421) and Moench (1997, 600136)] methods, do not provide an excellent fit to the CrEX-2 data. Figure D-3.0-4 shows a fit using the Neuman (1974, 085421) solution in AQTESOLV (Duffield 2007, 601723), but the late-time data are not comparable because they do not exhibit the typical delayed yield behavior. The fit produces T = 142 m^2/d (11400 gpd/ft), S = 0.040, S_y = 0.5, and $\beta = 1 \times 10^{-5}$. This method also produces an estimate of K = 4.7 m/d and K_v/K_h = 0.9, but these estimates are unreliable given the poor fit to the data.

Although true steady-state conditions cannot be achieved in an unconfined pumped aquifer of infinite extent, during the 24-h test drawdowns appear to become relatively stable at late times. Under steady-state assumptions, a pumped unconfined aquifer may more closely approximate a state of horizontal flow and the Thiem-Dupuit method may be used to estimate transmissivity. This method applies to head measurements in multiple observation wells, but an approximation to the method for a single-well test can be used (with caution) for a simple rough estimate based on steady-state drawdown s at pumping rate Q: $T = 1.22Q/s$ (Misstear 2001, 602535). At a stabilized late-time average drawdown of 11.1 ft (after 100 min of pumping), T ~ 128 m^2/d (10,300 gpd/ft) using this approximation. This may also be modified to account for partial penetration by replacing s with $s - s^2/2b$, where b is aquifer thickness. The effective saturated aquifer thickness is not known, but using a thickness of 75 ft results in T = 135 m^2/d (10,900 gpd/ft). Figure D-3.0-5 shows the results for T for variable unknown effective aquifer thicknesses.

Recovery Data Analysis

Recovery data after a pumping test can provide the best opportunity to evaluate transmissivity in the vicinity of the well, as described above. Residual drawdown (*s'*) is plotted on a semilog plot versus the ratio *t/t'* (Figure D-3.0-5), where *t* is the time since pumping began, and *t'* is the time since pumping stopped. The recovery at late times (in Figure D-3.0-5, time increases from right to left) shows two well-defined straight-line periods. These periods are fit by transmissivity values of 100 m^2/d (8050 gpd/ft) and 546 m^2/d (44,000 gpd/ft), respectively. The second segment value is considerably higher than most of the other transmissivity estimates from this set of pumping tests.

D-4.0 CONCLUSIONS

Table D-4.0-1 summarizes the transmissivity estimates developed in this appendix. Several methods are presented to analyze the CrEX-2 pumping test data. The Theis model/Cooper-Jacob approximation does not consider delayed water recharge from the vadose zone generally observed in unconfined aquifers. Other common model-type curves, available in AQTESOLV, that are specific to unconfined aquifers and allow for partial penetration were considered (e.g., Moench 1997, 600136; Neuman 1974, 085421), but these also do not provide an excellent fit to all the data. Better fits to standard models for unconfined aquifers are found in pumping test data from CrEX-1 (using Moench's method) and CrEX-3 (using Neuman's method).

Techniques more advanced than the approaches presented here may result in higher confidence in estimated transmissivity values, but as a result of the departure of the regional aquifer conditions from the simple, standard conditions assumed by most pumping test empirical fitting models, simplified models will likely still provide only rough estimates of aquifer parameters in the vicinity of CrEX-2.

A best-guess estimate of T = 212 m^2/d (17,100 gpd/ft) is calculated from the average of the mid- and late-time parameter fit to the Cooper-Jacob model in Table D-4.0-1. Despite the unreliability of S estimates for pumping test analyses at a single well, the same Cooper-Jacob best fits described above are averaged to give $S = 3.4 \times 10^{-7}$. The Neuman (1974, 085421) method provides an estimate of K = 4.7 m/d.

D-5.0 REFERENCES

The following reference list includes documents cited in this appendix. Parenthetical information following each reference provides the author(s), publication date, and ERID or ESHID. This information is also included in text citations. ERIDs were assigned by the Associate Directorate for Environmental Management's (ADEM's) Records Processing Facility (IDs through 599999), and ESHIDs are assigned by the Environment, Safety, and Health Directorate (IDs 600000 and above). IDs are used to locate documents in the Laboratory's Electronic Document Management System and in the Master Reference Set. The New Mexico Environment Department Hazardous Waste Bureau and ADEM maintain copies of the Master Reference Set. The set ensures that NMED has the references to review documents. The set is updated when new references are cited in documents.

Cooper, H.H., Jr., and C.E. Jacob, August 1946. "A Generalized Graphical Method for Evaluating Formation Constants and Summarizing Well-Field History," *American Geophysical Union Transactions,* Vol. 27, No. 4, pp. 526-534. (Cooper and Jacob 1946, 098236)

Duffield, G.M., June 16, 2007. "AQTESOLV for Windows, Version 4.5, User's Guide," HydroSOLVE, Inc., Reston, Virginia. (Duffield 2007, 601723)

LANL (Los Alamos National Laboratory), August 2007. "Corrective Measures Evaluation Report, Intermediate and Regional Groundwater, Consolidated Unit 16-021(c)-99," Los Alamos National Laboratory document LA-UR-07-5426, Los Alamos, New Mexico. (LANL 2007, 098734)

LANL (Los Alamos National Laboratory), January 2015. "Completion Report for Groundwater Extraction Well CrEX-1," Los Alamos National Laboratory document LA-UR-15-20165, Los Alamos, New Mexico. (LANL 2015, 600170)

LANL (Los Alamos National Laboratory), April 25, 2017 "Chromium Extraction Well Evaluation Report and Recommendations for CrEX-2," Los Alamos National Laboratory document LA-UR-17-23263, Los Alamos, New Mexico. (LANL 2017, 602333)

McLin, S., July-August 2005. "Estimating Aquifer Transmissivity from Specific Capacity Using MATLAB," *Ground Water,* Vol. 43, No. 4, pp. 611-614. (McLin 2005, 602537)

Misstear, B.D.R., March 2001. "Editors' Message, The Value of Simple Equilibrium Approximations for Analysing Pumping Test Data," *Hydrogeology Journal,* Vol. 9, pp. 125-126. (Misstear 2001, 602535)

Moench, A.F., June 1997. "Flow to a Well of Finite Diameter in a Homogenous, Anisotropic Water Table Aquifer," *Water Resources Research,* Vol. 33, No. 6, pp. 1397–1407. (Moench 1997, 600136)

Neuman, S.P., April 1974. "Effect of Partial Penetration on Flow in Unconfined Aquifers Considering Delayed Gravity Response," *Water Resources Research,* Vol. 10, No. 2, pp. 303-312. (Neuman 1974, 085421)

Tartakovsky, G.D., and S.P. Neuman, January 16, 2007. "Three-Dimensional Saturated-Unsaturated Flow with Axial Symmetry to a Partially Penetrating Well in a Compressible Unconfined Aquifer," *Water Resources Reseach,* Vol. 43, pp. 1-17. (Tartakovsky and Neuman 2007, 602536)

Theis, C.V., 1934-1935. "The Relation Between the Lowering of the Piezometric Surface and the Rate and Duration of Discharge of a Well Using Ground-Water Storage," *American Geophysical Union Transactions,* Vol. 15-16, pp. 519-524. (Theis 1934-1935, 098241)

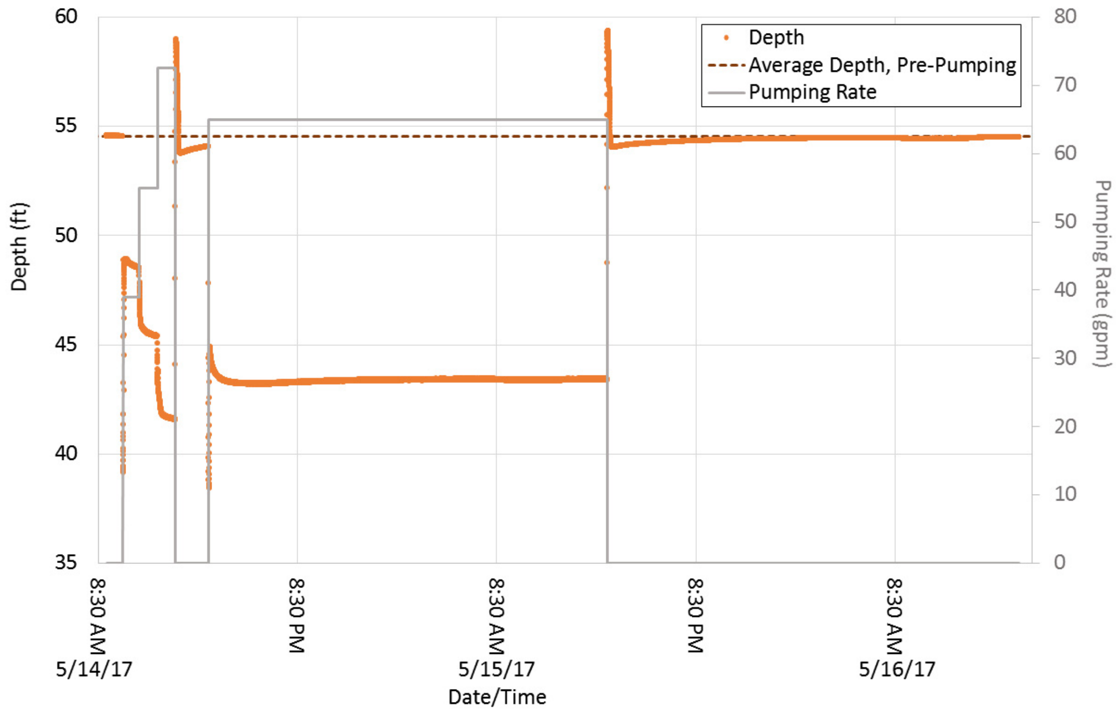


Figure D-1.0-1 **Water depth (left axis) and pumping rate (right axis) throughout the duration of the CrEX-2 pumping test; average pre-test elevation (*h_0*) shown as dashed line**

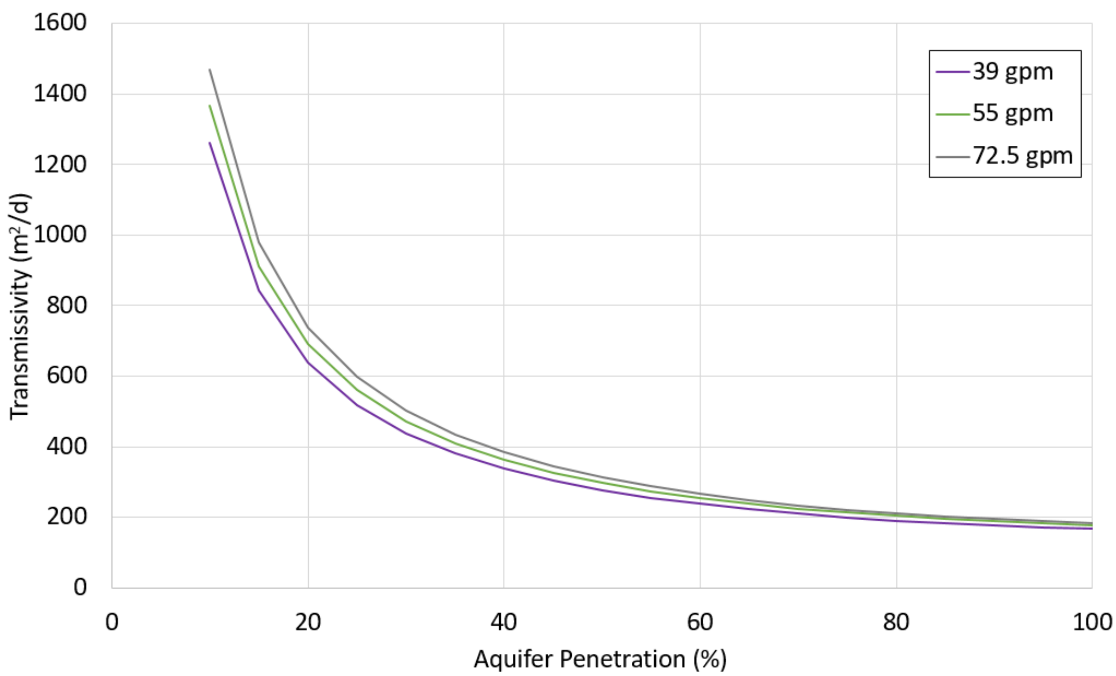


Figure D-3.0-1 **Transmissivities calculated using the MATLAB code of McLin (2005, 602537) based on the specific capacity method for each step of the variable-rate pumping test as a function of aquifer penetration**

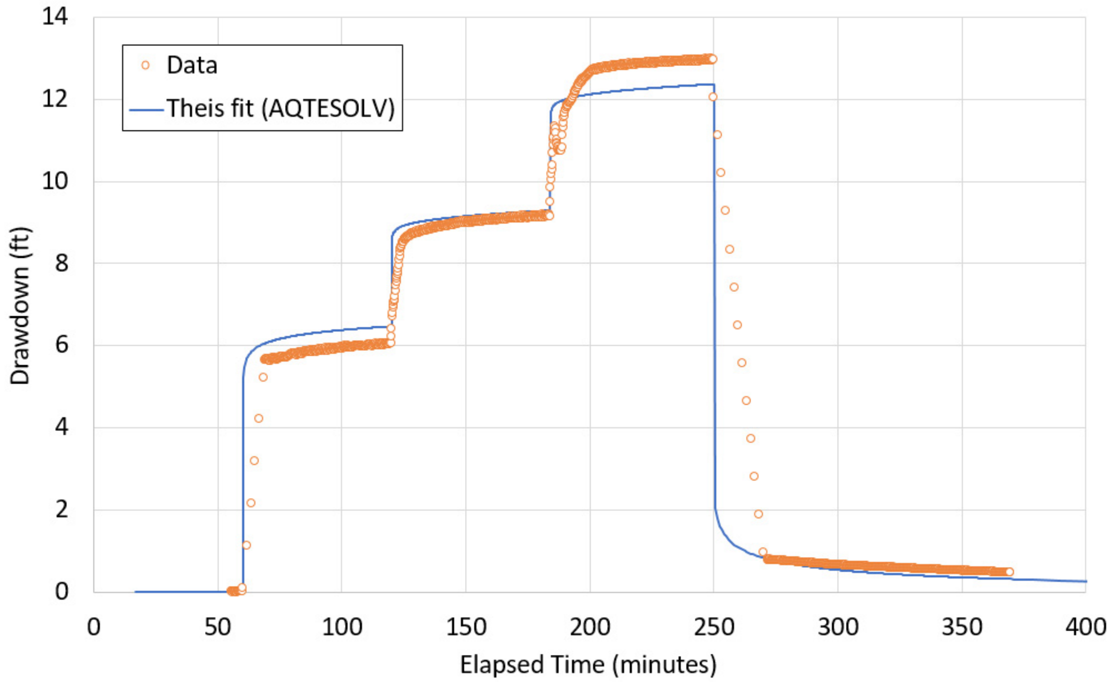


Figure D-3.0-2 Drawdown data (spikes removed and replaced with linear interpolation) and the best fit from AQTESOLV for the Theis solution to the step test, *T* = 255 m²/d

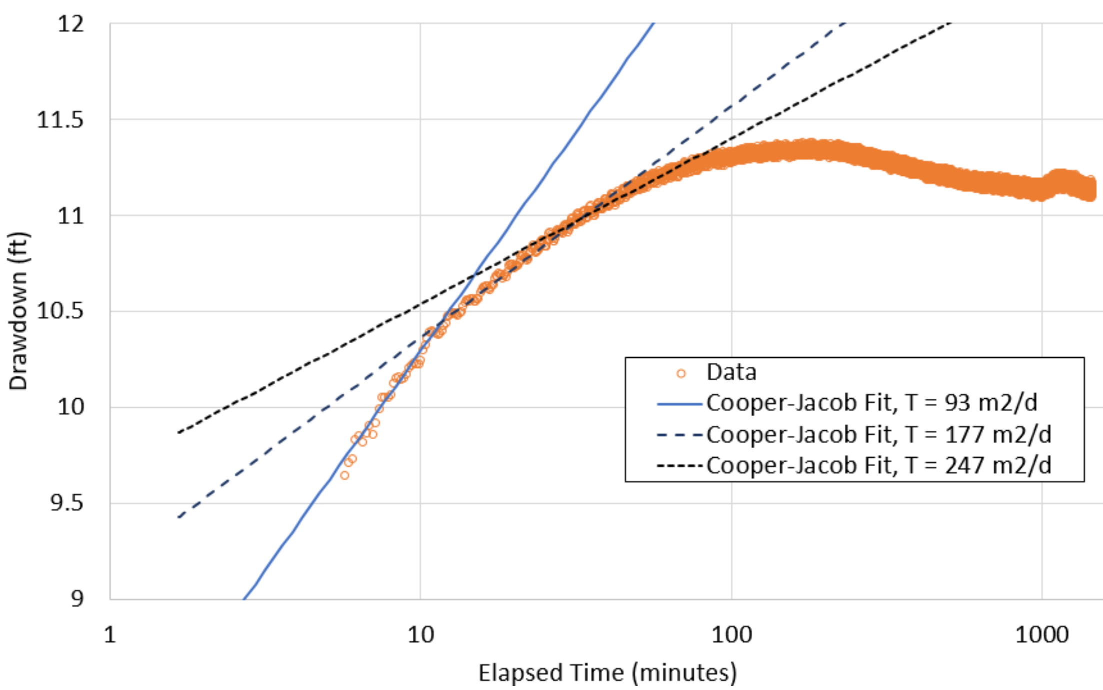


Figure D-3.0-3 Drawdown data (spikes removed) and multiple fits from AQTESOLV for the Cooper-Jacob solution to the 24-h pumping test data

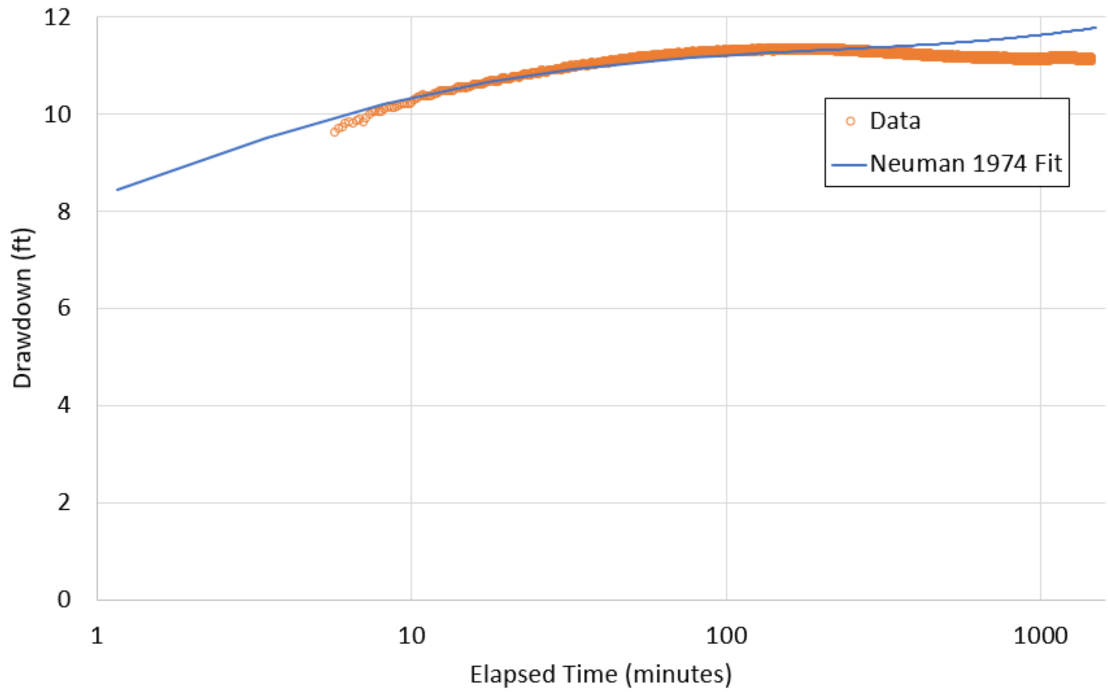


Figure D-3.0-4 Drawdown data (spikes removed) and fit from AQTESOLV for the Neuman (1974, 085421) solution to the 24-h pumping test data; fitting parameters are T = 142 m^2/d, S = 0.03981, Sy = 0.5, and $\beta = 1 \times 10^{-5}$; K_v/K_h = 0.9

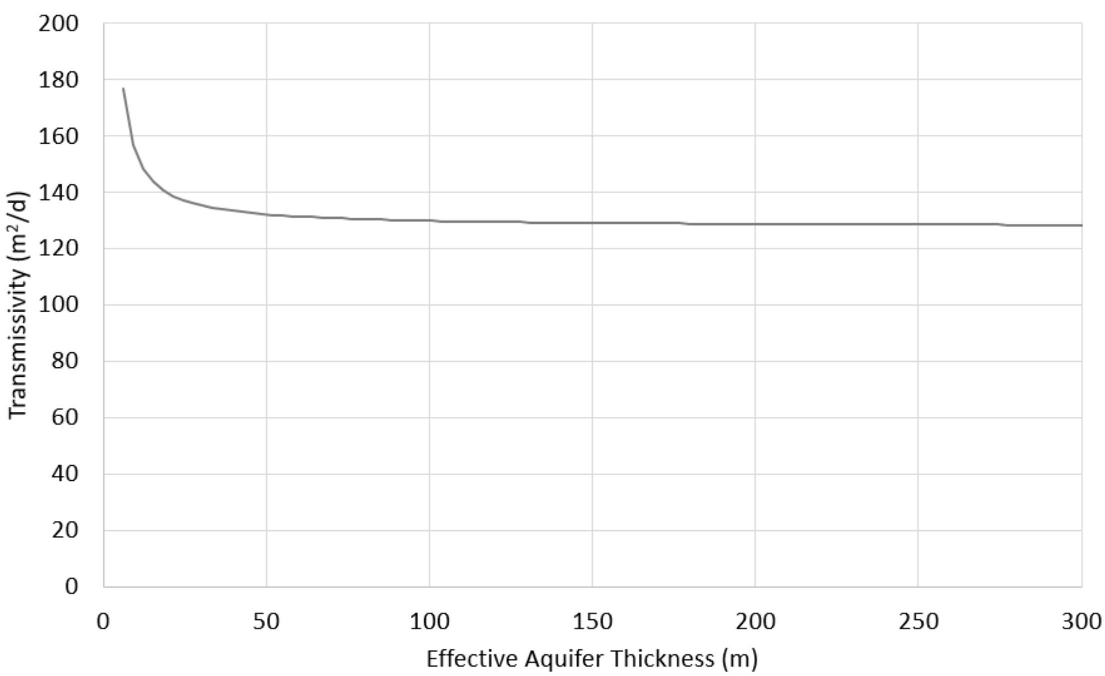


Figure D-3.0-5 Estimated transmissivities as a function of effective aquifer thickness using the Thiem-Dupuit approximation for unconfined groundwater flow

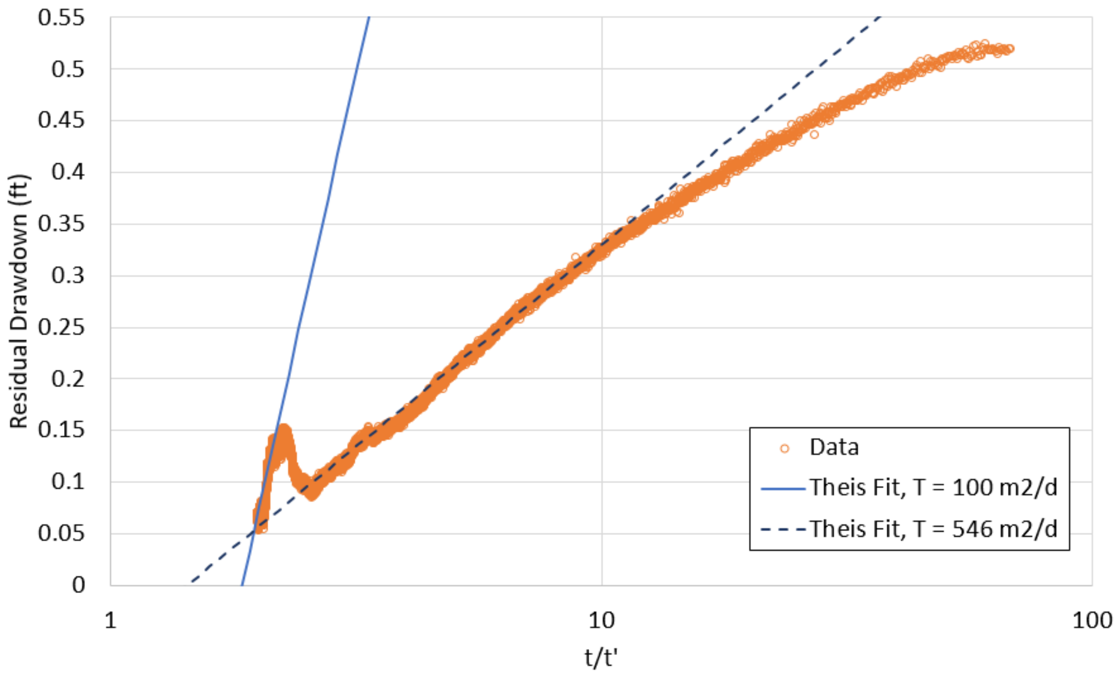


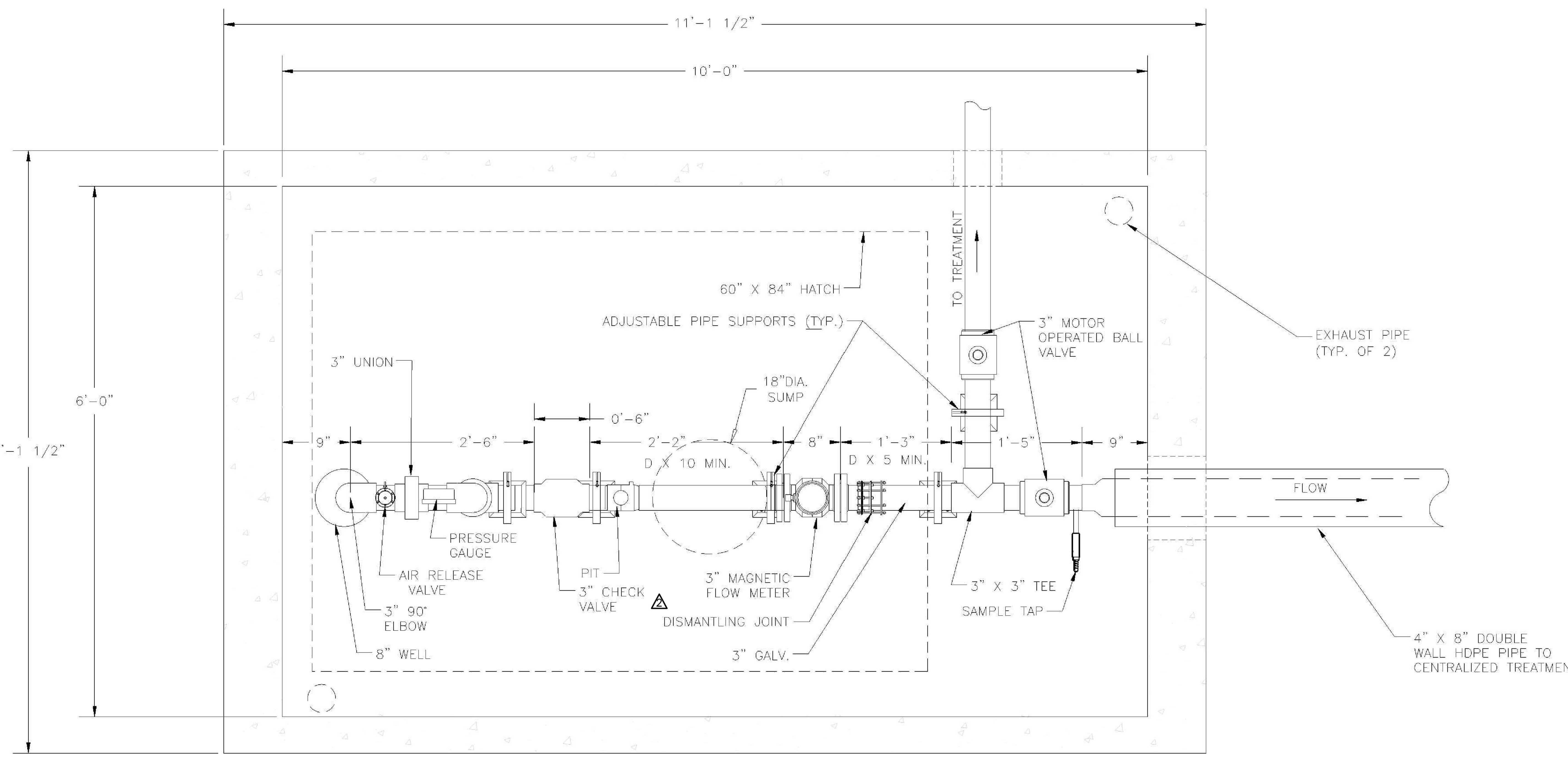
Figure D-3.0-5 Recovery data following the 24-h pumping test, with Theis recovery data best fit solutions from AQTESOLV for each of the two well-defined linear periods

Table D-3.0-1
Summary of Specific Capacity Data Obtained from CrEX-2 Aquifer Tests

Test	Pumping Rate (gpm)	Average Drawdown (ft)	Average Specific Capacity (gpm/ft)	Pumping Rate (m^3/d)	Average Drawdown (m)	Average Specific Capacity (m^2/d)
Step test #1	39	5.9	6.6	212	1.8	118
Step test #2	55	9.0	6.1	299	2.8	109
Step test #3	72.5	12.9	5.6	395	3.9	101
24-h test	65	11.2	5.8	354	3.4	104

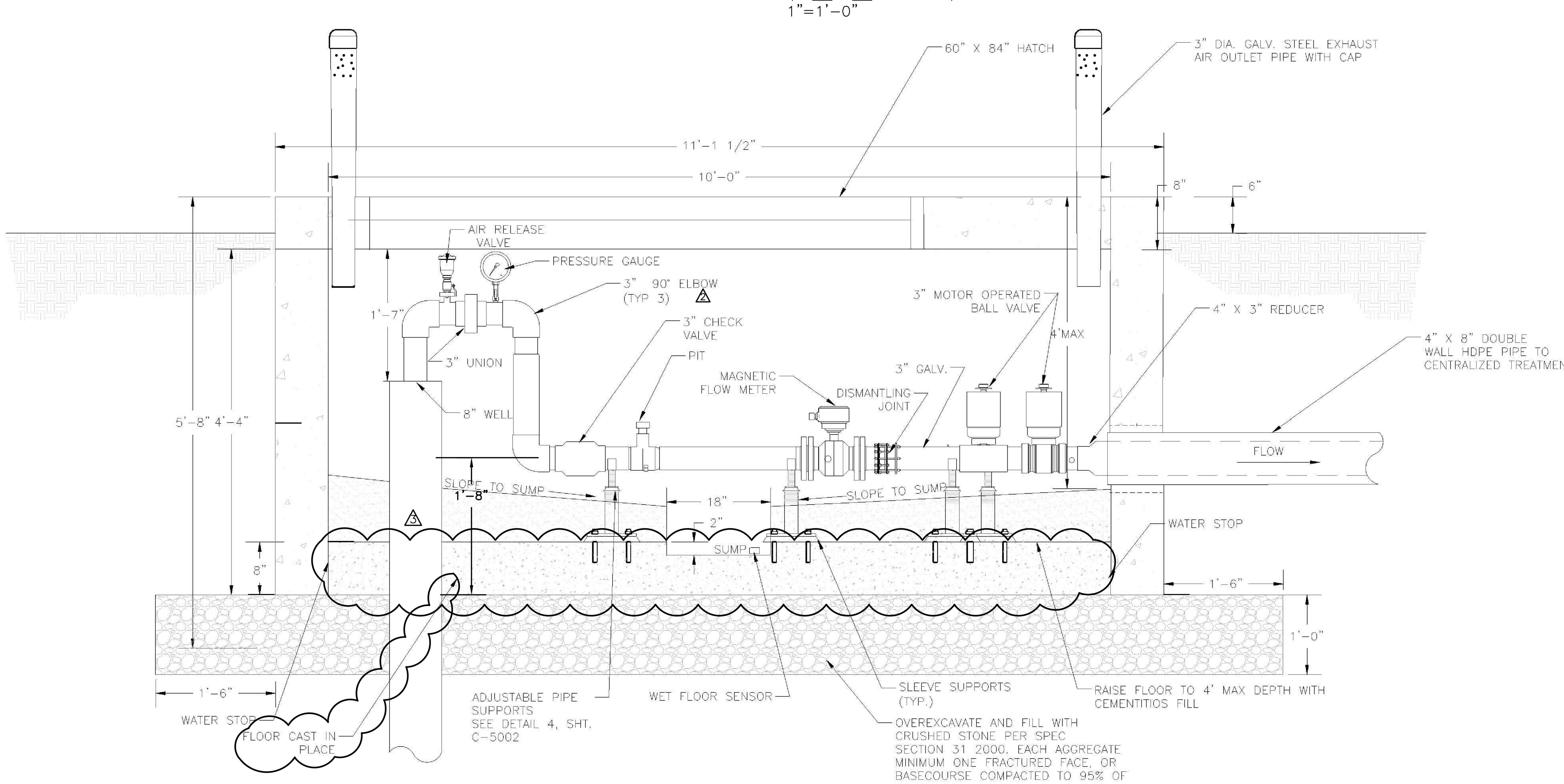
Table D-4.0-1
Summary of Transmissivities Estimated from All Analyses

Test	Transmissivity Estimate (m^2/d)	Transmissivity Estimate (gpd/ft)
McLin (2005) method (min/max)		
Step test #1	167/1260	13,400/101,000
Step test #2	177/1370	14,300/110,000
Step test #3	183/1470	14,700/118,000
Theis solution (AQTESOLV)		
Step test (all)	255	20,500
Cooper-Jacob solution (AQTESOLV)		
24-h test, early	93	7500
24-h test, mid	177	14,300
24-h test, late	247	19,900
Average of mid- and late-time fit	**212**	**17,100**
Thiem-Dupuit approximation		
24-h test, late, no correction for partial penetration	128	10,300
24-h test, late, with correction for partial penetration, *b* = 75 ft (23 m)	135	10,900
Neuman (1974, 085421) solution (AQTESOLV)		
24-h test, early	142	11,400
Theis recovery solution (AQTESOLV)		
Recovery from 24-h test, segment 1	100	8050
Recovery from 24-h test, segment 2	546	44,000



1 C-1001 TOP VIEW–CrEx–2 EXTRACTION WELL VALVE VAULT

1" 9" 6" 3" 0 1'
1"=1'-0"



2 C-1001 SECTION VIEW–CrEx–2 EXTRACTION WELL VALVE VAULT

1" 9" 6" 3" 0 1'
1"=1'-0"

GENERAL NOTES

1. ALL EXPOSED PIPING AND BURIED PIPING WITH <48" OF COVER SHALL BE HEAT TRACED PER SPECIFICATION SECTION 220525.
2. INSULATE EXPOSED PIPING PER SPECIFICATION SECTION 220713
3. PROVIDE VAULT AND HATCH PER SPECIFICATION SECTION 034100.
4. PROVIDE PIPE SUPPORTS PER SPECIFICATION SECTION 22-0529.
5. VAULT SHOWN FOR ILLUSTRATION ONLY. INSTALL PER MANUFACTURER INSTRUCTION. FIELD ADJUST DIMENSIONS AS NEEDED.
6. EXCAVATION FOR VAULTS SHALL BE INSPECTED TO DETERMINE SOIL CONDITIONS.
7. IN PLACE DENSITY TESTING SHALL BE CONDUCTED AND RESULTS PROVIDED TO VAULT MANUFACTURER.
8. DENOTES REVISION 3 MADE TO DRAWING.

PLATE 1

CrEX-2 surface completion vault detail

JENNIFER E. HILL NEW MEXICO 19055 PROFESSIONAL ENGINEER
5/1/2017

NO	DATE	CLASS REV	ADC	DESCRIPTION	DWN	DSGN	CHKD	SUB	APP
3	5/1/17			REVISED PER DRN-05-INFR-01193-00003 REVISED TO UPDATE SHEET NUMBERS, MODIFIED TO ADD CONCRETE SLAB	JBA	JBA	GP	JH	
2	3/13/17			REVISED PER FCR-05-INFR-01193-00010 TO UPDATE VAULT FOUNDATION RQMTS, RECONFIGURED COMPONENTS, AND REF PIPE SUPPORT ANCHOR DETAILS. REVISED PER DRN-05-INFR-01193-00002 TO REMOVE BOLLARDS AND UPDATE SHEET NUMBERS	JBA	JBA	GP	JH	
1	11/1/16			REVISED TO RELOCATE TEE, FLOWMETER AND ADDITIONAL PIPE SUPPORT PER DRN-05-INFR-01193-00001	JBA	JBA	GP	JH	
0				INITIAL ISSUE FOR DCF-05-INFR-01193					

Daniel B. Stephens & Associates, Inc.

CHROMIUM PIPING & INFRASTRUCTURE DESIGN–BUILD

CIVIL DETAILS 1– CrEX–2 EXTRACTION WELL VALVE VAULT

DRAWN	J. ARELLANO
DESIGN	J. HILL
CHECKED	G. PETERSON
DATE	07/28/16

BLDG N/A TA– 05

SUBMITTED: PROJECT ENGINEER JENNIFER HILL

APPROVED FOR RELEASE: DAR ED PITCHKOLAN

Los Alamos NATIONAL LABORATORY

PO Box 1663 Los Alamos, New Mexico 87545

SHEET C–5000

18 OF 55

CLASSIFICATION UNC

REVIEWER

DATE

PROJECT ID 103371

DRAWING NO C57366–DWG–05INFR– C–5000

REV 3