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Date: SEP 28 2017
Refer To: ADEM-17-0217
LAUR: 17-28238

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 Injection Well CrIN-6

Dear Mr. Kieling:

Enclosed please find two hard copies with electronic files of the Completion Report for Injection Well CrIN-6.

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

Sincerely,

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

Sincerely,

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

BR/DR/SS:sm

Enclosures: Two hard copies with electronic files – Completion Report for Injection Well CrIN-6 (EP2017-0115)

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LA-UR-17-28238
September 2017
EP2017-0115

Completion Report for Groundwater Injection Well CrIN-6

Los Alamos
NATIONAL LABORATORY
EST. 1943

Prepared by the Associate Directorate for Environmental Management

EP2017-0115

Completion Report for Groundwater Injection Well CrIN-6

September 2017

Responsible project manager:

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EXECUTIVE SUMMARY

This well completion report describes the drilling, well construction, development, aquifer testing, and dedicated injection and pumping system installation for groundwater injection well CrIN-6, located within Los Alamos National Laboratory (LANL or the Laboratory), New Mexico. The CrIN-6 injection well is intended to help achieve hydraulic control of off-site hexavalent chromium plume migration 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 Injection Well CrIN-6."

The CrIN-6 borehole was drilled at a 25-degree angle using dual-rotary air-drilling methods to a total depth of 1096.6 linear ft or approximately 994 vertical ft below ground surface. Fluid additives used included potable water and foam. Foam-assisted drilling was used to total depth.

The following geologic formations were encountered at CrIN-6: Quaternary alluvium, Otowi Member of the Bandelier Tuff, Guaje Pumice Bed of the Otowi Member, the Cerros del Rio volcanics, the Puye Formation, and transitional Pumiceous Puye Formation.

Well CrIN-6 was completed as a single-screen well within the regional aquifer. The screened interval is set between 980 ft and 1040 ft within Puye Formation sediments. The static depth to water after well installation was measured at 966.5 ft.

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 injection well CrIN-6 will perform effectively in meeting the planned objectives. An injection and pumping system and transducer were installed in the screened interval.

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Acronyms and Abbreviations

ADEM	Associate Directorate for Environmental Management
amsl	above mean sea level
ASTM	American Society for Testing and Materials
bgs	below ground surface
Consent Order	Compliance Order on Consent
DTW	depth to water
EES	Earth and Environmental Sciences (Laboratory group)
EM	Environmental Management
ENV-CP	Environmental Protection Division–Environmental Compliance Programs
ESH	Environment, Safety, and Health (Laboratory directorate)
ft btoc	feet below top of casing
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
WCSF	waste characterization strategy form

1.0 INTRODUCTION

This completion report summarizes borehole drilling, well construction, well development, aquifer testing, and dedicated pumping system installation for groundwater injection well CrIN-6. 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 CrIN-6 groundwater injection borehole was drilled between May 16 and June 9, 2017, and was completed between June 11 and July 2, 2017, at Los Alamos National Laboratory (LANL or the Laboratory) for the Associate Directorate for Environmental Management (ADEM). The objective of the injection well is to help control the migration of chromium-contaminated groundwater.

Well CrIN-6 is located in Mortandad Canyon (Figure 1.0-1), just east of the centroid of the hexavalent chromium contamination in the groundwater beneath the canyon. CrIN-6 is in the canyon bottom and is an angled completion drilled from injection well CrIN-1's pad at 25 degrees (from vertical) toward the north. The CrIN-6 borehole was drilled to a total depth (TD) of 1096.6 linear ft, or approximately 993.6 below ground surface (bgs). During drilling, cuttings samples were collected at 10-ft intervals from ground surface to TD. An injection well was installed with a screened interval between 980 ft and 1040 ft within Puye Formation volcaniclastic sediments. The depth to water (DTW) of 966.5 ft was recorded on July 13 after well installation.

Post-installation activities included well development, aquifer testing, preliminary geodetic surveying, and injection/pumping system installation. Future activities will include surface completion, final geodetic surveying, 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 CrIN-6 project.

2.0 ADMINISTRATIVE PLANNING

The following documents were prepared to guide activities associated with the drilling, installation, and development of injection well CrIN-6:

- "Drilling Work Plan for Groundwater Injection Well CrIN-6" (LANL 2016, 602049; NMED 2017, 602097);
- "Storm Water Pollution Prevention Plan CrIN-6 Well Pad and Construction Support Activities" (LANL 2017, 602605);
- "IWD [Integrated Work Document] for 2016 Drilling and Installation of LANL Wells CrIN-4, CrIN-5, and CrIN-3" (Holt Services Inc. 2016, 602106);
- "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 injection well CrIN-6.

3.1 Drilling Approach

The drilling method, equipment, and drill-casing were selected to drill CrIN-6 to the required depth. Further, the drilling approach ensured 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 CrIN-6 borehole. The drill rig was equipped with conventional direct-circulation drilling rods, tricone bits, downhole hammer bits, underreaming hammer bits, a deck-mounted air compressor, auxiliary compressors, and general drilling equipment. During drilling, A53 grade B flush-welded mild carbon-steel casing (20-in.-O.D., 18-in.-O.D., 16-in.-O.D., and 14-in.–inside diameter [I.D.]) was used.

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

The CrIN-6 borehole was drilled exclusively using dual-rotary casing-advance (no open-hole intervals) and relied on the rigidity of the drill casing to maintain the borehole angle. The rig's tower was braced with prefabricated structural steel to hold the tower at the proper angle. The drilling pad was also prepared specifically for the angled drilling operation. A shallow trench was excavated for the drill rig so the bottom of the rig's tower could be situated on firm ground.

The angled borehole was surveyed at several points during the drilling process, and upon reaching TD to ensure it remained and terminated on target. An inertial microsensor gyro surveying tool that is unaffected by magnetic environments was used for surveying. Figure 3.1-1 presents the TD survey and original drilling target (intersection with top of regional aquifer) for the borehole.

3.2 Chronological Drilling Activities for the CrIN-6 Well

The Foremost DR-24HD drill rig, drilling equipment, and supplies were mobilized to the CrIN-6 drill site from May 11 to 16, 2017. The equipment and tooling were decontaminated before mobilization to the site. On May 16, at 1040, following on-site equipment inspections, drilling of the injection well borehole began with the advancement of 20.0-in. surface conductor casing. At 36.0 ft, the 20.0-in. casing was stopped and drilling with 18.0-in. casing was started.

From May 17 to 18, the 18.0-in. casing was advanced from 36.0 ft to 300.0 ft when difficulty with the underreaming hammer bit was encountered. The leading edge of the 18.0-in. casing was dented and had collapsed above the arms of the underreaming bit, which prevented the bit from retracting. The drilling tools and 18.0-in. casing string were simultaneously removed from the borehole, and the 18.0-in. casing was reinstalled in the hole between May 19 and 20. The underreaming bit was found to be missing two of its three arms. Fishing for the arms took place between May 20 and 22. One of the missing arms was recovered, and the other was lost to the formation on the backside of the 18.0-in casing. Ultimately, the 18.0-in. casing was advanced to 319 ft and into the top of the Cerros del Rio basalt while the crew fished for the underreamer arm before switching to 16.0-in. casing.

Beginning on the night shift of May 22, 16.0-in. casing was installed to the bottom of the borehole at 319.0 ft. Drilling resumed with 16.0-in casing advance on May 23 and continued to 520 ft on May 26. The field crew did not work between May 27 and May 30 for a Memorial Day break. The 16.0-in. casing was advanced to 754 ft and into the top of the Puye Formation between May 30 and June 2. Difficulty was again encountered trying to retract the underreaming bit into the casing string and the drilling tools were removed from the borehole along with the entire string of 16.0-in. casing. The bottom of the lowermost joint of 16.0-in. casing was found to be deformed in a compressive manner, which would not allow the bit to be retracted. Since the borehole had been advanced through the basalt, the 16.0-in. casing was not reinstalled in the borehole.

Beginning on June 4, 14.0-in. casing was installed to the bottom of the borehole and drilling resumed on June 6. No obstructions were encountered while installing the 14.0-in. casing. TD was reached at 1096.6 ft on June 9. The 14.0-in. casing shoe was cut off at 1079.5 ft on June 10.

4.0 SAMPLING ACTIVITIES

This section describes the cuttings and groundwater sampling activities for injection well CrIN-6. No groundwater samples were collected during drilling. All sampling activities were conducted in accordance with applicable quality procedures.

4.1 Cuttings Sampling

Cuttings samples were collected from the CrIN-6 injection well borehole at 10.0-ft intervals from ground surface to the TD of 1096.6 ft. At each interval, the drillers collected approximately 500 mL of bulk cuttings from the discharge cyclone, placed them in canvas or 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 CrIN-6.

5.0 GEOLOGY AND HYDROGEOLOGY

A brief description of the geologic and hydrogeologic features encountered at CrIN-6 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 CrIN-6 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 CrIN-6.

Alluvium, Qal (0–30 ft)

The near-surface bulk sediment from CrIN-6 appeared muddy, brown, sticky, and matrix-supported possibly from the clayey matrix. After washing, the sample is medium gray, crystal-rich, poorly sorted, and unconsolidated sand. Minor pumice, devitrified tuff, and dacitic lava fragments were noted. A few grains of perlite and mafic minerals were also present. With depth, the cuttings appear light-medium brown, fairly consolidated and moderately sorted. Quartz and feldspars are abundant and are lightly coated with tuffaceous matrix. A tuffaceous crystal sand that is matrix-supported, moderately sorted, and unconsolidated represents the basal part of the alluvium. Some devitrified light pinkish gray tuff clasts are present but dacite lava fragments are sparse. The alluvium transitions to matrix-supported and poorly sorted oxidized ash-flow tuff that consists of pinkish-red pumice fragments.

Otowi Member of the Bandelier Tuff, Qbo (30–270 ft)

The oxidized cuttings are gravelly and consist of poorly sorted, unconsolidated, clast-supported pinkish-red devitrified tuff up to 1.5 in. in size and smaller pumice clasts. Minor dacite lava and devitrified tuff fragments were noted. Some matrix is present and consists of quartz and feldspar grains that are lightly coated with tuffaceous silt. With depth, the ash-flow tuff is grayish to reddish-pink, poorly sorted, and clast-supported. Larger clasts of pumice and devitrified tuff up to 2.5 in. in size are present. More perlite and light pale red lava fragments were also noted. Nearly equal amounts of pumice and dacitic lava fragments dominated by light pale red lava clasts were encountered, starting at the 80- to 90-ft depth interval. Lithic-rich ash-flow tuff that is moderately sorted, clast-supported, and unconsolidated continued to dominate the cuttings with depth. Pumice clasts are mostly light gray with rusty or wood chip-like stains (130 ft to 140 ft). The lithic-rich ash-flow tuff is dominated by coarse sand-size fraction (<0.25 in.) of medium to dark gray lava clasts, minor white pumice, and variable amounts of quartz and feldspars in the 140- to 180-ft depth. The lithic-rich ash-flow tuff transitioned to poorly sorted and clast-supported gravelly cuttings of devitrified pumices up to 1.5 in. in size in the 190- to 220-ft depth. Two types of pumices consisting of smaller (<0.25 in.) light to medium gray and larger (~1.2 ft) light pinkish-red mixed with medium to dark gray dacite lava fragments were noted within this interval.

The basal part of the Otowi Member tuff is lithic-rich, sandy, and mostly sorted. Gray pumice, quartz and feldspars, and medium to dark gray dacite clasts are abundant. Few light gray and pale red dacite lava clasts and light pinkish-gray pumices were also noted. The lithic-rich ash-flow tuff transitioned to moderately sorted crystal-rich cuttings (230 ft to 250 ft). Medium to dark gray lava fragments are sparse, whereas the light gray and light pinkish-red pumices are of comparable abundances. In most cases, the light pinkish-red pumices are larger in size. Moderately sorted lithic-rich ash-flow tuff, containing abundant subangular to subrounded medium to dark gray dacite lava clasts and subrounded gray to white pumices make up the basal part of the Otowi Member. Minor light gray and pale red lava fragments were also noted.

Guaje Pumice Bed of the Otowi Member of the Bandelier Tuff, Qbog (270–290 ft)

The upper part of the pumice deposit is lithic-rich, containing more medium to dark gray dacite lava fragments than light gray pumices and abundant coarse quartz and feldspars. The lava fragments consist of subangular to subrounded medium to dark gray and pale red dacite of coarse sand fraction. It is moderately sorted, clast-supported, and unconsolidated. In contrast, the lower part is dominated by gravelly white pumice that is subangular to subrounded and moderately sorted. The lava fragments are less abundant than white pumice quartz and feldspars are less abundant.

Cerros del Rio Volcanics, Tb4 (290–748 ft)

The cuttings consist of coarse sand of mixed scoria, pumice, and dacite fragments. The scoria deposit is about 40 ft thick and consists of reddish to dark brown clast-supported and poorly to moderately sorted unit. Medium-gray sparsely vesicular basalt mixed with reddish-brown scoria occurs beneath the scoria deposit. The lava flow is pulverized and of sandy fraction. It is dominated by porphyritic, medium-gray lava flow that contains plagioclase and partially altered and fractured pyroxene and olivine, mostly in a microcrystalline matrix that persists to the 400-ft depth. Starting at 400-ft depth, the cuttings contained a mixture of medium and dark gray lava fragments that are both porphyritic with microcrystalline matrix and continued to 440 ft. There was no recovery from the 440- to 450-ft depth interval.

Between 450 ft and 480 ft, sparsely vesicular and porphyritic dark gray lava fragments dominated the cuttings. The dark gray lava is partially weathered and contains abundant plagioclase, olivine, and pyroxene embedded in a microcrystalline matrix. Vesicle walls are coated with secondary minerals. Comparable amounts of mixed light to medium gray fragments were encountered beneath the dark gray lava flow, starting at 480 ft. Dark gray lava fragments decreased with depth while light to medium gray lava clasts increased until 570 ft. The cuttings below 570 ft contain abundant scoria and reddish-brown oxidized fragments mixed with light to medium gray lava clasts. The light to medium gray lava decreases with depth and a light reddish-gray lava is more abundant and persisted to 610 ft. At 610 ft, light to medium gray lava fragments are more abundant than the light reddish-brown fraction. A few clasts of light pinkish-gray claystone fragments started to appear at this depth. Starting at 680 ft, porphyritic and sparsely vesicular dark gray lava fragments become the dominant fraction. Minor light to medium gray, oxidized lava clasts, and light pinkish-gray claystone fragments occur within the dominant dark gray lava fraction down to the base of the Cerro del Rio volcanic sequence at 748 ft.

Puye Formation, Tpf (748–1030 ft)

The transition from the Cerro del Rio volcanic lava sequence to the Puye Formation is marked by a few grains of distinct Rendija Canyon lava clasts contaminated by abundant dark gray and minor light to medium gray lava clasts and a few light pinkish-gray claystone. The amounts of Rendija Canyon and other light to medium gray and light pale red dacite lava fragments of the Puye Formation increase as the basaltic lava contamination decreases with depth. The Puye Formation lava fragments exhibit a range of clast sizes and shapes and are dominated mostly by clast-supported subrounded to rounded clasts. Apart from the Rendija Canyon lava fragments, which are represented by white sugary-textured and light brownish-gray lava fragments containing abundant tiny needle-like weathered pyroxene crystals, the Puye Formation consists of light to medium gray and light pale red coarse sand-sized dacite lava clasts.

Starting at 810 ft, comparable amounts of subrounded to rounded light to medium gray and pale red dacite fragments were noted along with common Rendija Canyon clasts, minerals, and a few basalt contaminants. However, the pale red fraction continued to increase with depth until 870 ft. Even though the amounts of the Rendija Canyon lava fragments and fine to coarse quartz and feldspars remained constant, the light to medium gray and pale red dacite clasts fluctuated with depth. More light to medium gray dacite fragments dominated the cuttings between 870 ft to 910 ft, whereas light to medium pale red lava fragments are abundant in the lowermost part of the Puye Formation sequence (910 ft to 1010 ft). The cuttings from 1000 ft to 1010 ft are heavily coated with light yellowish-brown tuffaceous silt. When washed, the cuttings consisted of similar dacite fragments of light to medium gray and pale red fragments along with common Rendija Canyon clasts and fine to coarse quartz and feldspar grains. Below 1010 ft, pale red lava fragments were sparse while the amount of Rendija Canyon lava fragments increased significantly. Two types of Rendija Canyon fragments consisting of light gray and light pale red clasts with the usual needle-like weathered pyroxene minerals were noted. The basal unit of the Puye Formation consists of subrounded to rounded of lava fragments that are heavily coated with light yellowish tuffaceous silty matrix. Rendija Canyon fragments are common but minerals are sparse.

Pumiceous Puye Formation, Tpf(p) (1030–1096.6 ft)

The transition from the Puye Formation to pumiceous Puye Formation is marked by the first appearance of common pumice fragments mixed with abundant dacite lava clasts that are found in typical Puye Formation. In the CrIN-6 well, white, fairly dense pumices mixed with abundant Rendija Canyon clasts were noted in the 1030- to 1040-ft depth interval. Minor fine- to medium-grained quartz and feldspars occur in the matrix. The amount of white pumice increased in successive cuttings and then significantly decreased in the lowermost cuttings (1060 ft to 1096 ft). The Rendija Canyon lava fragments remained as the dominant fraction to TD.

5.2 Groundwater

Drilling at CrIN-6 proceeded without any groundwater indications until 980.0 ft as noted by the drilling crew. The borehole was then advanced to the TD of 1096.6 ft. The water level was 969.8 ft on June 10, 2017, before well installation. The DTW in the completed well was 966.5 ft on July 13.

6.0 BOREHOLE LOGGING

The CrIN-6 borehole was logged on June 10, 2017, by Jet West Geophysical Services, LLC (JWGS) upon reaching TD (Table 6.0-1). 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 document).

On July 20, a video log was run to document the condition of the completed well. Video logging was conducted with Laboratory logging equipment and staff.

7.0 WELL INSTALLATION CrIN-6 INJECTION WELL

The CrIN-6 well was installed between June 11 and July 2, 2017.

7.1 Well Design

The CrIN-6 well was designed in accordance with the objectives outlined in the approved "Drilling Work Plan for Groundwater Injection Well CrIN-6" (LANL 2016, 602049; NMED 2017, 602097). The drill cuttings and driller's logs as well as the results of the downhole geophysics and DTW were reviewed. The objectives in setting the screen were to help achieve hydraulic control of off-site plume migration.

Injection well CrIN-6 was designed with a screened interval between 980.0 ft and 1040.0 ft. CrIN-6 was designed with a 60-ft screen to yield an effective vertical submergence of 54 ft because of its 25-degree angle. The well design was submitted to NMED on June 10, 2017, and approved later that day. The final CrIN-6 design and NMED's approval are included in Appendix A.

7.2 Well Construction

From June 10 to 11, 2017, the stainless-steel well casing, screens, and tremie pipe were decontaminated, and well construction materials were mobilized to the site.

The CrIN-6 injection well was constructed of 8.0-in.-I.D./8.63-in.-O.D. type A304 passivated stainless-steel beveled casing fabricated to American Society for Testing and Materials A312 standards. The screened section utilized two 10.0-ft lengths and two 20.0-ft length of 8.0-in.-I.D. 0.040-in. slot, rod-based wire-wrapped screens to make up the 60.0-ft-long screen interval. A 21.0-ft-long stainless-steel sump was placed below the bottom of the well screen. Stainless-steel centralizers (two sets of four) were welded to the well casing approximately 2.0 ft above and below the screened interval. One set of four stainless-steel centralizers was welded to the well casing every 60 ft the entire length of the well. All individual casing and screen sections were welded together using compatible stainless-steel welding rods. A 2.0-in. steel tremie pipe was used to deliver backfill and annular fill materials downhole during well construction.

The well casing was welded together and installed into the borehole from June 11 to 13.

Figure 7.2-1 presents an as-built schematic showing construction details for the completed well. Table 7.2-1 presents the annular fill materials used in CrIN-6.

The lower bentonite backfill was installed between June 14 and 15 from 1077.9 ft to 1045.2 ft using 19.6 ft^3 of 3/8-in. bentonite chips. The filter pack was installed between June 15 and 18 from 1045.2 ft to 880.3 ft using 160.0 ft^3 of 10/20 silica sand. The filter pack was surged to promote compaction. The fine-sand collar was installed above the filter pack from 880.3 ft to 875.4 ft using 2.5 ft^3 of 20/40 silica sand. From June 18 to July 1, the bentonite seal was installed from 875.4 ft to 60.1 ft using 1068.2 ft^3 of 3/8-in. bentonite chips. On July 2, a cement seal was installed from 60.1 ft to 6.0 ft. The cement seal used 140.0 ft^3 of Portland Type I/II/V cement.

8.0 POST-INSTALLATION ACTIVITIES

Following well installation at CrIN-6, the well was developed and aquifer pumping tests were conducted. A temporary pumping system was installed. The wellhead surface completion will be constructed as part of the treatment system piping and infrastructure project in fall 2017. A final geodetic survey will be performed once the surface completion vault and piping are installed. Site-restoration activities will be completed following the final disposition of contained drill cuttings and groundwater, per the NMED-approved land application decision trees.

8.1 Well Development

The well was developed between July 8 and 15, 2017. Initially, the screened interval was swabbed and bailed from July 8 to 10 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.

From July 13 to 15, final well development was then performed with a submersible pump. A 30-horsepower (hp), 6-in. Grundfos submersible pump was installed in the well for the final stage of well development. The screened interval was pumped from top to bottom and from bottom to top in 2-ft increments. Approximately 74,893 gal. of groundwater was purged with the submersible pump during well development.

8.1.1 Well Development Field Parameters

The field parameters of turbidity, temperature, and pH were monitored via a flow-through cell at CrIN-6 during well development. The field parameter measurements toward the end of development on

July 15, 2017, were pH of 7.96, temperature of 21.4°C, and turbidity of 0.51 nephelometric turbidity units (NTU). Field water-quality parameters are presented in Table 8.1-1.

8.2 Aquifer Testing

Step testing was conducted on July 16, 2017. The well was pumped in three steps at 50 gallons per minute (gpm), 70 gpm, and 90 gpm in 1-h increments. A total of 12,540 gal. of water was removed during the step testing. A 24-h aquifer test was conducted between July 16 and 17, followed by a 20-h recovery period. The average pumping rate for the 24-h test was approximately 90.1 gpm. A 30-hp pump was used for the aquifer tests. A total of approximately 129,600 gal. of groundwater was purged during constant rate aquifer testing. Turbidity, temperature, and pH were measured during the aquifer tests. The CrIN-6 aquifer test results and analysis are presented in Appendix C.

8.3 Pumping System Installation

A dedicated injection and pumping system has been installed in the CrIN-6 well. The system has a 6-in. Grundfos submersible pump with a 30-hp Franklin Electric motor inside a stainless-steel pump shroud. A flow-control valve is positioned above the pump shroud and is separated from the pump by a check valve. The flow-control valves provide controlled, noncavitating head loss from the column pipe. An inflatable swellable element resides within the flow-control valve. The rate of water injection can be controlled by pneumatically manipulating the element. The element may be fully inflated to shut the flow-control valve and allow pumping from the well with a single column pipe. The pump and flow-control valve assemblies are fully positioned in the well sump to prevent the injected water from being delivered directly next to the screen interval. The column pipe consists of 3.0-in. spline-lock, schedule 80, 304 stainless-steel. Two 1.0-in.-I.D. schedule 80 polyvinyl chloride (PVC) tubes are installed along with, and banded to, the pump column. A dedicated 100 psi 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. Both PVC tubes are equipped with 5 ft sections of 0.010-in. slotted screen and a closed bottom.

Pumping system details for CrIN-6 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 will be installed at the CrIN-6 wellhead in fall 2017. The vault will be slightly elevated above ground surface and will provide long-term structural integrity for the well. A brass monument marker will be 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 provisional survey of the top of the stainless-steel well was performed on July 19, 2017. The preliminary survey data will be used for water-level monitoring until the surface completion is constructed and the final survey is performed. Current survey data for CrIN-6 are presented in Table 8.5-1.

A licensed professional land surveyor will conduct a geodetic survey once the wellhead is completed. The survey data will conform 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 will be 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 will include ground-surface elevation near the concrete pad, the top of the monument marker in the concrete pad, the top of the well casing, and the top of the protective casing.

8.6 Waste Management and Site Restoration

Waste generated from the CrIN-6 project includes drilling fluids, drill cuttings, and contact waste. A summary of the waste characterization samples collected during drilling, construction, and development of the CrIN-6 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 DP-1793 (NMED 2014, 600128).

Cuttings produced during drilling were sampled, and the analytical results will be reviewed with the goal of land application. A composite volatile organic compound (VOC) sample of the cuttings will be collected and evaluated against land-application criteria (ENV-RCRA-QP-011, “Land Application of Drill Cuttings”). If cuttings meet the land-application criteria, the materials will be spread across the pad area, and the site will be reseeded as required for site restoration.

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

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

9.0 DEVIATIONS FROM PLANNED ACTIVITIES

Drilling and well construction at CrIN-6 were performed as specified in the approved “Drilling Work Plan for Groundwater Injection Well CrIN-6” (LANL 2016, 602049; NMED 2017, 602097).

10.0 ACKNOWLEDGMENTS

Holt Services, Inc. drilled and installed injection well CrIN-6.

11.0 REFERENCES AND MAP DATA SOURCES

11.1 References

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

Holt Services Inc., March 13, 2016. "IWD [Integrated Work Document] for 2016 Drilling and Installation of LANL Wells CrIN-4, CrIN-5, and CrIN-3," Los Alamos, New Mexico. (Holt Services Inc., 2016, 602106)

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), December 2016. "Drilling Work Plan for Groundwater Injection Well CrIN-6," Los Alamos National Laboratory document LA-UR-16-29285, Los Alamos, New Mexico. (LANL 2016, 602049)

LANL (Los Alamos National Laboratory), March 20, 2017. "Storm Water Pollution Prevention Plan, CrIN-6 Well Construction Support Activities, Los Alamos National Laboratory," Los Alamos National Laboratory, Los Alamos, New Mexico. (LANL 2017, 602605)

NMED (New Mexico Environment Department), August 8, 2014. "Temporary Permission to Discharge, Treated Ground Water from Aquifer Testing at Pilot Pumping Well CrEX-1 (AI: 856, PRD20140007)," New Mexico Environment Department letter to A. Dorries (LANL) and G. Turner (DOE) from J. Schoeppner (NMED-GWQB), Santa Fe, New Mexico. (NMED 2014, 600128)

NMED (New Mexico Environment Department), January 4, 2017. "Approval [for the] Drilling Work Plan for Groundwater Injection Well CrIN-6," New Mexico Environment Department letter to D. Hintze (DOE-EM-LA) and M. Brandt (LANL) from J.E. Kieling (NMED-HWB), Santa Fe, New Mexico. (NMED 2017, 602097)

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.

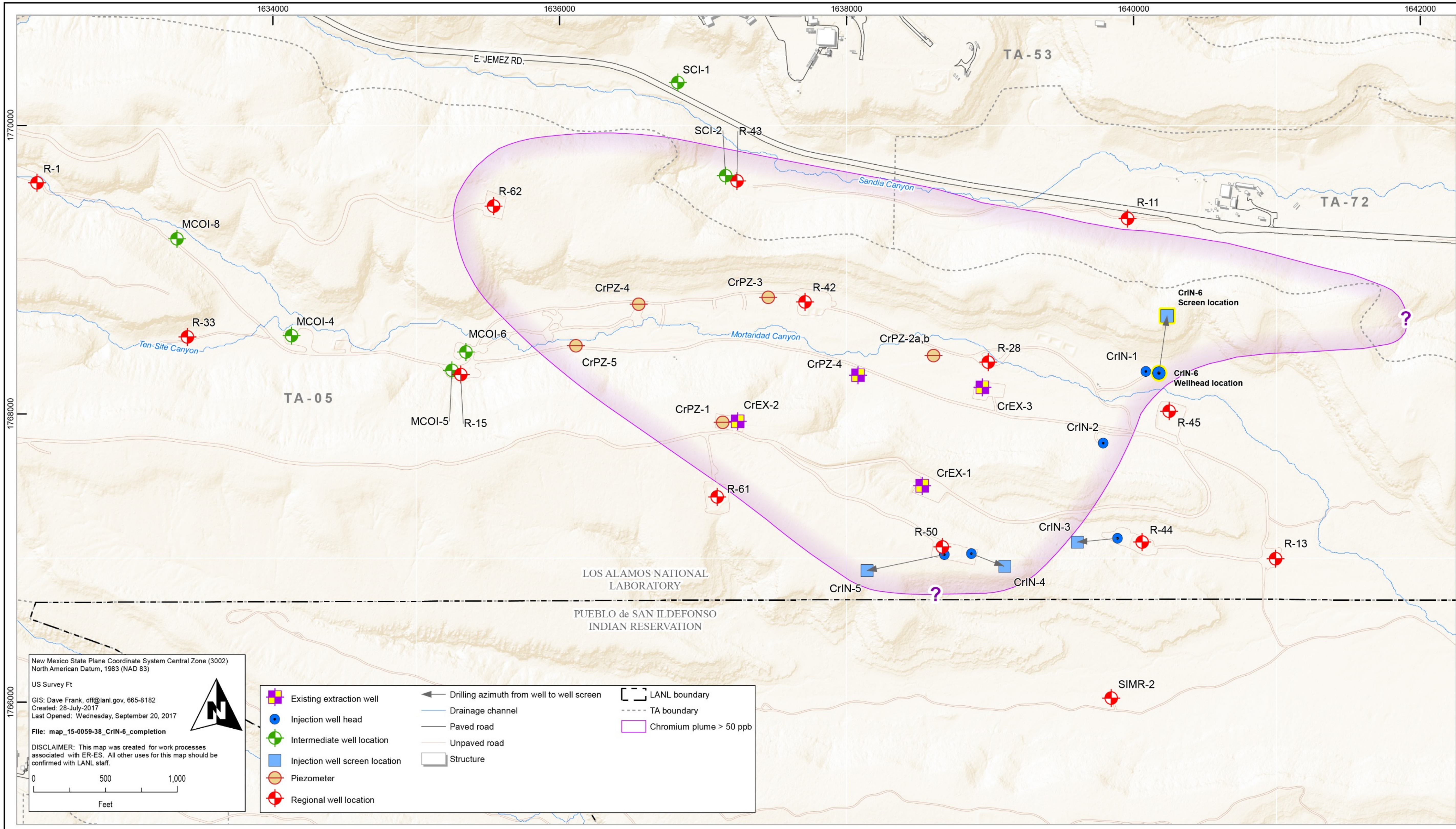


Figure 1.0-1 Location of injection well CrIN-6

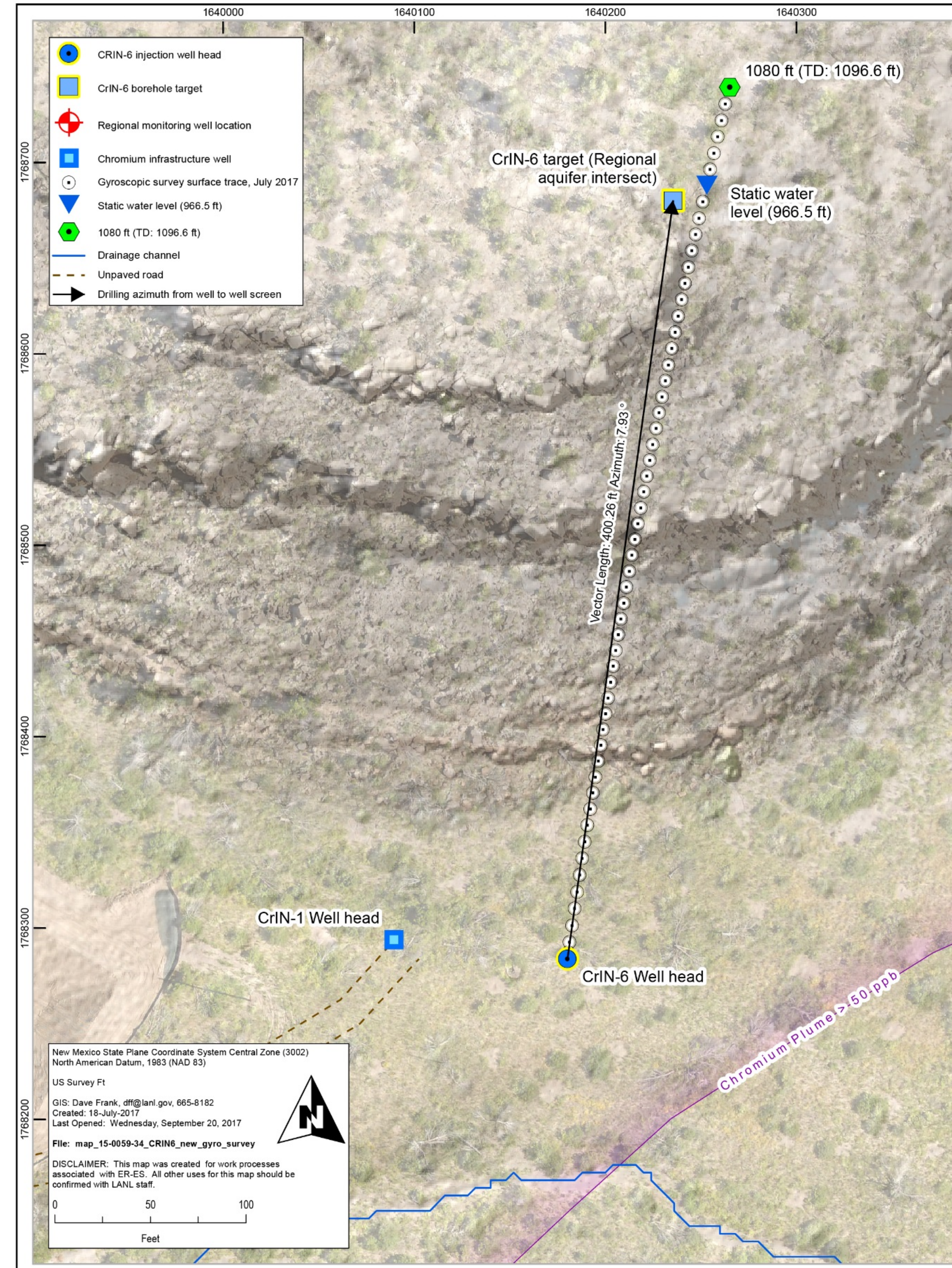


Figure 3.1-1 TD survey and original drilling target (intersection with top of regional aquifer) for the borehole

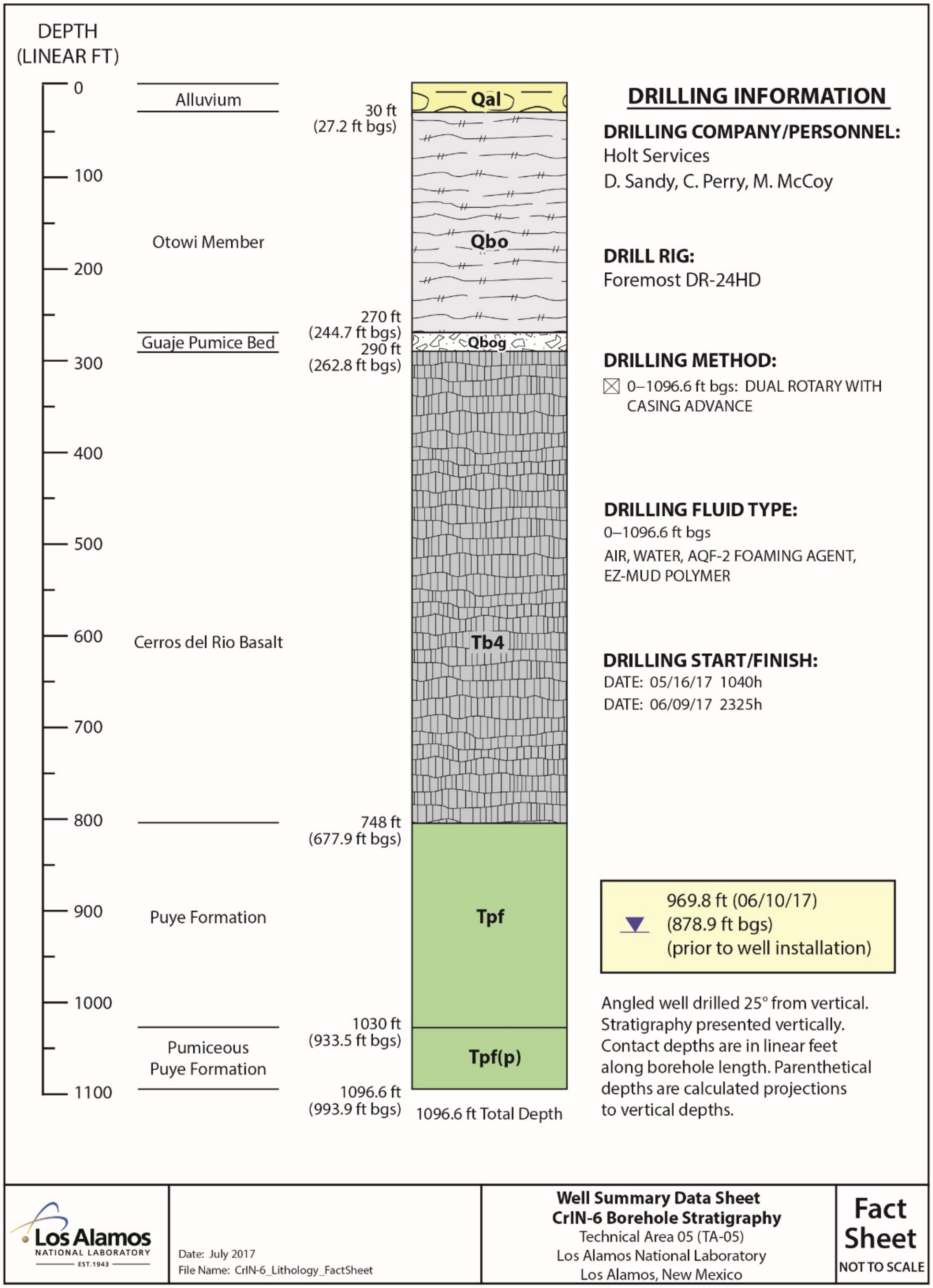


Figure 5.1-1 Injection well CrIN-6 borehole stratigraphy

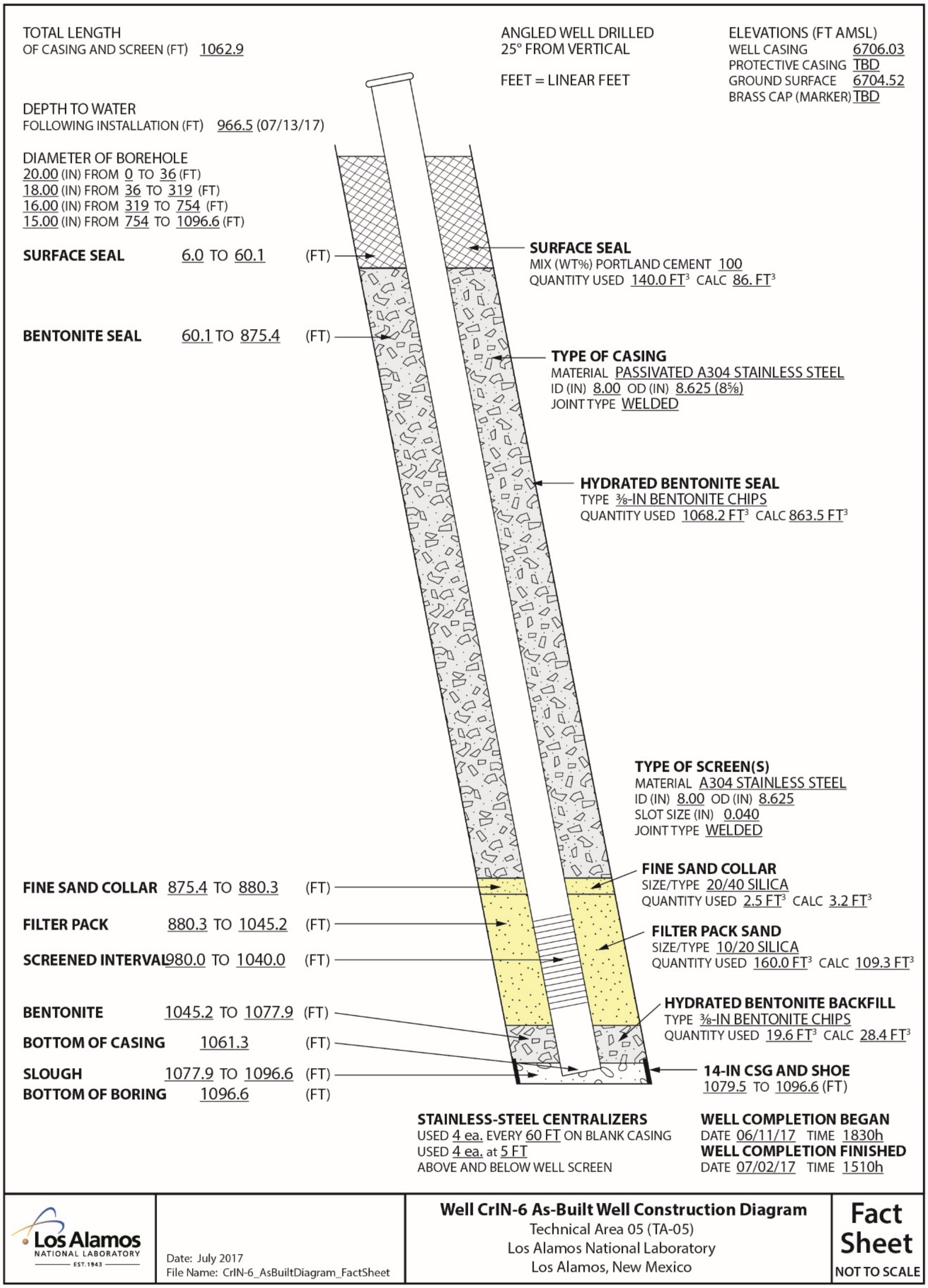


Figure 7.2-1 Injection well CrIN-6 as-built well construction diagram

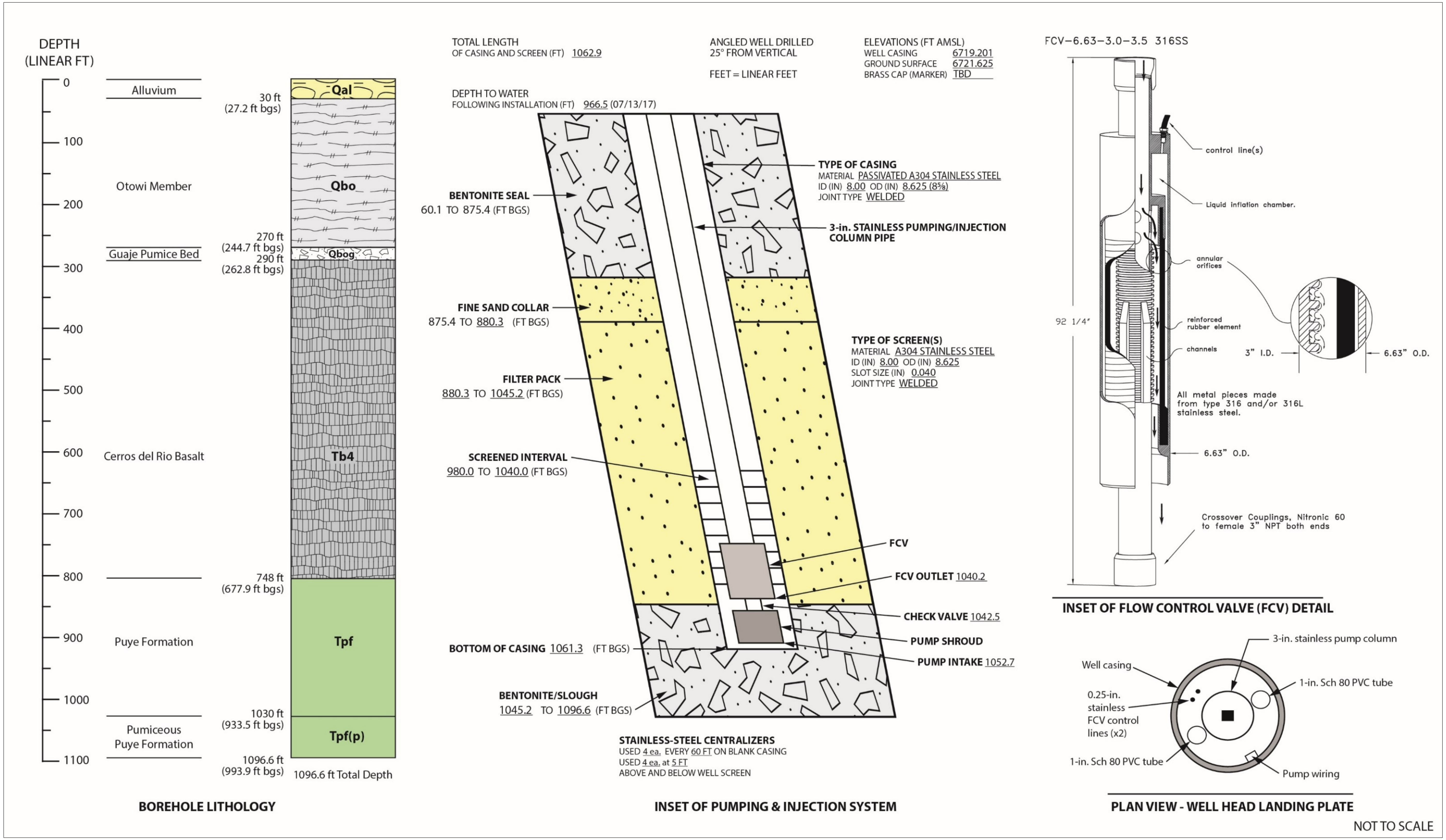


Figure 8.3-1a Injection well CrIN-6 as-built diagram with borehole lithology and technical well completion details

CrIN-6 TECHNICAL NOTES:

SURVEY INFORMATION*

Brass Marker
Northing: TBD
Easting: TBD
Elevation: TBD

Well Casing (top of stainless steel)
Northing: TBD
Easting: TBD
Elevation: TBD

BOREHOLE GEOPHYSICAL LOGS

Logger: Jet West Geophysical Services
Logs: Natural Gamma Ray, Neutron Density
Date: 06/10/2017

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, EZ Mud

MILESTONE DATES

Drilling
Start: 05/16/2017
Finished: 06/09/2017

Well Completion
Start: 06/11/2017
Finished: 07/02/2017

Well Development
Start: 07/08/2017
Finished: 07/15/2017

WELL DEVELOPMENT

Development Methods
Swabbing, bailing, and pumping

Parameter Measurements (Final)
pH: 7.96
Temperature: 21.4°C
Turbidity: 0.5 NTU

AQUIFER TESTING

Step Tests
Pumping Rates: 50, 70, 90 gpm
Performed on: 07/16/2017

24-h Constant-Rate Pumping Test
Water Produced: 129,600 gal.
Pumping Rate: 90 gpm
Performed on: 07/16/2017–07/17/2017

DEDICATED SAMPLING SYSTEM

Pump
Make: Grundfos
Type: 85S300-26

Motor
Make: Franklin Electric
Model: 2366168120

Flow Control Valve
Make: Baski
S/N: 28866

Pump Column
3-inch, sch. 80, 304 stainless steel, spline lock couplings

Gauge Tubes
2x 1.0-in. flush threaded sch. 80 PVC
with 5 ft 0.010-slot screens

Transducer
Make: In-Situ Level TROLL
Model: LT 500
Range: 100 psig/231 ft
S/N: TBD

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 injection well CrIN-6

Table 6.0-1
Logging Runs

Date(s)	Type of Log	Depth (ft)	Description
06/10/2017	Gamma ray and neutron density	0–1082	JWGS-cased hole stacked gamma ray and neutron density to TD
07/20/2017	Video	0-1062	LANL video to confirm screen condition.

Table 7.2-1
CrIN-6 Injection Well Annular Fill Materials

Material	Volume
Upper surface seal: cement slurry	140.0 ft^3
Upper bentonite seal: bentonite chips	1068.2 ft^3
Fine sand collar: 20/40 silica sand	2.5 ft^3
Filter pack: 10/20 silica sand	160.0 ft^3
Backfill: bentonite chips	19.6 ft^3

Table 8.1-1
Field Water-Quality Parameters and Well Performance for Development of Well CrIN-6

Date	Time (h)	Pumping Rate (gpm)	Depth to Water (ft)	Drawdown (ft)	Cumulative Purge Volume (gal.)	pH	Turbidity (NTU)	Temp C°
Well Development								
7/15/2017	11:31	92	NC*	NC	52,075	7.92	1.88	21.6
	11:45	92	970.93	4.41	53,363	7.93	0.68	21.6
	12:00	92	970.89	4.37	54,743	7.93	0.75	21.7
	12:15	92	970.92	4.40	56,123	7.93	0.42	21.9
	12:30	92	970.90	4.38	57,503	7.93	0.45	21.9
	12:45	92	970.91	4.39	58,883	7.94	0.4	21.8
	13:00	92	970.89	4.37	60,263	7.95	0.42	21.8
	13:15	92	970.90	4.38	61,643	7.94	0.3	21.9
	16:30	90	970.55	4.03	66,793	7.96	1.05	21.3
	16:45	90	970.73	4.21	68143	7.96	1.14	21.3
	17:00	90	970.82	4.30	69,493	7.96	0.53	21.3
	17:15	90	970.77	4.25	70843	7.96	0.65	21.3
	17:30	90	970.70	4.18	72,193	7.97	0.35	21.4
	17:45	90	970.70	4.18	73,543	7.96	0.49	21.6
	18:00	90	NC	NC	74,893	7.96	0.51	21.4

Table 8.1-1 (continued)

Date	Time (h)	Pumping Rate (gpm)	Depth to Water (ft)	Drawdown (ft)	Cumulative Purge Volume (gal.)	pH	Turbidity (NTU)	Temp C°
Step Test								
7/16/2017	9:00	50	NC	NC	74,893	7.61	NC	23.6
	9:15	50	968.68	2.16	75,643	8.06	1.38	21.9
	9:30	50	968.63	2.11	76,393	8.04	1.48	22.0
	9:45	50	968.64	2.12	77,143	8.02	1.01	21.9
	10:00	50	968.68	2.16	77,893	8.02	2.15	21.9
	10:15	69	969.60	3.08	78,928	8.00	1.73	21.5
	10:30	69	969.60	3.08	79,963	8.00	0.55	21.5
	10:45	69	969.65	3.13	80,998	8.00	0.63	21.5
	11:00	69	969.55	3.03	82,033	8.00	0.68	21.6
	11:15	90	970.57	4.05	83,383	7.90	0.39	21.3
	11:30	90	970.57	4.05	84,733	7.99	0.55	21.4
	11:45	90	970.57	4.05	86,083	7.99	0.33	21.4
	12:00	90	970.55	4.03	87,433	7.99	0.28	21.4
Constant Rate Test								
7/16/2017	15:00	90	NC	NC	87,433	6.98	NC	28.0
	15:15	90	970.46	3.94	88,783	7.95	0.57	21.5
	15:30	90	970.47	3.95	90,133	7.98	0.71	21.5
	15:45	90	970.48	3.96	91,483	7.98	0.42	21.5
	16:00	90	970.48	3.96	92,833	7.98	0.43	21.4
	16:15	90	970.48	3.96	94,183	7.98	0.31	21.6
	16:30	90	970.50	3.98	95,533	7.98	0.28	21.5
	16:45	90	970.48	3.96	96,883	7.99	0.3	21.4
	17:00	90	970.48	3.96	98,233	7.99	0.27	21.5
	17:15	90	970.48	3.96	99,583	7.99	0.3	21.4
	17:30	90	970.49	3.97	100,933	7.99	1.05	21.5
	17:45	90	970.48	3.96	102,283	7.99	0.28	21.5
	18:00	90	970.48	3.96	103,633	7.99	0.64	21.4
	18:15	90	970.48	3.96	104,983	7.99	0.31	21.4
	18:30	90	970.48	3.96	106,333	7.99	0.54	21.3
	18:45	90	970.48	3.96	107,683	7.99	0.23	21.3
	19:00	90	970.48	3.96	109,033	7.99	0.25	21.3
	19:15	90	970.48	3.96	110,383	7.99	0.56	21.3
	19:30	90	970.48	3.96	111,733	7.99	0.74	21.3
	19:45	90	970.48	3.96	113,083	8.00	0.3	21.3
	20:00	90	970.48	3.96	114,433	8.00	0.29	21.2
	20:15	90	970.50	3.98	115,783	8.00	0.27	21.2

Table 8.1-1 (continued)

Date	Time (h)	Pumping Rate (gpm)	Depth to Water (ft)	Drawdown (ft)	Cumulative Purge Volume (gal.)	pH	Turbidity (NTU)	Temp C°
7/16/2017	20:30	90	970.50	3.98	117,133	8.00	0.27	21.2
	20:45	90	970.50	3.98	118,483	8.00	0.25	21.2
	21:00	90	970.50	3.98	119,833	8.00	0.3	21.2
	21:15	90	970.50	3.98	121,183	7.99	0.3	21.2
	21:30	90	970.50	3.98	122,533	8.00	0.29	21.2
	21:45	90	970.52	4.00	123,883	8.00	0.25	21.2
	22:00	90	970.53	4.01	125,233	8.00	0.28	21.1
	22:15	90	970.52	4.00	126,583	8.00	0.31	21.1
	22:30	90	970.52	4.00	127,933	8.00	0.27	21.1
	22:45	90	970.53	4.01	129,283	8.00	0.31	21.1
	23:00	90	970.53	4.01	130,633	8.00	0.54	21.0
	23:15	90	970.53	4.01	131,983	8.00	0.25	21.0
	23:30	90	970.53	4.01	133,333	8.00	0.29	21.0
	23:45	90	970.53	4.01	134,683	8.00	0.24	21.0
7/17/2017	0:00	90	970.53	4.01	136,033	8.00	0.92	21.1
	0:15	90	970.53	4.01	137,383	8.00	0.25	21.1
	0:30	90	970.54	4.02	138,733	8.00	0.28	21.1
	0:45	90	970.53	4.01	140,083	8.00	0.25	21.0
	1:00	90	970.53	4.01	141,433	8.00	0.26	21.0
	1:15	90	970.53	4.01	142,783	8.00	0.23	21.0
	1:30	90	970.53	4.01	144,133	8.00	0.29	21.0
	1:45	90	970.53	4.01	145,483	8.00	0.27	21.0
	2:00	90	970.53	4.01	146,833	8.00	0.29	21.0
	2:15	90	970.53	4.01	148,183	8.00	0.21	21.0
	2:30	90	970.52	4.00	149,533	8.00	0.29	21.0
	2:45	90	970.52	4.00	150,883	8.00	0.24	20.9
	3:00	90	970.52	4.00	152,233	8.00	0.24	20.9
	3:15	90	970.52	4.00	153,583	8.00	0.22	20.9
	3:30	90	970.50	3.98	154,933	8.00	0.23	20.9
	3:45	90	970.50	3.98	156,283	8.00	0.24	20.9
	4:00	90	970.52	4.00	157,633	8.00	0.23	20.9
	4:15	90	970.52	4.00	158,983	8.00	0.48	20.9
	4:30	90	970.52	4.00	160,333	8.00	0.27	20.9
	4:45	90	970.52	4.00	161,683	8.00	0.29	20.9
	5:00	90	970.52	4.00	163,033	8.00	0.29	20.9
	5:15	90	970.52	4.00	164,383	8.00	0.24	20.9
	5:30	90	970.52	4.00	165,733	8.00	0.29	20.9

Table 8.1-1 (continued)

Date	Time (h)	Pumping Rate (gpm)	Depth to Water (ft)	Drawdown (ft)	Cumulative Purge Volume (gal.)	pH	Turbidity (NTU)	Temp C°
7/17/2017	6:00	90	970.52	4.00	168,433	8.00	0.23	20.9
	5:45	90	970.52	4.00	167,083	8.00	0.21	20.9
	6:15	90	970.52	4.00	169,783	8.00	0.23	20.9
	6:30	90	970.52	4.00	171,133	8.00	0.22	20.9
	6:45	90	970.52	4.00	172,483	8.00	0.22	21.0
	7:00	90	970.52	4.00	173,833	8.00	0.23	21.0
	7:15	90	970.52	4.00	175,183	8.00	0.22	21.0
	7:30	90	970.52	4.00	176,533	8.00	0.18	21.1
	7:45	90	970.52	4.00	177,883	8.00	0.26	21.1
	8:00	90	970.52	4.00	179,233	8.00	0.28	21.1
	8:15	90	970.52	4.00	180,583	8.00	0.29	21.1
	8:30	90	970.52	4.00	181,933	8.00	0.22	21.1
	8:45	90	970.52	4.00	183,283	8.00	0.29	21.2
	9:00	90	970.52	4.00	184,633	8.00	0.23	21.3
	9:15	90	970.52	4.00	185,983	8.00	0.2	21.3
	9:30	90	970.52	4.00	187,333	8.00	0.25	21.4
	9:45	90	970.52	4.00	188,683	8.00	0.23	21.5
	10:00	90	970.52	4.00	190,033	8.00	0.22	21.6
	10:15	90	970.52	4.00	191,383	8.00	0.22	21.6
	10:30	90	970.52	4.00	192,733	8.00	0.2	21.6
	10:45	90	970.52	4.00	194,083	8.00	0.23	21.6
	11:00	90	970.52	4.00	195,433	8.00	0.29	21.6
	11:15	90	970.52	4.00	196,783	8.00	0.23	21.6
	11:30	90	970.52	4.00	198,133	8.00	0.22	21.6
	11:45	90	970.52	4.00	199,483	8.00	0.28	21.6
	12:00	90	970.52	4.00	200,833	7.99	0.2	21.6
	12:15	90	970.52	4.00	202,183	7.99	0.24	21.6
	12:30	90	970.52	4.00	203,533	7.99	0.24	21.6
	12:45	90	970.52	4.00	204,883	7.99	0.23	21.4
	13:00	90	970.52	4.00	206,233	7.99	0.2	21.4
	13:15	90	970.52	4.00	207,583	7.99	0.21	21.4
	13:30	90	970.52	4.00	208,933	7.99	0.25	21.4
	13:45	90	970.52	4.00	210,283	7.99	0.29	21.3
	14:00	90	970.52	4.00	211,633	7.99	0.2	21.4
	14:15	90	970.52	4.00	212,983	7.99	0.38	21.5
	14:30	90	970.52	4.00	214,333	7.99	0.25	21.5
	14:45	90	970.52	4.00	215,683	7.99	0.23	21.5
	15:00	90	970.52	4.00	217,033	7.99	0.24	21.5

*NC = Not collected.

Table 8.5-1
CrIN-6 Preliminary Survey Coordinates

Identification	Northing	Easting	Elevation
CrIN-6 top of stainless-steel well casing	1768184.223	1638949.276	6734.601

Notes: All coordinates are expressed as New Mexico State Plane Coordinate System Central Zone (NAD 83); elevation is expressed in ft amsl using the National Geodetic Vertical Datum of 1929. Provisional survey conducted. Will be resurveyed when vault is installed.

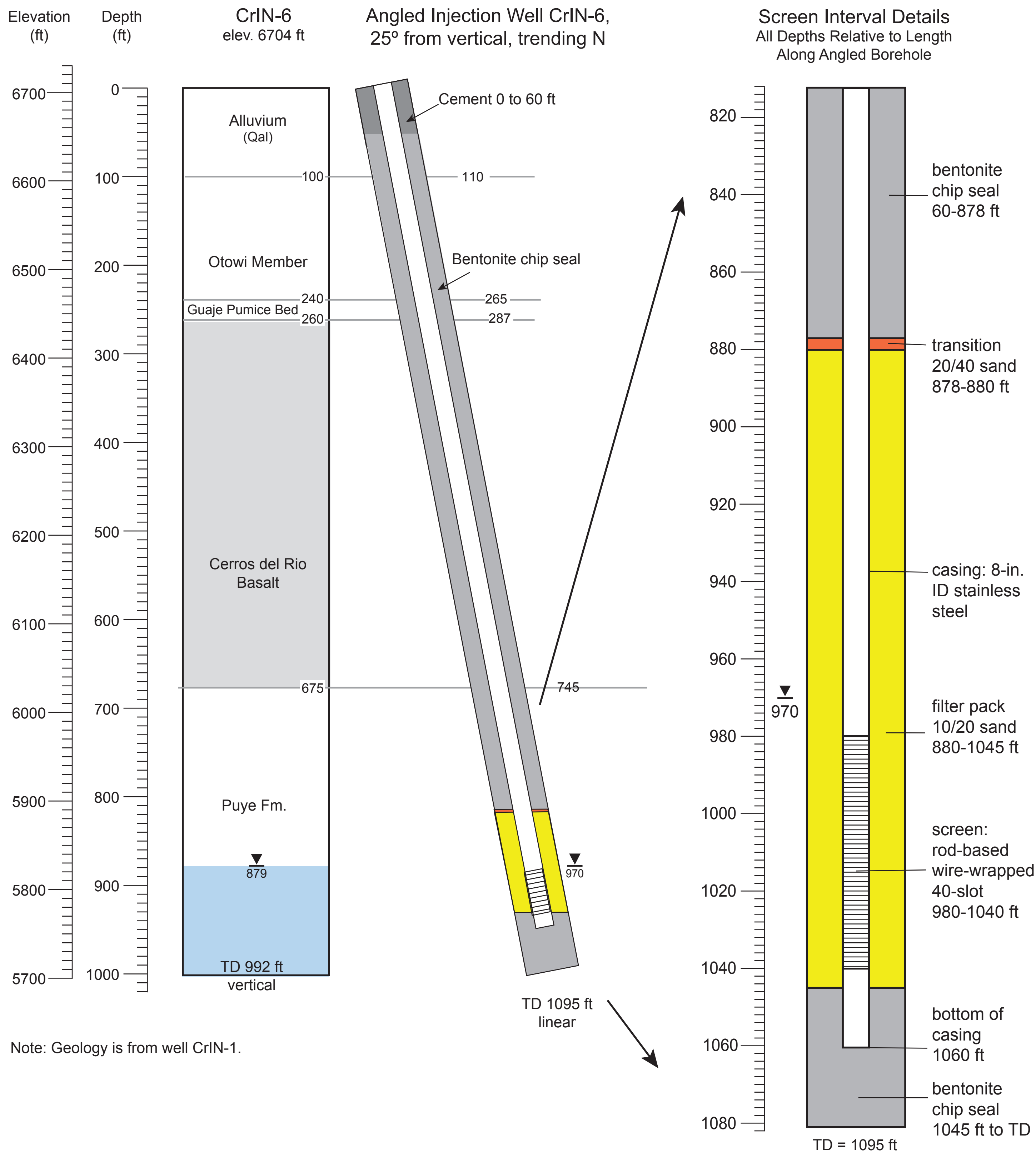
Table 8.6-1
Summary of Waste Characterization Samples Collected during Drilling, Construction, and Development of CrIN-6

Event ID	Sample ID	Date Collected	Description	Sample Matrix
11283	WSTMO-17-136836	05/16/2017	CrIN-6 drilling fluids (top) VOC	Liquid
11283	WSTMO-17-136837	05/16/2017	CrIN-6 drilling fluids trip blank VOC	Liquid
11283	WSTMO-17-136838	06/02/2017	CrIN-6 drilling fluids (middle) VOC	Liquid
11283	WSTMO-17-136839	06/02/2017	CrIN-6 drilling fluids trip blank VOC	Liquid
11283	WSTMO-17-136840	06/09/2017	CrIN-6 drilling fluids (Bottom) VOC	Liquid
11283	WSTMO-17-136841	06/09/2017	CrIN-6 drilling fluids trip blank VOC	Liquid
11408	WSTMO-17-143323	08/23/2017	CrIN-6 drilling fluids Comprehensive	Liquid
11408	WSTMO-17-143324	08/23/2017	CrIN-6 drilling fluids Comprehensive	Liquid
11408	WSTMO-17-143325	08/23/2017	CrIN-6 drilling fluids Comprehensive	Liquid
11283	WSTMO-17-136830	05/16/2017	CrIN-6 Drill Cuttings (top) VOC	Solid
11283	WSTMO-17-136831	05/16/2017	CrIN-6 Drill Cuttings trip blank VOC	Solid
11283	WSTMO-17-136832	06/02/2017	CrIN-6 Drill Cuttings (middle) VOC	Solid
11283	WSTMO-17-136833	06/02/2017	CrIN-6 Drill Cuttings trip blank VOC	Solid
11283	WSTMO-17-139496	06/09/2017	CrIN-6 Drill Cuttings (bottom) VOC	Solid
11283	WSTMO-17-136835	06/09/2017	CrIN-6 Drill Cuttings trip blank VOC	Solid
11407	WSTMO-17-143313	08/23/2017	CrIN-6 Drill Cuttings Comprehensive	Solid
11407	WSTMO-17-143314	08/23/2017	CrIN-6 Drill Cuttings Comprehensive	Solid

*TBD = To be determined.

Appendix A

Final Well Design and New Mexico Environment Department Approval



Note: Geology is from well CrIN-1.

From: Dale, Michael, NMENV
To: White, Stephen Spalding
Cc: Swickley, Stephani Fuller; Katzman, Danny; Rodriguez, Cheryl L; Shen, Hai; Ball, Ted; Dhawan, Neelam, NMENV; Murphy, Robert, NMENV; Fellenz, David, NMENV; Yanicak, Steve, NMENV; Granzow, Kim, NMENV
Subject: Re: CrIN-6 well design proposal
Date: Saturday, June 10, 2017 4:00:30 PM

Steve,

New Mexico Environment Department (NMED) hereby approves the installation of the regional-aquifer chromium injection well CrIN-6 as proposed in your e-mail, with attachment, that was received today, June 10, 2017 at 3:01 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 test, and aquifer testing at CrIN-6. 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

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: Saturday, June 10, 2017 3:01 PM
To: Dale, Michael, NMENV
Cc: Swickley, Stephani Fuller; Katzman, Danny; Rodriguez, Cheryl L; Shen, Hai; Ball, Ted
Subject: CrIN-6 well design proposal

Michael,

Please find attached our proposed well design for CrIN-6. Included in proposal: brief narrative, site map with gyro location survey showing intercept with the top of the regional aquifer, well design schematic, and the Jet West natural gamma and neutron logs (hot off the press).

Let me know if you have any questions.

Thanks,

SW

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

Appendix B

Geophysical Log

JET WEST
GEOPHYSICAL SERVICES, LLC.

State Plane 1927
Northing:
Easting:

COMPANY	Los Alamos National Labs
WELL ID	Crin No.6
FIELD	LANL (Los Alamos National Labs)
COUNTY	Los Alamos — STATE: New Mexico

TYPE OF LOG: Gamma Ray, Neutron Log

OTHER SERVICES
None

LOCATION

SEC TWP RGE

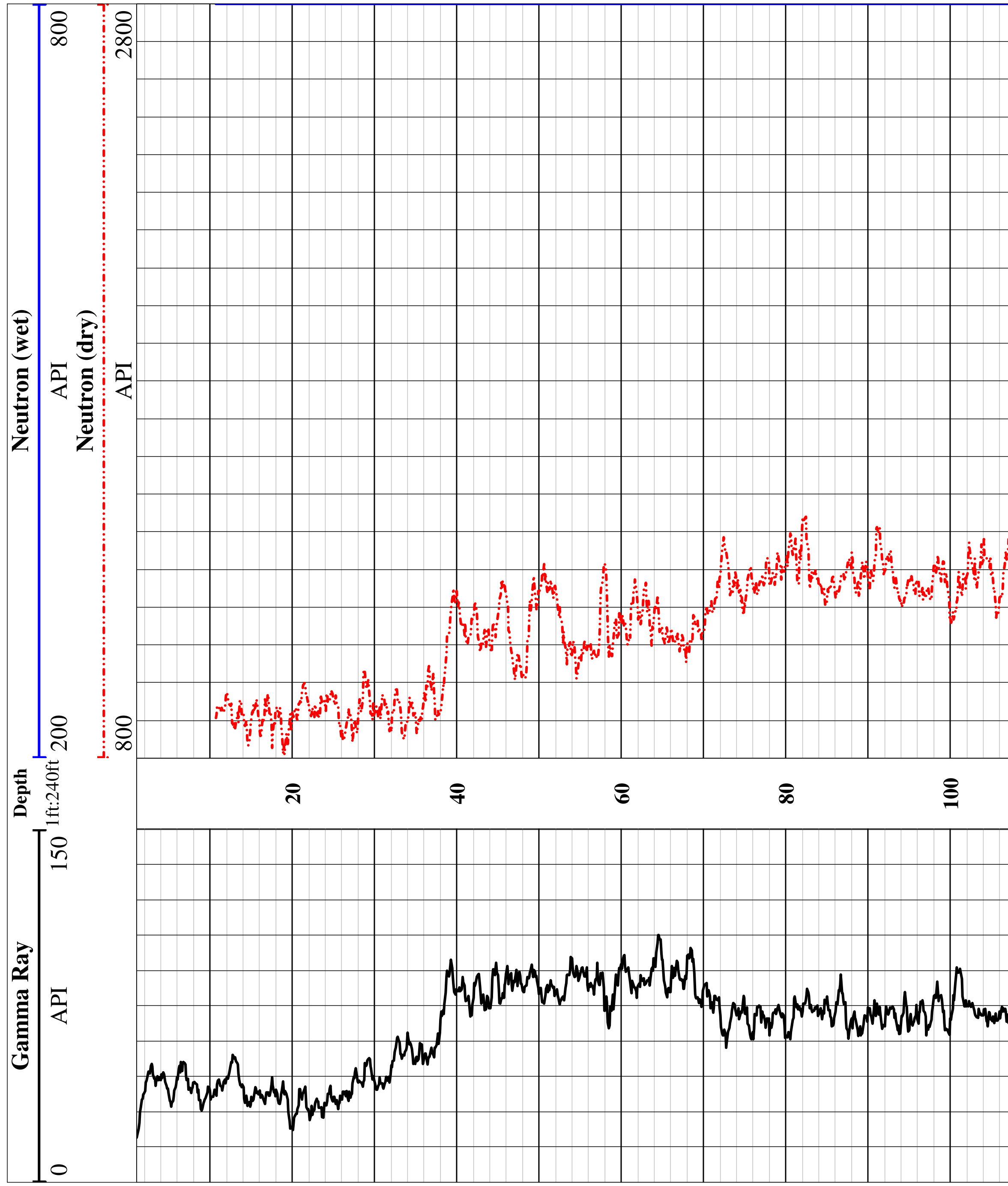
API No.

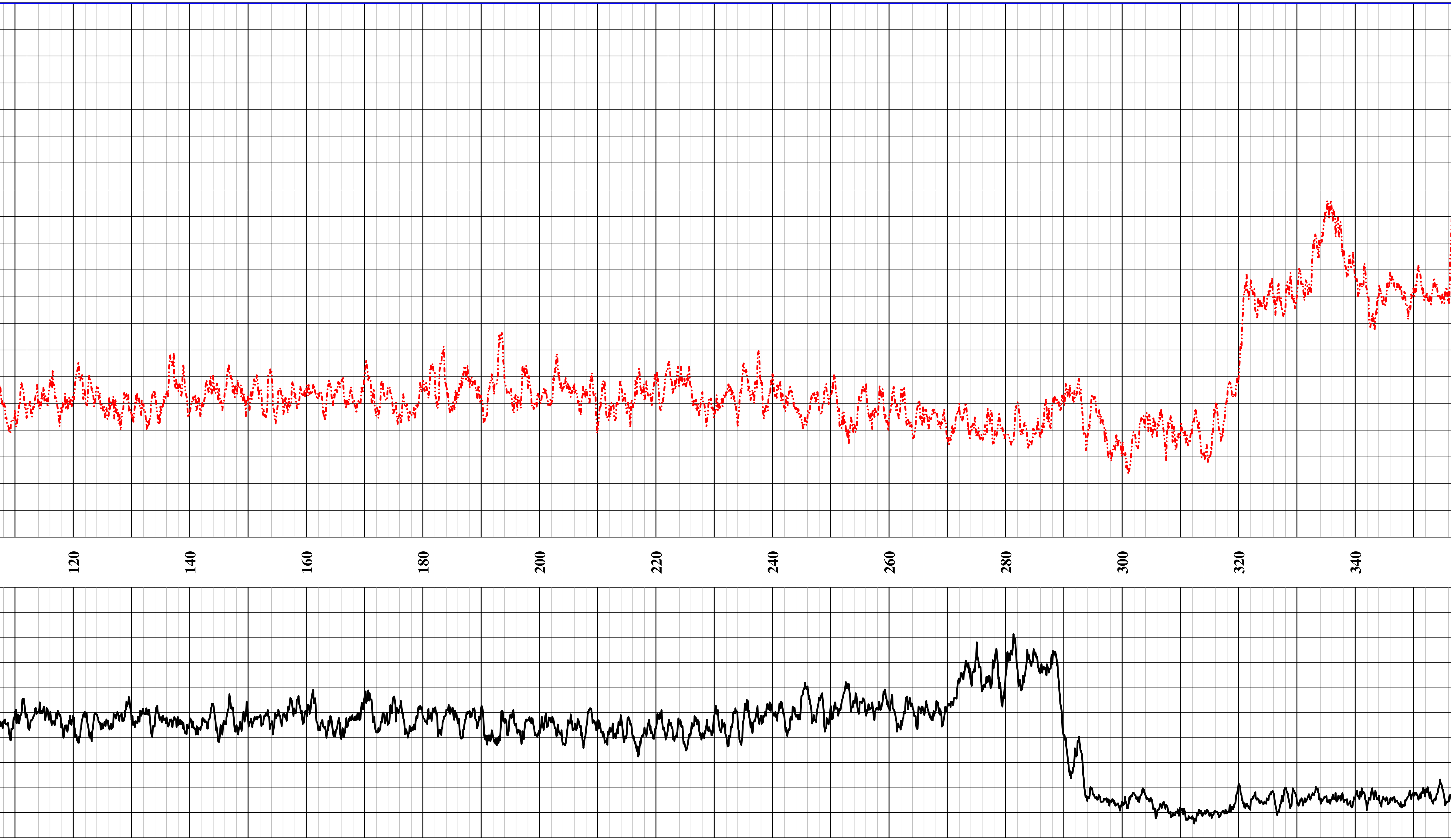
PERMANENT DATUM	Ground Level	ELEVATION		K.B.	
LOG MEAS. FROM	Ground Level	ABOVE PERM. DATUM		T.O.C	3.4 ft. Stickup
DRILLING MEAS. FROM	Ground Level			G.L.	

DATE	06-10-2010	TYPE FLUID IN HOLE	air/foam/water
RUN No.	one	SALINITY	
TYPE LOG	QL+NB696	DENSITY	
DEPTH-DRILLER	1097 ft.	LEVEL	964 ft.
DEPTH-LOGGER	1083 ft.	MAX. REG. TEMP	
BTM LOGGED INTERVAL	1082 ft.	DIGITIZE INTERVAL	0.1 ft.
TOP LOGGED INTERVAL	Surface		
OPERATING RIG TIME			
RECORDED BY	A.Henderson		
WITNESSED BY	Holt Services, Inc.		

RUN	BOREHOLE RECORD			CASING RECORD			
NO.	BIT	FROM	TO	SIZE	WGT.	FROM	TO
1				20 inch	steel	0 ft.	37.36 ft.
2				18 inch	steel	0 ft.	319.67 ft.
3				14 inch	steel	0 ft.	1097.68 ft.

REMARKS: Log thru 14" casing with 26° angle hole. Probe hung up on weld join up log at 280 ft. Foam level at 918 ft.

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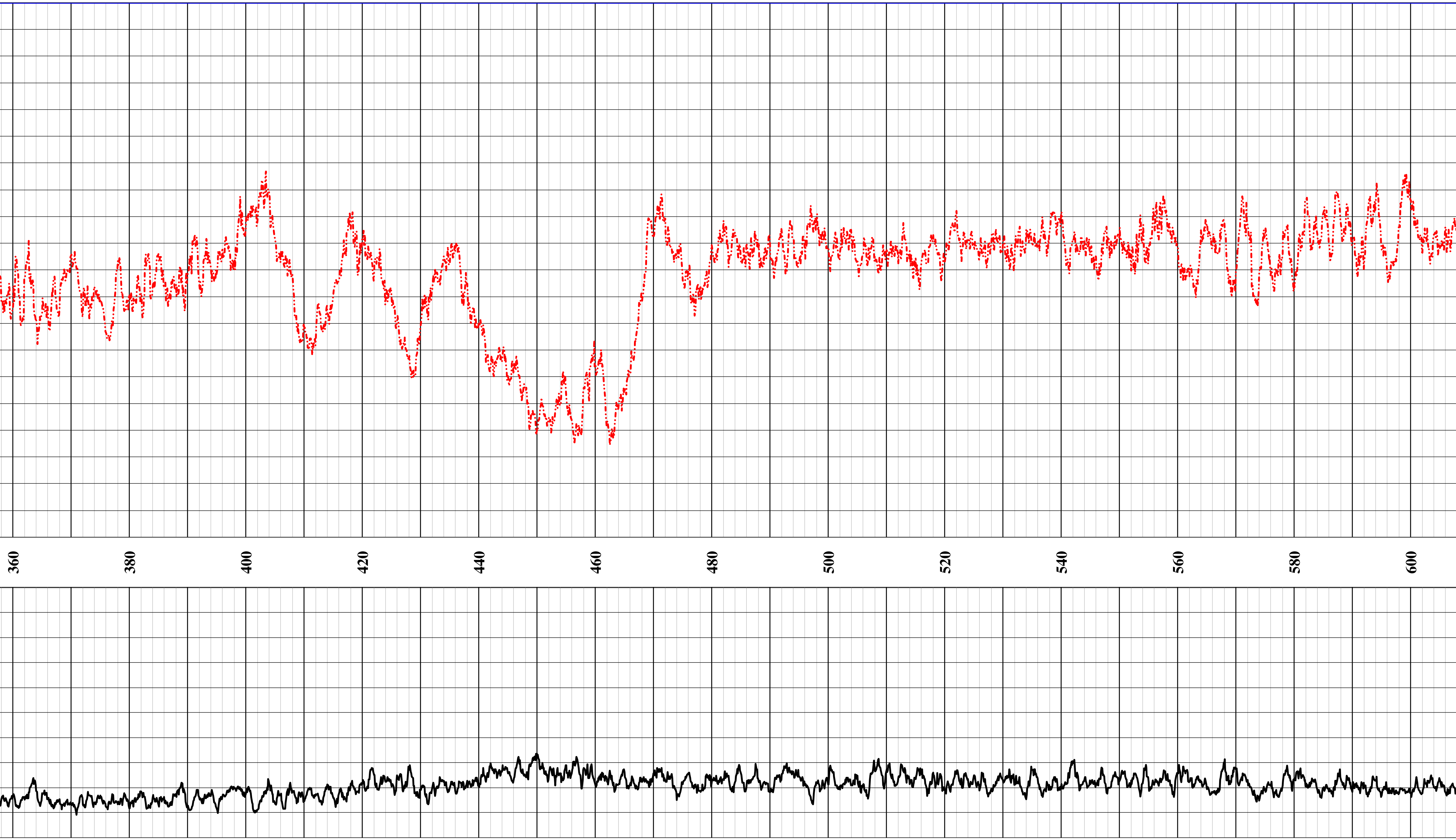
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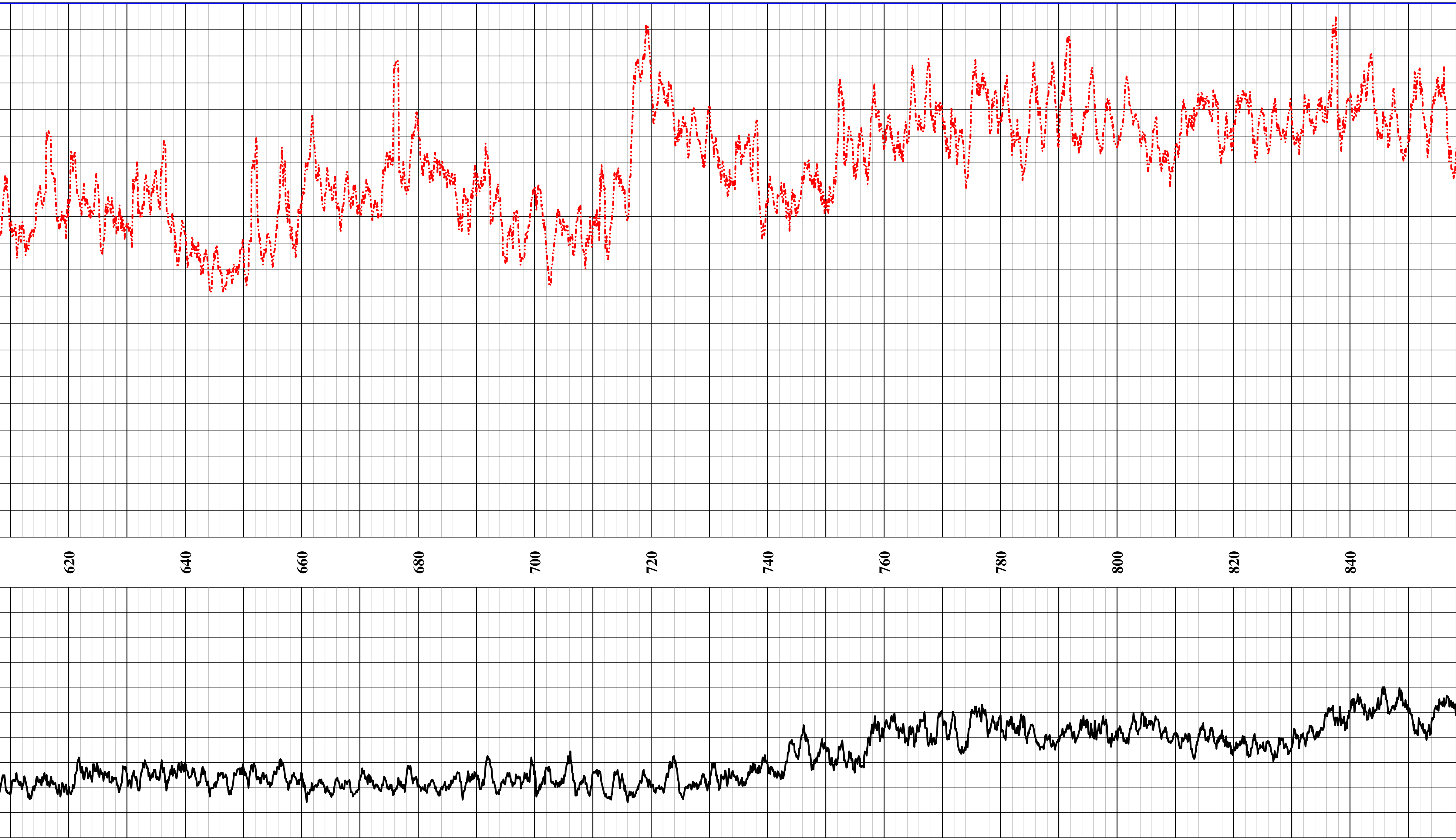
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700
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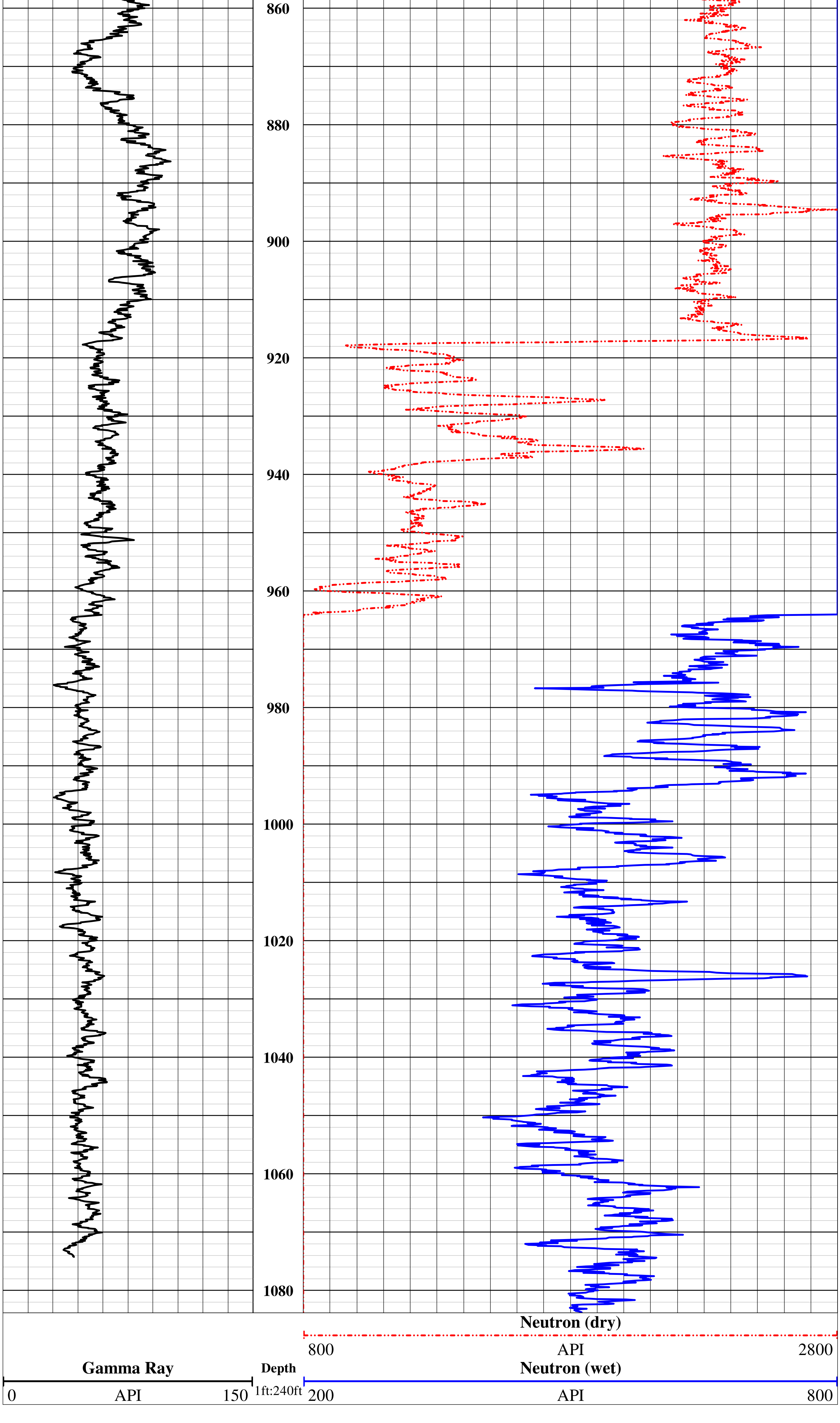
800
820
840



860
880
900
920
940
960
980
1000
1020
1040
1060
1080
Neutron (dry)
800
API
2800
Gamma Ray
Depth
Neutron (wet)
0
API
150
1ft:240ft
200
API
800

Appendix C

CrIN-6 Aquifer Testing Report

C-1.0 INTRODUCTION

This appendix describes the hydrogeological analysis of aquifer tests at well CrIN-6 located in Mortandad Canyon at Los Alamos National Laboratory (LANL or the Laboratory) within the existing chromium plume. A three-step variable rate and a 24-h constant rate pumping test were performed. The primary objective of the analysis was to determine the hydraulic properties of the aquifer zone screened by CrIN-6.

CrIN-6 is angled 25 degrees from vertical. Because the pumping test methods used for analysis below cannot be applied to angled wells, all distances have been converted to effective vertical lengths using the formula $L_{vert} = L_{well}$*cos(25°). By this conversion, the CrIN-6 screened interval consists of a 55-ft-long screen from 888 ft below ground surface (bgs) to 943 ft bgs. Static water level in the well (converted to vertical) is at 876 ft bgs. Therefore, the effective distance from the water table to the top of the screen is 12 ft.

Conceptual Hydrogeology

The aquifer tests performed provide information about the properties of the regional aquifer in the Puye Formation (Tpf; top surface 677.9 ft bgs at CrIN-6). Based on previous hydrogeological investigations, aquifer testing, and modeling, the following is known about the regional aquifer below the Pajarito Plateau. It is highly heterogeneous and anisotropic. A complex conceptual model is thought to describe the hydrologic regime, including unconfined (phreatic) behavior near the water table (where CrIN-6 is screened) and confined (or leaky confined) behavior at deeper depths, where the nearby municipal water-supply wells are screened (LANL 2007, 098734). Downward vertical head gradients are observed in several multi-screened wells.

The aquifer has unknown total thickness at CrIN-6, but it is greater than 1000 ft. The effective thickness of the phreatic zone relative to the CrIN-6 well screen for these pumping tests is also not known.

Monitoring well data demonstrate barometric pressure effects on measured head, which may be reflected in aquifer testing that takes place over periods of time longer than typical barometric fluctuations. The regional aquifer is pumped at varying rates by several municipal water supply wells in the area, which may also impact pumping test data, although the effect is typically small because of the apparent hydraulic separation between the confined and phreatic zones described above. At the nearby well R-11 (which is also screened near the regional water table), modeling results suggest pumping at O-4 may affect drawdowns by about 0.1 m (LANL 2017, 602333). Observed transients in the CrIN-6 pumping data (Figure C-1.0-1) suggest some impact on drawdown from nearby wells of ~0.15 m (0.5 ft) throughout the duration of the 24-h test and recovery period (3:00 p.m. July 16, 2017, to the end of the test on July 18). These changes have some symmetry on July 17 and July 18, with a decrease in drawdown around 6:00 p.m. and slow increase after 6:00 a.m. A sudden drop in water levels at 2:00 p.m. on July 16, is likely the result of a transducer slip and does not affect the data analysis presented below. The water level appears to increase slightly when supply wells PM-2 and PM-5 were turned on, perhaps as a result of the Noordbergum effect. This phenomena has been observed at the Laboratory site in the past. When groundwater is pumped from an aquifer, hydraulic heads in adjacent aquifers increase almost immediately after the start of pumping and eventually decline. This effect is usually disregarded in analyses of aquifer pumping tests (Kim and Parizek 1987, 602568).

Aquifer Testing

CrIN-6 was tested from July 16 to 18, 2017. Testing consisted of a three-step pumping test beginning at 9:00 a.m. July 16, and a 24-h constant rate pumping test beginning the same day at 3:03 p.m. The pumping rates during the three-step test were 50, 70, and 90 gallons per minute (gpm), respectively. The steps were 1 h each with no pump stops between steps. The 24-h test pumping rate was 90 gpm. Water-level and pumping-rate data from CrIN-6 for the duration of the tests are shown in Figure C-1.0-1.

There are no check valves in the pump column, which leads to unusable data in the moments after the pump is activated or shut off, as shown in Figure C-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. 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 shutdown may also be caused by groundwater recharge from the vadose zone. However, in this case, the observed spikes in water levels during changes in well operation are primarily from the lack of check valves, as confirmed by pressure data from the test.

C-2.0 AQUIFER-TEST INTERPRETATION

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

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

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

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

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

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

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

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

Recovery data after pumping ceased are typically analyzed using the Theis recovery method, which is a semilog analysis method similar to the Cooper-Jacob method described above. The recovery data are particularly useful compared with drawdown data. Because the pump is not running, data responses associated with temporal discharge rate fluctuations are eliminated. The result is that the recovery data set is generally “smoother” and easier to analyze. However, given the transient behavior in the data set and lack of complete recovery to pre-pumping levels, the recovery data following the 24-h test could not be analyzed using this method.

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 C-2.0-4:

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

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

All these analyses assume the aquifer is homogeneous and isotropic. For other fitting models, anisotropy can be investigated as a parameter (K_v/K_h). The thickness of the aquifer affected by the pumping test is 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 thickness of the aquifer.

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.

C-3.0 DATA ANALYSIS

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

Three-Step Variable-Rate Aquifer Test

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

The specific capacity data obtained from the CrIN-6 three-step pumping test are summarized in Table C-3.0-1. The table also includes specific capacity data obtained during the 24-h constant-rate pumping test. During the step tests, the specific capacity varied between about 391 m^2/d and 426 m^2/d

(21.9 gpm/ft and 23.9 gpm/ft). The step-test data demonstrate a slight decline in specific capacity with pumping rate.

Using the average drawdowns presented in Table C-3.0-1, time since pumping began, and a storage coefficient *S* of 0.0001 (the results are relatively insensitive to *S*), the Matlab code of McLin (2005, 602537) was used to estimate *T* for varying values of uncertain percent aquifer penetration. Figure C-3.0-1 shows the results from each of three steps of the three-step aquifer test. The minimum transmissivities for the three steps, estimated at 100% aquifer penetration, range from 1170–1210 m^2/d (94,200–97,400 gallons per day [gpd]/ft).

AQTESOLV was also used to estimate transmissivity using a fit to the data of the Theis solution (1934-1935, 098241). Figure C-3.0-2 shows the best fit curve using automated fitting methods, along with the adjusted data (spikes removed, as described above). Estimated parameters are T = 894 m^2/d (72,000 gpd/ft) and $S = 5.0 \times 10^{-6}$ (unreliable), with negligible wellbore skin factor and well loss parameters C = 1 s^2/ft^5 and P = 1.939 (Duffield 2007, 601723).

24-h Constant-Rate Aquifer Test

Figure C-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 = 490 m^3/d (90 gpm). The removed spike covered the first 230 s (3.8 min) of the data. The corrected data on a semilog plot do not show sustained linear behavior in any portion of the curve.

Nonetheless, the linear Cooper-Jacob approximation to the Theis solution was applied in AQTESOLV for two short segments of the semilog plot (Figure C-3.0-3). The earliest-available time best fit solution resulted in T = 882 m^2/d (71,000 gpd/ft) and $S = 1.1 \times 10^{-11}$. Fitting the middle segment of the rising drawdown curve resulted in T = 1510 m^2/d (122,000 gpd/ft) and $S = 3.0 \times 10^{-21}$. Both these fits are for before t = 100 min. The later time curve showed anomalously variable behavior and was not fit with any solution.

There are several possible reasons the data do not follow the Theis-type curve and are therefore inappropriate for the Cooper-Jacob estimation of transmissivity. The well is angled and partially penetrating. The aquifer is heterogeneous, may have dual unconfined/confined behavior with depth, and is likely experiencing three-dimensional flow effects during the well test. The well drawdowns might be affected by groundwater flow in the vadose zone, causing time-delayed recharge (Tartakovsky and Neuman 2007, 602536). There also may be fluctuations in nearby municipal water-supply pumping. As discussed above, a slight increase in the water level appears to occur when the PM-2 and PM-5 supply wells were turned on, perhaps as a result of the Noordbergum effect. This also impacts the observed transient drawdowns in a way that prevents performing reliable pumping test analyses of the late-time drawdown data.

The effect of partial aquifer penetration is to modify the direction of flow towards the screen from the horizontal assumed in the more simplistic confined aquifer analyses or Dupuit assumptions of horizontal flow for unconfined aquifers. (Strong vertical anisotropy in aquifer hydraulic conductivity can diminish the observed effects of partial penetration, however.) During a pumping test, the cone of depression expands both vertically and horizontally. The test thus represents increasing thickness of aquifer, leading to typically increased transmissivities in the late-time data. This type of pattern is observed for the CrIN-6 24-h pumping test, based on the transmissivities estimated above using the Cooper-Jacob method. It hinders attempts to determine hydraulic conductivities because each transmissivity is calculated at an unknown effective aquifer thickness. If the cone of depression reaches an aquitard, drawdown may flatten; in this 24-h test, drawdown reached a peak and then began to decrease with time, followed by variable spikes, which is not expected behavior.

Expected unconfined aquifer behavior during a pumping test includes Theis-type behavior or a slightly slower rise in drawdown compared with the confined aquifer, followed by a flatter miC-time section where drawdown rise is halted due to 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 CrIN-6.

Although true steady-state conditions are not achievable in an unconfined pumped aquifer of infinite extent, during the 24-h test drawdowns appear to become relatively stable at miC-late times. Under steady-state assumptions, a pumped unconfined aquifer may more closely approximate a state of horizontal flow and the Thiem-Dupuit method may be used to estimate transmissivity. This method applies to head measurements in multiple observation wells, but an approximation to the method for a single-well test can be used (with caution) for a simple rough estimate based on steady-state drawdown s at pumping rate Q: $T = 1.22Q/s$ (Misstear 2001, 602535). At a late-time average drawdown of 4.2 ft (800–1200 min of pumping), $T \sim 467$ m^2/d (37,600 gpd/ft) using this approximation. This may also be modified to account for partial penetration by replacing s with $s - s^2/2b$, where b is aquifer thickness. The effective saturated aquifer thickness is not known, but using a thickness of 75 ft results in $T = 480$ m^2/d (38,600 gpd/ft). Figure C-3.0-4 shows the results for T for variable unknown effective aquifer thicknesses.

C-4.0 CONCLUSIONS

Table C-4.0-1 summarizes the transmissivity estimates developed in this document. Several methods are discussed to analyze the CrIN-6 pumping test data. The three-step variable-rate test data were judged to be the most useful for analysis, and were well-fit by the Theis model (Figure C-3.0-2). The Theis model/Cooper-Jacob approximation does not consider delayed water recharge from the vadose zone generally observed in unconfined aquifers. Other common model type curves, available in AQTESOLV, 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 CrIN-6 data and were not used.

A best-guess estimate of $T = 894$ m^2/d (72,000 gpd/ft) is calculated from the Theis fit to the three-step test. Despite the unreliability of S estimates for pumping test analyses at a single well, the fit gives $S = 5.0 \times 10^{-6}$. Hydraulic conductivity K is not estimated using this method. If effective aquifer depth is known, it may be calculated by $K = T/b$. The rule of thumb is that effective b is approximately the screen length to 1.5 times the screen length, and thus K is roughly estimated as 35–50 m/d (115–170 ft/d).

C-5.0 REFERENCES

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

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

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

Kim, J.-M., and R.R. Parizek, April 1997. “Numerical Simulation of the Noordbergum Effect Resulting from Groundwater Pumping in a Layered Aquifer System,” *Journal of Hydrology,* Vol. 202, pp. 231-243. (Kim and Parizek 1987, 602568)

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

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

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

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

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

Tartakovsky, G.D., and S.P. Neuman, January 16, 2007. “Three-Dimensional SaturateC-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 GrounC-Water Storage,” *American Geophysical Union Transactions,* Vol. 15-16, pp. 519-524. (Theis 1934-1935, 098241)

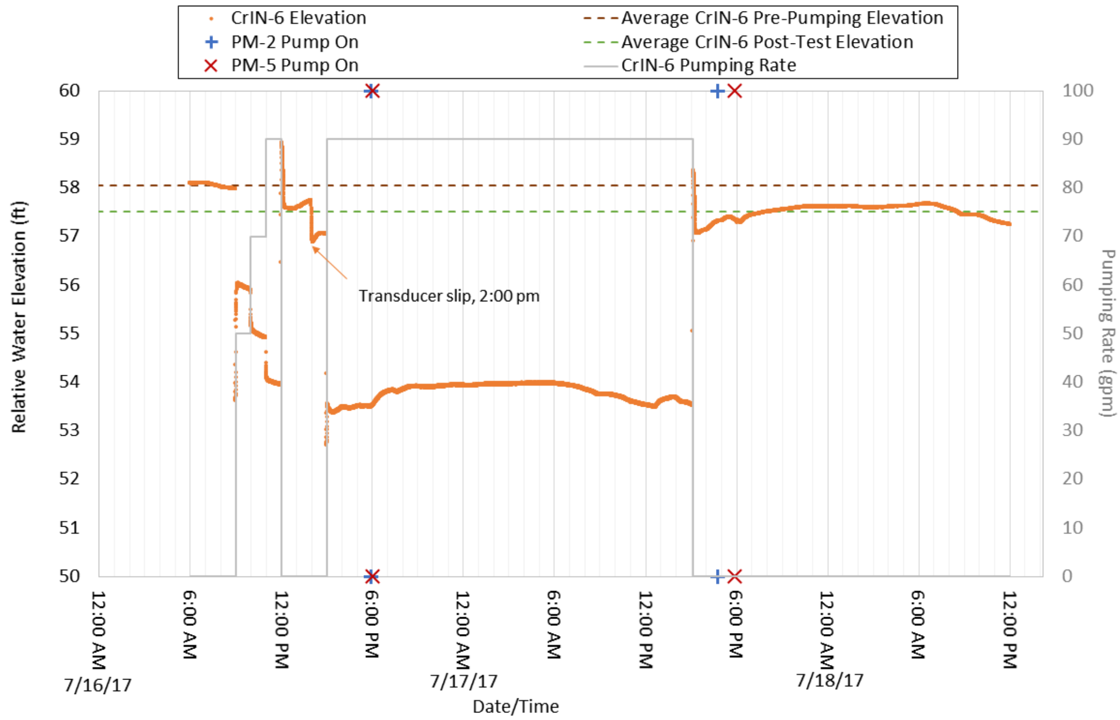


Figure C-1.0-1 Relative water elevation above transducer (left axis) and pumping rate (right axis) for the duration of the CrIN-6 pumping test. A slip in the transducer cable occurred at around 2:00 p.m. on July 16, 2017, causing a shift in the observed static level (dashed lines). A slight increase in the water level occurred when the PM-2 and PM-5 supply wells were turned on.

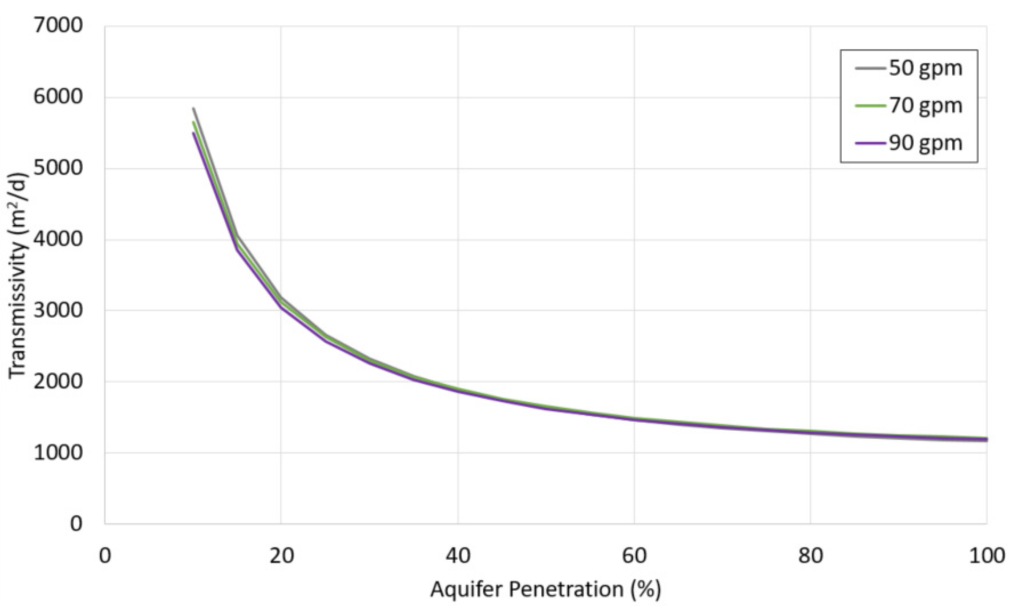


Figure C-3.0-1 Transmissivities calculated using the Matlab code of McLin (2005, 602537) based on the specific capacity method for each step of the variable-rate pumping test as a function of aquifer penetration

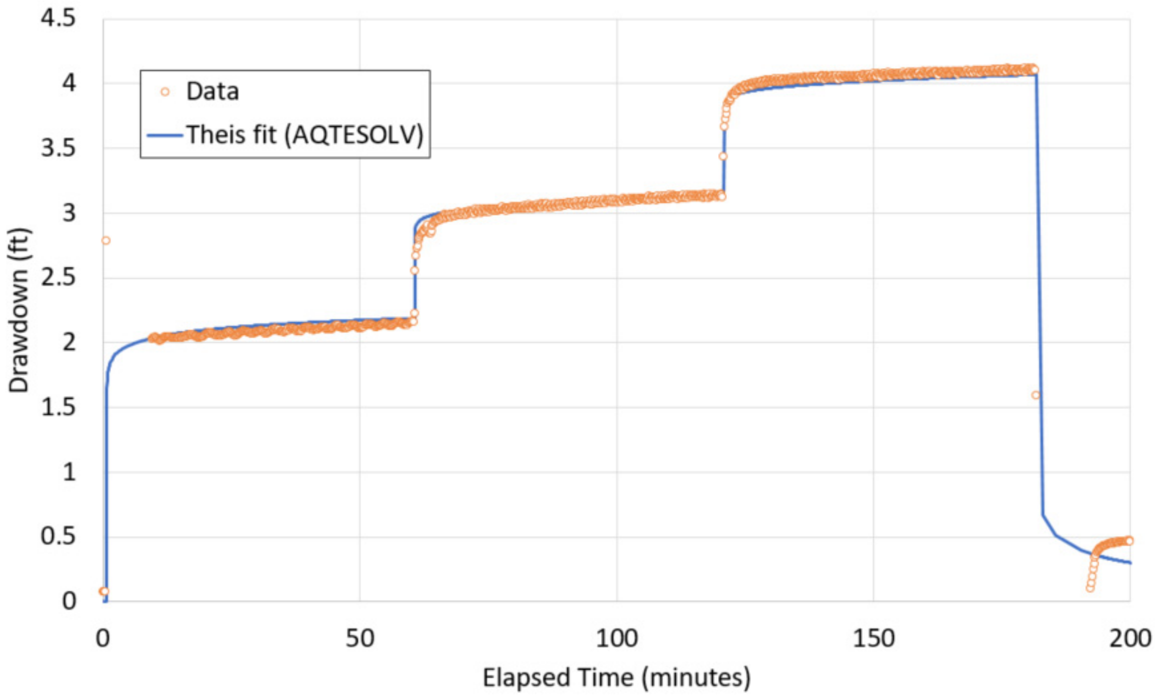


Figure C-3.0-2 Drawdown data during three-step pumping test (spikes removed) and the best fit from AQTESOLV for the Theis solution to the step test, *T* = 894 m²/d

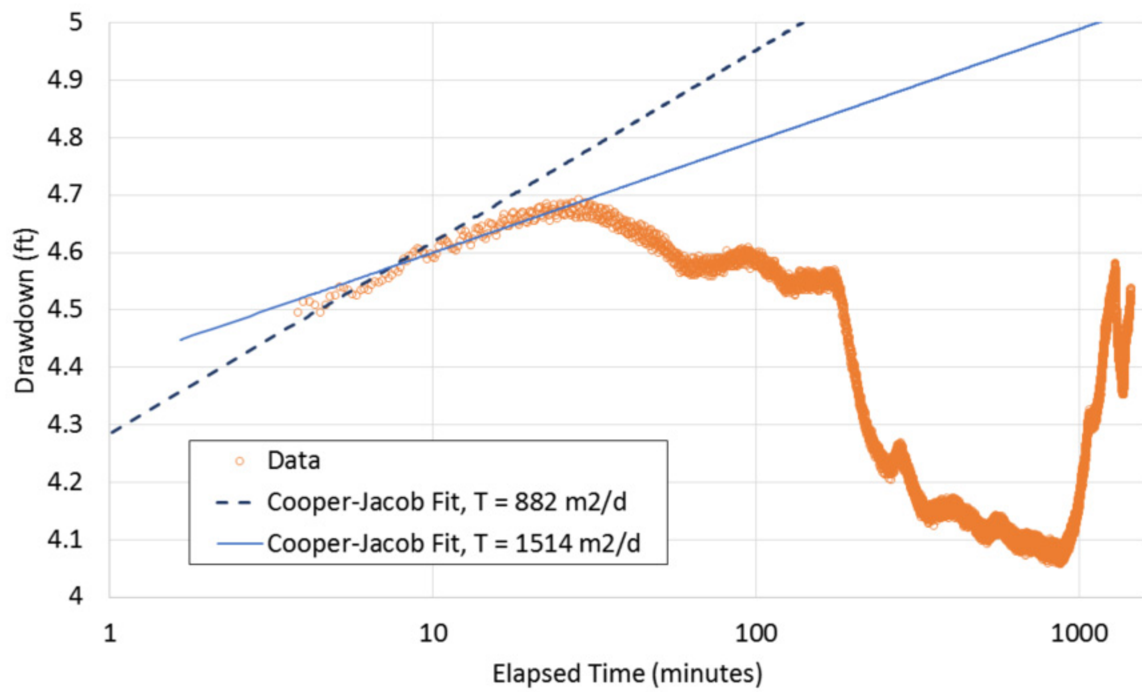


Figure C-3.0-3 Drawdown data (spikes removed) and multiple fits from AQTESOLV for the Cooper-Jacob solution to the 24-h pumping test data

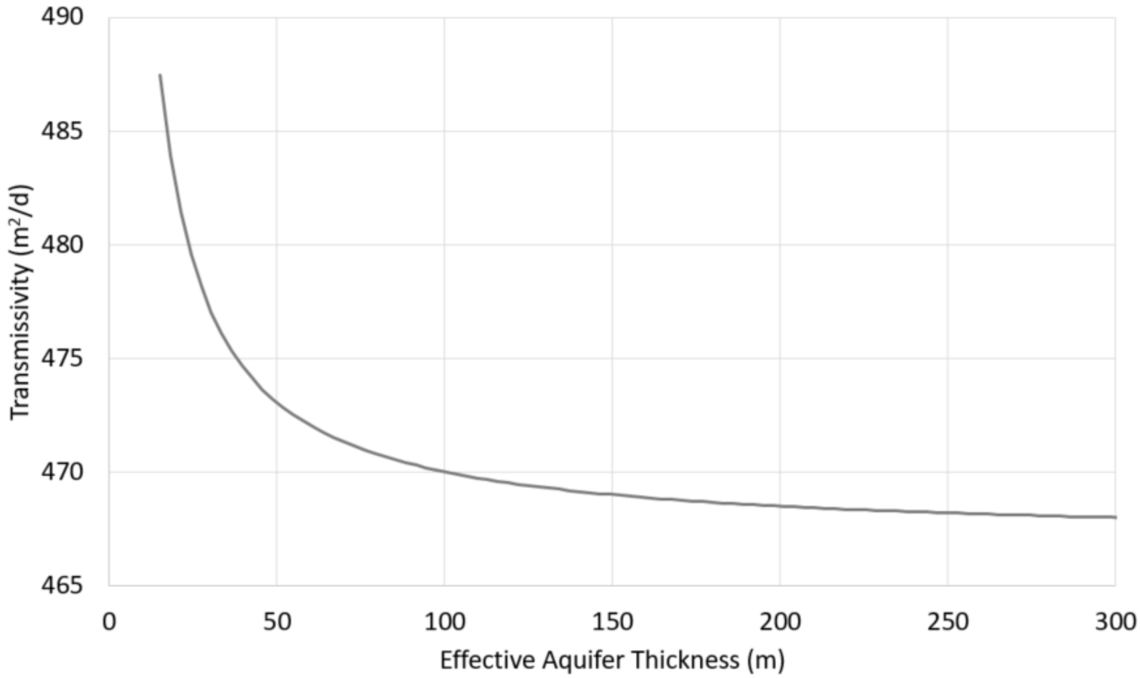


Figure C-3.0-4 Estimated transmissivities as a function of effective aquifer thickness using the Thiem-Dupuit approximation for unconfined groundwater flow

Table C-3.0-1
Summary of Specific Capacity Data Obtained from CrIN-6 Aquifer Tests

Test	Pumping Rate (gpm)	Average Drawdown (ft)	Average Specific Capacity (gpm/ft)	Pumping Rate (m^3/d)	Average Drawdown (m)	Average Specific Capacity (m^2/d)
Step test #1	50	2.1	23.9	272	0.6	426
Step test #2	70	3.1	22.8	381	0.9	406
Step test #3	90	4.1	22.1	490	1.2	395
24-h test	90	4.1	21.9	490	1.3	391

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

Test	Transmissivity Estimate (m^2/d)	Transmissivity Estimate (gpd/ft)
McLin (2005, 602537) method (min)		
Step test #1	1170	94,200
Step test #2	1210	97,400
Step test #3	1200	96,600
Theis solution (AQTESOLV)		
Step test	894	72,000
Cooper-Jacob solution (AQTESOLV)		
24-h test, early	882	71,000
24-h test, mid	1510	122,000
Average	1200	96,300
Thiem-Dupuit approximation		
24-h test, late, no correction for partial penetration	467	37,600
24-h test, late, with correction for partial penetration, *b* = 75 ft (23 m)	480	38,600