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Summary Report for Redevelopment of Regional Well R-61



Prepared by the Environmental Programs Directorate

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March 2013

Responsible project manager:

Printed Name	Signature	Title	Organization	Date
Steve Paris		Project Manager	Environmental Programs	3/18/13

Responsible LANS representative:

Printed Name	Signature	Title	Organization	Date
Jeff Mousseau		Associate Director	Environmental Programs	3/21/13

Responsible DOE representative:

Printed Name	Signature	Title	Organization	Date
Peter Maggiore		Assistant Manager	DOE-NA-00-LA	03/28/2013

CONTENTS

1.0 INTRODUCTION 1

2.0 BACKGROUND 1

3.0 INITIAL SPECIFIC CAPACITY TESTING 1

4.0 RETRIEVAL OF BASKI SAMPLING SYSTEM 2

5.0 VIDEO LOGGING 2

6.0 REDEVELOPMENT ACTIVITIES 2

6.1 Redevelopment at Screen 1 3

6.2 Redevelopment at Screen 2 3

7.0 FINAL CLEAN-UP PURGING AND SAMPLING ACTIVITIES 4

7.1 Purging and Sampling at Screen 2 4

7.2 Purging and Sampling at Screen 1 4

8.0 INSTALLATION OF THE DEDICATED SAMPLING SYSTEM 5

9.0 DEVIATIONS 5

10.0 WASTE MANAGEMENT 6

11.0 REFERENCES AND MAP DATA SOURCES 6

11.1 References 6

11.2 Map Data Sources 7

Figures

Figure 2.0-1 Location of well R-61 9

Figure 2.0-2 Monitoring well R-61 as-built well construction diagram 10

Figure 4.0-1 Monitoring well R-61 dedicated sampling system diagram 11

Tables

Table 3.0-1 Summary of R-61 Redevelopment Screening Samples Collected 13

Table 7.1-1 R-61 Redevelopment Field Parameters and Purge Volumes at Screen 2 14

Table 7.2-1 R-61 Redevelopment Field Parameters and Purge Volumes at Screen 1 15

Appendixes

Appendix A R-61 Hydraulics Summary

Appendix B Groundwater Screening Analytical Results (on CD included with this document)

Appendix C R-61 Well Video Logs (on DVDs included with this document)

Appendix D R-61 Redevelopment Treatment Volumes

Acronyms and Abbreviations

amsl	above mean sea level
bgs	below ground surface
Consent Order	Compliance Order on Consent
DO	dissolved oxygen
DRO	diesel range organics
Eh	oxidation-reduction potential
FTL	field team leader
gpm	gallons per minute
GRO	gasoline range organics
hp	horsepower
I.D.	inside diameter
IDW	investigation-derived waste
LANL	Los Alamos National Laboratory
NAD	North American Datum
NMED	New Mexico Environment Department
NTU	nephelometric turbidity unit
NW	Nu-Well
O.D.	outside diameter
ORP	oxidation-reduction potential
PVC	polyvinyl chloride
RPF	Records Processing Facility
SOP	standard operating procedure
SVOA	semivolatile organic analysis
TA	technical area
TD	total depth
TOC	total organic carbon
VOA	volatile organic analysis
WCSF	waste characterization strategy form

1.0 INTRODUCTION

This report summarizes field activities associated with the redevelopment of regional aquifer well R-61 at Los Alamos National Laboratory (LANL or the Laboratory) between September 4 and October 29, 2012. Plans for well redevelopment were presented in the "Work Plan for Redevelopment of Monitoring Well R-61" (LANL 2012, 221454) that was approved by the New Mexico Environment Department (NMED) on July 10, 2012 (NMED 2012, 520923). A proposed revision to the work plan for redevelopment of R-61 was submitted to, and approved by, NMED on August 30, 2012 (Kulis 2012, 227669). The revision modified the frequency at which screening samples identified in the original work plan were collected.

Field activities planned as part of the R-61 redevelopment included testing for specific capacity, removing the dedicated Baski sampling system, video logging, introducing chemicals for well development and physical redevelopment, purging with temporary pumping assemblies and sampling, reinstalling the sampling system, and final purging and sampling.

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 Laboratory's Records Processing Facility (RPF). This report contains brief descriptions of field activities and supporting figures, tables, and appendixes associated with the redevelopment of well R-61 and has been prepared in accordance with the requirements in Section IV.A.3.e.iv of the March 1, 2005 (revised 2008) Compliance Order on Consent (the Consent Order).

2.0 BACKGROUND

R-61 is located on the mesa top to the south of Mortandad Canyon in Technical Area 05 (TA-05) in Los Alamos County, New Mexico (Figure 2.0-1). The well was installed to monitor water quality in the regional aquifer and to help define the vertical and lateral extent of chromium contamination known to exist in the area. The R-61 borehole was drilled using fluid-assisted air-rotary methods. Installation of the 5.563-in.–outside diameter (O.D.) stainless-steel well was completed on May 3, 2011, at a total depth (TD) of 1251.6 ft below ground surface (bgs) with two screened intervals (Figure 2.0-2):

- The 5-in.–inside diameter (I.D.) rod-based 0.020-in.-slot upper screen (10.0 ft long) was set from 1125.0 to 1135.0 ft bgs near the top of the regional aquifer.
- The 5-in.-I.D. rod-based 0.020-in.-slot lower screen (20.6 ft long) was set from 1220.4 to 1241.0 ft bgs within the regional aquifer. A 10.6-ft-long sump was placed below the bottom of the well screen.

Following final well development activities, a Baski-manufactured dual zone sampling system was installed in the well to isolate and allow discrete sampling of the screened intervals.

3.0 INITIAL SPECIFIC CAPACITY TESTING

Short-duration specific capacity pumping tests were conducted with the dedicated sampling system at both screened intervals on September 5, 2012. Each screened interval was pumped at three different rates for 1 h per rate. A 1-h rest period was allowed between the testing at each screen.

The results from the initial testing and observations of hydraulic response throughout the project are included with this report as Appendix A.

One groundwater screening sample was collected from each screened interval during the pumping tests. Each sample was collected after purging the drop pipe volume plus 1 casing volume. A summary of all samples collected during the redevelopment of R-61 is presented on Table 3.0-1. Analytical results from all screening samples collected during the project are included with this report as Appendix B.

Total groundwater purged at each screen during the pumping tests was approximately 250 gal. (500 gal. total).

4.0 RETRIEVAL OF BASKI SAMPLING SYSTEM

The dedicated Baski sampling system was removed from the well on September 6, 2012. No difficulties were encountered during removal and all sampling system components were observed to be in excellent condition. A schematic of the Baski sampling system is presented on Figure 4.0-1.

5.0 VIDEO LOGGING

Following sampling system removal, a video log of the well was recorded on September 7, 2012, to document the well screens and casing conditions and to confirm the composite water level in the well. The Laboratory's geophysical trailer and camera were used to complete video logging from the surface to 1251 ft bgs.

A final video log of the well was recorded on October 18 to document the screen and casing conditions after redevelopment activities.

The well video log DVDs are presented in Appendix C.

6.0 REDEVELOPMENT ACTIVITIES

Before redevelopment at screen 1 began, a single-set bridge plug was installed between the screens at 1172 ft bgs on September 8, 2012. The bridge plug was removed after redevelopment was completed at the upper screen and before it began at the lower screen on September 28.

Three separate chemical treatments were proposed for the screen intervals at R-61. The treatments were selected after consultation with Johnson Screens and relied on Johnson's Nu-Well (NW) line of well-rehabilitation products. Each chemical treatment was volumetrically calculated for the given screen length using a sufficient volume of chemical solution to fill the well screen and filter pack and to reach approximately 1.5 to 2.3 ft into the formation, depending on the effective porosity of the formation. The treatment chemicals were batch-mixed at ground surface and introduced in the screen intervals by pumping downhole via a tremie pipe. Following the introduction of the various chemicals, each well-screen interval was jetted and surged to ensure the treatment agents were dispersed throughout the filter pack and near-screen formation. The chemical treatment agents remained in contact with the filter packs for a minimum of 12 to 24 h. Both well screens were subjected to identical chemical treatments and redevelopment methods, with the exception of treatment-dosage volumes. The lower screen treatment volumes were two times greater than the upper screen because its screened interval is twice as long. Each upper screen treatment volume totaled approximately 310 gal., and each lower screen treatment volume totaled approximately 620 gal. The treatment volumes and concentrations are presented in Appendix D.

The first treatment was a caustic solution of potassium hydroxide and NW 320 biocaustic dispersant for the purpose of enhancing the solubility of organic carbon and mineral precipitates. The second treatment was a bioacid polymer solution of NW 120 liquid (phosphoric) acid and NW 310 bioacid dispersant for the purpose of breaking down any biofilm that may be present, dispersing mineral salts, and further enhancing the removal of organic carbon compounds. The final treatment was a chlorine solution of sodium hypochlorite and NW 410 chlorine enhancer for the purpose sanitizing the well screen(s) and filter pack(s) and promoting the additional removal of iron and manganese scale, biofilm, and organic carbon compounds.

The chemical treatments were mixed in concentrations according to manufacturer's specifications. Since the objective was to treat the well screens, the filter packs, and the surrounding formation material, the treatment volume selected was 30 gal./ft of well screen. Appendix D details the rationale and volumetric calculations for the treatment volumes implemented during the redevelopment of R-61.

Chemical treatments were introduced and evacuated via a stainless-steel drop pipe with various submersible pumps. The treatments were introduced through the drop pipe with a pump-and-jetting tool installed in the well. Following their introduction, the chemical treatments were jetted within the entire screened interval and into the filter pack. High-velocity jetting was performed using a 10-horsepower (hp) submersible pump and jetting tool. The jetting tool, installed just above the pump discharge, directed all the pump output through the screen openings to deliver the chemical treatment(s) to the filter pack and formation. Then, the jetting pump assembly was removed and a surge block was deployed to move the treatments through the filter pack and near-screen formation. The surge block employed was a 4.25-in.-O.D. 1-in.-thick nylon disc attached to a weighted steel rod.

The chemical treatments were introduced early in the morning shift to leave enough time to complete the jetting, remove the jetting pump assembly, and surge. The treatments were allowed to remain in the well overnight and were briefly surged again the following morning. Finally, a purging pump was installed and the spent chemicals were evacuated from the screen intervals. During the chemical treatment purging events following caustic and acid treatments, purge water was monitored only for pH with pH test paper and a pH meter. During the purging event following the chlorine treatment, free chlorine levels were monitored until the measured chlorine levels were negligible. Complete groundwater quality parameters were collected and recorded during the final clean-up pumping.

6.1 Redevelopment at Screen 1

Redevelopment was conducted at screen 1 between September 11 and September 27, 2012. The introduction of the chemical treatments, jetting, surging, and purging were conducted as outlined above. Because of the relatively low yield of screen 1, removing the chemical agents was a slow process.

While each phase of the chemical treatments had a purging event following appropriate chemical contact time, final cleanup pumping was delayed until after the chemical treatments had been performed at the lower screen.

Total groundwater purged at screen 1 during the chemical treatments and redevelopment activities was approximately 10,609 gal.

6.2 Redevelopment at Screen 2

Before redevelopment activities began at screen 2, the bridge plug between the screens was removed on September 28, 2012, and the well sump was bailed on September 29 to remove accumulated sediment. The water from the sump had a strong organic odor, and samples were collected several days later from the

drum containing the bailed sump water and analyzed for volatile organic compounds, semivolatile organic compounds, diesel range organics (DRO), and gasoline range organics (GRO). The results are included in Appendix B.

Redevelopment was conducted at screen 2 between September 30 and October 13. The introduction of the chemical treatments, jetting, surging, and purging were conducted as described above. Inflatable packers were installed above the various pumps while working in screen 2 to isolate the screens. Some activities (i.e., jetting and/or pumping from the sump) required deflation of the packer(s) to execute the task.

Each phase of the chemical treatments had a purging event following appropriate chemical contact time. Final clean-up pumping took place immediately following the final chlorine treatment.

Total groundwater purged at screen 2 during the chemical treatments and redevelopment activities was approximately 32,150 gal.

7.0 FINAL CLEAN-UP PURGING AND SAMPLING ACTIVITIES

Following chemical treatments and redevelopment activities, both screens were purged to remove all residual chemical agents and to achieve representative geochemical conditions.

7.1 Purging and Sampling at Screen 2

Final clean-up purging and sampling took place at screen 2 first, following redevelopment activities. Purging at screen 2 took place between October 14 and October 16, 2012.

A 10-hp submersible pump in a stainless-steel pump shroud and stainless-steel drop pipe were used to purge the lower screen with the pump shroud intake set at 1215.4 ft bgs. An inflatable packer was positioned above the pump shroud to isolate the screen. Approximately 24,821 gal. of groundwater was purged with the submersible pump at an average flow rate of approximately 18.3 gallons per minute (gpm).

During purging activities, the discharge from the pump was monitored for pH, temperature, specific conductance, oxidation-reduction potential (ORP), turbidity, and dissolved oxygen (DO) using a flow-through cell and YSI 6920 multiparameter meter. Table 7.1-1 summarizes the volumes purged during cleanup purging at screen 2 as well as the measured and calculated water-quality parameters.

During purging, screening samples were collected at nominal 4-h intervals. Table 3.0-1 presents a summary of samples collected.

7.2 Purging and Sampling at Screen 1

Final cleanup purging and sampling took place at screen 1 after purging at screen 2. Purging at screen 1 took place on October 17 with a temporary pump and between October 24 and October 29, 2012, with the dedicated Baski sampling system. Details of the installation of the dedicated sampling system are described in section 8.0.

A 5-hp submersible pump in a stainless-steel pump shroud and stainless-steel drop pipe was used to purge the lower screen on October 17. The pump shroud intake was set at 1124.5 ft bgs, and an inflatable packer was positioned below the pump shroud to isolate the screens. Approximately 1852 gal. of groundwater was purged with the temporary pump at an average flow rate of approximately 3.8 gpm.

The dedicated sampling system was used to continue final clean-up pumping at screen 1 between October 24 and October 29. Approximately 4805 gal. of groundwater was purged with the dedicated system at an average flow rate of approximately 2.0 gpm.

During purging activities, the discharge from the pump was monitored for pH, temperature, specific conductance, ORP, turbidity, and DO using a flow-through cell and YSI 6920 multiparameter meter. Table 7.2-1 summarizes volumes purged during the cleanup purging at screen 1 as well as the measured and calculated water-quality parameters.

During purging, screening samples were collected at nominal 6-h intervals. Table 3.0-1 summarizes the samples collected.

8.0 INSTALLATION OF THE DEDICATED SAMPLING SYSTEM

The dedicated sampling system for R-61 was reinstalled between October 18 and October 21, 2012. The pumping system was installed in the well in the same position as it was located originally. No difficulties were encountered during installation.

Before it was installed, the pumping system was decontaminated, air dried, and wrapped in plastic. The pump and pump shroud were back-flushed with the same chlorine solution used for well screen redevelopment to sanitize these sealed components. The 0.010-slot polyvinyl chloride (PVC) screen for the upper screen gauge tube and the bottom cap assembly for the lower screen gauge tube were also sanitized with the chlorine solution.

Several components of the dedicated sampling system were replaced with new pieces. All the pressurized 0.25-in. 316 stainless-steel tubes were replaced because the original tubes were rendered unusable when they were removed. New stainless-steel fittings were used in plumbing the new 0.25-in. pressurized lines. The submerged sections of the two PVC gauge tubes (three sections on each tube) and the uppermost sections (two sections on each tube) were also replaced.

Details of the R-61 sampling system are presented on Figure 4.0-1.

9.0 DEVIATIONS

Field activities associated with the R-61 redevelopment were conducted as described in the “Technical Approach” section of the approved “Work Plan for Redevelopment of Monitoring Well R-61” (LANL 2012, 221454; NMED 2012, 520923), with the exception of final pumping (cleanup) and time-series sampling.

The work plan indicated pumping would be sufficient to remove all chemical treatment agents and to restore representative geochemical conditions. The final pH at the upper screen at the end of purging activities was lower than during pretreatment conditions. The final pH at the upper screen was 6.53. The pH during the previous routine sampling round in May of 2012 was 7.00.

The frequency of the time-series sampling was also modified during the pumping activity to better suit real-time pumping conditions encountered in the field. The “Proposed Revision to the Work Plan for Redevelopment of Monitoring Well R-61” (Kulis 2012, 227669) reduced the frequency of sampling originally prescribed in the work plan. Because of the unanticipated slow rebound of pH values, the frequency of sampling was further reduced. Instead of collecting samples every 4-h during the purging, samples were collected every 6 h.

10.0 WASTE MANAGEMENT

All investigation-derived waste (IDW) generated during the redevelopment activities is being managed in accordance with the applicable standard operating procedures (SOP). The SOP incorporates the requirements of all applicable U.S. Environmental Protection Agency and NMED regulations, U.S. Department of Energy orders, and Laboratory requirements. The SOP applicable to the characterization and management of IDW is

- EP-DIR-SOP-10021, Characterization and Management of Environmental Program Waste.

A waste characterization strategy form (WCSF) (LANL 2011, 204885) was prepared and approved per requirements of EP-DIR-SOP-10021. The WCSF provides detailed information on IDW characterization methods, management, containerization, and potential volumes.

Fluids (e.g., redevelopment and decontamination waters) and contact waste (e.g., gloves, paper towels, plastic, and/or glass sample bottles) were the primary waste streams generated during R-61 redevelopment activities. The fluids produced were sampled and analyzed for the suite of constituents listed in the WCSF.

Fluids produced during R-61 redevelopment activities were containerized and sampled for compliance with the New Mexico Water Quality Control Commission Regulation 3103 groundwater standards and applicable Resource Conservation and Recovery Act regulatory limits. The decontamination water, contact waste, and any other IDW are being managed in accordance with the approved WCSF.

11.0 REFERENCES AND MAP DATA SOURCES

The following list includes all documents cited in this report. Parenthetical information following each reference provides the author(s), publication date, and ER ID. This information is also included in text citations. ER IDs are assigned by the Environmental Programs Directorate's RPF and are used to locate the document at the RPF and, where applicable, in the master reference set.

Copies of the master reference set are maintained at the NMED Hazardous Waste Bureau and the Directorate. The set was developed to ensure that the administrative authority has all material needed to review this document, and it is updated with every document submitted to the administrative authority. Documents previously submitted to the administrative authority are not included.

11.1 References

Kulis, J., August 30, 2012. RE: Proposed Revisions to R-61 Redevelopment Work Plan. E-mail message to T. Goering (LANL) and M. Dale (NMED) from J. Kulis (NMED), Santa Fe, New Mexico. (Kulis 2012, 227669)

LANL (Los Alamos National Laboratory), March 8, 2011. "Waste Characterization Strategy Form for Installation of Regional Aquifer Well R-61," Los Alamos National Laboratory, Los Alamos, New Mexico. (LANL 2011, 204885)

LANL (Los Alamos National Laboratory), June 2012. "Work Plan for Redevelopment of Monitoring Well R-61," Los Alamos National Laboratory document LA-UR-12-20284, Los Alamos, New Mexico. (LANL 2012, 221454)

NMED (New Mexico Environment Department), July 10, 2012. "Approval, Work Plan for Redevelopment of Monitoring Well R-61," New Mexico Environment Department letter to P. Maggiore (DOE-LASO) and M.J. Graham (LANL) from J.E. Kieling (NMED-HWB), Santa Fe, New Mexico. (NMED 2012, 520923)

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.

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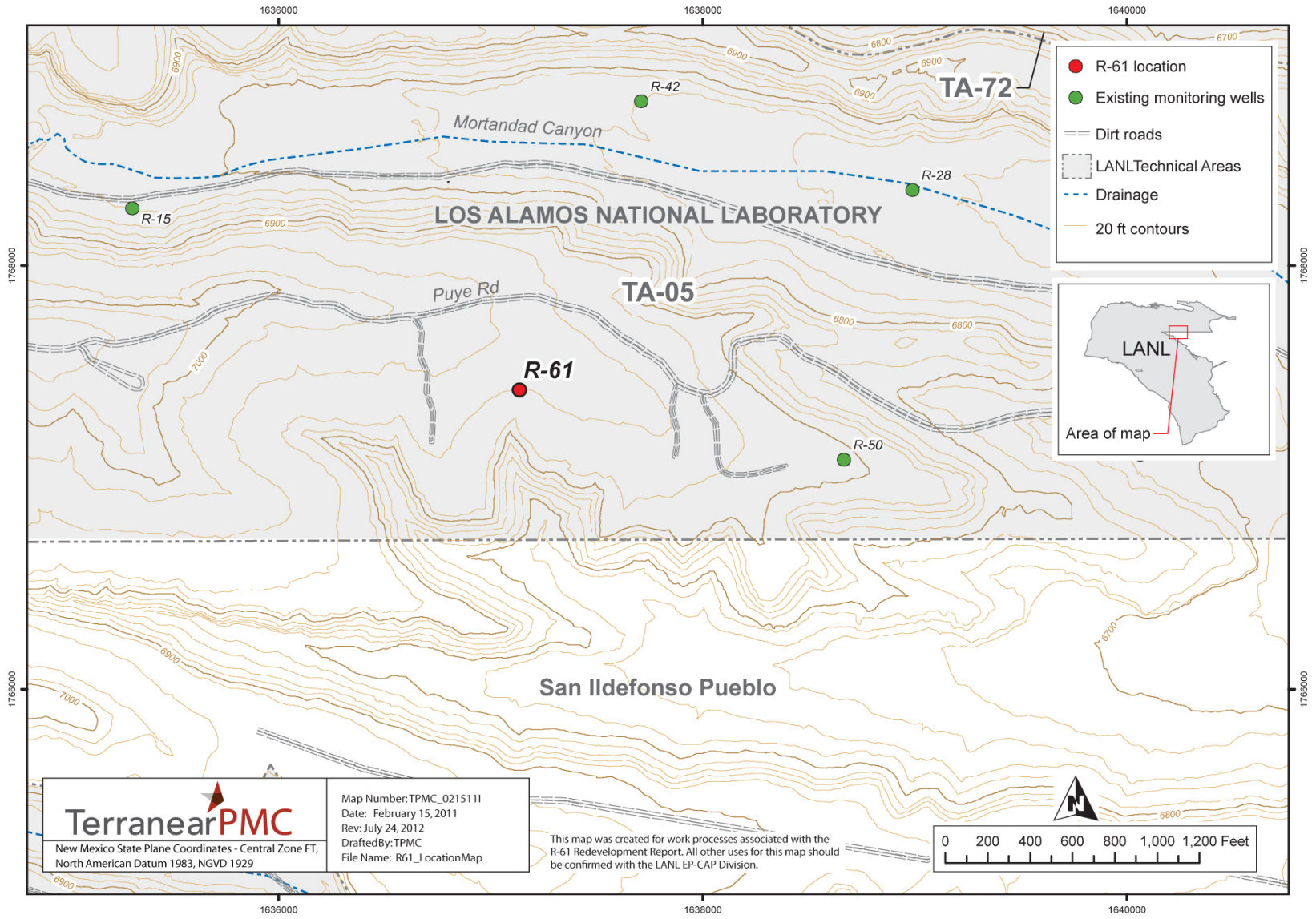

Figure 2.0-1 Location of well R-61

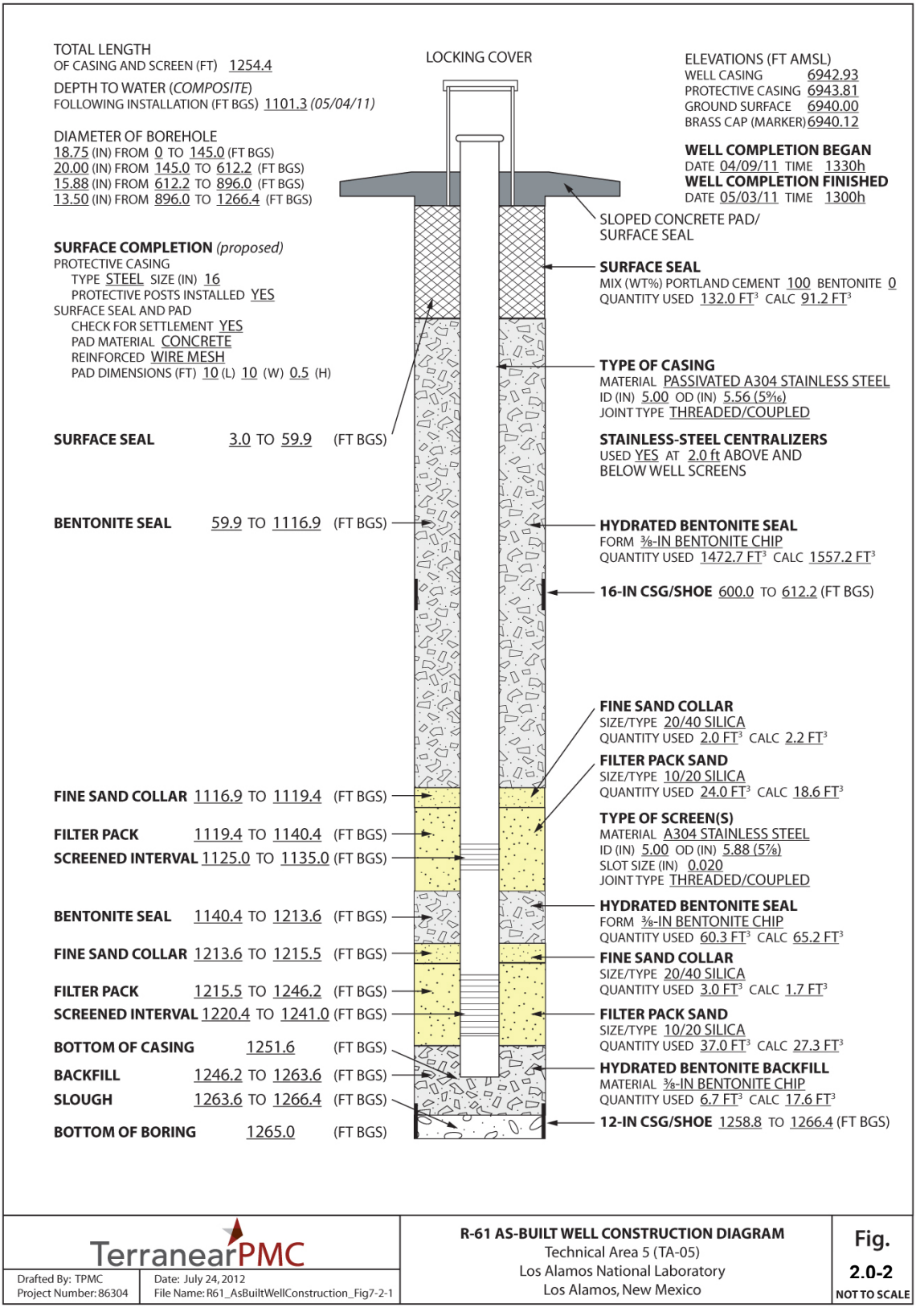

Figure 2.0-2 Monitoring well R-61 as-built well construction diagram

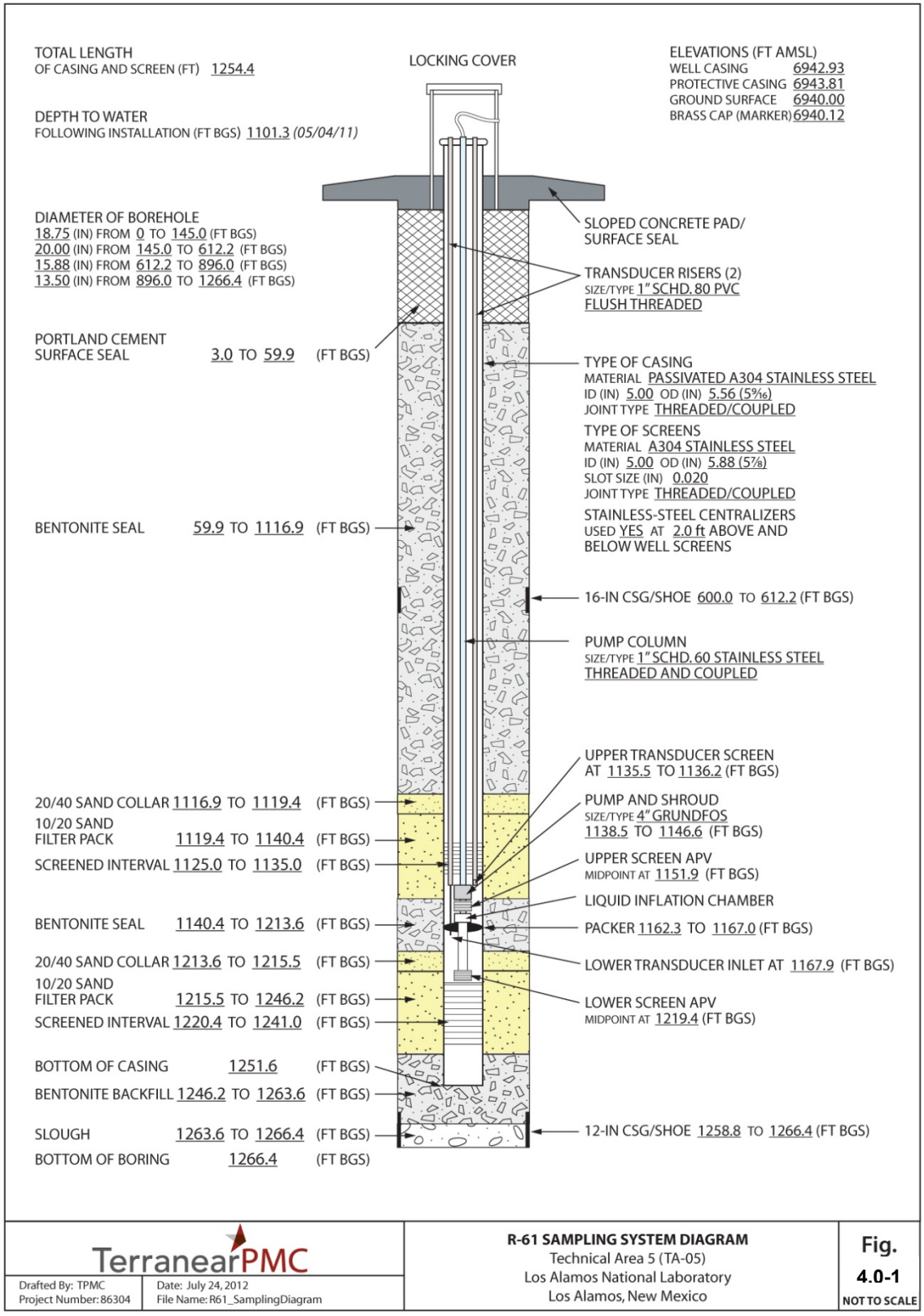

Figure 4.0-1 Monitoring well R-61 dedicated sampling system diagram

Table 3.0-1
Summary of R-61 Redevelopment Screening Samples Collected

Location ID	Sample ID	Date Collected	Screen (1 = Upper 2 = Lower)	Analysis
Before Well Redevelopment (before treatments, via Baski system)				
R-61	GW61-12-23257	9/5/12; 1158 h	Screen 1	VOA, SVOA, DRO, GRO
R-61	GW61-12-23258	9/5/12; 1623 h	Screen 2	VOA, SVOA, DRO, GRO
After All Upper Screen Treatments (via well development pump)				
R-61	GW61-12-23260	9/27/12; 1625 h	Screen 1	ALK, ANIONS, MET, SULFIDE, TOC
Sump Water Sample (via bailer)				
R-61	GW61-13-23967	10/2/12*; 1610 h	Screen 2	VOA, SVOA, DRO, GRO
After All Lower Screen Treatments (via well development pump)				
R-61	GW61-12-23261	10/13/12; 1830 h	Screen 2	ALK, ANIONS, MET, SULFIDE, TOC
R-61	GW61-12-23262	10/14/12; 1100 h	Screen 2	ALK, ANIONS, MET, SULFIDE, TOC
R-61	GW61-12-23263	10/14/12; 1500 h	Screen 2	ALK, ANIONS, MET, SULFIDE, TOC
R-61	GW61-12-23264	10/14/12; 1830 h	Screen 2	ALK, ANIONS, MET, SULFIDE, TOC
R-61	GW61-12-23265	10/15/12; 1100 h	Screen 2	ALK, ANIONS, MET, SULFIDE, TOC
R-61	GW61-12-23266	10/15/12; 1830 h	Screen 2	ALK, ANIONS, MET, SULFIDE, TOC
R-61	GW61-12-23267	10/16/12; 1100 h	Screen 2	ALK, ANIONS, MET, SULFIDE, TOC
R-61	GW61-12-23268	10/17/12; 1400 h	Screen 1	ALK, ANIONS, MET, SULFIDE, TOC
R-61	GW61-12-23269	10/17/12; 1750 h	Screen 1	ALK, ANIONS, MET, SULFIDE, TOC
During Final Clean-Up Purging after All Upper and Lower Screen Treatments (via Baski system)				
R-61	GW61-12-23271	10/24/12; 1315 h	Screen 1	ALK, ANIONS, MET, TOC
R-61	GW61-12-23272	10/24/12; 1735 h	Screen 1	ALK, ANIONS, MET, TOC
R-61	GW61-12-23273	10/25/12; 1315 h	Screen 1	ALK, ANIONS, MET, TOC
R-61	GW61-12-23274	10/25/12; 1730 h	Screen 1	ALK, ANIONS, MET, TOC
R-61	GW61-12-23275	10/26/12; 1245 h	Screen1	ALK, ANIONS, MET, TOC
R-61	GW61-12-23276	10/26/12; 1715 h	Screen 1	ALK, ANIONS, MET, TOC
R-61	GW61-12-23277	10/29/12; 1230 h	Screen 1	ALK, ANIONS, MET, TOC
R-61	GW61-12-23278	10/29/12; 1740 h	Screen 1	ALK, ANIONS, MET, TOC

Notes: ALK = alkalinity, ANIONS = positive (+) ions, MET = metals, SULFIDE = sulfides, SVOA = semivolatile organic anaytes, TOC = total organic carbon, VOA = volatile organic analytes.

* Sump was bailed on 9/29/12 to remove accumulated sediment; sample of bailed water was collected from waste drum on 10/2/12.

Table 7.1-1
R-61 Redevelopment Field Parameters and Purge Volumes at Screen 2

Date	pH	Temp (°C)	DO (mg/L)	ORP (mV)	Eh (mV)	Specific Conductivity (µS/cm)	Turbidity (NTU)	Purge Volume between Samples (gal.)	Cumulative Purge Volume (gal.)
Well Redevelopment									
10/14/12	6.67	20.08	6.64	237.7	441.6	0.136	1.3	1168	33568
	6.71	20.03	6.38	229.4	433.3	0.134	1.4	564	34132
	6.77	20.14	6.67	221.4	425.3	0.132	1.1	564	34696
	6.80	20.18	7.04	216.2	420.1	0.132	0.8	564	35260
	6.82	20.21	7.06	212.3	416.2	0.131	0.8	564	35824
	6.85	20.34	6.99	208.5	412.4	0.131	0.6	564	36388
	6.88	20.44	6.56	205.5	409.4	0.131	0.7	564	36952
	6.89	20.42	7.17	204.0	407.9	0.131	0.6	564	37516
	6.91	20.48	7.19	201.7	405.6	0.131	1.3	564	38080
	6.93	20.43	7.64	200.4	404.3	0.130	0.4	564	38644
	6.94	20.34	7.65	200.8	404.7	0.130	0.3	564	39208
	6.96	20.30	7.33	201.4	405.3	0.130	0.7	564	39772
	6.99	20.34	7.35	201.4	405.3	0.130	0.5	1128	40900
	7.00	20.47	7.40	199.6	403.5	0.130	0.6	564	41464
	7.01	20.52	7.20	198.2	402.1	0.130	0.2	564	42028
	7.00	20.48	7.32	196.1	400.0	0.130	0.1	564	42592
	7.01	20.54	7.39	195.1	399.0	0.130	0.1	564	43156
	7.02	20.48	7.59	194.9	398.8	0.130	0.4	564	43720
	7.04	20.15	7.59	193.4	397.3	0.130	0.1	564	44284
	7.04	20.20	7.57	195.5	399.4	0.130	1.5	564	44848
10/15/12	6.69	19.18	6.01	270.5	474.4	0.154	1.5	261	45109
	6.86	19.95	6.22	214.9	418.8	0.138	3.5	546	45655
	6.91	20.08	6.17	212.8	416.7	0.133	3.5	546	46201
	6.95	20.14	6.33	208.9	412.8	0.131	3.7	546	46747
	6.97	20.28	6.32	204.2	408.1	0.130	4.7	546	47293
	7.00	20.32	6.33	200.8	404.7	0.130	0.8	728	48021
	7.02	20.33	7.17	197.8	401.7	0.130	1.2	364	48385
	7.03	20.56	7.26	190.4	394.3	0.130	0.5	546	48931
	7.05	20.65	6.43	188.7	392.6	0.129	0.4	546	49477
	7.06	20.54	6.61	186.4	390.3	0.129	1.1	546	50023
	7.06	20.70	6.89	155.8	359.7	0.131	3.7	819	50842
	7.08	20.73	6.76	158.1	362.0	0.130	0.3	546	51388
	7.09	20.76	6.83	159.8	363.7	0.129	0.1	546	51934

Table 7.1-1 (continued)

Date	pH	Temp (°C)	DO (mg/L)	ORP (mV)	Eh (mV)	Specific Conductivity (µS/cm)	Turbidity (NTU)	Purge Volume between Samples (gal.)	Cumulative Purge Volume (gal.)
Well Redevelopment									
10/15/12 (cont.)	7.10	20.79	6.62	159.4	363.3	0.129	0.1	546	52480
	7.11	20.55	6.60	161.6	365.5	0.128	0.3	546	53026
	7.13	20.36	6.98	163.7	367.6	0.128	0.5	546	53572
	7.16	20.26	6.95	164.8	368.7	0.128	0.3	546	54118
10/16/12	7.00	20.17	6.48	232.8	436.7	0.141	1.7	166	54284
	7.03	20.22	6.90	218.9	422.8	0.135	1.3	534	54818
	7.07	20.22	6.93	208.4	412.3	0.132	1.6	534	55352
	7.07	20.23	6.99	202.0	405.9	0.131	3.3	534	55886
	7.09	20.48	7.02	181.0	384.9	0.132	0.5	1335	57221

Notes: Eh = oxidation-reduction potential; NTU = nephelometric turbidity unit.

Table 7.2-1
R-61 Redevelopment Field Parameters and Purge Volumes at Screen 1

Date	pH	Temp (°C)	DO (mg/L)	ORP (mV)	Eh (mV)	Specific Conductivity (µS/cm)	Turbidity (NTU)	Purge Volume between Samples (gal.)	Cumulative Purge Volume (gal.)
Well Redevelopment									
10/17/12	6.19	21.41	5.67	204.8	408.7	0.194	14.9	484	11343
	6.20	21.35	6.02	197.8	401.7	0.186	9.1	114	11457
	6.26	21.23	6.30	193.8	397.7	0.179	10.1	114	11571
	6.26	21.28	6.19	193.4	397.3	0.175	8.8	114	11685
	6.34	21.41	5.79	189.4	393.3	0.171	12.4	114	11799
	6.32	21.34	6.06	190.0	393.9	0.168	8.3	114	11913
	6.33	21.43	6.47	189.3	393.2	0.166	4.9	114	12027
	6.38	21.40	6.51	189.9	393.8	0.163	4.3	228	12255
	6.41	21.34	6.68	188.2	392.1	0.162	4.3	114	12369
	6.40	21.26	6.23	189.1	393.0	0.161	3.7	114	12483
	6.41	21.16	6.64	189.9	393.8	0.160	7.5	114	12597
	6.44	21.18	6.35	190.0	393.9	0.160	3.8	114	12711
10/24/12	6.28	19.08	3.61	23.3	227.2	0.181	14.6	102	13108
	6.27	19.56	4.34	25.3	229.2	0.178	17.3	63	13171
	6.26	20.17	4.70	44.0	247.9	0.174	3.7	63	13234
	6.27	20.05	5.22	48.7	252.6	0.171	2.2	63	13297

Table 7.2-1 (continued)

Date	pH	Temp (°C)	DO (mg/L)	ORP (mV)	Eh (mV)	Specific Conductivity (µS/cm)	Turbidity (NTU)	Purge Volume between Samples (gal.)	Cumulative Purge Volume (gal.)
Well Redevelopment									
10/24/12	6.27	20.21	5.95	54.6	258.5	0.168	3.0	63	13360
	6.27	20.24	6.35	59.4	263.3	0.164	2.6	63	13423
	6.29	20.31	5.82	60.3	264.2	0.163	2.7	63	13486
	6.29	20.54	6.44	62.8	266.7	0.161	1.8	63	13549
	6.30	20.43	6.48	64.9	268.8	0.159	1.4	63	13612
	6.32	20.29	6.20	69.3	273.2	0.155	0.4	189	13801
	6.32	20.31	6.47	70.2	274.1	0.154	1.8	63	13864
	6.33	20.02	6.63	73.2	277.1	0.153	2.9	63	13927
	6.36	20.33	6.32	71.6	275.5	0.153	2.1	63	13990
	6.37	20.32	6.15	72.2	276.1	0.152	2.8	63	14053
	6.37	20.26	6.37	74.2	278.1	0.151	4.8	63	14116
10/25/12	6.43	16.86	6.44	47.5	251.4	0.151	6.1	120	14236
	6.39	19.04	6.06	57.4	261.3	0.158	10.6	60	14296
	6.35	19.43	6.52	62.9	266.8	0.156	4.0	90	14386
	6.37	19.48	6.44	67.4	271.3	0.155	3.2	60	14446
	6.38	19.55	6.63	68.7	272.6	0.154	3.0	60	14506
	6.39	19.74	7.04	75.6	279.5	0.154	1.8	60	14566
	6.39	19.61	6.46	78.5	282.4	0.153	1.1	60	14626
	6.40	19.73	6.74	80.5	284.4	0.152	2.0	90	14716
	6.42	19.92	6.30	82.1	286.0	0.152	1.7	60	14776
	6.41	19.80	6.68	80.7	284.6	0.151	2.3	60	14836
	6.42	19.83	6.83	79.6	283.5	0.150	2.8	60	14896
	6.42	19.74	6.87	80.8	284.7	0.150	4.4	60	14956
	6.43	19.82	6.81	79.1	283.0	0.149	3.9	60	15016
	6.44	19.84	6.56	80.8	284.7	0.148	4.6	120	15136
	6.44	19.79	7.02	82.6	286.5	0.149	6.6	60	15196
	6.45	19.76	7.11	85.5	289.4	0.148	5.6	60	15256

Table 7.2-1 (continued)

Date	pH	Temp (°C)	DO (mg/L)	ORP (mV)	Eh (mV)	Specific Conductivity (µS/cm)	Turbidity (NTU)	Purge Volume between Samples (gal.)	Cumulative Purge Volume (gal.)
Well Redevelopment									
	6.47	18.66	6.92	76.1	280.0	0.168	3.4	170	15426
	6.46	18.98	6.45	80.2	284.1	0.161	11.6	60	15486
	6.46	19.20	6.49	85.2	289.1	0.156	3.6	60	15546
	6.46	19.40	6.51	88.7	292.6	0.154	2.6	60	15606
	6.46	19.50	6.60	91.0	294.9	0.152	3.5	60	15666
	6.47	19.63	6.61	97.2	301.1	0.151	8.4	60	15726
	6.47	19.52	6.69	93.8	297.7	0.150	3.2	60	15786
	6.47	19.60	6.76	94.2	298.1	0.150	3.1	60	15846
10/26/12	6.48	19.71	6.85	94.9	298.8	0.149	2.3	80	15926
	6.49	19.68	6.67	95.1	299.0	0.148	2.5	60	15986
	6.48	19.62	6.75	95.9	299.8	0.148	3.3	60	16046
	6.50	19.74	6.72	94.6	298.5	0.148	2.6	60	16106
	6.50	19.74	6.71	96.2	300.1	0.147	4.8	60	16166
	6.51	19.66	6.75	95.6	299.5	0.147	7.8	60	16226
	6.51	19.44	6.83	95.7	299.6	0.146	4.1	60	16286
	6.52	19.36	6.85	95.2	299.1	0.146	3.8	60	16346
	6.52	19.41	6.72	95.0	298.9	0.146	14.4	30	16376
	6.48	15.96	7.08	189.0	397.9	0.164	6.1	60	16436
	6.48	18.80	5.15	162.0	365.9	0.168	9.4	60	16496
	6.46	19.65	5.13	145.0	348.9	0.166	3.9	60	16556
	6.46	19.95	6.09	136.0	339.9	0.161	1.2	60	16616
	6.46	19.94	6.33	133.0	336.9	0.158	1.1	60	16676
	6.47	20.10	6.48	132.0	335.9	0.156	1.4	60	16736
	6.47	20.08	6.55	132.0	335.9	0.154	8.4	60	16796
	6.48	20.34	6.80	131.0	334.9	0.154	1.4	60	16856
10/29/12	6.48	20.54	6.76	131.0	334.9	0.152	5.3	60	16916
	6.48	20.76	6.64	132.0	335.9	0.151	1.8	60	16976
	6.49	20.30	6.80	131.0	334.9	0.150	2.7	60	17036
	6.50	20.40	7.03	130.0	333.9	0.150	2.1	60	17096
	6.50	20.49	7.11	130.0	333.9	0.149	1.9	60	17156
	6.51	20.41	6.87	131.0	334.9	0.148	1.5	60	17216
	6.51	20.53	6.76	131.0	334.9	0.148	4.1	60	17276
	6.51	20.42	6.93	131.0	334.9	0.147	1.6	60	17336
	6.51	20.40	6.86	131.0	334.9	0.147	2.1	60	17396

Table 7.2-1 (continued)

Date	pH	Temp (°C)	DO (mg/L)	ORP (mV)	Eh (mV)	Specific Conductivity (µS/cm)	Turbidity (NTU)	Purge Volume between Samples (gal.)	Cumulative Purge Volume (gal.)
Well Redevelopment									
10/29/12 (cont.)	6.52	20.37	7.13	130.0	333.9	0.146	1.7	60	17456
	6.53	20.25	6.82	129.0	332.9	0.146	2.0	60	17516

Notes: Eh = oxidation-reduction potential; NTU = nephelometric turbidity unit.

Appendix A

R-61 Hydraulics Summary

The pumping performance of screens 1 and 2 in regional aquifer well R-61 was monitored carefully throughout the well rehabilitation effort. The data obtained were used to evaluate the hydraulic effectiveness of the redevelopment procedures and to formulate estimates of cross-flow that occurred when both screens were open. Post-development yield data were compared with predevelopment pumping performance to determine the yield increase attributable to the chemical treatments and mechanical redevelopment procedures applied to the screen zones. The hydraulic performance of the two screen zones also supported a determination of cross-flow rates and volumes. The cross-flow volumes were compared with purge volumes to evaluate the completeness of the purging effort at removing the cross-flow.

Numerous pumping tests have been performed on screen zones 1 and 2 in R-61. Extensive trial tests and 24-h tests were conducted in May 2011 when the well was completed. Screen 1 was tested on May 17, 2011, by conducting brief trial tests having durations of 30 and 60 min and on May 19 and 20 with a 24-h test. Similar trial tests were conducted on screen 2 on May 22 and were followed by a 24-h test that began on May 23. Further specific capacity testing was performed in July 2011 when the Baski sampling system was first installed. This testing included a 35-min test on screen 2, followed by a 99-min test on screen 1. It is important to note that both screen zones produced water with increased gaseous content. The gas appears to be accumulated in the aquifer pores. The gas content apparently increased at screen 1 during well development (reducing the screen efficiency) and apparently decreased at screen 2 during well development (increasing the screen efficiency). Finally, additional specific capacity tests and purging were conducted as part of the rehabilitation effort, in early September 2012, immediately before the screen zones were rehabilitated, and in late October, after well treatment and reinstallation of the sampling equipment.

Table A-1 summarizes the documented pumping tests from screens 1 and 2. The data presented include the measured discharge rate, the corresponding drawdown, the duration of the pumping event, and the computed specific capacity. The information in Table A-1 was used to quantify the improvement in well yield that resulted from the rehabilitation efforts.

The yield and drawdown data show that on September 5, before well treatment, screen 1 produced 1.84 gallons per minute (gpm) for 60 min with a drawdown of 13.34 ft. The resulting specific capacity was 1.84/13.34 = 0.138 gpm/ft. On October 23, following well treatment and reinstallation of the sampling system, screen 1 was pumped for 60 min at a discharge rate of 2.3 gpm with a drawdown of 4.96 ft, yielding a specific capacity of 0.464 gpm/ft. This value was 3.36 times greater than the predevelopment specific capacity, representing a 236% increase in performance.

On September 5, screen 2 produced 1.95 gpm for 60 min with a drawdown of 3.12 ft, resulting in a specific capacity of 0.625 gpm/ft. On October 23, following well treatment and reinstallation of the sampling system, screen 2 was pumped for 32 min at a discharge rate of 2.2 gpm, with a stabilized drawdown of 2.71 ft and with an estimated specific capacity of 0.812 gpm/ft, 30% greater than the initial value. The smaller increase in the screen 2 specific capacity compared with the larger increase in the screen 1 specific capacity can be explained by the higher initial permeability of screen 2.

These results show that in addition to the targeted chemical alteration of the zones around the well screens, a corollary benefit of the development activities was a substantial improvement in pumping performance, as reflected in the specific capacity data.

The available data were used to estimate the cross-flow that occurred when both screens were open to flow. The cross-flow rate is a function of the specific capacities of the two screen zones and the head difference between the zones.

Table A-2 shows water levels measured in the two screen zones at several times. The initial head difference when the well was drilled, developed, and test pumped (May 2011) was zero. Subsequently, on July 29, 2011, when the Baski sampling system and permanent transducers were installed, an upward gradient was observed with a head difference of 0.24 ft. The water levels shown for September 5 were taken directly from the transducer output record and showed an upward gradient (flow from screen 2 to screen 1) with a head difference of 0.26 ft. On September 6, manual water-level measurements were made before the transducers were pulled from the well. The data confirmed the upward gradient, showing a head difference of 0.15 ft. Manual water-level measurements were made again on October 21 when the transducers were run back into the well after the sampling system was reinstalled. These measurements also showed an upward gradient, with a head difference of 0.17 ft. The average of the three measurements made in 2012 (19 ft) was used to compute representative cross-flow rates.

The cross-flow from one screen to another can be computed from the following equation (derivation included at the end of this appendix):

$$Q = h\frac{c_1 c_2}{c_1 + c_2}$$

where, Q = cross-flow rate, in gpm

c_1 = specific capacity of screen 1, in gpm/ft

c_2 = specific capacity of screen 2, in gpm/ft

h = head difference between screen 1 and screen 2, in ft

Before screen 1 was treated, a temporary bridge plug was installed between screens 1 and 2 to hydraulically separate the screens. The minor cross-flow that occurred from screen 2 to screen 1 between removal of the Baski sampling system and installation of the bridge plug was not a concern because thousands of gallons of water had been purged from screen 1 during the treatment procedures. The only cross-flow of concern was that which occurred subsequently during treatment of screen 2. During this period, the two screens were open to flow part of the time and isolated with a downhole inflatable packer part of the time.

When the two screen zones were in hydraulic communication, the cross-flow rate was computed using the post-development short-term specific capacity values from Table A-1: 0.464 gpm/ft for screen 1 and 0.812 gpm/ft for screen 2. Using the above equation and the average head difference of 0.19 ft, the cross-flow rate was calculated to be 0.056 gpm, or 81 gallons per day. This flow rate was applied to all time intervals when the downhole packer used in the screen 2 treatment procedures was not inflated. This estimate is based on assumption that the head difference was not increased/decreased/flipped during well redevelopment. It is possible rehabilitation activities could have altered the head difference between screens 1 and 2 via the injection of treatment fluids into screen 2 and subsequent purging from screen 2. However, these effects are expected to have been small because of the large transmissivity of the screen 2 zone. Furthermore, the possible head rise in screen 2 would have been influenced by injection of just a few hundred gallons of fluid, whereas the possible head reduction would have been associated with purging of tens of thousands of gallons. The latter effect would be expected to be the larger of the two and, thus, if rehabilitation activities altered the head difference between the zones, it would have been manifested as a reduction in the upward gradient or possibly even a gradient reversal. Thus, the calculated cross-flow into screen 1 based on the stated assumptions is considered conservative. (Note that heads in the two screen zones were not measured during the rehabilitation activities and were measured only before and after.)

Following each chemical treatment of screen 2, purging was performed to remove the spent chemicals and reaction products from the screen 2 interval. Periodically during this process, the downhole packer was deflated to allow purging both screen zones simultaneously. This allowed periodic purging of screen 1 to remove cross-flow following each treatment step. At the conclusion of the rehabilitation effort, following the reinstallation of the Baski sampling system, extensive purging of screen 1 was performed.

Table A-3 summarizes the cross-flow and purge volumes for screen 1 during the period of interest. The times when the screen zones were in hydraulic communication are shown along with the computed cross-flow volume using the estimated cross-flow rate of 0.056 gpm. The far right column shows the periodic purge volumes that were removed from screen 1 only following the indicated cross-flow events. It is clear that at each step of the process, the purge volume exceeded the antecedent cross-flow that had occurred from screen 2 to screen 1. The final purge volume of 4761 gal. from screen 1 only included (1) a 60-min pumping test conducted on screen 1 following installation of the sampling system, and (2) 4 d of steady purging for final cleanup for screen 1. The pumped volume greatly exceeded the previous cross-flow volumes, implying adequate purging of the cross-flow. It should be noted that the cross-flow volume into screen 1 would tend to drift slightly from west to east with the natural hydraulic gradient, creating the possibility that a portion of the water volume could migrate beyond the hydraulic capture reach of purging activities. Robust analyses of fate of water and contaminants introduced by cross-flow would require more detailed computation incorporating properties such as true hydraulic conductivity, hydraulic gradient, hydrodynamic dispersion, retardation and porosity. These parameters are largely unknown, precluding such a detailed analysis. However, rough estimates (not included here) suggest that the bulk of the introduced fluid likely would have been recovered by the extensive purging that was performed.

Derivation of Cross-Flow Formula

The cross-flow rate, Q, from screen 2 to screen 1 is equal to the product of either (1) the specific capacity of screen 1 (c_1) and the water level rise at screen 1 (h_1), or (2) the specific capacity of screen 2 (c_2) and the water level decline at screen 2 (h_2):

$$Q = c_1 h_1 = c_2 h_2$$

In this expression, the total head difference (h) between screens 1 and 2 is equal to the sum of the head rise at screen 1 and the head decline at screen 2:

$$h = h_1 + h_2$$

or

$$h_2 = h - h_1$$

The right-hand portion of the first equation can be rewritten as

$$h_1 = \frac{c_2}{c_1} h_2$$

Substituting for h_2:

$$h_1 = \frac{c_2}{c_1}(h - h_1)$$

Multiplying out and rearranging terms:

$$h_1 \left(1 + \frac{c_2}{c_1}\right) = \frac{c_2}{c_1} h$$

Solving for h_1:

$$h_1 = \frac{\frac{c_2}{c_1}h}{1 + \frac{c_2}{c_1}}$$

Thus:

$$h_1 = \frac{\frac{c_2}{c_1}h}{\frac{c_1 + c_2}{c_1}}$$

And, finally, cancelling terms:

$$h_1 = \frac{c_2}{c_1 + c_2}h$$

Recalling that Q is the product of c_1 and h_1:

$$Q = h\frac{c_1 c_2}{c_1 + c_2}$$

Table A-1
R-61 Screen 1 and Screen 2 Pumping Results

Date	Zone	Pumping Rate (gpm)	Drawdown (ft)	Pumping Time (min)	Specific Capacity (gpm/ft)
Predevelopment Data					
5/17/2011	Screen 1	1.02	6.59	30	0.155
5/17/2011	Screen 1	0.98	7.59	60	0.129
5/19/2011	Screen 1	0.95	16.21	1440	0.059
7/29/2011	Screen 1	1.69	10.20	99	0.166
9/5/2012	Screen 1	1.84	13.34	60	0.138
9/5/2012	Screen 1	1.32	9.85	120	0.134
9/5/2012	Screen 1	0.96	7.67	180	0.125
5/22/2011	Screen 2	21.8	40.1	30	0.544
5/22/2011	Screen 2	21.7	41.0	60	0.529
5/23/2011	Screen 2	21.6	41.4	300	0.522
5/23/2011	Screen 2	12.7	24.9	600	0.510
5/23/2011	Screen 2	22.3	39.3	1440	0.567
7/29/2011	Screen 2	1.63	2.55	35	0.639
9/5/2012	Screen 2	1.95	3.12	60	0.625
9/5/2012	Screen 2	1.23	1.96	120	0.628
9/5/2012	Screen 2	0.98	1.52	180	0.645
Post-Development Data					
10/23/2012	Screen 1	2.3	4.96	60	0.464
10/24/2012	Screen 1	2.0	5.07	555	0.394
10/25/2012	Screen 1	2.1	5.24	570	0.401
10/26/2012	Screen 1	2.1	5.38	560	0.390
10/29/2012	Screen 1	2.0	5.36	570	0.373
10/23/2012	Screen 2	2.2	2.71	32	0.812

Table A-2
R-61 Screen 1 and Screen 2 Water Levels

Date	Screen 1 (ft amsl*)	Screen 2 (ft amsl)	Difference (ft)
7/29/2011	5837.62	5837.86	0.24
9/5/2012	5837.76	5838.02	0.26
9/6/2012	5837.64	5837.79	0.15
10/21/2012	5837.70	5837.87	0.17
2012 Average	5837.70	5837.89	0.19

* amsl = Above mean sea level.

Table A-3
Cross-Flow and Purged Volumes at Screen 1 in R-61

Deflate Packer (date and time)	Inflate Packer (date and time)	Elapsed Time (min)	Maximum Cross-Flow Volume (gal.)	Cumulative Cross-Flow Volume in Screen 1 (gal.)	Estimated Purge Volume from Screen 1 (gal.)
09/28/12 13:15	09/29/12 15:00	1545	87	87	180
09/30/12 11:40	09/30/12 13:45	125	7	94	
09/30/12 13:58	10/01/12 13:45	1427	80	173	
10/02/12 07:00	10/03/12 08:14	1514	85	85	254
10/03/12 12:12	10/03/12 14:12	120	7	92	
10/03/12 14:24	10/04/12 11:45	1281	72	163	
10/04/12 13:08	10/04/12 14:25	77	4	168	
10/05/12 16:07	10/05/12 17:32	85	5	172	
10/11/12 09:02	10/11/12 15:22	380	21	21	641
10/12/12 11:46	10/12/12 13:40	114	6	28	
10/12/12 13:56	10/13/12 12:00	1324	74	102	
10/15/12 12:10	10/15/12 15:01	171	10	111	
10/16/12 11:20	10/16/12 18:20	420	24	24	4761
10/17/12 07:07	10/17/12 09:38	151	8	32	
10/18/12 08:00	10/20/12 17:15	3435	192	224	

Appendix B

Groundwater Screening Analytical Results
(on CD included with this document)

Appendix C

R-61 Well Video Logs
(on DVDs included with this document)

Appendix D

R-61 Redevelopment Treatment Volumes

D-1.0 INTRODUCTION

The following calculations and rationale were prepared for the lower screen at regional aquifer well R-61 and were assembled from various correspondences. While the calculations presented are specific to the lower screen, the same arithmetic and assumptions apply to the upper screen as well. The treatments at the upper screen were calculated in the same manner, with the only difference being the upper screen is half the length. As such, treatment volumes for the upper screen were half the volumes presented in the following rationale.

D-2.0 TREATMENT VOLUMES FOR LOWER SCREEN

The goal was to push the chemical solution through the screen and filter pack, deep into the formation. A solution volume of 30 gal./ft of screen was used for R-61. This volume was selected to balance the need to reach out into the formation while constraining the volume of the chemical to a level that was readily handled (mixed) and purged from the well. The lower well screen is 20.6 ft long, and a total of 620 gal. of chemical solution was used.

Ignoring vertical flow, the distance that the mixed solution reaches beyond the borehole wall can be calculated as follows:

$$d = \sqrt{\frac{V}{7.48\pi n} - \frac{(1-n)r_s^2}{n}} - r_w$$

where, V = volume of solution per foot of screen, in gallons (30 gal.)

rs = inside radius of well screen, in feet (0.21 ft)

rw = borehole radius, in feet (0.52 ft)

n = effective porosity

For several assumed values of effective porosity, the following are the penetration distances:

Effective Porosity	Penetration Distance (ft)
0.15	2.35
0.20	1.97
0.25	1.71
0.30	1.52

The distance, d, is the bulk average. The penetration distance will be less in tight strata and greater in permeable zones.

D-3.0 TREATMENT METHODS

D-3.1 Caustic Treatment

A concentration of 3% of the total mixture volume was required for both the potassium hydroxide and Nu-Well (NW) 320 enhancer. The 620-gal. treatment volume weighed 5171 lb. Three percent of this is 155 lb of each chemical required to make up the mixture.

The potassium hydroxide flakes were of 90% purity. Thus, 155/0.9 = 172 lb of flakes, or 78 kg, was used.

The NW 320 enhancer weighed 9.5 lb/gal. Thus, 155/9.5 = 16.3 gal. of this chemical was used.

D-3.2 Acid Treatment

The acid treatment incorporated NW 120 Liquid Acid (phosphoric acid) in a mixture with NW 310 bioacid dispersant.

NW 120 acid was used at a rate of 5% of the total volume of the solution. The 620-gal. treatment volume weighed 5171 lb. Five percent of this volume is 259 lb of chemical product. The acid weighed 13 lb/gal., so 20 gal. was used.

NW 310 was used at a rate of 3% of the total volume of the solution, or 155 lb. This chemical weighs 10 lb/gal., so 15.5 gal. was used.

D-3.3 Chlorine Treatment

The chorine treatment incorporated sodium hypochlorite and NW 410 chlorine enhancer.

The NW 410 enhancer was used at a rate of 0.4 qt per 100 gal. of water per 100 ppm alkalinity (expressed as $CaCO_3$). Based on 620 gal. of water, the amount of NW 410 computes to 2.5 qt per 100 ppm alkalinity. Many of the regional wells have alkalinity values of approximately 60 ppm. It was assumed that the municipal wells (the source for mix water) were similar. At this concentration, it would require 2.5 × 0.60 = 1.5 qt. The objective of NW 410 is to lower the water pH to just under 5.0. Therefore, less than the calculated amount was added, the pH was measured, and addition of NW 410 was repeated until the desired pH was reached. Approximately 1.5 qt of NW 410 was used.

The desired free chlorine concentration is 200 ppm minimum; greater concentrations have no deleterious side effects. A 12.5% strength sodium hypochlorite solution was used, mixed at a minimum concentration of 200/0.125 = 1600 ppm, or 0.16%. Thus, the total weight of the chemical added was 0.16% of the total weight of the solution or 5171 × 0.0016 = 8.3 lb. The bulk sodium hypochlorite weighs 10 lb/gal., making the minimum volume requirement 8.3/10 = 0.83 gal. When the chlorine is mixed, some chemical is lost via evolution of chlorine gas. This loss, coupled with other chlorine demand such as the unsanitized mixing tank, hoses, piping, and residual acid in the formation, resulted in the use of additional chemical. Approximately 1 gal. more was used.