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Date: APR 25 2018
Refer To: ADEM-18-0019
LAUR: 18-23083

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

Subject: Completion Report for Groundwater Extraction Well CrEX-4

Dear Mr. Kieling:

Enclosed please find two hard copies with electronic files of the Completion Report for Groundwater Extraction Well CrEX-4.

If you have any questions, please contact Steve White at (505) 667-9005 (ssw@lanl.gov) or Cheryl Rodriguez at (505) 665-5330 (cheryl.rodriguez@em.doe.gov).

Sincerely,

Enrique Torres, Program Director
Environmental Remediation Program
Los Alamos National Laboratory

Sincerely,

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

ET/DR/SW

Enclosures: Two hard copies with electronic files – Completion Report for Groundwater Extraction Well CrEX-4 (EP2018-0037)

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LA-UR-18-23083
April 2018
EP2018-0037

Completion Report for Groundwater Extraction Well CrEX-4

Los Alamos
NATIONAL LABORATORY
EST. 1943

Prepared by the Associate Directorate for Environmental Management

EP2018-0037

Completion Report for Groundwater Extraction Well CrEX-4

April 2018

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EXECUTIVE SUMMARY

This well completion report describes the drilling, well construction, development, aquifer testing, and dedicated pumping system installation for groundwater extraction well CrEX-4, located within Los Alamos National Laboratory (LANL or the Laboratory) in Los Alamos, New Mexico. The CrEX-4 extraction well was installed in support of the chromium plume control interim measure and chromium plume-center characterization 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-4."

The CrEX-4 borehole was drilled using dual-rotary air-drilling methods to a total depth of 1025 ft below ground surface (bgs). Fluid additives used included potable water and foam. Foam-assisted drilling was used to total depth.

The following geologic formations were encountered at CrEX-4: alluvium, Otowi Member of the Bandelier Tuff, Guaje Pumice Bed of the Otowi Member, the Cerros del Rio basalt, the Puye Formation, pumiceous Puye Formation, and Miocene riverine sediments.

Well CrEX-4 was completed as a dual-screen well within the regional aquifer. The screened intervals are set between 929.9 and 964.9 (upper) and 974.9 and 994.9 (lower) ft bgs within Puye Formation sediments. The static depth to water after well installation was measured at 920.0 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-4 will perform effectively in meeting the planned objectives. A pumping system and transducer were installed in the well.

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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
TA	technical area
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-4. 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-4 groundwater extraction borehole was drilled between October 2 and October 9, 2017, and was completed between October 24 and November 10, 2017, at Los Alamos National Laboratory (LANL or the Laboratory) for the Associate Directorate for Environmental Management (ADEM).

Well CrEX-4 is located in 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 provide additional water for distribution to injection wells and to provide additional plume-center characterization data in an area of the plume with the highest chromium concentrations.

The CrEX-4 borehole was drilled to a total depth (TD) of 1025 ft below ground surface (bgs). During drilling, cuttings samples were collected at 10-ft intervals from ground surface to TD. An extraction well was installed with two screened intervals between 929.9 ft and 964.9 ft bgs and 974.9 ft and 994.9 ft bgs within Puye Formation volcaniclastic sediments. The composite depth to water (DTW) of 920.0 ft bgs was recorded on November 14 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-4 project.

2.0 ADMINISTRATIVE PLANNING

The following documents were prepared to guide activities associated with the drilling, installation, and development of extraction well CrEX-4:

- “Drilling Work Plan for Groundwater Extraction Well CrEX-4 (LANL 2017, 602594);
- “Storm Water Pollution Prevention Plan, CrEX-4 Well Construction Support Activities Project, Los Alamos National Laboratory” (LANL 2017, 602924);
- “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-4.

3.1 Drilling Approach

The drilling method, approach, equipment, and drill casing were selected to drill CrEX-4 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-4 borehole. The drill rig was equipped with conventional drilling rods, tricone bits, downhole hammer bits, under-reaming hammer bits, deck-mounted air compressor, auxiliary compressors, and general drilling equipment. Two sizes of A53 grade B flush-welded mild carbon-steel casing (16-in.-O.D., and 14-in.–inside diameter [-I.D.]) were used for drilling CrEX-4.

The dual-rotary drilling technique at CrEX-4 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. The fluids were used to cool the bit and help lift cuttings from the borehole.

3.2 Chronological Drilling Activities for the CrEX-4 Well

The Foremost DR-24HD drill rig, drilling equipment, and supplies were mobilized to the CrEX-4 drill site from September 29 to October 1, 2017. The equipment and tooling were decontaminated before equipment was mobilized to the site. Drilling started on October 2 by advancing a temporary 16.0-in. surface conductor casing to 76 ft bgs.

From October 3 to 5, a 15.0-in. open hole was advanced from 76 ft to 887 ft bgs through the Cerros del Rio basalt and into the top of the Puye Formation. Open-hole video and gamma logs were collected to depth by Laboratory personnel on October 6. From October 6 to 8, 14-in. casing was installed in the open borehole. The borehole was advanced to 1025 ft bgs with 14-in. casing-advance and dual-rotary methods using a 15-in. underreaming hammer bit on October 8 and 9.

Natural gamma and neutron logs were collected at TD by Jet West Geophysical Services, LLC (JWGS) on October 10. No drilling work occurred between October 11 and 22 while the field crew was on days off. The drive shoe was cut off the 14-in. casing at 1012.1 ft bgs on October 23, concluding drilling activities.

4.0 SAMPLING ACTIVITIES

This section describes the cuttings sampling activities for extraction well CrEX-4. No groundwater screening samples were collected from the CrEX-4 borehole during drilling activities. All sampling activities were conducted in accordance with applicable quality procedures.

4.1 Cuttings Sampling

Cuttings samples were collected from the CrEX-4 extraction well borehole at 10.0-ft intervals from ground surface to the TD of 1025 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-4.

5.0 GEOLOGY AND HYDROGEOLOGY

A brief description of the geologic and hydrogeologic features encountered at CrEX-4 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-4 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-4.

Alluvium, Qal (0–50 ft bgs)

The alluvium cuttings were wet, light to medium brown, moderately sorted sand with silty to fine sand matrix. Cuttings contain mixtures of dacite lava, pumice, and tuff fragments and abundant minerals all coated with tuffaceous matrix. The sediments are poorly to moderately consolidated. The amount of pumices increases with depth and are up to 1 in. in size. The pumice fragments are subangular to subrounded and heavily coated with tuffaceous silt. The basal unit is sorted, light-brown fine sand, consisting of abundant quartz and feldspars in a tuffaceous matrix of pumiceous silt.

Otowi Member of the Bandelier Tuff, Qbo (50–354 ft bgs)

Crystal-rich, poorly sorted, and lithic-poor white pumice with a crystal-dominated fine to medium sandy matrix underlies the alluvium. The pumice deposits (ash-flow tuff) are poorly sorted, massive, and unconsolidated. In general, the pumice clasts are subangular to subrounded and are partially inflated. The white pumice strata (50–70 ft bgs) transitions to a reworked deposit that consists of light brownish gray pumices mixed with abundant lithic fragments in a tuffaceous sandy matrix of minerals and pulverized glass shards (70–90 ft bgs). Perlite fragments mixed with subrounded to rounded pumices and felsic lava clasts partially coated with a light brownish gray tuffaceous matrix of glass shards were commonly noted in the underlying beds (90–110 ft bgs). Perlite clasts totally disappeared and the lithic contents significantly decreased in the next interval (110–140 ft bgs) while the amount of light brownish gray pumice and crystal contents remained high. With depth, the amounts of white and light brownish gray pumices, minerals, and lithic fragments varied. The basal deposit is dominated by subangular to subrounded and partially inflated white to grayish pumices that are mixed with sparse lithic contents and embedded in a sandy crystal-rich tuffaceous matrix of silty glass shards.

Guaje Pumice Bed of the Otowi Member of the Bandelier Tuff, Qbog (354–370 ft bgs)

The pumice deposit is fairly sorted, unconsolidated, and contains a sandy matrix of clear quartz and feldspar crystals. The strata consist of abundant subangular to subrounded, partially inflated white pumices and moderately abundant lava fragments. The lava fragments consist of subangular to subrounded, medium to dark gray and pale red dacite clasts of coarse sand fraction. The lava fragments are less abundant compared with the white pumices and mineral contents.

Upper Puye Formation, Tpf (370–400 ft bgs)

The cuttings are poorly sorted, clast supported, and unconsolidated. Mixed lava fragments of dacite, vesicular basalt, white pumice, and light brown siltstone were noted. The light brown siltstone clasts are soft and less abundant. Dacite lava fragments and white pumices are more abundant than the basaltic clasts.

Cerros del Rio Basalt, Tb4 (400–686 ft bgs)

The uppermost basaltic flow is vesicular, fairly weathered, and partially coated with grayish silt. A few pumice and light brown siltstone fragments occur with the basaltic cuttings. The basalt fragments are sparsely vesicular, medium gray with a grayish brown matrix and porphyritic, containing fairly abundant partially weathered and fractured coarse pyroxene and plagioclase crystals. Similar cuttings were noted between 400 and 480 ft bgs. The upper flow transitioned to a medium gray lava flow with a whitish matrix of fine-grained plagioclase. This lava flow persisted to a depth of 570 ft bgs. Light reddish brown partially weathered scoriaceous lava underlies the medium gray flow. The cuttings contain a minor amount of light pinkish gray claystone fragments. The scoriaceous lava transitioned to a weathered medium brown lava and moderate amount of light pinkish gray claystone. Mixed lava of comparable amounts of medium gray and medium brownish gray fragments with minor scoriaceous clasts and light pinkish gray claystone persisted to a depth of 670 ft bgs. The basal part of the lava sequence is dominated by medium to dark gray fragments mixed with minor amounts of scoriaceous brownish gray clasts. No claystone fragments were noted at this depth.

Puye Formation, Tpf (686–925 ft bgs)

The cuttings are mostly gravelly coarse sand, clast-supported, massive, and unconsolidated except for isolated coarse sand fractions with moderate amounts of fine to medium sand matrix in the intervals of 730 to 740 ft bgs and 750 to 760 ft bgs. Cuttings of coarse sand fractions were also encountered at the base of the Puye Formation (890–900 ft bgs and 910–925 ft bgs). The uppermost cuttings contain a mixture of comparable amounts of basaltic and dacite lava clasts, including common Rendija Canyon fragments. The amount of Rendija Canyon clasts significantly increased with depth, and these clasts are characterized by pale red fragments with micro-phenocrysts of oxidized pyroxene crystals. Moderate amounts of light and medium to dark gray dacite fragments were also noted. Below 750 ft bgs, the Rendija Canyon fragments increased while other lava clasts drastically decreased. The lithologic transition was noted in the gamma and neutron logs. The amount of Rendija Canyon fragments started to decrease starting at 780 ft bgs and a dark gray lava dominated the cuttings (800–810 ft bgs). The interval is clearly distinguished by the abrupt decrease of the gamma signal between 780 and 820 ft bgs. The amount of Rendija Canyon clasts significantly increased in the interval 820–840 ft bgs. Comparable amounts of pale-red Rendija Canyon fragments and other light to medium gray lava fragments were noted in the interval between 840 and 860 ft bgs. However, pale red fragments of Rendija Canyon are the dominant fragment below 860 ft bgs to the base of the deposit at 925 ft bgs.

Pumiceous Puye Formation (925–1015 ft bgs)

The transition from the Puye Formation to pumiceous Puye Formation subunit is marked by the presence of white subrounded pumice clasts (10-15%). The cuttings are mostly coarse pumiceous sand, poorly sorted, and fines depleted and contain minor Rendija Canyon lava fragments. The amount of pumice increased with depth and two types of rounded pumice (white and light brown) were noted while the Rendija Canyon clast content decreased. Crystals are generally sparse. Some of the cuttings are gravelly to fine sand, matrix supported, and dominated by banded rhyolites, few perlite, and other dacite fragments. The Rendija Canyon clasts represent <5% of the cuttings. The pumices are generally dense and poorly inflated. The pumice content continued to increase with depth (60–90%), and fine tuffaceous sand fractions, consisting of minerals and silty pumice fragments, varied with depth while Rendija Canyon clasts became sparse. The basal strata contain mixed rounded pumice and lava clasts lightly coated with brownish tuffaceous silt.

Miocene Riverine Sediments, Tcar (1015–1025 ft bgs)

The riverine sediments consist of abundant quartzite, minor intermediate well-rounded lava fragments, and light brown sandstone clasts in a poorly sorted mixture of pumice, minerals, and other lava fragments.

5.2 Groundwater

Drilling at CrEX-4 proceeded without any groundwater indications until approximately 960.0 ft bgs as noted by the drilling crew. The borehole was then advanced to the TD of 1025 ft bgs. The water level was 920.46 ft bgs on October 10, 2017, before well installation. The DTW in the completed well was 920.02 ft bgs on November 14, 2017.

6.0 BOREHOLE LOGGING

On October 6, 2017, Laboratory video and gamma logs were run in the open borehole (Table-6.0-1). Video was run from the surface to 874 ft bgs because of drilling foam standing in the bottom of the borehole. The video log is included in Appendix A (on DVD included with this report). The gamma log was run by Laboratory personnel from 880 ft bgs to surface. The borehole was logged by JWGS upon reaching TD of 1025 ft bgs with the 14-in. casing on October 10. Logging consisted of cased-hole gamma-ray and neutron density. The gamma and neutron logs are included in Appendix B (on CD included with this report).

On December 7, 2017, a video log was run to document the as-built condition of the completed well.

7.0 WELL INSTALLATION CREX-4 EXTRACTION WELL

The CrEX-4 well was installed between October 24 and November 10, 2017.

7.1 Well Design

The CrEX-4 well was designed in accordance with the objectives outlined in the "Drilling Work Plan for Groundwater Extraction Well CrEX-4" (LANL 2017, 602594). The results from the 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 supply additional water to help with hydraulic control of the chromium plume and to provide additional plume-center characterization data.

Extraction well CrEX-4 was designed with two screened intervals between 930.0 ft and 965.0 ft bgs and 975.0 ft and 995.0 ft bgs to obtain a profile of the chromium concentrations between the two screened intervals and also to characterize the hydraulics of each zone. The well design was submitted to NMED on October, 2017, and approved the next day. The final CrEX-4 design and NMED's approval are included in Appendix C.

7.2 Well Construction

The CrEX-4 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 sections used various lengths of 8.0-in.-I.D. 0.040-in. slot, rod-based wire-wrapped screens to make up the upper 35.0-ft-long screen interval and lower 20.0-ft-long screen interval. Stainless-steel centralizers (two sets of four) were welded to the well casing approximately2.0 ft above and below the screened intervals. 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.

The well casing was welded together and installed into the borehole from October 24 to 27, 2017. Backfilling began on October 28 and was completed on November 10.

Figure 7.2-1 presents an as-built schematic showing construction details for the completed well. Table 7.2-1 presents the quantities of annular fill materials used in CrEX-4.

A 2.0-in. steel tremie pipe was used to deliver backfill and annular fill materials downhole during well construction. The lower bentonite backfill was installed on October 28 and 29 from 1011.9 ft to 999.3 ft bgs using 9.4 ft^3 of 3/8-in. bentonite chips and ¼-in. coated bentonite pellets. The lower filter pack was installed between October 29 and 30 from 999.3 ft to 970.3 ft bgs using 28.5 ft^3 of 10/20 silica sand. The filter pack was surged to promote compaction. A transition sand interval was not installed between the lower filter pack and intermediate bentonite seal. An intermediate bentonite seal was installed on October 30 from 970.3 ft to 967.6 ft bgs using 2.7 ft^3 of ¼-in. coated bentonite pellets. The upper filter pack was installed between October 31 and November 3 from 967.6 ft to 924.4 ft bgs using 57.5 ft^3 of 10/20 silica sand. The filter pack was surged to promote compaction. Both filter sand intervals exceeded the calculated volumes and this is attributed to surging the screen intervals during construction. The fine-sand collar was installed above the filter pack from 924.4 ft to 920.8 ft bgs using 4.0 ft^3 of 20/40 silica sand. From November 3 to 10, the bentonite seal was installed from 920.8 ft to 60.1 ft bgs using 776.3 ft^3 of 3/8-in. and 3/4-in. bentonite chips. On November 10, a cement seal was installed from 60.1 ft to 9.2 ft bgs. The cement seal used 69.5 ft^3 of Portland Type I/II/V cement.

8.0 POST-INSTALLATION ACTIVITIES

Following well installation at CrEX-4, the well was developed and aquifer pumping tests were conducted. A dedicated pumping system was installed. The wellhead surface completion has been constructed as part of the treatment system piping and infrastructure project. A geodetic survey has been performed. Site-restoration activities will be completed in the summer of 2018.

8.1 Well Development

The well was developed between November 11 and 28, 2017. Initially, the screened intervals were swabbed and bailed from November 11 to 12 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 980 gal. of groundwater was removed during bailing activities.

From November 16 to 28, 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 intervals were 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 in both screen intervals, but particularly the lower screen. The CrEX-4 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 intervals. The solution was surged throughout the screen interval and allowed to sit in the well for approximately 12 h on both occasions. Pump development was completed on November 28.

Approximately 102,495 gal. of groundwater was purged from both screen intervals combined during well development pumping.

The field parameters of turbidity, temperature, and pH were monitored via a flow-through cell at CrEX-4 during well development. During development, the screened intervals were not isolated and pumping discharge was composite water from both screens. The field parameter measurements toward the end of development pumping from both screens together on November 18, 2017, were pH of 7.79, temperature of 19.99°C, and turbidity of 2.5 nephelometric turbidity units (NTU).

8.2 Aquifer Testing

Aquifer testing at CrEX-4 consisted of five events. Both screen intervals underwent isolated 24-h constant rate tests, the upper screen interval underwent step testing, and the integrated well (both screen intervals open) underwent step testing and a 24-h constant rate test. The lower screen interval alone could not produce enough water separately to warrant step testing given the size of the pump used for testing.

A 24-h constant rate aquifer test was conducted on the lower screen between November 28 and 29, followed by a 16-h recovery period. The average pumping rate for the lower screen 24-h test was approximately 35 gallons per minute (gpm). Approximately 51,994 gal. of water was removed during the test. Step testing was conducted on the integrated well on November 30. The well was pumped in three steps at 50 gpm, 65 gpm, and 80 gpm in 1-h increments. A total of 12,200 gal. of water was removed during the step testing. A 24-h constant rate aquifer test was conducted on the integrated well between November 30 and December 1, followed by an 18-h recovery period. The average pumping rate for the 24-h test was approximately 75 gpm. Approximately 109,338 gal. of water was removed during the constant rate testing. On December 2 and 3, the pump and packer assembly was removed from the well in order to reconfigure the position of the packer. Before removal, the pump was advanced to the bottom of the well sump in order to perform clean-out pumping of the sump. Approximately 2045 gal. of water was removed during this process. The pumping assembly was reinstalled in the well on December 3. Step testing was conducted on the upper screen on December 3. The upper screen was pumped in two steps at 40 gpm and 35 gpm in 1-h increments. Approximately 4459 gal. of water was removed during the step testing. A 24-h constant rate aquifer test was conducted on the upper screen between December 4 and 5, followed by an 18-h recovery period. The average pumping rate for the 24-h test was approximately 35 gpm. Approximately 50,217 gal. of water was removed during the constant rate testing.

A 30-hp pump was used for the aquifer tests. A total of approximately 230,253 gal. of groundwater was purged during aquifer testing. The CrEX-4 aquifer test results and analysis are presented in Appendix D.

8.2.1 Aquifer Testing Field Parameters and Sampling

The field parameters of turbidity, temperature, and pH were monitored via a flow-through cell at CrEX-4 during aquifer testing. Field parameters during aquifer testing were collected for both isolated screen intervals and composite water from both screens together. Field water-quality parameters for aquifer testing are presented in Table 8.2-1.

Water samples were collected during each of the 24-h aquifer tests. Samples were collected at the beginning of each test and every 4 h thereafter (seven total samples for each test). The samples were analyzed at the Laboratory’s Geochemistry and Geomaterials Research Laboratory (GGRL) for metals, anions, alkalinity, and Ph. One sample was collected at the end of each 24-h test and analyzed for perchlorate and low-level tritium at off-site laboratories. Sample results for aquifer testing samples are presented on CD in Appendix E.

8.3 Pumping System Installation

A dedicated pumping system for CrEX-4 was installed between December 8 and December 9, 2017. The system uses a 6-in. Grundfos submersible pump and 30-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 3.0-in. I.D. threaded and coupled, schedule 40 galvanized steel with API NPT couplings. 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-4 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-4 wellhead. The vault is 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.

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-4 is presented in Table 8.5-1.

8.6 Waste Management and Site Restoration

Waste generated from the CrEX-4 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-4 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 will include evaporating drilling fluids, removing cuttings from the pit and managing the development/pump test fluids in accordance with applicable procedures. The polyethylene liner will be removed following land application of the cuttings, and the containment area berms will be removed and leveled. Final activities will also include backfilling and regrading the containment area, as appropriate.

9.0 DEVIATIONS FROM PLANNED ACTIVITIES

Drilling and well construction at CrEX-4 were performed as specified in "Drilling Work Plan for Groundwater Monitoring Well CrEX-4" (LANL 2017, 602594). The final dual-screen well design 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-4.

11.0 REFERENCES AND MAP DATA SOURCES

11.1 References

The following reference list includes documents cited in this plan. 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 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), August 31, 2017. "Storm Water Pollution Prevention Plan, CrEX-4 Well Construction Support Activities Project, Los Alamos National Laboratory," Los Alamos National Laboratory, Los Alamos, New Mexico. (LANL 2017, 602924)

LANL (Los Alamos National Laboratory), September 5, 2017. "Drilling Work Plan for Groundwater Extraction Well CrEX-4," Los Alamos National Laboratory letter (ADEM-17-0211) to J. Kieling (NMED-HWB) from B. Robinson (LANL) and D. Rhodes (DOE-EM-LA), Los Alamos, New Mexico. (LANL 2017, 602594)

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.

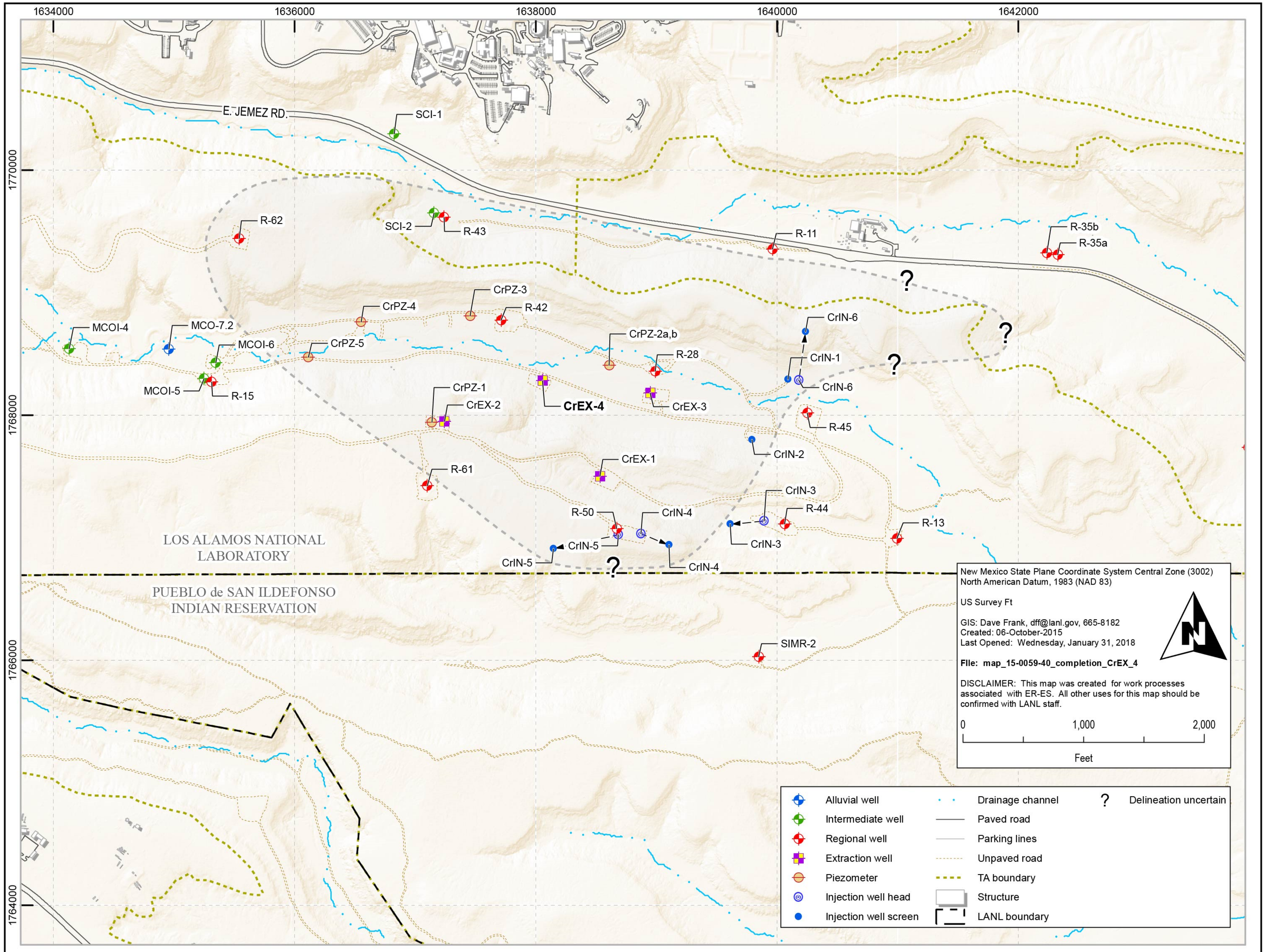


Figure 1.0-1 Location of extraction well CrEX-4

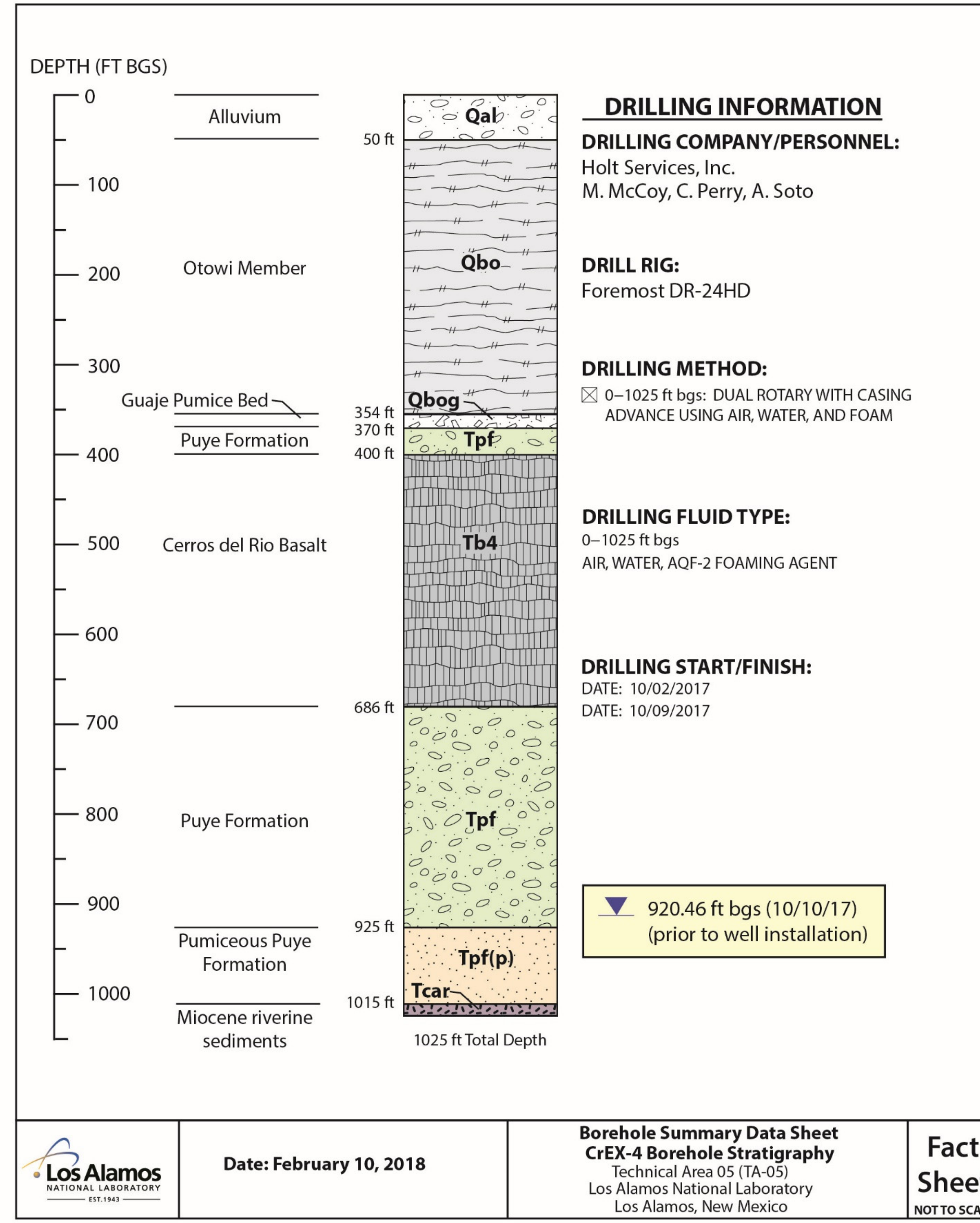


Figure 5.1-1 Extraction well CrEX-4 borehole stratigraphy

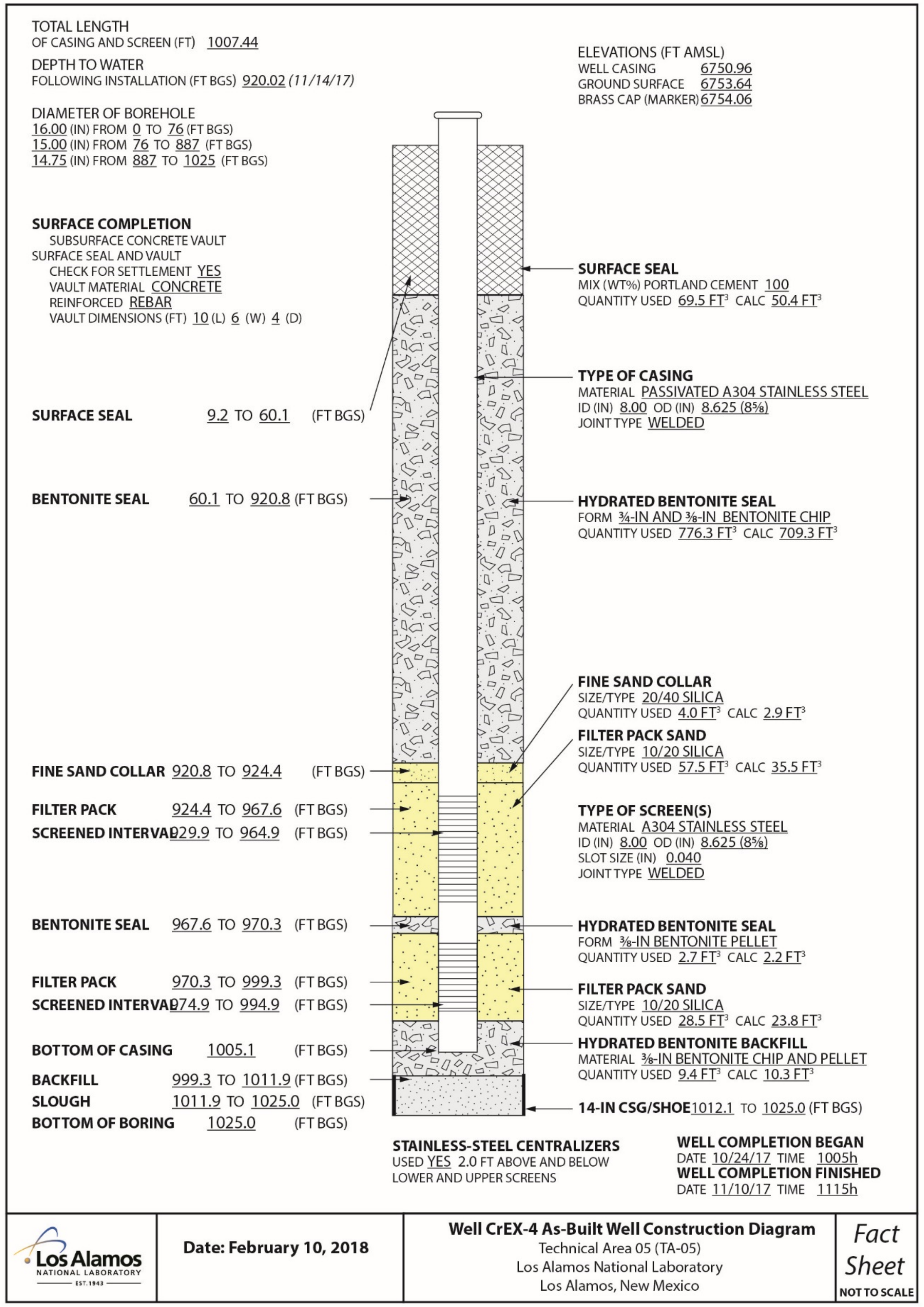


Figure 7.2-1 Extraction well CrEX-4 as-built well construction diagram

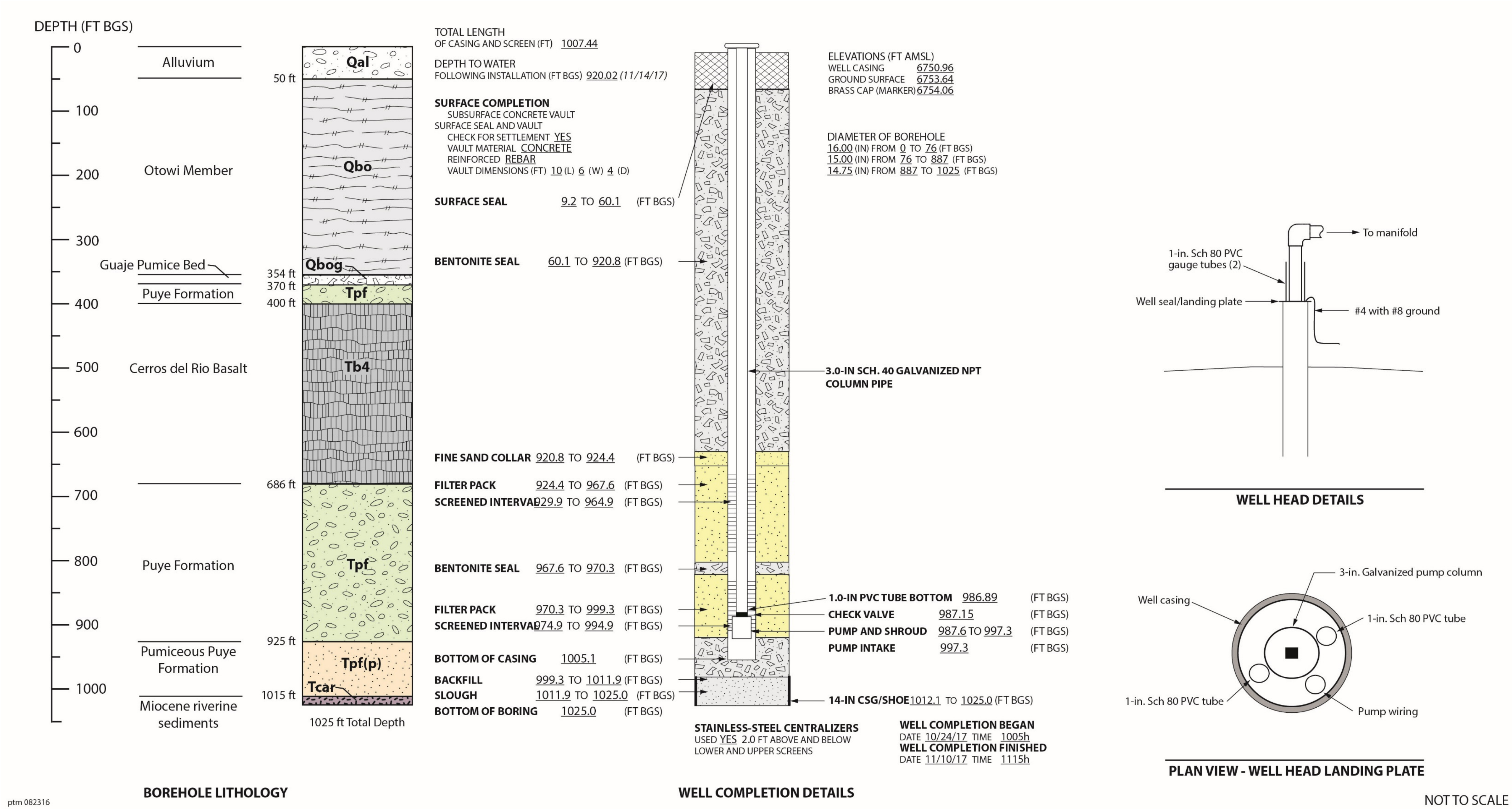


Figure 8.3-1a Extraction well CrEX-4 as-built diagram with borehole lithology and technical well completion details

CrEX-4TECHNICAL NOTES:

SURVEY INFORMATION *

Brass Marker
Northing: 1768292.092
Easting: 1638048.746
Elevation: 6754.056

Well Casing (top of well seal)
Northing: 1768288.305
Easting: 1638049.190
Elevation: 6750.960

Well Seal Thickness:
0.08 ft.

BOREHOLE GEOPHYSICAL LOGS

Logger: Jet West Geophysical Services
Logs: Natural Gamma Ray, Neutron Density
Date: 10/10/2017

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 foam

MILESTONE DATES

Drilling
Start: 10/02/2017
Finished: 10/09/2017

Well Completion
Start: 10/24/2017
Finished: 11/10/2017

Well Development
Start: 11/11/2017
Finished: 11/28/2017

WELL DEVELOPMENT

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

Parameter Measurements (Final, composite)
pH: 7.79
Temperature: 19.99°C
Turbidity: 2.5 NTU

AQUIFER TESTING

24-h Constant Rate: Lower Screen
Water Produced: 51,994 gal.
Pumping Rate: 35 gpm
Performed on: 11/28/2017–11/29/2017

Step Tests: Integrated Well
Water Produced: 12,000 gal.
Pumping Rates: 50, 65, 80 gpm
Performed on: 11/30/2017

24-h Constant-Rate: Integrated Well
Water Produced: 109,338 gal.
Pumping Rate: 75 gpm
Performed on: 11/30/2017–12/01/2017

24-h Constant-Rate: Upper Screen
Water Produced: 50,217 gal.
Pumping Rate: 35 gpm
Performed on: 12/04/2017–12/05/2017

DEDICATED PUMPING SYSTEM

Pump
Make: Grundfos
Type: 85S300-26

Motor
Make: Franklin Electric
Model: 2366168120, 30 HP

Pump Column
3.0-inch, Sch. 40, galvanized, API
NPT 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

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-4

Table 6.0-1
Logging Runs

Date(s)	Type of Log	Depth (ft bgs)	Description
10/06/2017	Video	0–874	LANL video from ground surface to 874 ft bgs. Observe open-hole interval.
10/06/2017	Gamma log	0–880	LANL gamma log through open-hole section.
10/10/2017	Gamma log	0–1011	JWGS gamma log at drilling TD.
10/10/2017	Neutron log	0–1011	JWGS neutron log at drilling TD.
12/07/2017	Video	0–1005	LANL video to confirm well completion condition.

Table 7.2-1
CrEX-4 Extraction Well Annular Fill Materials

Material	Volume (ft^{3})
Upper surface seal: cement slurry	69.5
Upper bentonite seal: bentonite chips	776.3
Fine sand collar: 20/40 silica sand	4.0
Upper filter pack: 10/20 silica sand	57.5
Intermediate seal: bentonite pellets	2.7
Lower filter pack: 10/20 silica sand	28.5
Backfill: bentonite chips and pellets	9.4

Table 8.2-1
Field Water-Quality Parameters and Well Performance for Aquifer Testing of Well CrEX-4

Date	Time	Pumping Rate (gpm)	Depth to Water (ft bgs)	Draw Down (ft)	Cumulative Purge Volume	pH	Temp (Deg C)	Turbidity (NTU)
Lower Screen 24-h Constant Rate Test								
11/29/2017	15:30	36	958.05	37.92	104555	7.88	20.94	10.9
	16:00	36	958.26	38.13	105563	7.89	21.06	1.9
	16:30	36	958.20	38.07	106571	7.90	21.00	1.7
	17:01	36	958.24	38.11	107687	7.90	20.96	1.1
	17:31	36	958.25	38.12	108803	7.90	21.22	2.4
	18:00	36	958.18	38.05	109847	7.84	21.23	84.0
	18:30	36	958.13	38.00	110927	7.91	21.13	1.4
	19:00	36	958.14	38.01	112007	7.89	21.20	1.6
	19:30	36	958.04	37.91	113087	7.90	21.19	1.1
	20:00	36	958.05	37.92	114167	7.90	21.17	0.5
	20:30	36	958.04	37.91	115247	7.91	21.07	0.8
	21:00	36	958.18	38.05	116327	7.92	21.12	0.9
	21:30	36	958.13	38.00	117407	7.92	21.17	0.8
	22:00	36	958.08	37.95	118487	7.89	21.20	0.7

Table 8.2-1 (continued)

Date	Time	Pumping Rate (gpm)	Depth to Water (ft bgs)	Draw Down (ft)	Cumulative Purge Volume	pH	Temp (Deg C)	Turbidity (NTU)
11/29/2017 (cont.)	22:30	36	958.33	38.20	119567	7.90	21.07	0.6
	23:00	36	958.29	38.16	120647	7.91	21.15	0.7
	23:30	36	958.26	38.13	121727	7.91	21.15	0.8
11/30/2017	0:00	36	958.19	38.06	122807	7.91	21.16	0.8
	0:30	36	958.32	38.19	123887	7.91	21.14	0.8
	1:00	36	958.27	38.14	124967	7.91	21.17	1.2
	1:30	36	958.23	38.10	126047	7.92	21.08	1.6
	2:00	36	958.25	38.12	127127	7.91	21.14	1.6
	2:30	36	958.26	38.13	128207	7.92	21.12	1.5
	3:00	36	958.27	38.14	129287	7.92	21.05	1.5
	3:30	36	958.24	38.11	130367	7.93	21.01	1.6
	4:00	36	958.32	38.19	131447	7.91	20.90	1.5
	4:30	36	958.26	38.13	132527	7.91	20.92	1.3
	5:00	36	958.19	38.06	133607	7.91	20.92	1.3
	5:30	36	958.20	38.07	134687	7.89	20.97	1.9
	6:00	36	958.18	38.05	135767	7.92	20.87	1.4
	6:30	36	958.15	38.02	136847	7.93	20.91	5.5
	7:00	36	958.09	37.96	137927	7.92	20.92	1.1
	7:30	36	958.41	38.28	139007	7.91	21.04	1.1
	8:00	36	958.33	38.20	140087	7.92	21.10	2.2
	8:30	36	958.38	38.25	141167	7.92	21.41	0.2
11/30/2017	9:00	36	958.39	38.26	142247	7.90	21.23	2.1
	9:30	36	958.46	38.33	143327	7.92	21.31	2.4
	10:00	36	958.43	38.30	144407	7.92	21.64	0.5
	10:30	36	958.41	38.28	145487	7.92	21.61	0.9
	11:00	36	958.38	38.25	146567	7.91	21.50	0.8
	11:30	36	958.31	38.18	147647	7.91	21.68	5.0
	12:00	36	958.32	38.19	148727	7.91	21.60	3.8
	12:30	36	958.33	38.20	149807	7.91	21.74	0.8
	13:00	36	958.36	38.23	150887	7.90	19.21	0.1
	13:30	36	958.29	38.16	151967	7.93	21.53	0.2
	14:00	36	959.53	39.40	153047	7.93	21.35	0.3
	14:30	36	959.57	39.44	154127	7.92	21.52	0.5
	14:59	36	959.48	39.35	155207	7.90	21.48	0.6

Table 8.2-1 (continued)

Date	Time	Pumping Rate (gpm)	Depth to Water (ft bgs)	Draw Down (ft)	Cumulative Purge Volume	pH	Temp (Deg C)	Turbidity (NTU)
Composite Well Step Test								
11/30/2017	7:15	50	908.21	12.23	155957	7.24	20.90	107.7
	7:45	50	908.17	12.26	157457	7.62	20.46	2.4
	8:15	65	903.55	16.89	159182	7.71	20.26	1.5
	8:45	65	903.31	17.12	161132	7.76	20.17	1.6
	9:10	80	899.21	21.22	162907	7.76	19.96	2.5
	9:40	80	898.94	21.49	165307	7.82	20.05	1.0
Composite Well 24-h Constant Rate Test								
11/30/2017	13:01	76	907.11	13.32	166983	7.66	13.27	6.6
	13:17	76	900.85	19.58	168199	7.76	20.22	4.2
	13:30	76	900.61	19.82	169187	7.77	20.20	1.2
	14:00	76	900.41	20.02	171467	7.81	20.18	0.5
	14:30	76	900.31	20.13	173747	7.85	20.21	0.5
	15:00	76	900.25	20.18	176027	7.86	20.26	0.4
	15:31	76	900.22	20.21	178383	7.86	20.19	0.3
	16:01	76	900.21	20.22	180663	7.88	20.18	0.3
	16:31	76	900.19	20.24	182943	7.89	20.17	0.3
	17:02	76	900.18	20.25	185299	7.87	20.08	0.2
	17:30	76	900.16	20.27	187427	7.89	19.98	0.3
	18:00	76	900.16	20.27	189707	7.89	19.92	0.3
	18:30	76	900.16	20.27	191987	7.88	19.95	0.3
	19:00	76	900.16	20.28	194267	7.89	19.88	0.3
11/30/2017	19:30	76	900.15	20.28	196547	7.88	19.78	0.3
	20:00	76	900.18	20.25	198827	7.89	19.82	0.3
	20:30	76	900.19	20.24	201107	7.89	19.81	0.3
	21:00	76	900.20	20.23	203387	7.89	19.96	0.3
	21:30	76	900.20	20.23	205667	7.89	19.85	0.2
	22:00	76	900.22	20.21	207947	7.89	19.90	0.2
	22:30	76	900.22	20.21	210227	7.89	19.95	0.2
	23:00	76	900.23	20.20	212507	7.89	19.98	0.2
	23:30	76	900.26	20.18	214787	7.89	19.82	0.3

Table 8.2-1 (continued)

Date	Time	Pumping Rate (gpm)	Depth to Water (ft bgs)	Draw Down (ft)	Cumulative Purge Volume	pH	Temp (Deg C)	Turbidity (NTU)
12/1/2017	0:00	76	900.25	20.18	217067	7.89	19.97	0.2
	0:30	76	900.27	20.16	219347	7.89	20.04	0.2
	1:00	76	900.29	20.14	221627	7.69	20.03	0.7
	1:30	76	900.29	20.14	223907	7.89	20.11	0.2
	2:00	76	900.29	20.14	226187	7.90	20.07	0.2
	2:30	76	900.32	20.11	228467	7.91	19.94	0.2
	3:00	76	900.32	20.11	230747	7.91	19.86	0.2
	3:30	76	900.33	20.10	233027	7.91	19.90	0.2
	4:00	76	900.33	20.10	235307	7.91	19.86	0.2
	4:30	76	900.33	20.10	237587	7.92	19.84	0.2
	5:00	76	900.35	20.08	239867	7.91	19.91	0.2
	5:30	76	900.38	20.06	242147	7.87	19.79	0.5
	6:00	76	900.36	20.07	244427	7.90	19.86	0.2
	6:30	76	900.36	20.07	246707	7.90	19.89	0.2
	7:00	76	900.40	20.03	248987	7.89	19.88	0.2
	7:30	76	900.40	20.03	251267	7.90	19.90	0.2
	8:00	76	900.43	20.00	253547	7.91	20.00	0.2
	8:30	76	900.42	20.01	255827	7.88	20.17	0.2
	9:00	76	900.44	19.99	258107	7.87	20.07	0.2
	9:30	76	900.40	20.03	260387	7.97	20.41	0.1
	10:00	76	900.41	20.02	262667	7.96	20.39	0.1
	10:30	76	900.45	19.98	264947	7.93	20.62	0.1
	11:00	76	900.47	19.96	267227	7.96	20.57	0.4
	11:30	76	900.46	19.97	269507	7.96	20.50	0.1
	12:00	76	900.45	19.98	271787	7.97	20.85	0.1
	12:30	76	900.49	19.95	274067	8.00	20.66	0.1
Composite Well 24-h Constant Rate Test								
12/1/2017	13:00	76	900.50	19.94	276347	7.95	20.62	0.1
Upper Screen 24-h Constant Rate Test								
12/4/2017	7:04	36	899.37	20.92	282995	5.51	6.69	0.6
	7:34	36	909.67	10.62	284075	7.82	21.16	8.9
	8:04	36	909.33	10.96	285155	7.87	21.09	6.2
	8:34	36	909.48	10.81	286235	7.89	21.26	16.9
	9:04	36	909.91	10.38	287315	7.9	21.14	569.3
	9:34	36	909.91	10.38	288395	7.91	21.24	41.9
	10:04	36	909.46	10.83	289475	7.92	21.33	12.2
	10:30	36	909.46	10.83	290411	7.91	20.97	0.9
	11:00	36	910.10	10.19	291491	7.91	21.05	0.4
	11:30	36	910.10	10.19	292571	7.92	21.13	0.8
	12:00	36	910.17	10.12	293651	7.91	21.2	0.3

Table 8.2-1 (continued)

Date	Time	Pumping Rate (gpm)	Depth to Water (ft bgs)	Draw Down (ft)	Cumulative Purge Volume	pH	Temp (Deg C)	Turbidity (NTU)
	12:30	36	910.52	9.77	294731	7.92	21.27	0.3
	13:00	36	909.29	11.00	295811	7.9	21.28	0.4
	13:30	36	909.06	11.24	296891	7.92	20.99	0.4
	14:02	36	909.10	11.19	297899	7.79	21.11	1.5
	14:32	36	909.33	10.96	298979	7.9	20.84	0.5
	15:02	36	909.26	11.03	300059	7.9	20.91	0.4
	15:33	36	909.04	11.25	301175	7.9	20.87	0.3
	16:01	36	909.10	11.19	302183	7.94	20.84	0.5
	18:08	36	909.05	11.25	306755	7.2	20.61	0.5
	18:30	36	909.07	11.23	307547	7.67	20.88	0.4
	19:00	36	908.92	11.37	308627	7.79	20.86	0.4
	19:30	36	909.04	11.26	309707	7.84	20.83	0.4
	20:00	36	909.05	11.24	310787	7.87	20.97	0.3
	20:30	36	909.08	11.21	311867	7.88	20.93	0.4
	21:00	36	909.20	11.09	312947	7.89	20.88	0.4
	21:30	36	909.08	11.21	314027	7.9	20.87	0.3
	22:00	36	909.00	11.29	315107	7.9	20.89	0.3
	22:30	36	908.77	11.53	316187	7.9	20.93	570.3
	23:00	36	909.09	11.21	317267	7.91	20.96	0.1
	23:30	36	909.20	11.09	318347	7.91	20.93	0.5
12/5/2017	0:00	36	909.21	11.08	319427	7.91	20.96	0.4
	0:30	36	909.33	10.97	320507	7.89	21.09	0.3
Composite Well 24-h Constant Rate Test								
12/5/2017	1:00	36	909.45	10.84	321587	7.91	21.06	0.4
	1:30	36	909.51	10.78	322667	7.92	21.12	0.4
	2:00	36	908.62	11.67	323747	7.92	21	0.3
	2:30	36	909.07	11.22	324827	7.92	20.92	0.3
	3:00	36	909.22	11.07	325907	7.93	21.04	0.3
	3:30	36	909.08	11.21	326987	7.93	20.9	0.3
	4:00	36	909.05	11.24	328067	7.93	20.95	0.3
	4:30	36	909.23	11.06	329147	7.93	20.93	0.3
	5:00	36	909.10	11.19	330227	7.95	20.98	0.4
	5:31	36	909.12	11.17	331343	7.95	20.84	0.4
	6:01	36	908.45	11.84	332423	7.97	20.63	0.7
	6:25	36	908.92	11.37	333287	7.99	20.04	0.4

Table 8.5-1
CrEX-4 Well Survey Coordinates

Identification	Northing (ft)	Easting (ft)	Elevation (ft)
CrEX-4 brass cap embedded in vault	1768292.092	1638048.746	6754.056
CrEX-4 top of well casing	1768288.305	1638049.190	6750.960

Table 8.6-1
Summary of Waste Characterization Samples Collected during Drilling, Construction, and Development of CrEX-4

Event ID	Sample ID	Date Collected	Description	Sample Matrix
11547	WSTMO-17-147945	10/05/2017	CrEx-4 drill cuttings (top) VOC	Solid
11547	WSTMO-17-147948	10/05/2017	CrEx-4 drill cuttings trip blank VOC	Solid
11547	WSTMO-17-147946	10/05/2017	CrEx-4 drill cuttings(middle) VOC	Solid
11547	WSTMO-17-147949	10/05/2017	CrEx-4 drill cuttings trip blank VOC	Solid
11547	WSTMO-17-147947	10/09/2017	CrEx-4 drill cuttings (bottom) VOC	Solid
11545	WSTMO-17-147933	10/05/2017	CrEx-4 drilling fluids (top) VOC	Liquid
11545	WSTMO-17-147944	10/05/2017	CrEx-4 drilling field dup. VOC	Liquid
11545	WSTMO-17-147936	10/05/2017	CrEx-4 drilling fluids trip blank VOC	Liquid
11545	WSTMO-17-147934	10/05/2017	CrEx-4 drilling fluids(middle) VOC	Liquid
11545	WSTMO-17-147943	10/05/2017	CrEx-4 drilling field dup. VOC	Liquid
11545	WSTMO-17-147937	10/05/2017	CrEx-4 drilling fluids trip blank VOC	Liquid
11545	WSTMO-17-147935	10/09/2017	CrEx-4 drilling fluids (bottom) VOC	Liquid
11545	WSTMO-17-147942	10/09/2017	CrEx-4 drilling field dup. VOC	Liquid
11545	WSTMO-17-147950	10/09/2017	CrEx-4 drilling fluids trip blank VOC	Liquid

* VOC = Volatile organic compound.

Appendix A

Borehole Video Logging
(on DVD included with this document)

Appendix B

Geophysical Logs
(on CD included with this document)

Appendix C

Final Well Design and
New Mexico Environment Department Approval

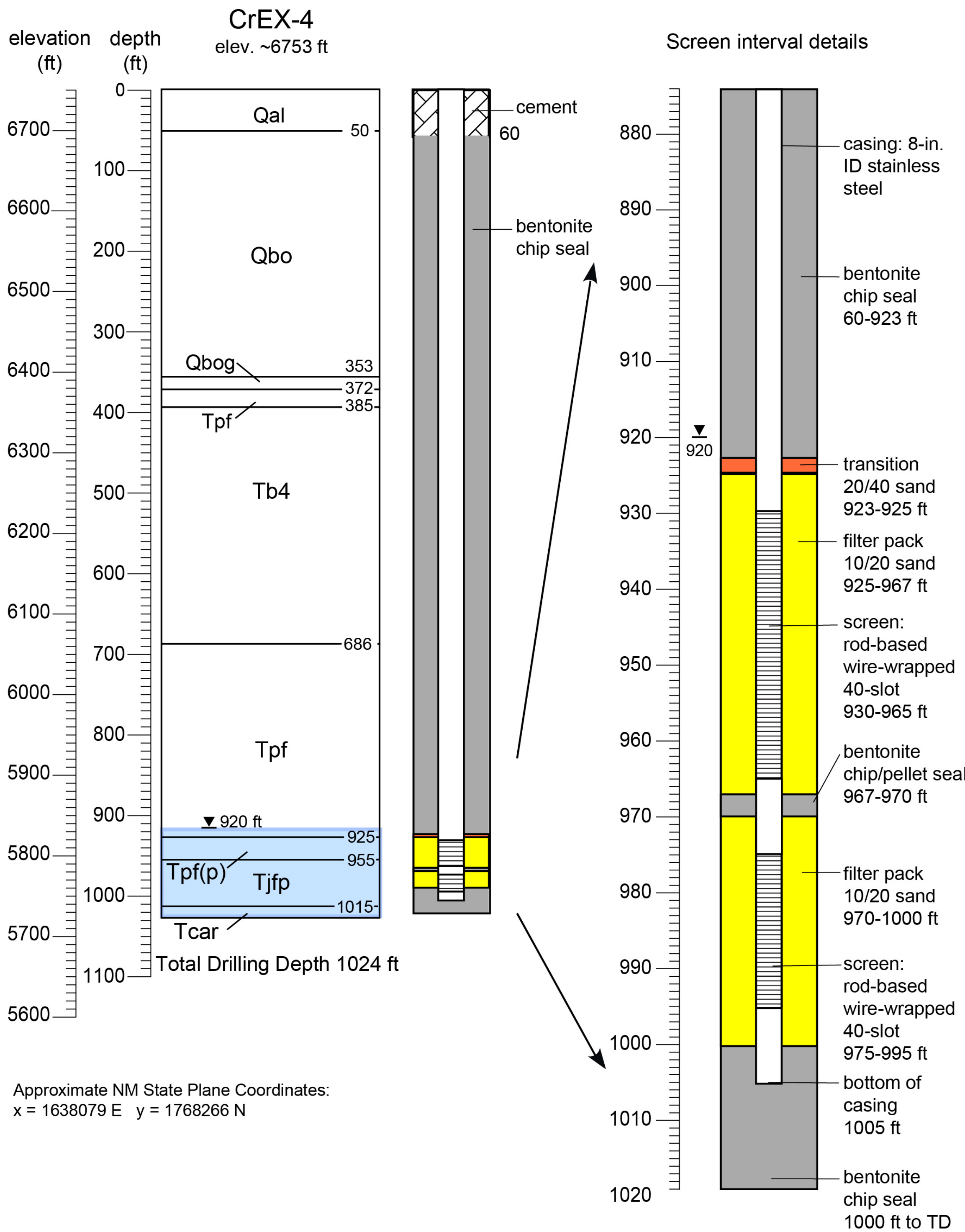


Figure 1 **CrEX-4 proposed well design**

From: Dale, Michael, NMENV
To: White, Stephen Spalding
Cc: Murphy, Robert, NMENV; Dhawan, Neelam, NMENV; Rodriguez, Cheryl L; Katzman, Danny; Swickley, Stephani Fuller; Longmire, Patrick, NMENV; Yanicak, Steve, NMENV; Fellenz, David, NMENV
Subject: Re: CrEX4 well design proposal resubmittal
Date: Thursday, October 19, 2017 5:56:12 AM

Steve,

New Mexico Environment Department (NMED) hereby approves the installation of the regional-aquifer chromium extraction well CrEX-4 as proposed in your e-mail, with attachment, that was received yesterday, October 18, 2017 at 5:10 PM. 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 information becomes available. In addition, please provide NMED reasonable-time (e.g., 1 -2 days) notification prior to the initiation of well development, step-drawdown tests, and aquifer testings at CrEX-4. 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 <ssw@lanl.gov>
Sent: Wednesday, October 18, 2017 5:10 PM
To: Dale, Michael, NMENV
Cc: Rodriguez, Cheryl L; Katzman, Danny; Swickley, Stephani Fuller
Subject: CrEX4 well design proposal resubmittal

Michael,

Please find attached a revision of the CrEX4 well design proposal.

Let us know what you think.

Thanks,

SW

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

From:	Dale, Michael, NMENV
To:	White, Stephen Spalding
Cc:	Rodriguez, Cheryl L; Katzman, Danny; Swickley, Stephani Fuller; Dhawan, Neelam, NMENV; Murphy, Robert, NMENV; Longmire, Patrick, NMENV
Subject:	Re: Minor CrEX4 design revision
Date:	Friday, October 20, 2017 6:59:41 AM

Steve,

The minor changes to the well completion for CrEX-4, as described in your e-mail below, seem appropriate and NMED supports the adjustments. NMED appreciates the notice concerning adjustments to the well design.

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 <ssw@lanl.gov>
Sent: Thursday, October 19, 2017 4:30 PM
To: Dale, Michael, NMENV
Cc: Rodriguez, Cheryl L; Katzman, Danny; Swickley, Stephani Fuller
Subject: Minor CrEX4 design revision

Hello Michael,

Please take a look at the attached well design figure for CrEX4.

Two minor tweaks:

1. The lower 1-ft interval of 20/40 transition sand (formerly 970 to 971 ft bgs) has been eliminated. Mark Everett and I discussed the necessity of that sand yesterday and neither one of us loved it. While speaking to our drilling subcontractor this morning, it was the only thing they questioned. We would rather have an additional foot of primary sand above the lower screen than the transition sand. If the sand should ever migrate downward that far, the 20/40 will simply pour right through the slots where the 10/20 will not. For chips and pellets the transition sand isn't a necessity anyway. It's nice insurance, but in tight quarters I don't feel eliminating it to be risky in the least.
2. The addition of the word 'pellet' in the description of the intermediate bentonite seal.

That's it. Let me know if you see any problems. We won't start installing backfill materials until mid to late next week.

Thanks,

SW

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

Appendix D

CrEX-4 Aquifer Testing Report

D-1.0 INTRODUCTION

This appendix describes the hydrogeological analysis of aquifer tests at well CrEX-4 located in Mortandad Canyon within the existing chromium plume. CrEX-4 has two screened intervals, with the upper interval from 930 to 965 ft below ground surface (bgs) and the lower from 975 to 995 ft bgs. Static water level in the well is at 920.46 ft bgs.

The following pumping tests were performed during the period from November 28, 2017 to December 5, 2017. The lower screen was tested at a constant pumping rate for 24 h. Next, a composite (both screens open) three-step variable rate pumping test and a 24-h constant rate pumping test were performed. The upper screen was then isolated for a two-step variable rate test followed by a 24-h constant rate pumping test. The primary objective of this analysis is to estimate the hydraulic properties of the aquifer zone screened by CrEX-4.

D-1.0-1 Conceptual Hydrogeology

The performed aquifer tests provide information about the properties of the regional aquifer in the Pumiceous Puye Formation, Tpf(p). The lithologic log for CrEX-4 indicates the top surface of the Puye Formation (Tpf) is at 686 ft bgs at this location. The Tpf(p) unit begins at 925 ft bgs, 5 ft above the start of the upper screen. Miocene sediments start at 1015 ft bgs, below the lower screen.

Based on prior 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-4 is screened) and confined (or leaky confined) behavior at deeper depths, where the municipal water-supply wells are screened (LANL 2007, 098734). The aquifer has unknown total thickness at CrEX-4, but it is greater than 1000 ft. The effective thickness of the phreatic zone relative to the CrEX-4 well screens during the pumping tests is also unknown.

Downward vertical head gradients are observed in several multi-screened wells (LANL 2009, 106427). At CrEX-4, separating the upper and lower screens with a packer caused the static water level to drop by 0.13 ft in the lower screen and rise by 0.06 ft in the upper screen, indicating a head difference of 0.19 ft between screens separated by 10 ft. The downward gradient at this location between these closely spaced screens is therefore 0.019 ft/ft, consistent with other wells on the Plateau, which show a great deal of variability in vertical gradients.

The regional aquifer is pumped at varying rates by several municipal water supply wells in the area, which likely impact the pumping-test data, although the effect is usually small because of an apparent hydraulic separation between the confined and phreatic zones described above. At the nearby well R-42, model results suggest pumping at PM-5 may affect drawdowns by about 0.2 m, with lesser effects from PM-2, PM-4, and O-4 (LANL 2017, 602333).

D-1.0-2 Aquifer Testing

CrEX-4 was tested from November 28 to December 5, 2017. Each screened interval (upper and lower) was tested separately and together. The full suite of tests performed is listed in Table D-1.0-1. Water-level and pumping-rate data from CrEX-4 for all tests are shown in Figures D-1.0-1 through D-1.0-3.

There are no check valves in the pump column, which, along with other storage effects, leads to unusable data in the moments after the pump is activated or shut off, as seen 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 seen. These spikes were removed before analysis; all subsequent plots show the corrected data with spikes removed, except where noted. Casing storage effects can also be responsible for anomalous early-time behavior when pumping begins but would not explain the drop in drawdown when pumping ends. An over-shooting of water levels during recovery after pump shut down 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 due to the lack of check valves.

Monitoring well data can show barometric pressure effects, depending on the barometric efficiency of the well, the type of monitoring equipment (vented versus non-vented transducer), and aquifer type. The CrEX-4 pumping tests were performed with non-vented transducers, which measure absolute pressure (barometric plus water pressure). All data were corrected before analysis by subtracting out the effective pressure due to barometric overburden recorded by the transducer at the start of the recording session, converted to ft of water (26.08 ft for the lower and composite tests; 26.72 ft for the upper screen test).

To test whether the data needed further correction for fluctuations in barometric pressure, the data were compared with calculated downhole barometric pressure based on records from the Los Alamos National Laboratory Technical Area 54 (TA-54) tower site (http://weather.lanl.gov, accessed 12/22/17). The conversion between pressure at the TA-54 station and the borehole is given by (LANL 2009, 106427):

$$P_{WT} = P_{TA54} \exp\left[-\frac{g}{3.281R}\left(\frac{E_{WELL}-E_{TA54}}{T_{TA54}} + \frac{E_{WT}-E_{WELL}}{T_{WELL}}\right)\right] \qquad \textbf{Equation D-1}$$

where P_{WT} = barometric pressure at the water table in the well [psi],

P_{TA54} = barometric pressure at the TA-54 weather station [psi],

g = acceleration due to gravity (9.80665 m s^{-2}),

R = the gas constant (287.04 J kg^{-1} K^{-1}),

E_{WELL} = surface elevation at the well, approximated as the same elevation as R-42 (6759.02 ft),

E_{TA54} = elevation of the pressure measuring point at TA-54 (6548 ft),

E_{WT} = elevation of the water table at the well (E_{WELL} minus 920.46 ft bgs),

T_{TA54} = estimated air temperature at TA-54 (277.4 K), and

T_{WELL} = estimated air temperature inside the well (299.8 K).

The estimated downhole barometric pressure was plotted alongside the adjusted pumping data and analyzed for correlations. No correlation was observed between the barometric pressure and pumping data. Figure D-1.0-4 shows data collected during times of comparatively steep barometric pressure change. Because the larger barometric events (coincidentally) coincided with periods during the pumping tests (as opposed to the quiescent periods between pumping), Figure D-1.0-4 shows data collected during the 24-h tests of the lower and composite screens. No change is observed in the monitoring data for several major barometric events such as a large rise beginning around 11/28/17 at 12:00 p.m., a steep drop beginning near 10:00 a.m. on 11/29/17, or a drop immediately followed by a rise beginning around 12:00 a.m. on 12/1/17. This is similar to results from R-44 and R-45, where no effect was observed from barometric pressure with the use of non-vented transducers, and across the Pajarito Plateau, where pumping tests have suggested barometric efficiencies of 90–100% (LANL 2009, 106427). Therefore, these data were corrected for the atmosphere with a single correction (described above) and not throughout the testing period as a result of fluctuating barometric pressure.

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 (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**

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). When using AQTESOLV software, (Duffield 2007, 601723), selection of the Theis option also includes the Hantush (1961, 106003) modification for partially penetrating wells.

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-3**

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. Then 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-4**

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 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.

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:

$$T = \frac{Q}{4\pi(s-s_w)}\left[ln\left(\frac{2.25Tt}{r_w S}\right) + 2s_p\right],$$ **Equation D-5**

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 unknown, varying values may be used; alternatively, the minimum transmissivity at 100% well efficiency (s_w = 0) may be computed.

Although true steady-state conditions are not achievable in an unconfined pumped aquifer of infinite extent, during the 24-h test, drawdowns may appear to become relatively stable at mid-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* (in m) at pumping rate *Q* (in m^3/d) (Misstear 2001, 602535):

$$T = \frac{1.22Q}{s}.$$ **Equation D-6**

This may also be modified to account for partial penetration by replacing *s* with $s-s^2/2b$, where *b* is aquifer thickness in m.

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, *b*, is unknown—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. Transmissivity is related to hydraulic conductivity, *K* (in m/d), by aquifer thickness *b*: $K = T/b$.

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 pumping tests and the results of the analytical interpretations. The isolated pumping tests (upper or lower) were analyzed as single-well tests using the transducer data from the pumping interval, as well as data from the non-pumping interval. The dual analysis of both screens allows for estimations of vertical anisotropy. The composite pumping test treated the two intervals as one connected screen of total length 65 ft (screen lengths plus the 10-ft separation), and the average of the transducer data measured in both screens.

D-3.0-1 Lower Screen

24-Hour Constant Rate Aquifer Test

The 24-h constant rate test was performed at a pumping rate of Q = 35 gallons per minute (gpm) (191 m^3/d). As shown in Figure D-1.0-1, pumping at this rate in the lower screen caused significant drawdown, much higher than pumping at the same rate in the upper screen alone. This can be caused by a “skin effect” that diminishes the hydraulic connection between the well screen and the aquifer. Determining whether excessive drawdown is likely caused by skin effects can be done by comparison of the slope-based (e.g., Theis) and specific capacity–based calculations of transmissivity. This is provided in the section D-3.0-4 below.

Figure D-3.0-1 shows a semilog plot of the corrected drawdown data recorded during the 24-h constant rate pumping test. The removed spike covered a significant portion of the early-time data (the first 17 min). Because early-time data is the most reliable for many methods of estimating aquifer properties, the results from this test in the post-17-min range are questionable. The corrected data on a semilog plot do show somewhat linear behavior, however.

The linear Cooper-Jacob approximation (Eq. D-2.0-3) to the Theis solution was applied in AQTESOLV for two segments of the semilog plot (Figure D-3.0-1). The earliest-available time best fit solution resulted in T = 328 m^2/d (26,400 gallons per day [gpd]/ft). Fitting the entire segment of the rising drawdown curve resulted in T = 484 m^2/d (40,000 gpd/ft), although the later time curve showed anomalously variable behavior rather than a linear trend. The analysis for the lower screen alone based on Theis solution (Equation D-2.0-1) in AQTESOLV yields *T* = 225 m^2/d (18,100 gpd/ft). The Neuman method (1974, 085421), applied in AQTESOLV and set to automatic calibration, gives *T* = 226 m^2/d (18,200 gpd/ft), S_y = 0.001, and $\beta = 1.2 \times 10^{-5}$.

Using the data from both the upper and lower screens allows an estimation of anisotropy in the aquifer. The Theis solution, fit both automatically and visually to data from both screened intervals during the lower-screen 24-h test (Figure D-3.0-2), produces *T* = 136 m^2/d (11,000 gpd/ft) and $S = 3.4 \times 10^{-6}$ (unreliable). By fitting data from both screens, this method produces an estimate of the aquifer anisotropy ratio, K_v/K_h = 0.00003. In order to establish a reasonable fit during automated parameter estimation, the aquifer thickness, *b*, was varied. A value of 114 ft produced a good match to the data, but this is not expected to accurately represent actual aquifer thickness.

Estimates using other simplified methods result in significantly lower transmissivity estimates for this test, which is expected because these estimates provide lower-bound values when 100% well efficiency is assumed (LANL 2009, 106427), and also because of potential skin effects (discussed below). The analysis based on the Thiem estimate (Eq. D-2.0-5) gives an uncorrected value of *T* = 20 m^2/d (1600 gpd/ft), but if it is assumed that the well screen captures a greater effective aquifer thickness, the transmissivity estimate increases to a maximum of *T* = 364 m^2/d (29,300 gpd/ft) at 100% penetration, which is more in line with other estimates but is not necessarily indicative of actual effective aquifer thickness. Using the specific capacity approach and MATLAB code of McLin (2005, 602537), Equation D-2.0-4 results in estimates of *T* = 170 m^2/d (13,700 gpd/ft) at 10% aquifer penetration and *T* = 72 m^2/d (5800 gpd/ft) at 100% penetration, both assuming 100% well efficiency.

D-3.0-2 Composite Tests

24-Hour 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* = 75 gpm (408 m^3/d). The removed spike covered the first 300 s (5 min) of the data, significantly less than for the lower- and upper-screen isolated tests. The drawdown curve peaks around 360 min (6 h) and then declines slightly for the remainder of the 24-h test. The corrected data on a semilog plot do not show sustained linear behavior in any portion of the curve and were not well matched by the Theis solution. Nonetheless, a visual match between the Theis solution and the data produced an estimated *T* = 650 m^2/d (52,300 gpd/ft). The data were very poorly matched by the Neuman and Moench approximation methods (Neuman 1974, 085421; Moench 1997, 600136), so those results are not presented.

The linear Cooper-Jacob approximation to the Theis solution was also applied in AQTESOLV for two short segments of the semilog plot (Figure D-3.0-3). The earliest-available time best fit solution resulted in *T* = 94 m^2/d (7600 gpd/ft) and $S = 7.1 \times 10^{-6}$. Fitting the middle segment of the rising drawdown curve resulted in *T* = 298 m^2/d (24,000 gpd/ft) and $S = 1.3 \times 10^{-21}$. Both of these fits are for drawdown data before *t* = 100 min.

An average value for drawdown for the 24-h test was calculated after drawdown initially stabilized (600–800 minutes). This value is approximate because the drawdown did not flatten during this test, as seen in Figure D-3.0-3. The specific capacity obtained from this test is given in Table D-3.0-1. Following the specific capacity approach of McLin (2005, 602537) and the drawdown reported in Table D-3.0-1, Equation D-2.0-4 results in an estimated *T* = 620 m^2/d (50,000 gpd/ft) at 10% aquifer penetration and *T* = 111 m^2/d (8900 gpd/ft) at 100% penetration. As before, these should be considered lower-bound estimates because they assume 100% well efficiency.

Three-Step Variable-Rate Aquifer Test

AQTESOLV was used to estimate transmissivity for the three-step-test data using the Theis solution (1934-1935, 098241). Figure D-3.0-4 shows the best fit curve using automated fitting methods, along with the adjusted data (spikes removed). Estimated parameters are T = 122 m^2/d (9830 gpd/ft) and $S = 1.3 \times 10^{-5}$, with negligible wellbore skin factor and well loss parameters C = 0 s^2/ft^5 and P = 2 (Duffield 2007, 601723).

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. These average drawdowns and the specific capacity data obtained from the CrEX-4 composite three-step pumping test are summarized in Table D-3.0-1. During the step tests, the specific capacity varied between about 66 m^2/d and 73 m^2/d (3.7 gpm/ft and 4.1 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 1.3×10^{-5} (the results are relatively insensitive to S), the MATLAB code of McLin (2005, 602537) was used to estimate lower-bound T for varying values of uncertain percent aquifer penetration. Figure D-3.0-5 shows the results from each of three steps of the three-step aquifer test, plus the 24-h test reported above. The average transmissivities for the three steps range from 105 m^2/d (8420 gpd/ft), estimated at 100% aquifer penetration, to 634 m^2/d (51,200 gpd/ft) at 10% aquifer penetration.

D-3.0-3 Upper Screen

24-Hour Constant Rate Aquifer Test

Figure D-3.0-6 shows a semilog plot of drawdown data recorded during the 24-h constant rate pumping test conducted at an average pumping rate of Q = 90 gpm (490 m^3/d). The initial spike has not been removed, to demonstrate the difficulty of using the standard solutions with these data. The spike covers the first 1210 s (20 min) of the data, even longer than the spike for the lower-screen test (17 min). The early-time data are generally considered the most useful for solutions approximated by the Cooper-Jacob and Theis methods. The data on a semilog plot also show inconsistent linear behavior, with periods of flat, increasing, and decreasing drawdown over time. A visual match between the Theis solution and the data yields T = 205 m^2/d (16,500 gpd/ft). The data were very poorly matched by the Neuman and Moench approximation methods (Neuman 1974, 085421; Moench 1997, 600136); those results are not presented.

The linear Cooper-Jacob approximation to the Theis solution was applied in AQTESOLV (Figure D-3.0-6). Fitting the entire drawdown curve resulted in T = 141 m^2/d (11,300 gpd/ft) and $S = 2.4 \times 10^{-10}$. The Theis approximation (Equation D-2.0-1) in AQTESOLV yields T = 205 m^2/d (16,500 gpd/ft) and $S = 3.4 \times 10^{-10}$.

An average value for drawdown for the 24-h test was calculated after drawdown stabilized (500–1000 min) (Table D-3.0-2). Using this average, the Thiem estimate (Equation D-2.0-5) suggests an uncorrected value of T = 71 m^2/d (5700 gpd/ft), or if it is assumed that the well screen captures a 100% effective aquifer thickness, the transmissivity estimate is T = 84 m^2/d (6800 gpd/ft). Using the approach and MATLAB code of McLin (2005, 602537), as above, Equation D-2.0-4 results in lower-bound estimates of T = 531 m^2/d (42,800 gpd/ft) at 10% aquifer penetration and T = 136 m^2/d (11,000 gpd/ft) at 100% penetration.

Two-Step Variable-Rate Aquifer Test

AQTESOLV was used to estimate transmissivity using a fit to the step-test data of the Theis solution (1934-1935, 098241), which accounts for partial penetration following the method of Hantush (1961, 106003). In this case, the data from both the pumping interval and the non-pumping screen (separated by a packer) were analyzed. Figure D-3.0-7 shows the best fit curve to data from both screens using automated and visual fitting methods. When only the pumping interval (upper screen) is analyzed, the estimated parameters are T = 220 m^2/d (17,700 gpd/ft) and S = 3.0 × 10^{-10} (unreliable). Fitting data from both intervals yields T = 331 m^2/d (26,700 gpd/ft), S = 1.2 × 10^{-6}, and K_v/K_h = 0.0004. In order to establish a reasonable fit, the estimate for aquifer thickness, *b*, required adjustments. A final value of 130 ft produced a good match to the data; this can be considered to be the representative (effective) aquifer thickness of the aquifer, which is vertically interrogated during the pumping test. However, this effective aquifer thickness is not expected to accurately represent actual aquifer thickness, which is known to be much greater.

Average values for drawdown at each of the two 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. These values and the specific capacity data obtained from the CrEX-4 two-step pumping test are summarized in Table D-3.0-2. For these tests, the estimated specific capacity varied between about 56 m^2/d and 64 m^2/d (3.1 gpm/ft and 3.6 gpm/ft).

Using the average drawdowns in Table D-3.0-2, time since pumping began, and a storage coefficient S of 2.4 × 10^{-10} (the results are relatively insensitive to S), the MATLAB code of McLin (2005, 602537) was used to estimate T for varying values of uncertain percent aquifer penetration. Figure D-3.0-8 shows the results from each of two steps of the two-step aquifer test, along with the results from the 24-h test. The transmissivity results are similar for the step tests and for the 24-h test.

D-3.0-4 Discussion

All of the pumping tests in both screens produce estimated transmissivities of similar magnitude (~100–600 m^2/d) based on curve or slope-matching methods (e.g., Theis, Cooper-Jacob) (Table D-3.0-3). However, the lower-screen 24-h test caused much greater drawdown (average of 37.8 ft over a relatively stabilized period) for a pumping rate of 35 gpm compared with the upper-screen drawdown caused by the same pumping rate (10.7 ft). This yields a lower specific capacity (0.9 versus 3.1 gpm/ft) and lower transmissivity estimates calculated from specific capacity–based methods. The cause of the excessive lower screen drawdown may be the skin effect, which impacts the hydraulic connection between the aquifer formation and the well’s screen.

All three 24-h pumping tests do not closely resemble the Theis-type curve, which is particularly seen in the plots showing the Cooper-Jacob estimation of transmissivity. There are several possible reasons for this behavior: (1) partial well penetration, (2) three-dimensional flow effects, (3) pronounced aquifer heterogeneity, (4) unconfined aquifer behavior, (5) delayed-yield effects and infiltration from the vadose zone (Tartakovsky and Neuman 2007, 602536; Mishra and Neuman 2010, 602981; Mishra and Neuman 2011, 602980), and (6) drawdown impacts caused by nearby municipal water-supply wells [the fluctuations in nearby municipal water-supply pumping may also cause Noordbergum effects (Fabian and Kumpel 2003, 602982)].

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 (Freeze and Cherry 1979, 088742). (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 is seen for the CrEX-4 24-h pumping tests, based on the early/mid/late transmissivities estimated above using the Cooper-Jacob method. It frustrates attempts at determining hydraulic conductivities, because each transmissivity is calculated at an unknown effective aquifer thickness. If the three-dimensional cone of depression reaches a horizontal aquitard, the groundwater flow will become vertically constrained and the flow regime will become more two dimensional, consistent with the assumptions associated with some of the analytical solutions (e.g., Theis solution).

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 because 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 not observed at CrEX-4 in the composite 24-h test, where drawdown increased to a maximum and then declined (Figure D-3.0-3).

D-4.0 CONCLUSIONS

Table D-3.0-3 summarizes the transmissivity estimates developed in this document. Several methods are presented here to analyze the CrEX-4 pumping-test data. The step-test data were judged to be the most useful for analysis, and were fit by the Theis model (Figures D-3.0-4 and D-3.0-7). The Theis model/Cooper-Jacob approximation do not consider delayed water recharge from the vadose zone generally seen 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., Neuman 1974, 085421; Moench 1997, 600136), but these do not provide an excellent fit to the CrEX-4 data either.

The lower screen had a single 24-h pumping test, for which the Theis fit to both upper- and lower-screen data gives T = 136 m^2/d (11,000 gpd/ft) and $S = 3.4 \times 10^{-6}$. Hydraulic conductivity K is not estimated using this method. If effective aquifer depth is known, it may be calculated by $K = T/b$. Using a rule of thumb that effective b is approximately the screen length to 1.5 times the screen length, K is estimated as 4.5–6.8 m/d (22–15 ft/d). This method also produced estimates of vertical anisotropy, with K_v/K_h estimated at 0.00003.

The lower transmissivity estimates discussed above which were calculated from specific capacity–based methods might be caused by a “skin effect” on the lower screen impacting the hydraulic connection between the aquifer formation and the screen. This may also suggest that the composite pumping test is representative of the upper screen only, and most of the groundwater pumped from CrEX-4 when there is no packer between the two screens is coming from the upper screen.

A best-guess estimate of T = 122 m^2/d (9800 gpd/ft) is calculated from the Theis fit to the composite three-step pumping test. Despite the unreliability of S estimates for pumping-test analyses at a single well, the fit gives $S = 1.3 \times 10^{-5}$. Using for the screen length 65 ft (the distance between the top of the upper screen and bottom of the lower screen), K is roughly estimated as 1.3–1.9 m/d (4.1–6.2 ft/d).

For the upper screen, which also had a variable-rate step test, the Theis fit produced a best-guess estimate of T = 331 m^2/d (26,700 gpd/ft) and $S = 1.2 \times 10^{-6}$. K is estimated as 6.3–9.5 m/d (21–31 ft/d). For this test, K_v/K_h is estimated at 0.0004. The pronounced vertical anisotropy suggests that the groundwater flow during the pumping test might be predominantly two dimensional (lateral) with a minor vertical component.

These transmissivity and permeability estimates are generally consistent and within the range of the values that have been estimated for other wells at the Chromium site and within the Pajarito Plateau. However, the CrEX-4 transmissivity and permeability are at the lower end compared with the other wells. It corroborates the hypotheses that (1) the aquifer is highly heterogeneous, and (2) there is a lower-permeability zone in the aquifer near R-42 (LANL 2014, 255110).

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 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.

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)

Fabian, M., and H.-J. Kumpel, 2003. "Poroelasticity: Observations of Anomalous Near Surface Tilt Induced by Ground Water Pumping," *Journal of Hydrology,* Vol. 281, pp. 187-205. (Fabian and Kumpel 2003, 602982)

Freeze, R.A., and J.A. Cherry, January 1979. *Groundwater*, Prentice-Hall, Inc., Englewood Cliffs, New Jersey. (Freeze and Cherry 1979, 088742)

Hantush, M.S., September 1961. "Aquifer Tests on Partially Penetrating Wells," Journal of the Hydraulics Division, Proceedings of the American Society of Civil Engineers, pp. 171–195. (Hantush 1961, 106003)

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), May 2009. "Completion Report for Regional Aquifer Well R-45," Los Alamos National Laboratory document LA-UR-09-3065, Los Alamos, New Mexico. (LANL 2009, 106427)

LANL (Los Alamos National Laboratory), March 2014. "Summary Report for the 2013 Chromium Groundwater Aquifer Tests at R-42, R-28, and SCI-2," Los Alamos National Laboratory document LA-UR-14-21642, Los Alamos, New Mexico. (LANL 2014, 255110)

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)

Mishra, P.K., and S.P. Neuman, July 2010. "Saturated-Unsaturated Flow to a Well with Storage in a Compressible Unconfined Aquifer," *Water Resources Research,* Vol. 46, pp. 1-16. (Mishra and Neuman 2010, 602981)

Mishra, P.K., and S.P. Neuman, May 2011. "Saturated-Unsaturated Flow to a Well with Storage in a Compressible Unconfined Aquifer," *Water Resources Research,* Vol. 47, pp. 1-15. (Neuman et al. 2011, 602980)

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)

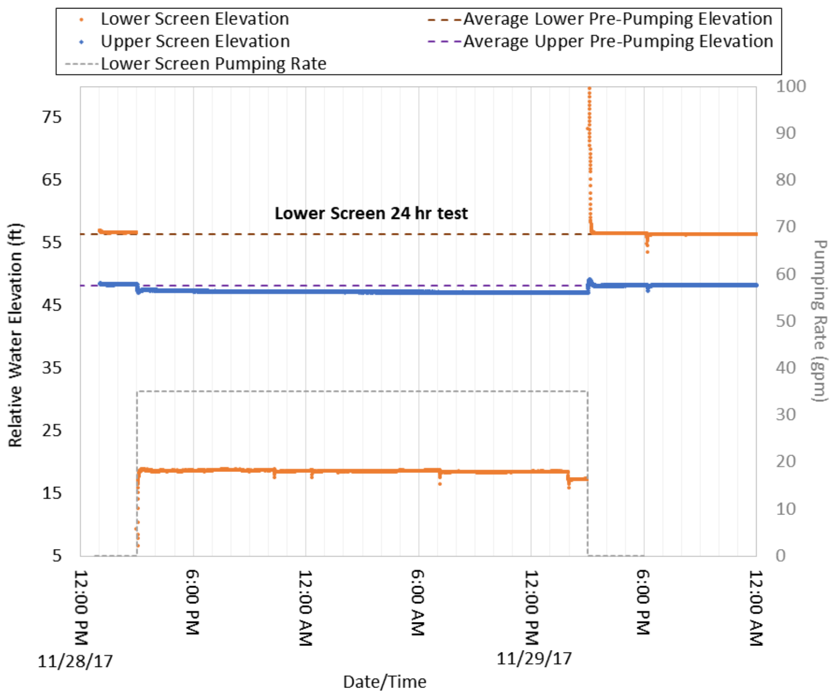


Figure D-1.0-1 Relative water elevation above transducers (left axis) and pumping rate (right axis) throughout the duration of the CrEX-4 lower-screen 24-h pumping test

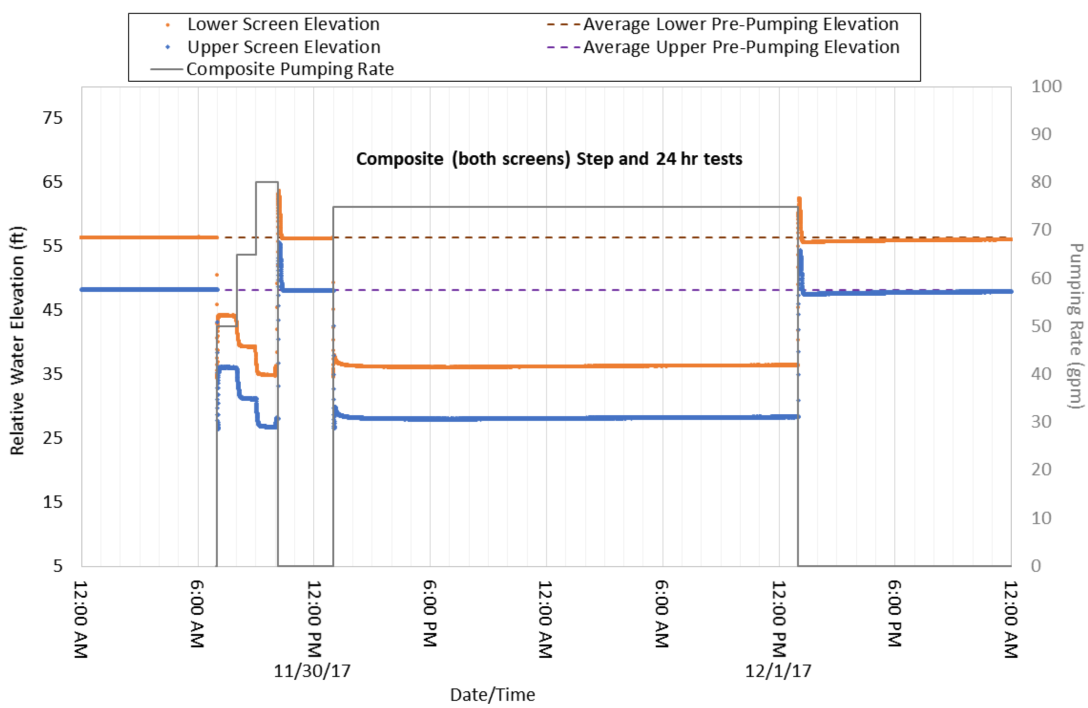


Figure D-1.0-2 Relative water elevation above transducers (left axis) and pumping rate (right axis) throughout the duration of the CrEX-4 composite pumping tests

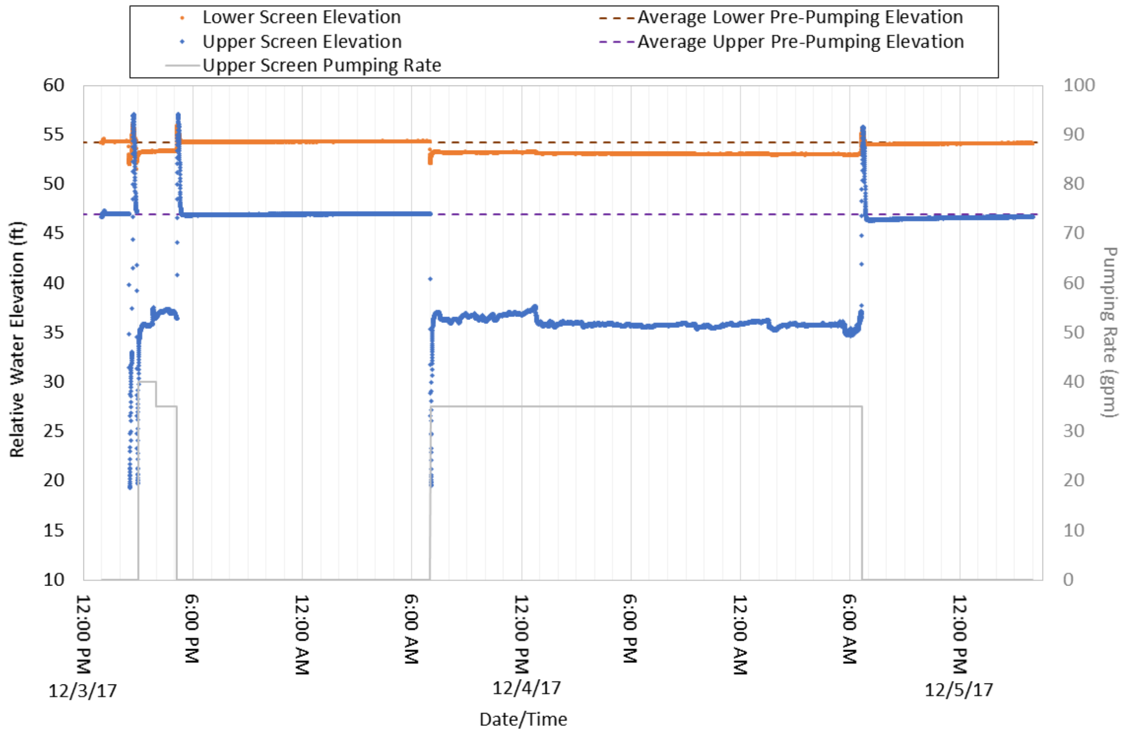
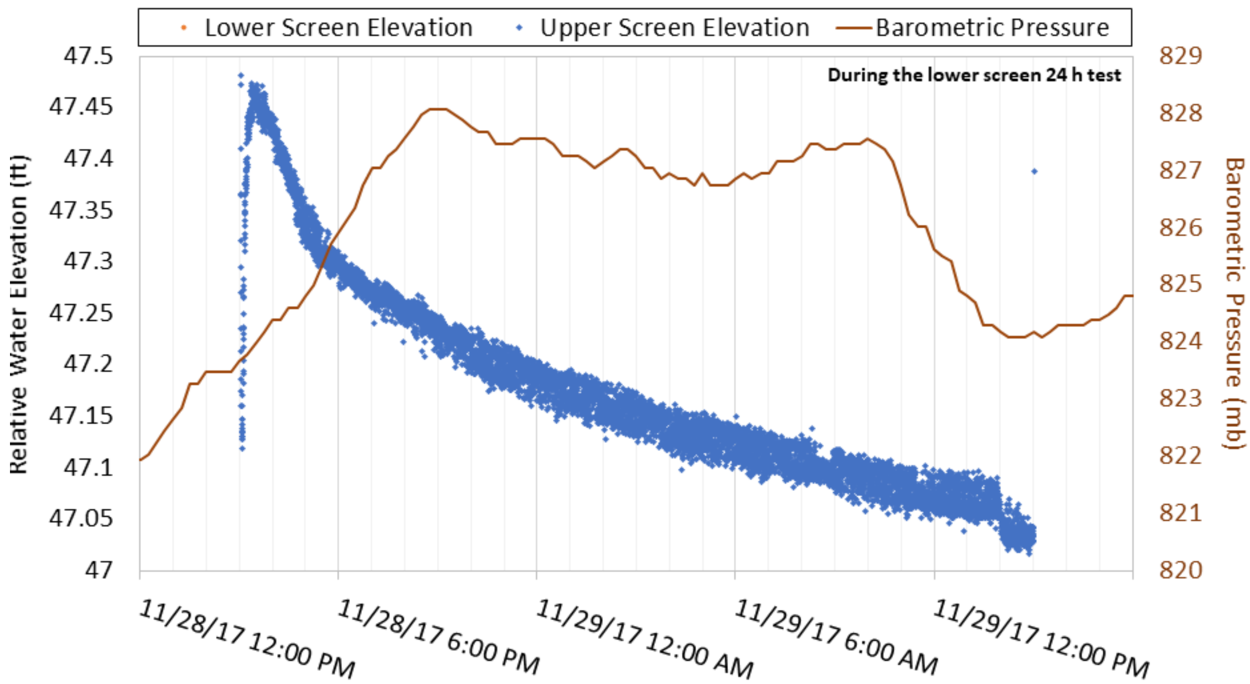


Figure D-1.0-3 Relative water elevation above transducer (left axis) and pumping rate (right axis) throughout the duration of the CrEX-4 upper-screen pumping tests



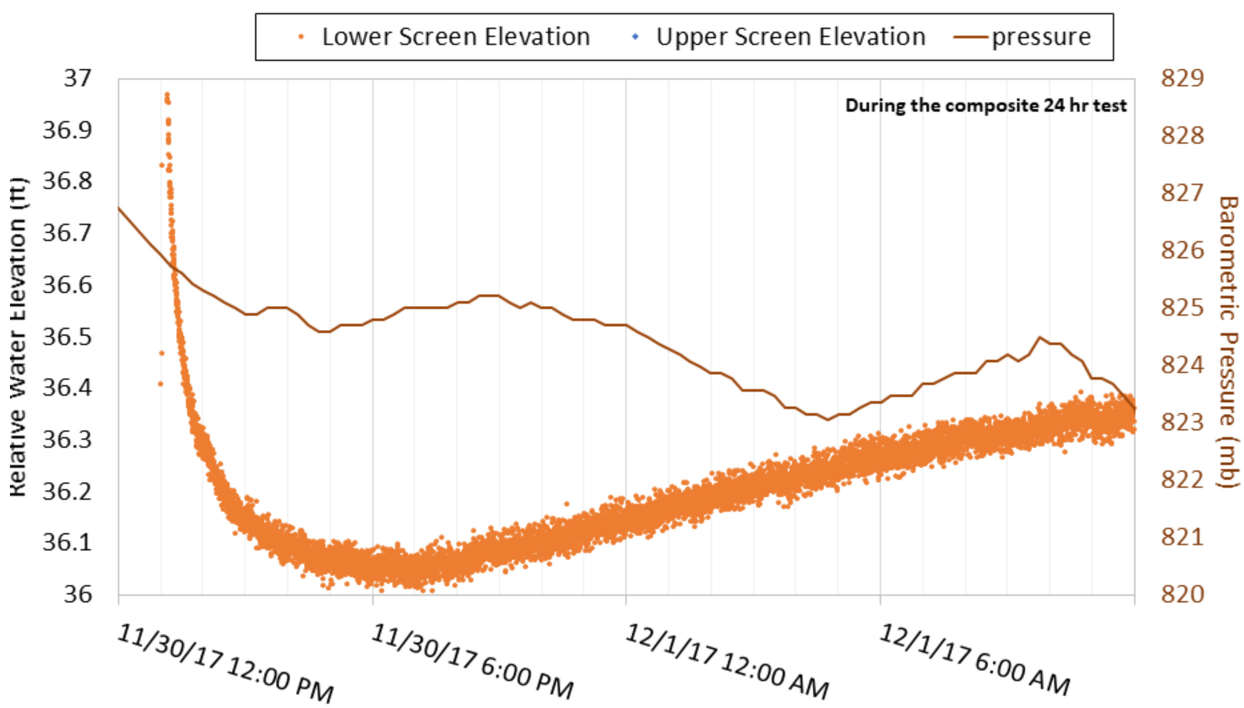


Figure D-1.0-4 Relative water elevation above transducer (left axis) and barometric pressure (right axis) during the CrEX-4 lower-screen and composite pumping tests

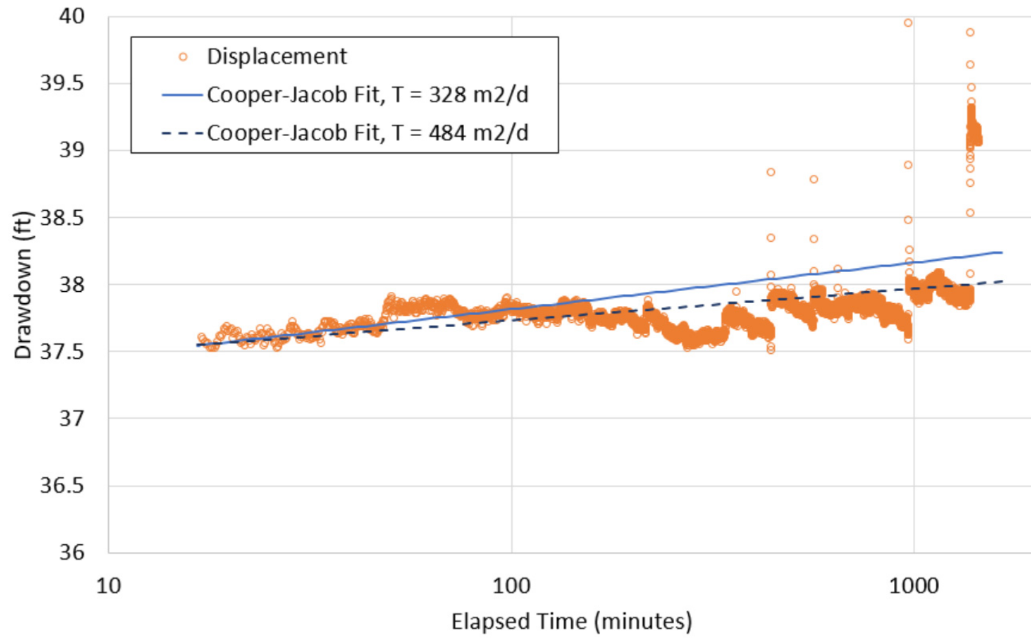


Figure D-3.0-1 Corrected drawdown data (spikes removed) and multiple fits from AQTESOLV for the Cooper-Jacob solution to the lower-screen 24-h pumping test

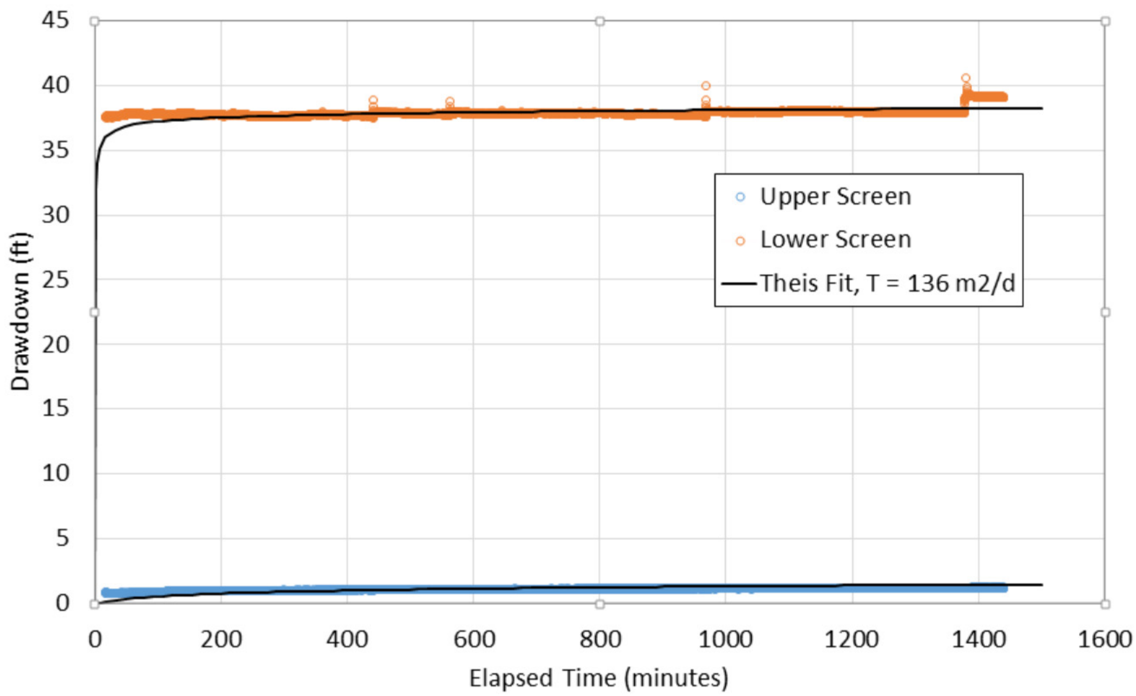


Figure D-3.0-2 Corrected drawdown data for both screens (spikes removed) and the Theis fit from AQTESOLV for the lower-screen 24-h pumping test, T = 136 m^2/d

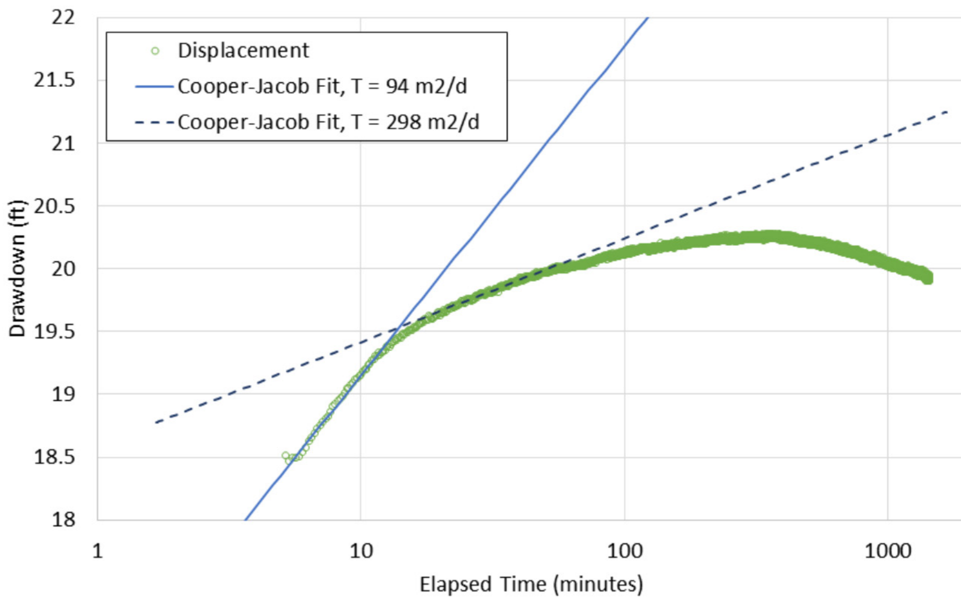


Figure D-3.0-3 Corrected drawdown data (spikes removed) and multiple fits from AQTESOLV for the Cooper-Jacob solution to the composite 24-h pumping test

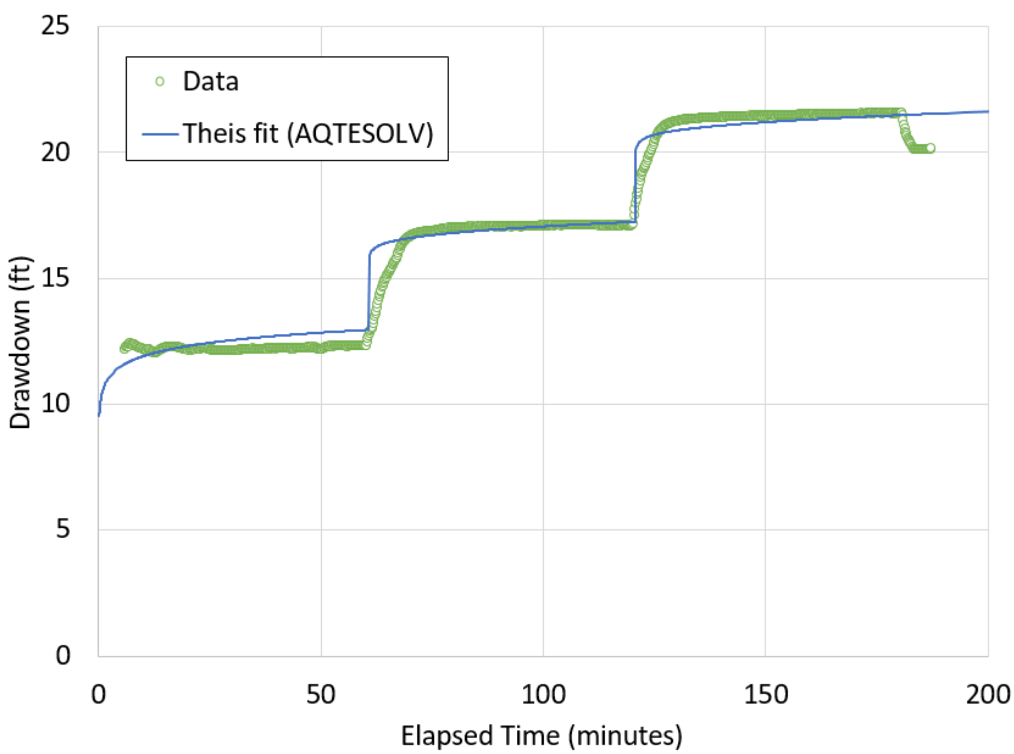


Figure D-3.0-4 Drawdown data (spikes removed) and the best fit from AQTESOLV for the Theis solution to the composite step test, *T* = 122 m^2/d

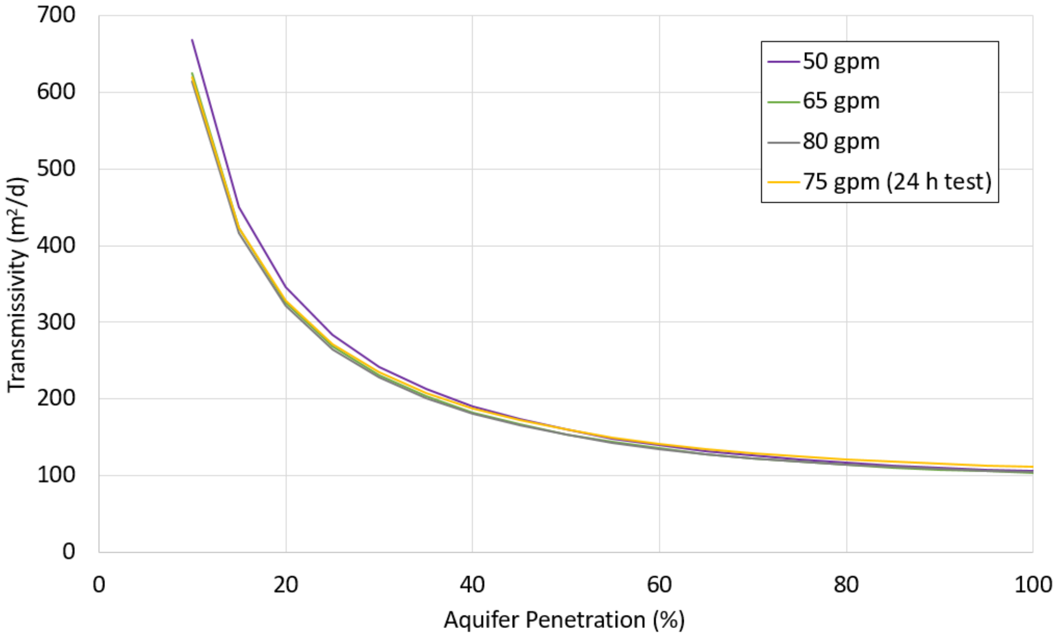


Figure D-3.0-5 Transmissivities calculated using the MATLAB code of McLin (2005, 602537), based on the specific capacity method, for each step of the composite variable-rate pumping test (50, 65, and 80 gpm) and the 24-h test (75 gpm) as a function of aquifer penetration

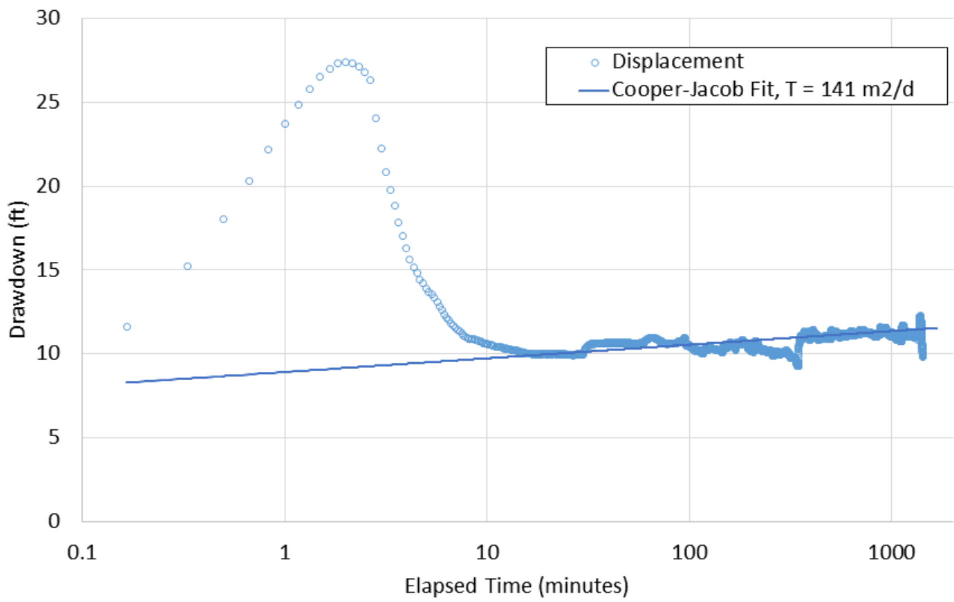


Figure D-3.0-6 Complete drawdown data (spike not removed) and fit from AQTESOLV for the Cooper-Jacob solution to the upper-screen 24-h pumping test

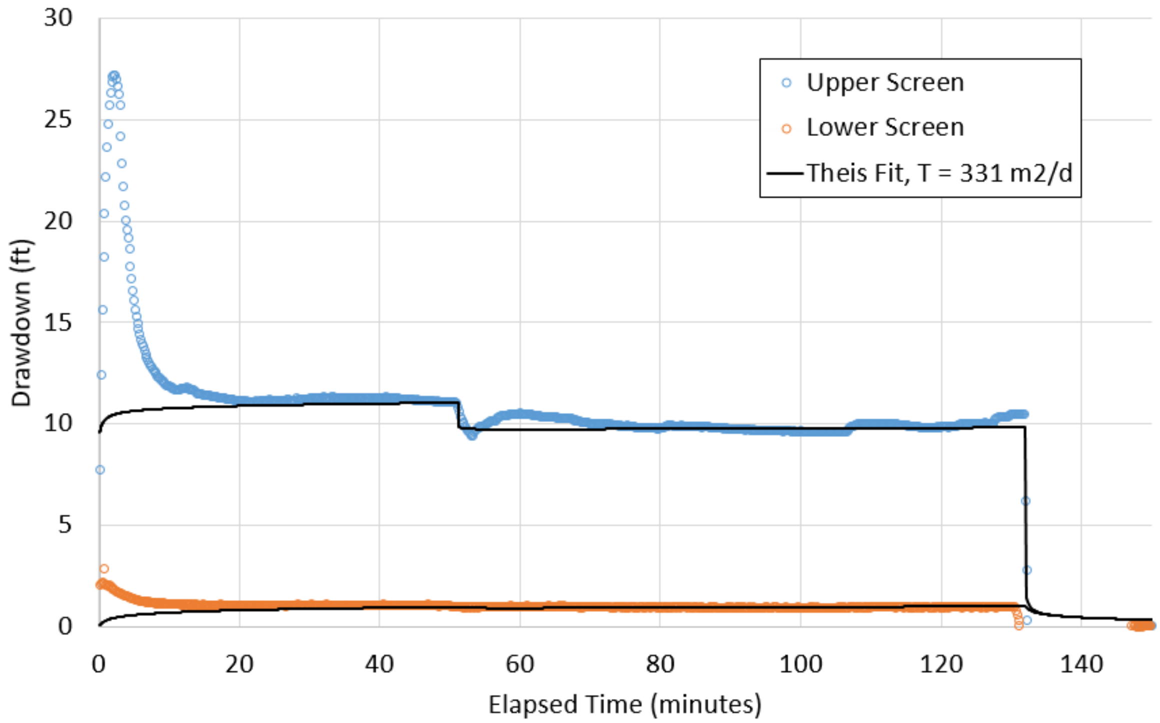


Figure D-3.0-7 Drawdown data and the best fit from AQTESOLV for the Theis solution to the upper-screen step test, *T* = 331 m²/d

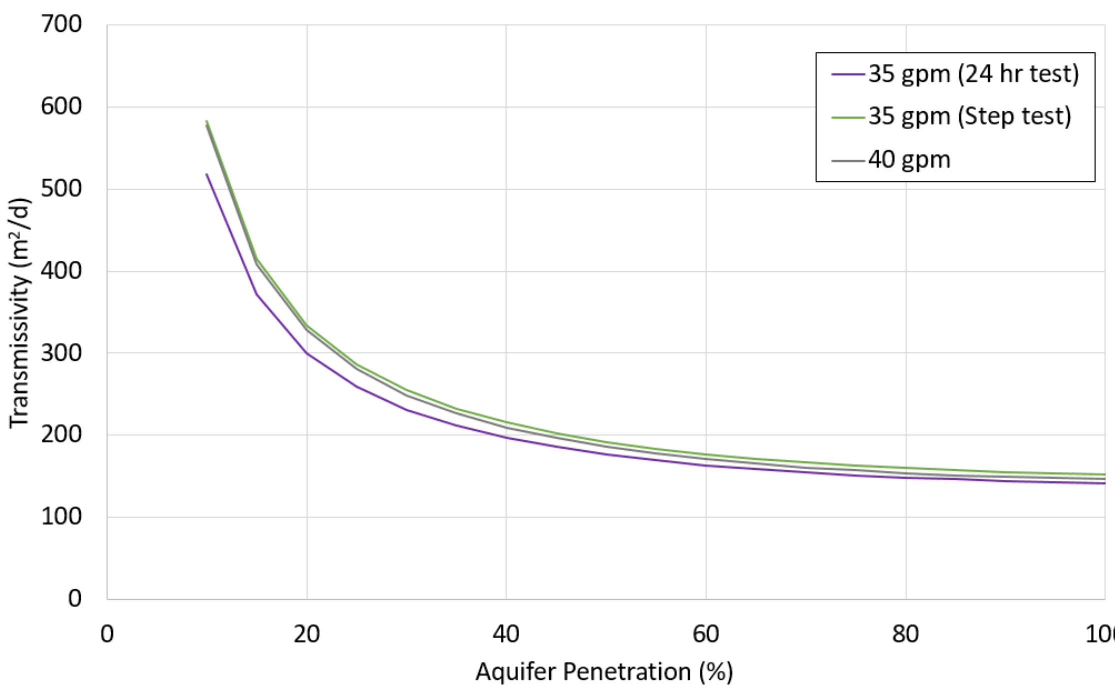


Figure D-3.0-8 Transmissivities calculated using the MATLAB code of McLin (2005, 602537), based on the specific capacity method, for each step of the upper-screen variable-rate pumping test (35 and 40 gpm) and the 24-h test (35 gpm) as a function of aquifer penetration

Table D-1.0-1
Pumping Tests Performed at CrEX-4

Screen/Test	Pumping Rate (gpm)	Dates	Start Time	End Time
Lower				
24-h test	35	11/28/17–11/29/17	14:59	14:59
Composite				
Step test #1	50	11/30/17	06:59	08:00
Step test #2	65	11/30/17	08:00	09:00
Step test #3	80	11/30/17	09:00	10:07
24-h test	75	11/30/17–12/1/17	12:59	12:59
Upper				
Step test #1	40	12/3/17	14:55	15:47
Step test #2	35	12/3/17	15:47	17:07
24-h test	35	12/4/17–12/5/17	06:59	06:38

Table D-3.0-1
Summary of Specific Capacity Data Obtained from the Composite Pumping 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)
Composite						
24-h test	75	20.2	3.7	408	6.2	66
Step test #1	50	12.2	4.1	272	3.7	73
Step test #2	65	17.1	3.8	354	5.2	68
Step test #3	80	21.5	3.7	435	6.5	66

Table D-3.0-2
Summary of Specific Capacity Data Obtained from the Upper-Screen Pumping 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)
Upper Screen						
24-h test	35	11.2	3.1	191	3.4	56
Step test #1	40	11.2	3.6	218	3.4	64
Step test #2	35	9.8	3.6	191	3.0	64

Table D-3.0-3
Summary of Transmissivities Estimated from All Analyses

Screen/Test	Theis (One/Both)[a] [m^2/d]	Cooper-Jacob (Early/Mid)[b] [m^2/d]	Neuman [m^2/d]	Specific Capacity (10%/100%)[c] [m^2/d]	Thiem [m^2/d]
Lower					
24-h test	225/136	328/484	226	170/72	20
Composite					
24-h test	650	94/298	n/a[d]	620/111	81
Three-step test	122	n/a	n/a	636/105	n/a
Upper					
24-h test	205	141	n/a	518/142	71
Two-step test	220/331	n/a	n/a	580/149	n/a

[a] If two values are given, the first is estimated using only the screened interval; the second is estimated using data from both intervals when separated by a packer.

[b] Early or middle times as shown in the corresponding figures. If one value is given, it corresponds to the whole range.

[c] Estimates at 10% aquifer penetration and 100% aquifer penetration.

[d] n/a = Not applicable

Appendix E

CrEX-4 Aquifer Testing Sample Results
(on CD included with this document)