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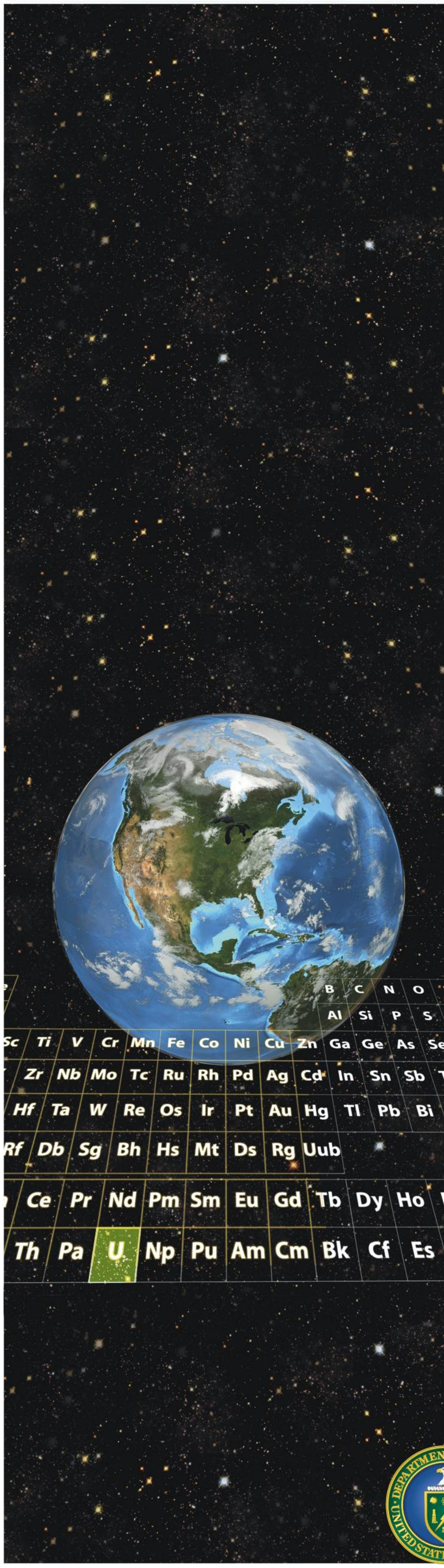

Evaluation of Pre- and Post-Redevelopment Groundwater Chemical Analyses from LM Monitoring Wells

May 2016

U.S. DEPARTMENT OF ENERGY | Legacy Management

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Abbreviations

AS&T	Applied Studies and Technology
AWP	Ancillary Work Plan
btoc	below top of casing
COCs	contaminants of concern
DOE	U.S. Department of Energy
EDGE	EQuIS Data Gathering Engine
EMO	Environmental Monitoring Operations (group)
EQuIS	Environmental Quality Information System
ESL	Environmental Sciences Laboratory
ft	feet or foot
gal	gallon(s)
gpm	gallon(s) per minute
LM	Office of Legacy Management
LMS	Legacy Management Support
µS/cm	microsiemens per centimeter
mg/L	milligrams per liter
NTU	nephelometric turbidity units
SAP	Sampling and Analysis Plan
SC	specific conductance
SCT	specific conductance and temperature
SOARS	System Operation and Analysis at Remote Sites
SRE	Slick Rock East (processing site)
SRW	Slick Rock West (processing site)
UMTRCA	Uranium Mill Tailings Radiation Control Act
USGS	U.S. Geological Survey

Executive Summary

This report documents the efforts and analyses conducted for the Applied Studies and Technology (AS&T) Ancillary Work Plan (AWP) project titled *Evaluation of Pre- and Post-Redevelopment Groundwater Sample Laboratory Analyses from Selected LM Groundwater Monitoring Wells*. This effort entailed compiling an inventory of nearly 500 previous well redevelopment events at 16 U.S. Department of Energy Office of Legacy Management (LM) sites, searching the literature for impacts of well redevelopment on groundwater sample quality, and—the focus of this report—evaluating the impacts of well redevelopment on field measurements and sample analytical results.

Study Catalyst

Monitoring well redevelopment, the surging or high-volume pumping of a well to loosen and remove accumulated sediment and biological build-up from a well, is considered an element of monitoring well maintenance that is implemented periodically during the lifetime of the well to mitigate its gradual deterioration. Well redevelopment has been conducted fairly routinely at a few LM sites in the western United States (e.g., the Grand Junction office site and the Gunnison processing site in Colorado), but at most other sites in this region it is not a routine practice. Also, until recently (2014–2015), there had been no specific criteria for implementing well redevelopment, and documentation of redevelopment events has been inconsistent. A catalyst for this evaluation was the self-identification of these inconsistencies by the Legacy Management Support contractor. As a result, in early 2015 Environmental Monitoring Operations (EMO) staff began collecting and documenting additional field measurements during well redevelopment events. In late 2015, AS&T staff undertook an independent internal evaluation of EMO's well redevelopment records and corresponding pre- and post-well-redevelopment groundwater analytical results.

Study Findings

Although literature discussions parallel the prevailing industry-wide assumption that well redevelopment is necessary to increase production or to extend the life of a well, no data in the literature indicate that redevelopment affects chemical signatures in monitoring wells. The comprehensive evaluation undertaken for this study also yielded no evidence that redevelopment has any quantifiable or predictable effect on groundwater sample quality. Both short-term and long-term changes in groundwater chemistry were assessed relative to preceding and subsequent well redevelopment events.

Although short-term changes in specific conductance or contaminant concentrations likely attributable to well redevelopment were found at some sites, these cases were limited to a small subset of wells in which chemical stratification had been observed. Redevelopment causes mixing of the well water, resulting in short-term impacts, but not in a consistent direction. Long-term groundwater concentration trends of uranium, the primary contaminant of concern at most LM Uranium Mill Tailings Radiation Control Act (UMTRCA) sites, were evaluated for all 16 sites addressed in this study. Based on the data evaluated, there are no apparent impacts of well redevelopment on uranium trends. In most cases where deviations in trends were found, these could be attributed to water level fluctuations or other factors. A few exceptions were found where spikes or marked decreases in uranium concentrations could potentially be related

to the preceding well redevelopment, but apparent impacts were neither predictable nor quantifiable.

Summary and Recommendations

A catalyst for this project was a concern that there was a need for strict criteria for a program-wide approach to well redevelopment at LM sites. There was also an implicit question as to whether well redevelopment was a necessary practice that was being overlooked at some sites. The primary objective of this study was to determine if there are significant differences in laboratory analytical results between pre- and post-redevelopment groundwater samples. Results of this evaluation indicate that this is not the case—groundwater concentrations of uranium, the primary contaminant of concern at most LM UMTRCA sites, generally remained unchanged pre- and post-well-redevelopment.

The literature supports redevelopment of monitoring and municipal wells if signs of reduced productivity, biofouling, sediment buildup, or other conditions potentially affecting long-term well integrity are observed. In these cases, use of a downhole camera to examine the condition of the well screen and casing may be useful. However, based on the data sets examined for this study, there is no evidence that well redevelopment is needed in order to obtain samples that have the same chemical concentrations as those in the groundwater. To conclusively demonstrate that point—that is, to define chemical effects—the underlying mechanisms have to be understood. For example, if biofouling is observed in a well and is considered a potential cause of spurious or invalid chemical data, appropriate hypothesis-testing methodology should be used to test the validity of this claim.

Until late 2014, the onset of this project, there was no standard procedure for documenting well redevelopment events; some (perhaps many) had not been captured in the historical record. EMO has made notable progress in this regard since 2015, having established a format for documenting well redevelopment events and associated field measurements, as well as a data repository for capturing those records. This policy should be continued to ensure that all well redevelopment events and associated field observations are recorded and easily tracked.

1.0 Introduction

This report documents the efforts and analyses conducted for the Applied Studies and Technology (AS&T) Ancillary Work Plan (AWP) project titled *Evaluation of Pre- and Post-Redevelopment Groundwater Sample Laboratory Analyses from Selected LM Groundwater Monitoring Wells*, herein referred to as the Well Redevelopment Assessment. As requested by the U.S. Department of Energy (DOE) Office of Legacy Management (LM), in July 2014 the Legacy Management Support (LMS) contractor's Environmental Monitoring Operations (EMO) group prepared a draft white paper discussing the status of well redevelopment at LM sites (Campbell 2014). At the same time, EMO began collecting and documenting additional field measurements during well redevelopment events. In late 2015, AS&T staff undertook an independent internal evaluation of the EMO groundwater monitoring well redevelopment records and corresponding pre- and post- well-redevelopment groundwater analytical results.

Approximately 670 monitoring wells are currently monitored at LM Uranium Mill Tailings Radiation Control Act (UMTRCA) sites.[1] Much of the site characterization work was conducted in the 1990s, and most monitoring wells are about 15 to 20 years old. Well development—surging and evacuating fluid from a well to remove sediment or drill cuttings from the borehole wall and provide maximum flow of water into the well—is routinely conducted following well installation and is generally considered an industry "best-practice" (ASTM 2013, Ohio EPA 2009, Schnieders 2003, LMS *Environmental Procedures Catalog*).

Monitoring well redevelopment, the surging or high-volume pumping of a well to loosen and remove accumulated sediment and biological build-up from a well, is considered an element of monitoring well maintenance that is implemented periodically during the lifetime of the well to mitigate the gradual deterioration of groundwater monitoring wells. Well redevelopment has been conducted fairly routinely at a few LM sites in the western United States (e.g., the Grand Junction office site and the Gunnison processing site in Colorado), but at most other sites it is not a routine practice. Also, until recently (2014–2015), there had been no specific criteria for implementing well redevelopment (these have usually done at the discretion of the LMS site lead), and documentation of redevelopment events has been inconsistent.

This work is a comprehensive assessment of the monitoring well redevelopments that have been documented for LM UMTRCA sites in the western United States. For groundwater monitoring wells that have been redeveloped, an objective of this work is to determine if there are significant differences in laboratory analytical results between pre- and post-redevelopment groundwater samples, and to develop criteria for determining the need for future well redevelopment (AS&T 2015). Work performed under this AWP consisted of six tasks, summarized in Table 1. These tasks entailed (1) documenting the overall approach to, and criteria for, redevelopment of wells at LM sites; (2) compiling an inventory of previous redevelopment events and refining the mechanism for recording such events; (3) searching the literature for impacts of well redevelopment on sample analytical results; and (4) based on previous well redevelopment events and more detailed measurements recently compiled by EMO, evaluate differences between pre- and post-redevelopment field measurements and sample analytical results. These

[1] A search of the LM SEEPro/EQuIS site database conducted in January 2016 indicates that 677 wells are currently monitored at LM UMTRCA sites (search criterion was any well sampled since 2010). Three sites—Riverton, WY, Processing Site (70 wells); Shiprock, NM, Disposal Site (125 wells); and the Tuba City, AZ, Disposal Site (120 wells)—account for nearly half (315 wells) of this total.

combined efforts culminated in recommendations related to developing and implementing a programmatic approach to monitoring well redevelopment at LM sites.

Table 1. Well Redevelopment Assessment Tasks

AWP Task	LMS Organization	Description	Status/Outcome
1	EMO	Complete an inventory of well types that are currently monitored at all LM sites.	Summarized in Section 2.1; complete results provided in Campbell 2014 (Appendix A of this assessment).
2	EMO	Develop an Excel spreadsheet for input and storage of well redevelopment data. Include in the spreadsheet a place for field data (i.e., specific conductance, pH, temperature, and turbidity) to be recorded and stored prior to and a just after well redevelopment.	Complete. Templates and documentation provided in following EMO folder: \\lm\projects\SamplingProg\Maintenance\Well Redevelopment\.
3	EMO	As part of the transition to the EQuIS database, develop an EDGE form that will capture all pertinent data for storage in the new database.	EDGE form example provided in Figure 4 but is still under development.
4	EMO/AS&T	Literature search of industry best practice and documented impacts of well redevelopment on sample analytical results.	Summarized in Section 2.2; detailed search results provided in Appendix B. Most of the literature addresses well development as a necessary component of post-well-installation standard procedures. No studies were found addressing the impact of well redevelopment on groundwater chemistry or sample quality. Literature mostly qualitative and largely focused on the impacts of redevelopment on production (yield).
5	AS&T	Mine the LM data management system to identify and compile information on groundwater monitoring well redevelopment from FY 2010 through FY 2015.	Data mining effort yielded nearly 500 records of well redevelopments at LM sites.
6	AS&T	Assess pre- and post-redevelopment sample analytical results from wells identified in Task 5.	Results addressed in Section 6. Because of multiple factors potentially accounting for variations in well chemistry, combined with inconsistent approaches to well redevelopment (surging vs. pumping) and varying well redevelopment frequencies, no conclusive findings resulted from this subtask.
7	AS&T	Complete a draft report documenting the analysis and results from all tasks.	Task entails this report.

Abbreviations:
EQuIS = Environmental Quality Information System
EDGE = EQuIS Data-Gathering Engine

Source: Table 1 of AWP (AS&T 2015)

2.0 Task 1: Current Well Redevelopment Approach

This section documents the results of Task 1 of this AWP (Table 1), that entailed an inventory of well types currently monitored at LM sites and corresponding well maintenance and redevelopment approaches. In support of this task, an evaluation was undertaken in June 2014 that culminated in the development of a draft "white paper"—*Well Redevelopment at LM Sites, Discussion and Recommendations*. Although this paper was not formally accepted by LM, it does provide useful background information and reference material. This draft evaluation is provided in Appendix A, and salient portions are summarized below.

2.1 Well Redevelopment Methodology

Although there are several methods for redeveloping monitoring wells, the most common method used at LM sites is the surge block and pumping method. A surge block is a disk or cylinder with a diameter slightly smaller than the inside diameter of the well casing. Surging is the process of forcing water in and out of the filter pack and geologic formation by moving the surge block up and down in the water column of a well, thereby loosening sediment and biological material entrained in the filter pack and screen. Liberated debris is then removed from the well by pumping. Alternate cycles of surging and pumping continue until well-development criteria are met. In addition to pumping and surging, well brushes are commonly used to brush the screen of a well to remove adhered mineral and biological build-up on the screen.

2.2 Target Indicator Parameter

Because the goal of redevelopment is to loosen and remove accumulated sediment and biological build-up in a well, turbidity is the primary indicator parameter used to determine the progress and completion of redevelopment. Within the LM program, a turbidity of 10 nephelometric turbidity units (NTUs) or less indicates the completion of redevelopment. This criterion is used because it is the purge criterion specified in the LM Sampling and Analysis Plan (LMS/PRO/S04351) that must be met prior to unfiltered groundwater sample collection (additional related information is provided in Appendix A).[2]

2.3 Interim Approach to Well Redevelopment

As documented in Appendix A, EMO proposed a graded approach to well redevelopment at LM sites, whereby the frequency of redevelopment is determined from a combination of factors, including the type of well (e.g., extraction or monitoring well), visual observations during sampling, and downhole camera surveys. The rationale underlying the recommended program-wide approach is that natural processes cause the condition of groundwater monitoring wells to deteriorate with time due to mineral build-up, biological growth, and sediment accumulation within the well screen, filter pack, and adjacent formation. EMO concluded that routine monitoring well redevelopment is necessary to mitigate this deterioration.

[2] http://sp.lm.doe.gov/Contractor/ControlledDocuments/Controlled%20Documents/S04351_SAP.pdf

As a quality assurance component of LM's comprehensive groundwater monitoring program, EMO also concluded that a routine inspection and maintenance program should be in place that includes periodic well redevelopment to promote well longevity and collection of representative samples, especially when using low-flow purging and sampling techniques, which do not effectively stress a monitoring well to remove natural artifacts. As documented in Appendix A, EMO generally recommends a targeted well redevelopment approach, whereby a well is developed when any of the following conditions apply:

- Sample turbidity criterion of 10 NTU is not obtained or is difficult to obtain during sampling (e.g., greater than 30-minute purge time).
- Significant sediment has accumulated in the well—defined as occlusion of 20 percent or more of the screen with sediment.

EMO's proposed (draft) approach for determining the need for, or frequency, of well redevelopment is summarized below.

Monitoring Wells

- Bedrock wells—targeted well redevelopment based on well-specific observations.
- Alluvial wells greater than 50 feet (ft) deep—targeted well redevelopment based on well-specific observations.
- Alluvial wells less than 50 ft deep—redevelop annually for 2 years or prior to two sampling events (if sampling frequency is greater than annual) followed by targeted well redevelopment.

Extraction Wells

- Targeted site-specific program based on site-specific conditions.

All Wells

- Allow at least 1 week between redevelopment and sampling for wells that produce sufficient water.
- Allow more time between redevelopment and sampling for low-producing wells; the time frame will depend on water level recovery after redevelopment is complete.

3.0 Tasks 2 and 3: EMO Documentation

Until late 2014, the onset of this project, there was no standard procedure for documenting field measurements during well redevelopment events. Prior to 2014, field measurements were typically recorded on a well development log (example provided in Figure 1), but there was no repository for these logs, nor any formal data capture methodology. In 2014, EMO began routinely issuing well redevelopment trip reports (versus sporadically, as was the case in the past). These reports now typically include start and end times, the volume of water pumped, corresponding flow rates, the number of times the well was surged and the screen was brushed, and the final turbidity, a measurement of water clarity (Figure 2). A comment section captures qualitative information, including field observations and condition of the wells.

Well Development Log

Site Durango **Date** 06/30/14 – 07/01/14

Well ID	Time	Initial Water Level (ft btc)	Number of Well Surges	Final Turbidity (NTUs)	Cumulative Volume (gallons)	Flow Rate (gpm)	Comments
0629	6/30 1700	17.68	1	>100	2		Purged dry, recovering at 0.1ft per 7 min
0622	06/30 1800	11.26	1	3.77	25		
0866	06/30 1900	12.89	3	≈900	50+12		Left overnight, 12 gallons purged 7/1
0857	07/01 0800	15.58	2	>100	12		7gal purged till dry, 5 more then dry

Figure 1. Well Development Log Example

SUBJECT: Well Redevelopment Trip Report

Site: Slick Rock, Colorado, West Site

Dates of Redevelopment Event: September 28-29, 2015

Team Members:

Number of Wells Redeveloped: 8 monitoring wells.

Locations Not Redeveloped: 0319 (because of organic contamination).

Location Specific Information: Nothing to note.

Redevelopment Method: Wells were redeveloped according to the *Sampling and Analysis Plan (SAP) for the U. S. Department of Energy Office of Legacy Management Sites* (LMS/PRO/S04351, continually updated). Specifically, the wells were scrubbed with a brush to remove bio-slime, surged with a block to loosen fines and bio-slime residing in the sand pack, and then purged until the turbidity was lowered to the appropriate value. The surge and purge cycles were repeated at least two times at each well.

Equipment: All equipment functioned properly.

Figure 2. Well Redevelopment Trip Report Example
Extract from October 13, 2015, Trip Report for Slick Rock West Site

For some LM sites, trip reports had been prepared prior to 2014, but not on a routine basis. Furthermore, these reports have not been readily accessible, as they are usually filed as site correspondence rather than as quantitative records relevant to interpretation of site data. It is likely that some (perhaps many) well redevelopment efforts at some LM sites have not been captured in the historical record. Given the previous inability to quantitatively track well redevelopment efforts, in late 2015, EMO developed an Excel spreadsheet for input and storage of well redevelopment data that captures the following information:

- Field measurements of temperature, pH, specific conductance (SC), and turbidity before and after redevelopment; turbidity also measured during redevelopment.
- Redevelopment data, including water volume purged, flow rates, number of surges, and brushing of the screen (Figure 3).

Turbidity and flow rate measurements documented in these tables are similar to the level of information included in trip reports, but this information is now captured in a database format. SC, temperature, and pH had not been measured during previous well redevelopment events.

PRE-Redevelopment Data

Well ID	Date	Start Time (24 hour)	Reading Time (24 hour)	Elapsed Time (min)	Total Volume (mL)	Flow-Rate (mL/min)	Temperature (°C)	Specific Conductance (µmhos/cm)	pH (s. u.)	Turbidity (NTU)	Notes:
102	7/20/2015	14:36	14:38	2	700	350	12.28	487	7.13	2.69	
			14:42	6	2000	333	12.10	521	7.17	1.53	
			14:45	9	3000	333	11.94	530	7.21	0.92	
2	7/20/2015	15:01	15:04	3	400	133	12.63	579	7.11	0.92	
			15:08	7	1800	257	12.55	581	7.12	0.74	
			15:11	10	3000	300	12.56	579	7.14	4.00	
66	7/20/2015	17:09	17:10	1	500	500	10.00	691	7.21	8.25	
			17:14	5	1800	360	9.33	691	7.21	5.82	
			17:17	8	3000	375	9.25	689	7.20	2.92	

Redevelopment Data

Well ID	Date	Start Time (24-hour)	Stop Time (24-hour)	Total Time (min)	Interval Volume (gal)	Total Volume (gal)	Flow rate (gal/min)	Brush Screen	Surge Well	Turbidity (NTU)	Notes:
102	07/20/15	15:03	15:26	23	23		1.0	x	x	44.20	
		15:30	16:08	38	57	80	1.5		x	6.46	
2	07/20/15	15:42	15:52	10	10		1.0	x	x	5.86	
		15:55	16:06	11	11	21	1.0		x	2.04	
66	07/20/15	17:28	19:15	107	75	75	0.7	x	x	16.90	Could not meet turbidity on well

POST-Redevelopment Data

Well ID	Date	Start Time (24-hour)	Stop Time (24-hour)	Total Time (min)	Interval Volume (gal)	Total Volume (gal)	Flow rate (gal/min)	Brush Screen	Surge Well	Turbidity (NTU)	Notes:
102	07/20/15	15:03	15:26	23	23		1.0	x	x	44.20	
		15:30	16:08	38	57	80	1.5		x	6.46	
2	07/20/15	15:42	15:52	10	10		1.0	x	x	5.86	
		15:55	16:06	11	11	21	1.0		x	2.04	
66	07/20/15	17:28	19:15	107	75	75	0.7	x	x	16.90	Could not meet turbidity on well

Figure 3. Detailed Redevelopment Documentation Example

Screen shots of records taken during July 2015 Gunnison site well redevelopment event. Field data documentation includes specific conductance, pH, temperature, and turbidity, recorded prior to, during, and just after well redevelopment. This level of documentation began in summer 2015. Examples available in the following EMO project folder: \\lm\projects\SamplingProg\Maintenance\Well Redevelopment\

To facilitate transition to LM's EQUiS database[3], EMO was commissioned to develop an EDGE (EQuIS Data Gathering Engine) form intended to capture all pertinent data for storage in the new database. An example of the current EDGE form is shown in Figure 4. The EDGE form is still under development—implementation will coincide with the EQuIS transition, beginning in April 2016 for a subset of LM sites (e.g., the Gunnison processing site). Full implementation is expected to occur by summer 2016.

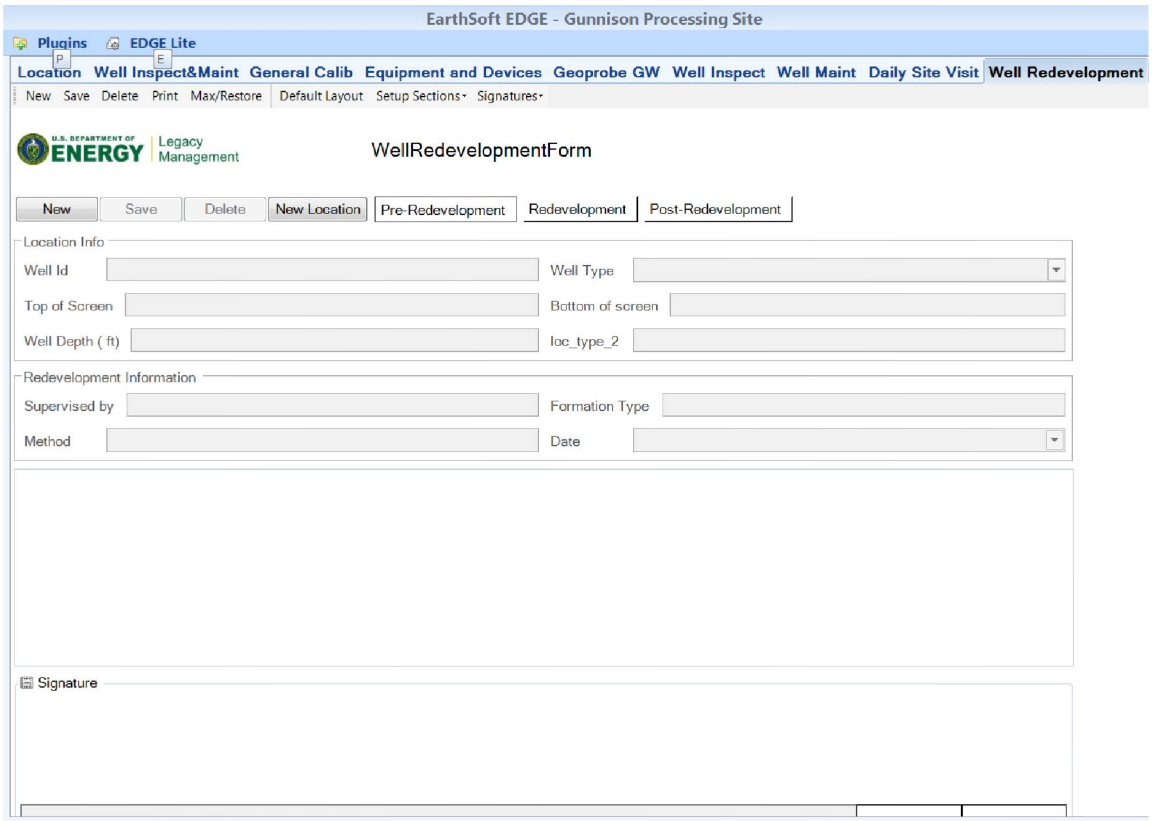

Figure 4. Screenshot of EDGE Well Redevelopment Form

[3] Developed by EarthSoft, EQuIS (Environmental Quality Information System) is the database the LM program is currently transitioning to. The related EQuIS Data Gathering Engine (EDGE) software was developed to facilitate data collection and field data management.

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4.0 Task 4: Literature Search

The white paper in Appendix A summarizes the practical, or industry best practice, guidance driving the LM well redevelopment program (e.g., ASTM 2013, OEPA 2009, and internal LMS guidance and procedures). To satisfy the requirements of Task 4 in Table 1, additional literature searches were conducted to locate studies that specifically address the impacts of well redevelopment on sample analytical results or groundwater sample quality. Results of this search are provided in Appendix B and summarized briefly here. While there is a plethora of literature or guidance addressing well "development" (e.g., Schnieders 2003), this is usually in the context of post-well-installation standard procedures. Only a few articles address well "redevelopment" and in most cases only briefly. Few articles or studies were found that quantitatively addressed the impacts of well redevelopment; most of these focused on the effect on production (e.g., for municipal wells) rather than on groundwater sample quality. Furthermore, the bulk of the discussions or findings cited in Appendix B are based on experience and professional judgment rather than actual data. For example, a prevailing assumption is that periodic well redevelopment is needed to extend the life of a well (Korte 2001, Schnieders 2003). Although this may be true, no data supporting this statement were presented.

In summary, no data in the literature were found to support the assumption that redevelopment of wells impacts data quality, or that redevelopment is necessary to obtain samples that have the same chemical concentrations as those in the groundwater. There is evidence that redevelopment would increase production, but production is not an issue at most LM site wells. Literature discussions parallel the prevailing industry-wide assumption that well redevelopment is recommended to extend the life of a well.

5.0 Task 5: Compilation of Monitoring Well Redevelopment Records: 2010–2015

In accordance with the AWP, the LM and EMO database was mined to identify and compile information on groundwater monitoring well redevelopment from fiscal year (FY) 2010 through FY 2015. This effort focused only on western LM UMTRCA sites. For some sites with a longer well redevelopment record (e.g., the Grand Junction office site), older records dating back to 2005 were also included. This information, consisting of nearly 500 records of well redevelopments at 17 sites, was compiled largely from documents provided by EMO. Results of pre- and post-redevelopment analyses conducted at the Shiprock, NM, site in July 2013 and supplementary information from the SOARS (System Operation and Analysis at Remote Sites) database are also included in this summary. As indicated in this table and discussed further in Section 6, detailed well redevelopment records are available for only a small subset of wells, mostly those provided by EMO since July 2015. For most LM site wells, only the most recent logs or trip reports include pre- and post-well-redevelopment field measurements of SC, temperature, pH, and turbidity. Older logs (most not available) document turbidity and pumping rates only for some wells.

6.0 Task 6: Evaluation of Pre-and Post-Well-Redevelopment Groundwater Chemistry

The compilation of well redevelopment records discussed in Section 5 yielded a data set that is mixed with regard to both well redevelopment frequency and the level of detail associated with each event. For example, Grand Junction office site wells have been routinely redeveloped since 2005 (annually except for 2013), while other sites (e.g., Bluewater, NM) have only one or two documented redevelopment events (Table 2). The level of detail documented for each event also varies, as shown in Table 3 and summarized below:

- "**Dates only**"**:** No record of the redevelopment is available apart from the date it occurred. This applies to the majority of well redevelopment events listed in Table 2.
- **Sites with relevant information from other sources:** This category applies to sites or wells where, although no field measurements were taken during well redevelopment, data allowing examination of pre- and post- redevelopment groundwater chemistry are available from other sources or studies. For example, at the New Rifle site, pre- and post-redevelopment groundwater salinity can be evaluated in wells instrumented with SOARS SC probes.
- **Detailed record of pre- and post-redevelopment field measurements:** Redevelopment was recorded using the template that EMO developed in 2015 (Figure 3). Parameters measured include flow (pumping) rates, turbidity, SC, pH, and temperature. This category applies to five sites: Grand Junction, CO, Office Site; Gunnison, CO, Processing Site; Naturita, CO, Processing Site; Riverton, WY, Processing Site; and the Slick Rock (East), CO, Processing Site.

Table 2. Well Redevelopment at Western LM Sites: 2005–2015

LM Site	Year										
	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Bluewater Disposal Site									x		
Durango, CO, Processing Site (Mill Tailings & Raffinate Pond)									x		
Grand Junction, CO, Office Site	x	x	x	x	x	x	x	x		x	x
Green River, UT, Disposal Site								x	x	x	
Gunnison, CO, Processing Site					x	x	x	x		x	x
Lakeview, OR, Processing Site								x			
Naturita, CO, Processing Site											x
New Rifle, CO, Processing Site							x	x	x	x	
Old Rifle, CO, Processing Site									x	x	
Riverton, WY, Processing Site					x	x	x	x	x		x
Monticello, UT, Processing Site									x	x	
Naturita, CO, Processing Site											x
Shiprock, NM, Disposal Site (Terrace and Floodplain)									x	x	
Slick Rock, CO, Processing Site								x			x
Tuba City, AZ, Disposal Site									X	x	

Adapted from Table 1 in "Well Redevelopment at LM Sites Discussion and Recommendations" (Appendix A). Supplemented by site records and more recent information compiled by EMO \\lm\projects\SamplingProg\Maintenance\Well Redevelopment\.

Table 3. Level of Documentation Associated with Each Site Redevelopment Event

Site	Routine Redevelopment?[a]	No. of Documented Redevelopment Events Since 2005	Level of Detail on Record	Comments
Bluewater Disposal	No	1 (July 2013)	Dates Only	Seven wells were redeveloped; 6/7 had been installed in July 2012.
Durango (Mill Tailings & Raffinate Pond) Processing Sites	No	1 (July 2013)	One development log on file for four of the wells; otherwise "Dates Only"	18 wells redeveloped one month after preceding June routine sampling, and nearly one year prior to the subsequent (2014) sampling.
Grand Junction Office	Yes (since 2005, the only years wells were not redeveloped were 2012 and 2013)	10 since 2005 5 since 2010 plus 1 redevelopment of well 8-4S in July 2013 by AS&T staff	Mixed For most events, only dates were recorded. More detailed records taken in January 2015	Well 8-4S is instrumented with a SOARS water level transducer and SC probe, allowing examination of well redevelopment on groundwater salinity.
Green River Disposal	No	3	None (Dates Only)	13 wells redeveloped in Oct 2012, 4 in late 2013, and 11 in Apr 2014.
Gunnison Processing	Yes	6 (annually since 2009 except for 2013)	Mixed (dates only except for 2015)	Detailed redevelopment field measurements recorded in July and October 2015.
Lakeview Processing	No	1 (May 2012)	None (Dates Only)	The four wells were redeveloped 0–1 day prior to sampling.
New Rifle Site		3 (2012, 2013, 2014)	Mixed—some wells are SOARS-instrumented	SC measured continuously (5-minute readings) in SOARS wells.
Old Rifle Site	No	2 (2013–2014)	None (Dates Only)	26 wells redeveloped in April–May 2013, and 5 in May 2014.
Riverton Processing	Yes	5 (since 2009)	Mixed (EDGE form used in May 2015)	Site wells have been redeveloped almost annually since 2009.
Monticello Processing	No	2-3 (2013, 2014)	None (Dates Only)	Redevelopment occurred in July 2013 (39 wells), May 2014 (13 wells) and June 2014 (1 well).
Naturita Processing	No	1 (July 2015)	Detailed EDGE form	Only one redevelopment event on record for this site.
Shiprock Disposal Site	No	1 (March 13, 2014)	None (Dates Only)	11 terrace wells redeveloped; one base of escarpment floodplain well (1113) included in this subset.
Shiprock Floodplain	No	1 (July 2013)	Detailed independent study	Work done at request of LM site lead. Pre- and post- redevelopment chemical profiles investigated in five near-river wells.
Slick Rock East (SRE) Site	No	2 (2012, 2015)	Mixed	No detail for 2012 effort; EDGE form used in 2015.
Slick Rock West (SRW) Site	No	2 December 2012 and September 2015)	Mixed	Dates only recorded for first event; detailed trip report for the most recent event.
Tuba City Disposal Site	No	3 (2013–2014)	Trip reports, downhole camera surveys, and monthly sampling data	Most extraction wells at the site were redeveloped in 2013–2014.

[a] Routine redevelopments apply to those sites where redevelopments are conducted annually or nearly annually (e.g., the Grand Junction office and Gunnison processing sites). Until recently, there has been no repository for this information, and drivers or catalysts for redevelopment events have not been documented or defined. Rather, well redevelopments have historically been done at the discretion of the LMS site lead.

Figure 5 provides a graphical portrayal of the information listed above, demonstrating the variability in frequencies and level of detail associated with redevelopment events across LM sites in the western United States.

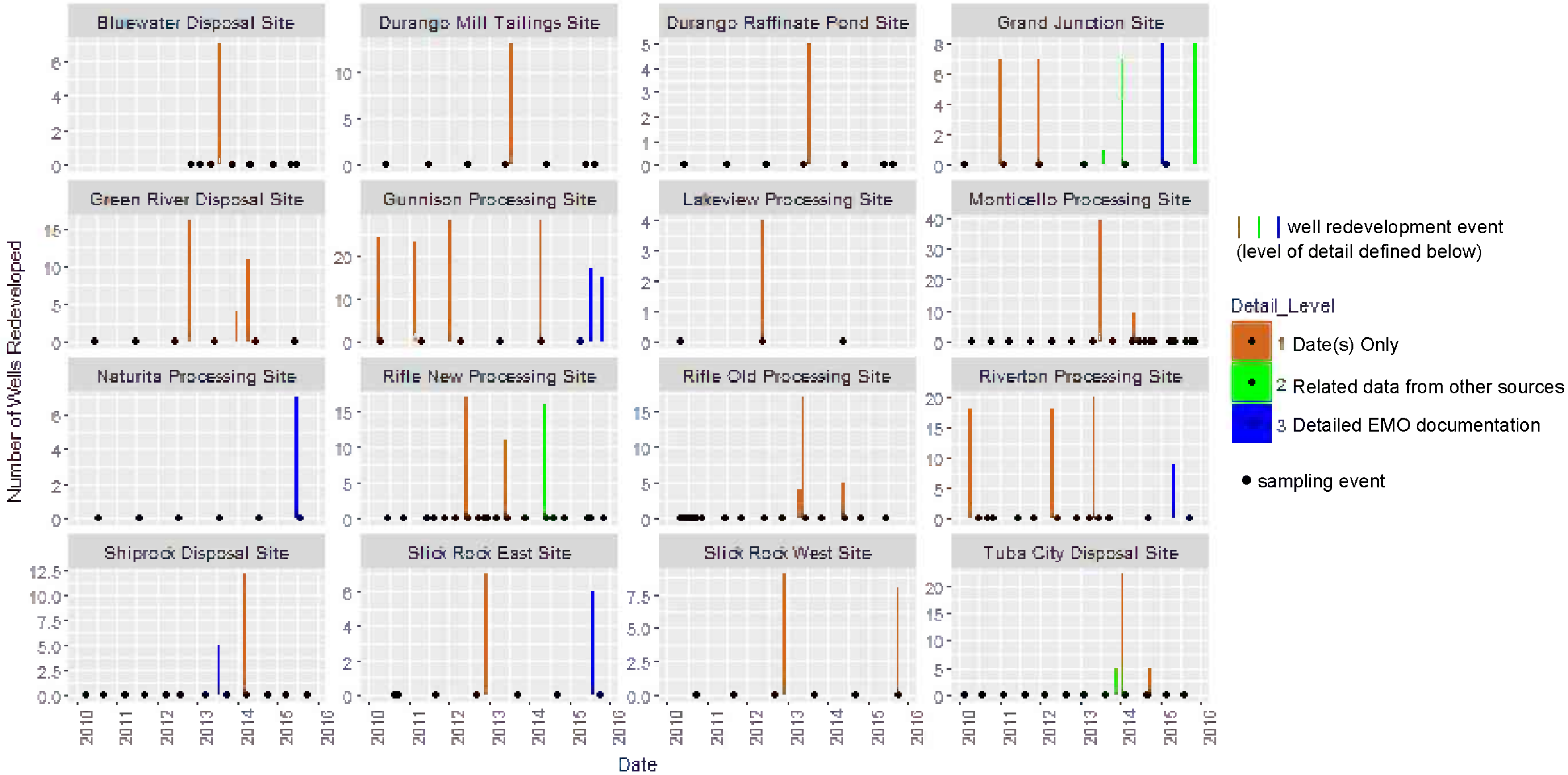


Figure 5. Overview of Well Redevelopment History and Documentation Status

For each site shown in this figure, vertical lines denote documented well redevelopment events. The height of the lines corresponds to the number of wells redeveloped; the color of the lines denotes the level of detail associated with each event (refer to legend).

6.1 Technical Approach

The primary questions driving this analysis are:

- *What, if any, short-term chemical changes are evident in post-redevelopment well water?*
- *What, if any, longer-term chemical changes are evident post-redevelopment well water?*

The first question can only be assessed for those sites/wells where pre- and post-redevelopment field or chemical measurements were collected. The second question—regarding whether a shift in contaminant trends is evident—is qualitatively assessed herein for all wells with documented redevelopments. Potential impacts of well redevelopment on groundwater chemistry are evaluated for the three categories of sites defined previously: (1) sites with no quantitative redevelopment records (i.e., "dates only" sites); (2) sites with relevant information from other sources (e.g., sites with SOARS-instrumented wells); and (3) sites/wells with at least one redevelopment during which pre- and post-redevelopment field measurements were taken. The data set defined in Section 5.0 was supplemented with the results of an independent evaluation of near-river Shiprock floodplain wells performed in July 2013 (Section 6.4).

Parameters of Interest Evaluated in this Assessment

For LM site wells addressed in this evaluation, the assessment of longer-term chemical impacts potentially related to well redevelopment focuses on uranium, the primary parameter used to assess groundwater remediation progress at UMTRCA sites. One of the greatest contributors to potential human health risks, and also one of the more mobile analytes, uranium is the most commonly monitored mill-tailings-related constituent at LM UMTRCA sites.

SC trends are evaluated for wells where this parameter was measured shortly before or after the well redevelopment event. This applies to SOARS-instrumented wells at the New Rifle processing and Grand Junction office sites, where specific conductance and temperature (SCT) and water level data are collected every 5 minutes and transmitted to the LM SOARS telemetry system. SC data are also evaluated for five Shiprock floodplain near-river wells and the five sites with recent detailed documentation of redevelopment field measurements.

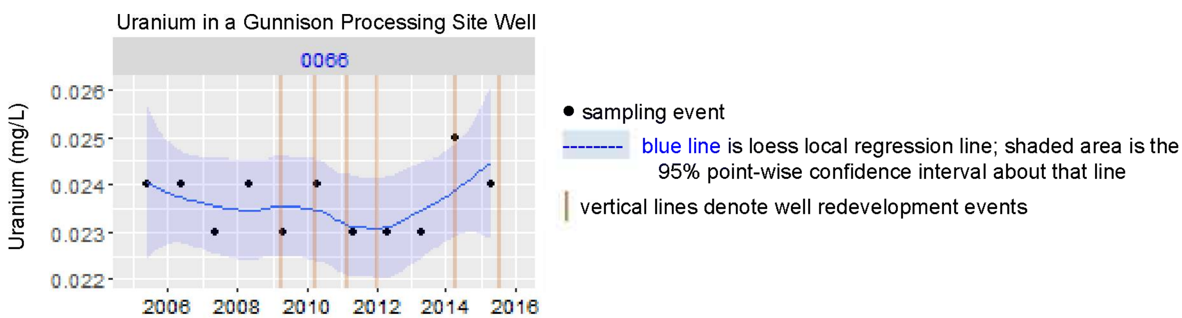
Although turbidity is the key (target) parameter monitored during redevelopment events, it is not useful as an indicator or predictor of short- or long-term contaminant trends in groundwater. In accordance with LMS sampling procedures (Section 3.1.1.1 of the Sampling and Analysis Plan), samples are pumped until turbidity meets the 10 NTU criterion. If the 10 NTU criterion is not met, samples are filtered. This protocol essentially invalidates any correlation between turbidity and contaminant concentrations for LM groundwater monitoring results. Although turbidity may be a useful indicator of water quality and for determining the *need* for redevelopment, it cannot be used as a reliable indicator of changes in chemical parameters.

For all sites with more detailed field documentation (Section 6.5), only nominal changes in pre- and post-redevelopment pH (generally ≤ 0.1) were noted. Due to pumping or surging of the well, changes in groundwater temperature after redevelopment would be expected. However, these changes would not necessarily indicate changes in chemical composition. For these reasons, pH and temperature were not evaluated in this assessment.

Approach Used to Evaluate Pre- vs. Post-Redevelopment Chemistry and Uranium Time-Trends

The approach used for evaluating pre- and post-redevelopment field measurements or analytical (uranium) results is for the most part qualitative. Because other variables—including water levels, river flows, precipitation, and (for active treatment sites) pumping rates—could affect groundwater chemistry, it would be difficult to identify any long-term chemical impacts of well redevelopment. Given these factors, combined with the large gaps in time between well redevelopment and monitoring for most of the sites assessed, developing a regression model to account for all possible variable influences would not be meaningful and might lead to spurious conclusions.

In lieu of a statistical approach, time-concentration plots are used to identify changes in contaminant concentrations potentially attributable to a well redevelopment event. In most of the subsequent figures plotting time-concentration trends for uranium, data for each well are plotted separately to facilitate interpretation of well-specific trends. In these figures, a non-parametric smoothing method or locally weighted regression—“loess” (not to be confused with the geologic term)—is used.[4] With this approach, overall trends in the data are more apparent and not obscured by “noise.” An example of this data presentation approach is shown in the inset below. For wells with only a few data points, the smoothing is not valid; in these cases, traditional line plots are used.



6.2 Sites with Nonroutine Well Redevelopment and No Associated Field Measurements

As defined previously, this category applies to sites for which no record of well redevelopment is available apart from the date it occurred. Neither field measurements nor the well redevelopment method (surging vs. pumping) were documented. Because few conclusions can be drawn about potential well redevelopment impacts for these sites, this section is limited to the provision of uranium time-concentration trends in redeveloped wells (most provided in Appendix C) and brief, if any, interpretations. The eight sites addressed in this section are:

- Bluewater disposal site
- Durango processing site
- Green River disposal site
- Lakeview processing site

[4] See http://www.inside-r.org/r-doc/stats/loess, http://docs.ggplot2.org/0.9.3.1/stat_smooth.html

- Monticello processing site
- Old Rifle processing site
- Shiprock disposal site (terrace)
- Slick Rock West processing site

To focus this report on the sites or wells with more detailed pre- and post-redevelopment data (Sections 6.3 and 6.4), time-concentration plots for all sites listed above are provided in Appendix C. A few of these figures are duplicated here, mainly to demonstrate the paucity of associated data and to identify factors potentially confounding interpretations of uranium time-concentration trends.

6.2.1 Bluewater Disposal Site

Only one redevelopment event has been documented for the Bluewater disposal site: seven wells, most of them constructed in summer 2012, were redeveloped in July 2013. Figure 6 shows time-concentration plots of uranium in this subset of wells. Increases in uranium in wells 14(SG) and 15(SG) between May 2013 and November 2013—0.03 to 0.07 milligram per liter (mg/L) and 0.045 to 0.17 mg/L, respectively—could be attributed to the July 2013 well redevelopment event if other potential factors, described below, were ignored (i.e., based on a simplistic cause and effect analysis). However, the available data are insufficient to draw that conclusion.

Several months prior to the July 2013 redevelopment, profiling work at the site revealed variations in both SC and uranium concentrations with depth (i.e., stratification) in some San Andres aquifer wells (the wells profiled are not part of the subset shown in Figure 6). These observations were a catalyst for paying closer attention to sampling depths, which were ultimately modified in some wells (samples were collected at deeper mid-screen intervals).

Notable variation in SC was not found in wells 14(SG) and 15(SG) during later profiling work conducted for the AS&T *Variation Project* (DOE 2015a); SC vertical profiles were relatively flat. There is also no apparent correlation between water levels and uranium in these wells. Although it is possible that well redevelopment may have caused the increases in uranium in wells 14(SG) and 15(SG)—the wells had just recently been installed—the data are insufficient to substantiate that conclusion. Sample depths, well redevelopment, normal variation ("noise"), some other factor, or a combination of factors, could have accounted for the observed increases.

6.2.2 Durango Processing Site

Similar to the Bluewater site, only one redevelopment event has been documented for the Durango disposal site. In July 2013, 13 wells were redeveloped at the mill tailings processing site (5 of these are no longer monitored), and 5 wells were redeveloped at the raffinate pond site (well 0623 is no longer monitored).

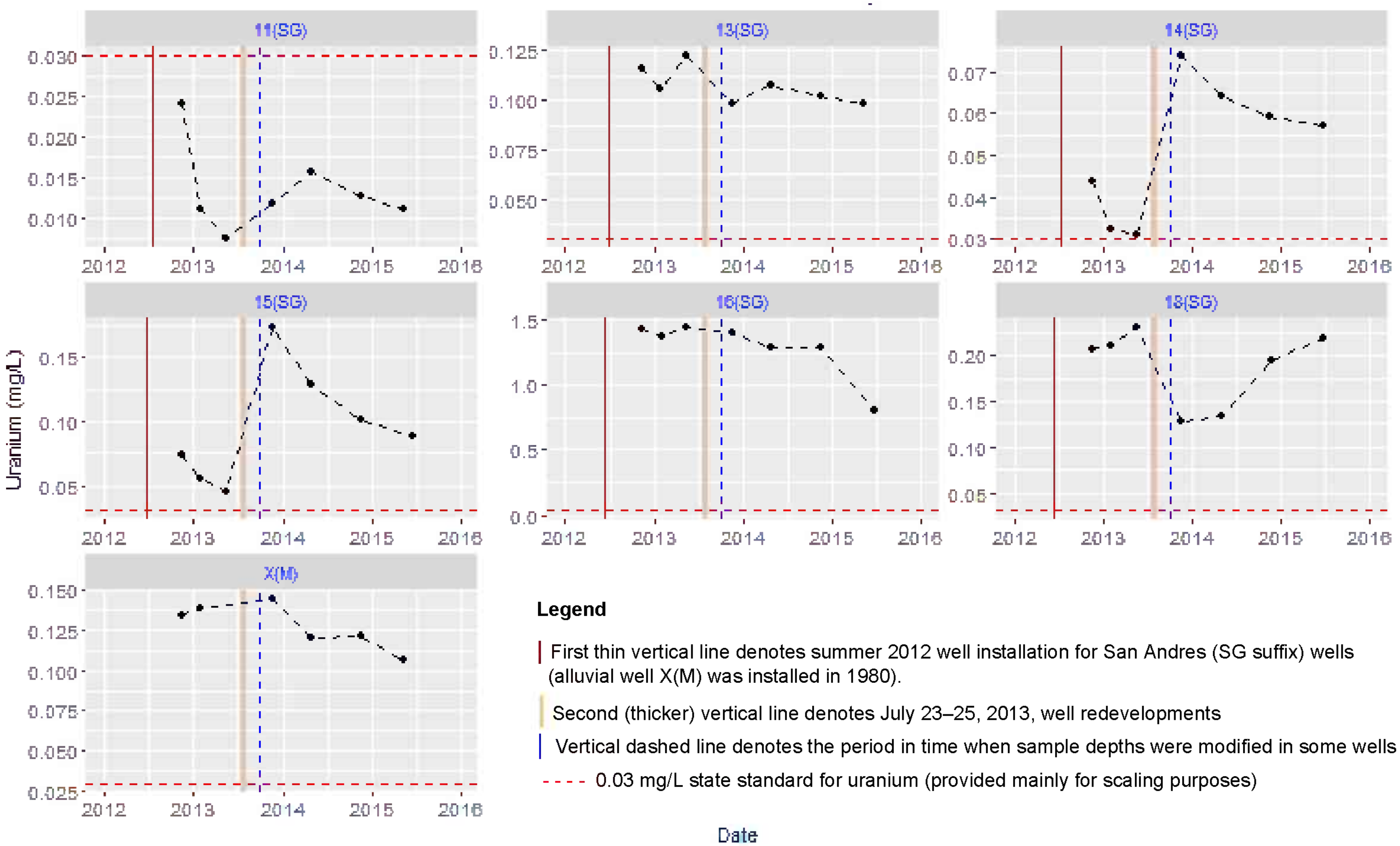


Figure 6. Time-Concentration Plots of Uranium in Bluewater Disposal Site Redeveloped Wells

This figure is duplicated in Appendix C, Figure C-1.

Limited documentation was recorded for 4 of 18 wells (development log shown in Figure 1); apart from that, only dates were recorded. Time-concentration plots of uranium in Durango processing site redeveloped wells are provided in Appendix C, Figures C-2 and C-3, for mill tailings and raffinate pond area wells, respectively. As shown in these figures, uranium trends are fairly stable in all wells, and no impact of well redevelopment is apparent. All site wells were redeveloped about 1 month after the June 2013 routine sampling event. Nearly 1 year had elapsed between well redevelopment and the subsequent (June 2014) sampling event. Given that large time lag, it would be difficult to identify any impacts of well redevelopment. Changing flows in the nearby Animas River and groundwater elevations are other factors potentially affecting groundwater chemistry.

6.2.3 Green River Disposal Site

Based on EMO records, Green River site wells have been redeveloped twice since 2010, first in October 2012 (16 wells) and again in December 2013 (4 wells) and April 2014 (11 wells). Figure 7 plots uranium versus time for the nine redeveloped wells that are regularly monitored. (Appendix C, Figure C-4 plots uranium trends for remaining wells.) As shown in Figure 7, uranium trends in most wells are stable, with no apparent impact of well redevelopment. However, in a few wells—0171, 0173, and most notably 0813—uranium concentrations deviate from pre-redevelopment levels (points fall outside the point-wise 95% confidence interval). These deviations cannot be explained by changes in groundwater elevations; there is no apparent correlation between water levels and uranium. Because of the time-scale in this figure, the 2014 sampling event appears to fall immediately after well redevelopment in most wells. However, well 0813 was sampled 2 months after the April 2014 redevelopment. Whether or not deviations in uranium trends in wells 0171 and 0813 are attributable to preceding well redevelopment cannot be determined from the available data.

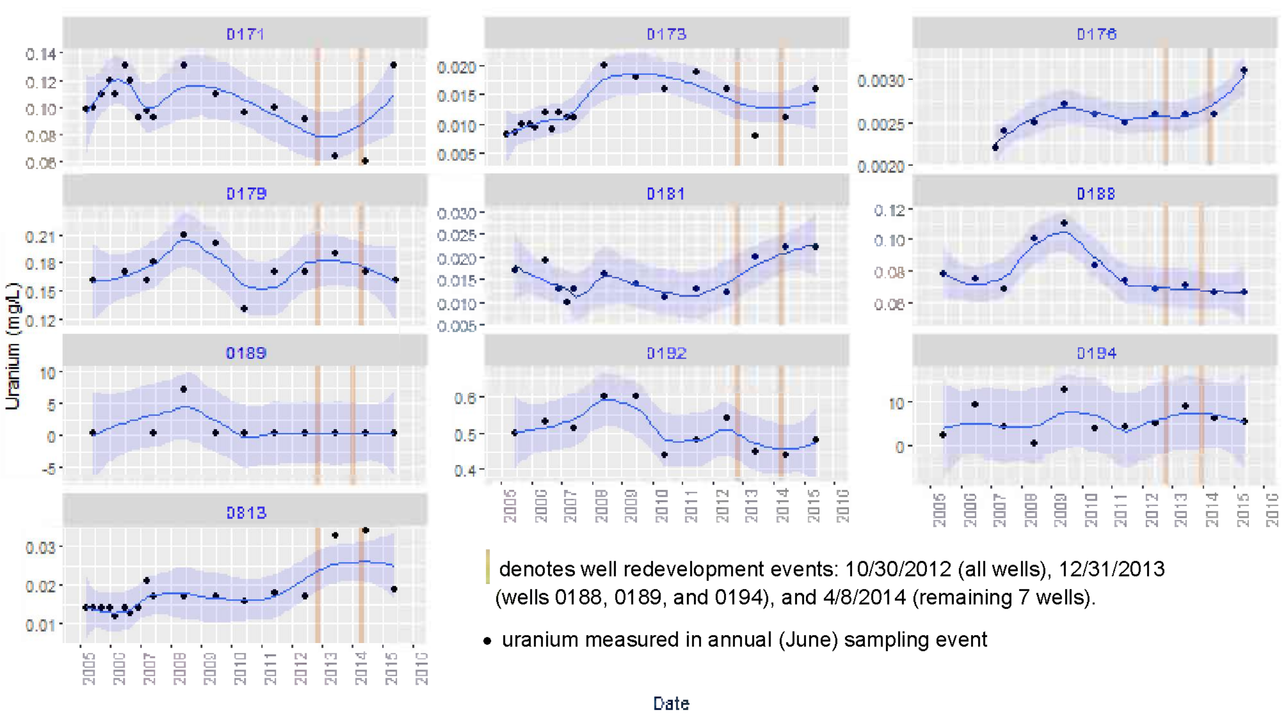


Figure 7. Time-Concentration Plots of Uranium in Green River Disposal Site Wells

6.2.4 Lakeview Processing Site

Four Lakeview processing site wells—0503, 0505, 0509, and 0540—were redeveloped in May 2012. Time-concentration plots of manganese and sulfate, the primary contaminants of concern at the site, are provided in Appendix C, Figure C-5. Uranium has generally not been detected in wells 0503, 0505, and 0509; uranium concentrations in well 0540 have varied but with one exception have been below the 0.044 mg/L uranium standard established for UMTRCA. No impact of well redevelopment is apparent in these wells, based on examination of manganese and sulfate trends in Figure C-5. What is noteworthy, however, is that very little time had elapsed between the 2012 redevelopment and the subsequent biannual sampling event. Wells 0503, 0505, and 0509 were sampled one day after the 5/15/2012 redevelopment; well 0540 was sampled on the same day (5/16/2012). Although this approach deviates from EMO's standard recommendation to allow at least 1 week between redevelopment and sampling (see white paper in Appendix A), no impacts of the well redevelopment are apparent.

6.2.5 Monticello Processing Site

Fifty-three Monticello processing site wells were developed in 2013–2014: 39 were redeveloped in July 2013, and the remaining 14 in May–June 2014. For about 15 of these wells, it appears that well development coincided with well construction, as monitoring of this subset did not begin until June–July 2014. Time-concentration plots of uranium for remaining redeveloped wells (i.e., those with a prior monitoring history) are shown in Appendix C, Figure C-6. Consistent with findings at most other sites addressed in this evaluation, there are no apparent impacts of well redevelopment on uranium trends in these wells. Other factors such as water levels and treatment system impacts are likely to be more influential.

6.2.6 Old Rifle Processing Site

Twenty-six Old Rifle processing site wells were redeveloped in April–May 2013. Five of those wells—those that are routinely monitored (0292A, 0304, 0305, 0309, and 0310)—were redeveloped again in May 2014. Rationales for these redevelopment efforts were not documented, and associated field measurements are not on record. About half of the wells redeveloped in 2013 (e.g., JD-series wells) are used to monitor water chemistry under an Integrated Field Research Challenge program sponsored by the DOE Office of Science; these wells are not sampled by LM. Time-concentration plots of uranium for the subset of Old Rifle site wells routinely monitored are provided in Appendix C, Figure C-7. There are no apparent impacts of well redevelopment on uranium trends in these wells. Even if apparent anomalies in concentration trends were found, the cause would more likely be attributable to seasonal fluctuations in Colorado River flows and groundwater elevations.

6.2.7 Shiprock Disposal Site Wells

Twelve Shiprock disposal site wells were redeveloped on March 14, 2014, two weeks before the subsequent semiannual sampling event. Eleven of these wells are on the terrace, and one (1113) is at the base of the escarpment on the floodplain. Time-concentration plots of uranium for these wells are provided in Appendix C, Figure C-8. Although the March 27, 2014, uranium result for terrace well 1068 is an outlier relative to previous and subsequent measurements, uranium trends are stable in all other wells. Without detailed information on other potential variables and the redevelopment event itself, the degree to which redevelopment of well 1068 influenced uranium concentrations in the well (if at all) cannot be determined.

6.2.8 Slick Rock West Processing Site

Two redevelopment events are on record for the Slick Rock West (SRW) processing site. The first occurred in December 2012 (nine wells), and the second in September 2015 (eight wells). Although associated field measurements were not recorded, the trip report documenting the most recent (2015) redevelopment effort nicely describes the methods used. Wells were scrubbed with a brush to remove bio-slime, surged with a block to loosen fines and bio-slime residing in the sand pack, and then purged until the turbidity reached ≤10 NTU. Surge and purge cycles were repeated at least two times at each well. Time-concentration plots of uranium for the seven SRW wells currently monitored are shown in Appendix C, Figure C-9. There is no apparent impact of the two redevelopment events on uranium concentrations in these wells.

6.3 Sites with Relevant Information from Other Sources

This section addresses past well redevelopment efforts at the New Rifle processing site and Tuba City disposal site. Although no field measurements were recorded during these events, data allowing examination of potential short-term impacts of well redevelopment on groundwater chemistry are available from other sources or studies.

6.3.1 New Rifle Processing Site

No development logs or redevelopment trip reports are on record for the New Rifle site. However, some site wells are instrumented with SOARS SCT probes, allowing examination of pre- and post-redevelopment groundwater salinity. Based on EMO records, there have been three well redevelopment events at the New Rifle site since 2010: May 2012 (17 wells), May 2013 (13 wells), and May 2014 (15 wells). Five of the wells redeveloped during this time frame—0201, 0214, 0590, 0683, and 0688—are instrumented with SOARS equipment, enabling continuous (5-minute) measurements of water levels and SC. Figure 8 plots daily average SC for four of these five wells, as measured between June 2008 and 2016.[5] (Well 0215 was also redeveloped in late 2011 based on SOARS maintenance records.)

Figure 8 demonstrates the normal variation in SC for this subset of wells. In well 0215, however, a number of the shifts (all increases) in SC appear to correlate with all four well redevelopment events. These shifts can be explained by the chemical stratification measured in this well in a previous study, the AS&T Variation Project. In support of this effort, SC profiles were measured in 34 New Rifle site wells in 2013 (DOE 2015a). Well 0215 had the greatest degree of variation of all wells profiled, with SC ranging from 969 to 4174 microsiemens per centimeter (µS/cm) over the 12.5 ft saturated interval (Figure 9). The shifts in SC shown in Figure 8 likely resulted from mixing of the well water during well redevelopments. Routine monitoring data were then evaluated to assess whether there were similar (long-term) impacts on uranium concentrations in SOARS-instrumented wells (Figure 10).

[5] SC for well 0688 is not plotted in Figure 8 because SCs have been fairly low: 445–1956 microsiemens per centimeter (µS/cm). Also, this well was sampled for only a limited time (2008–2009), with uranium ranging from 0.005–0.01 mg/L.

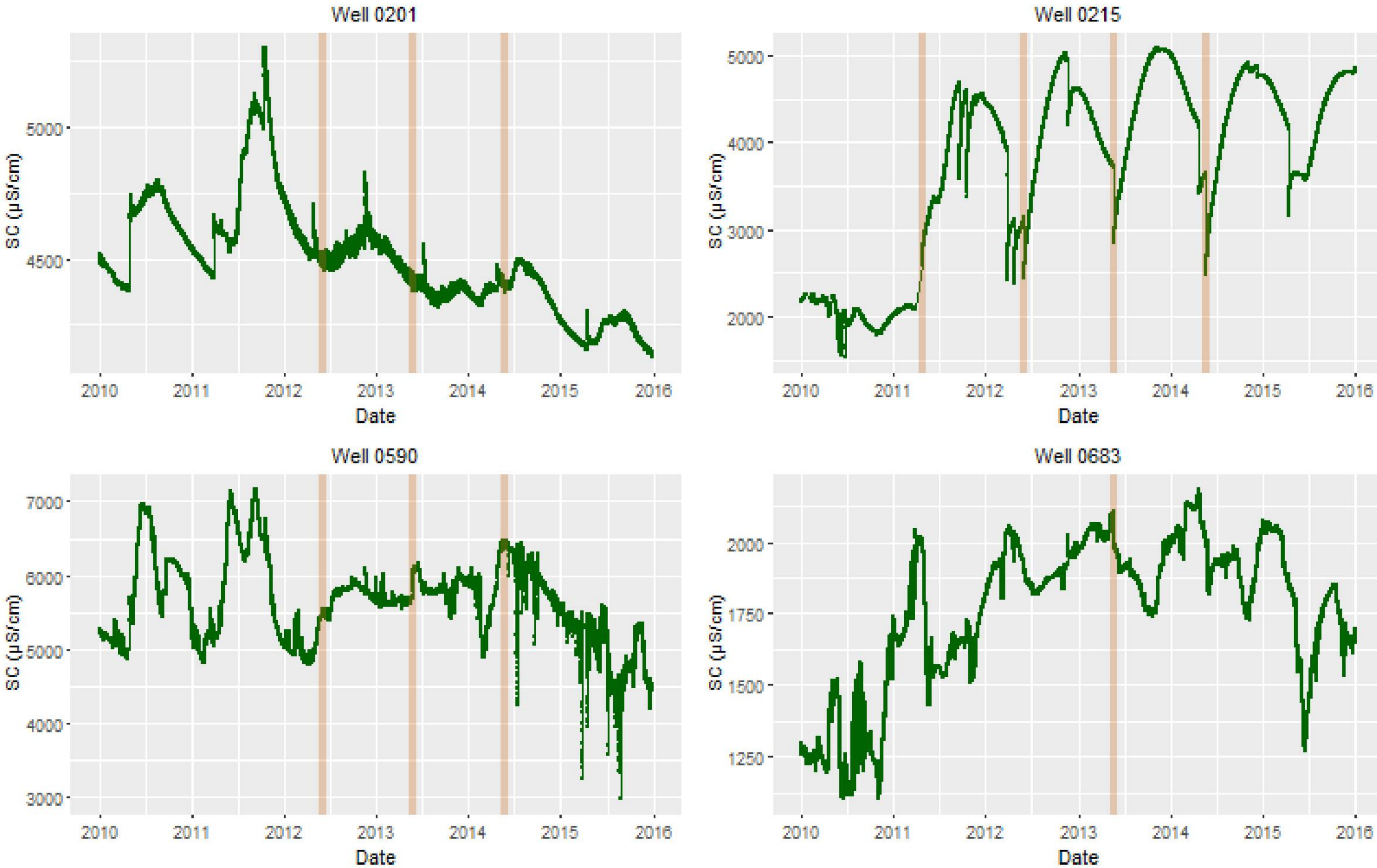


Figure 8. Specific Conductance Data from SOARS in New Rifle Processing Site Wells
Daily Average SCs from SOARs, 2009–2016

denotes well redevelopment events

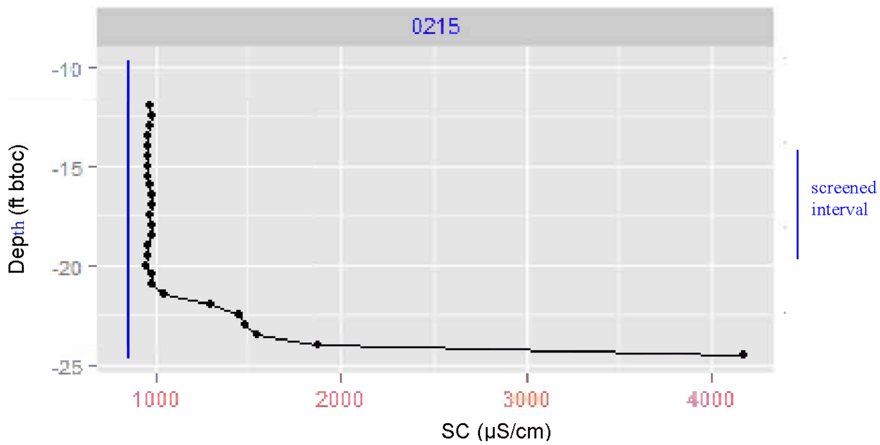


Figure 9. Vertical Profile of SC in New Rifle Site Well 0215, October 2013

Adapted from Figure 43 in DOE 2015a. Based on the coefficient of variation (standard deviation divided by the mean) of 0.54, well 0215 had the most variable SC profile of all 34 site wells profiled for the Variation Project.

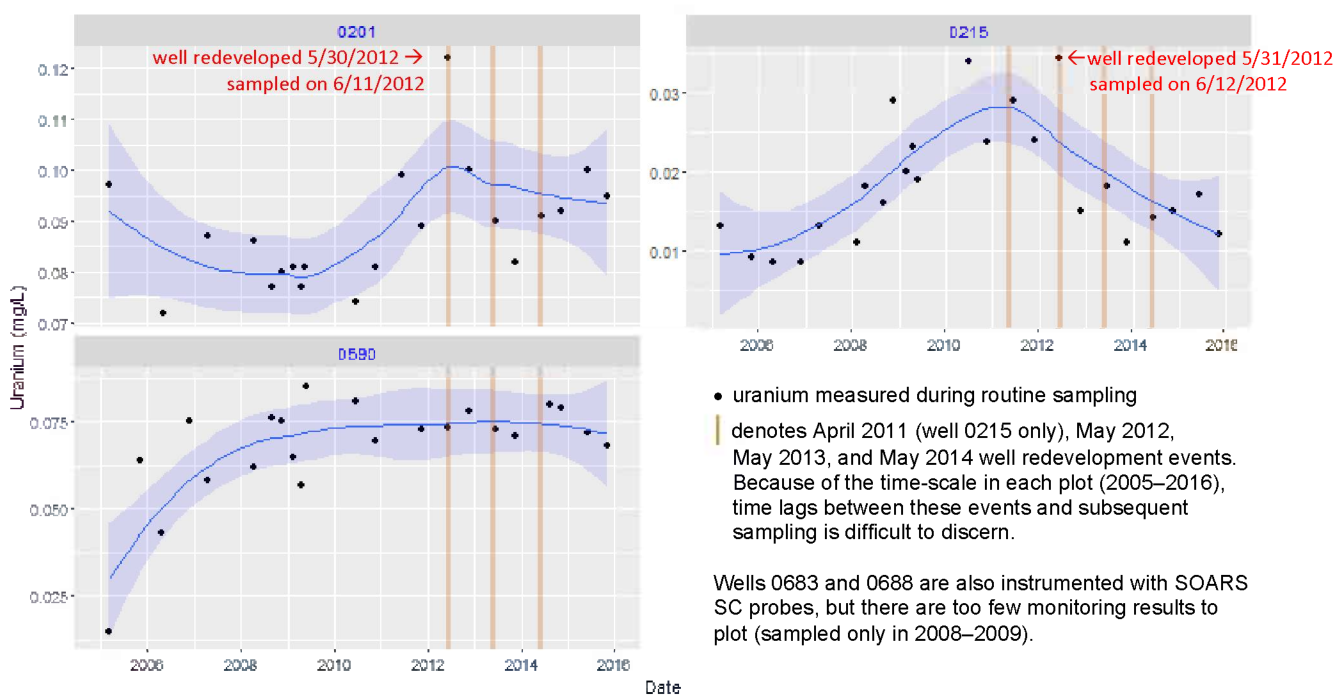


Figure 10. Time-Concentration Plots of Uranium in New Rifle Site Wells with SOARS SC Probes

Figure 10 shows no consistent impact of well redevelopment on uranium concentrations in wells 0201, 0215, and 0590. However, a few results—the June 2012 uranium levels measured in wells 0201 and 0215, twelve days after redevelopment—do deviate from historical observations. It is possible that these outlier measurements are attributable to the preceding redevelopment effort. But similar increases in uranium are not evident for the other redevelopment events, and no impacts are apparent in well 0590. As shown in Figure 11, uranium trends in remaining (non-instrumented) site wells are generally stable, also showing no apparent impact of well redevelopment.

Figure 11. Time-Concentration Plots of Uranium in Remaining New Rifle Site Redeveloped Wells

6.3.2 Tuba City Disposal Site

The Tuba City disposal site groundwater remediation system consists of 37 extraction wells, encompassing an area of approximately 100 acres. The system operated fairly continuously between mid-2002 and October 2010, when groundwater extraction and treatment was suspended. In October 2011, active remediation resumed intermittently until March 2014, when the system was suspended indefinitely (DOE 2016). To improve production efficiency, LM undertook a system-wide extraction well redevelopment effort in 2013 and 2014. There was also concern about well maintenance needs, given the age—most were installed in 1999—and depth of the wells (average screen depths and lengths of 80 and 100 ft, respectively).

Five extraction wells were developed in December 2013, 22 in January 2014, and the remaining 5 wells in October 2014.[6] Detailed trip reports documented these events (Price 2013, 2014a, and 2014b). Extraction wells were redeveloped using traditional methods of brushing, surging, and purging. In most wells, borehole video recordings were made to document the condition of the well screen prior to redevelopment. The downhole camera inspections and physical examination of pipes and pumps removed from the wells indicated that two types of well-fouling were occurring. The first was gypsum precipitating and forming a scale on the drop-pipe and most likely on the well screen; this was limited to the shallower wells (~100–130 ft). The second type of well-fouling observed was a bacterial slime coating, found only in deeper (250 ft) wells. The bacterial slime is easily removed physically; however, the gypsum scale is not (Price 2013). Figure 12 shows screen captures of downhole videos taken in extraction well 1105, before and after redevelopment of the well. The gypsum scale is evident in the pre-development video (Figure 12a), as is the effectiveness of well development in removing the scale (Figure 12b).

It is not clear what, if any, impacts the redevelopment had on production capacity, as treatment was suspended in March 2014. However, a question more pertinent to this evaluation is: what impact did redevelopment have on groundwater chemistry in these wells? Field measurements were not taken during the redevelopment effort, and the time lag between redevelopment and the subsequent annual sampling event was about 7 to 9 months (annual sampling of extraction wells typically occurs in August). To better evaluate potential impacts of redevelopment on well chemistry, results of monthly samples analyzed at the AS&T Environmental Sciences Laboratory (ESL) were examined.

Between August 2009 and October 2015, extraction wells were sampled monthly; analytes were nitrate, sulfate, and uranium—the primary contaminants of concern (COCs) at the site—and calcium and chloride. Using well 1105 as an example, Figure 13 includes time-concentration plots for each of these analytes based on ESL results reported for the 2009–2015 monthly monitoring period. Although COC concentrations fluctuate in this well (these fluctuations might be related to varying pumping rates), there is no apparent impact of well redevelopment on overall trends. Figure 14, a zoom view of these data focusing on the period before and after well redevelopment (2013–2015), further supports this conclusion.

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[6] Five extraction wells were not redeveloped: 1122 (electrical problems); 1128 and 1131 (wells were dry); and 1129 and 1133, which were observed to be clean and therefore not redeveloped.

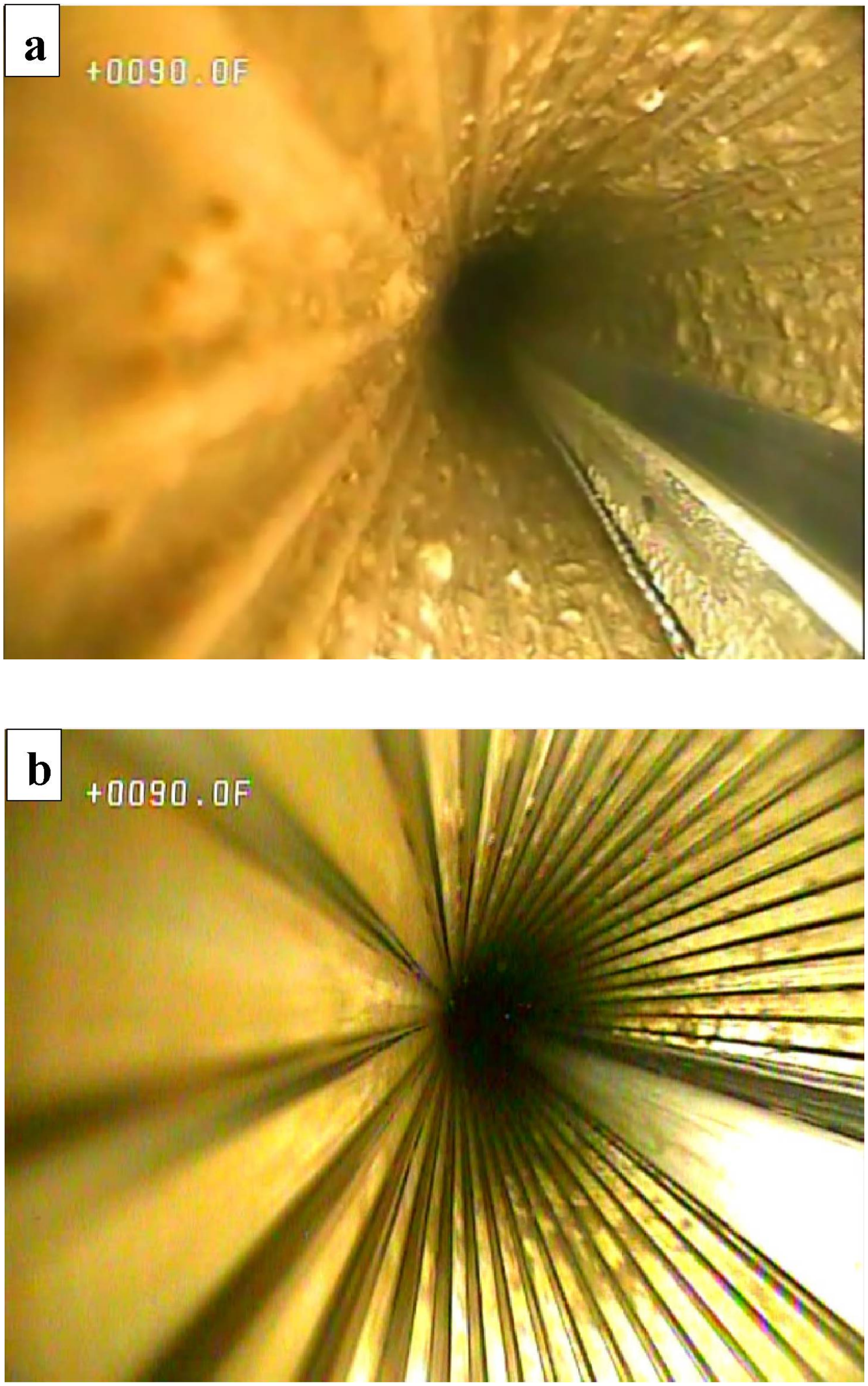


Figure 12. Screen Captures at 90 ft Depth of Tuba City Site Extraction Well 1105
(a) Before and (b) After Redevelopment; Screen Depth: 87 ft below top of casing; Screen Length=155 ft

Although downhole videos were taken in most wells, well 1105 is the only well for which there is an associated audio. All videos taken during the 2013–2014 Tuba City site well redevelopment effort can be found using the following links:

\\lm\gis\Sites_Prod\Sites\AZ\TUBACITYDISPOSAL\Images\2014\20140108_Price_Video
\\lm\gis\Sites_Prod\Sites\AZ\TUBACITYDISPOSAL\Images\2014\20141008_Price_Video

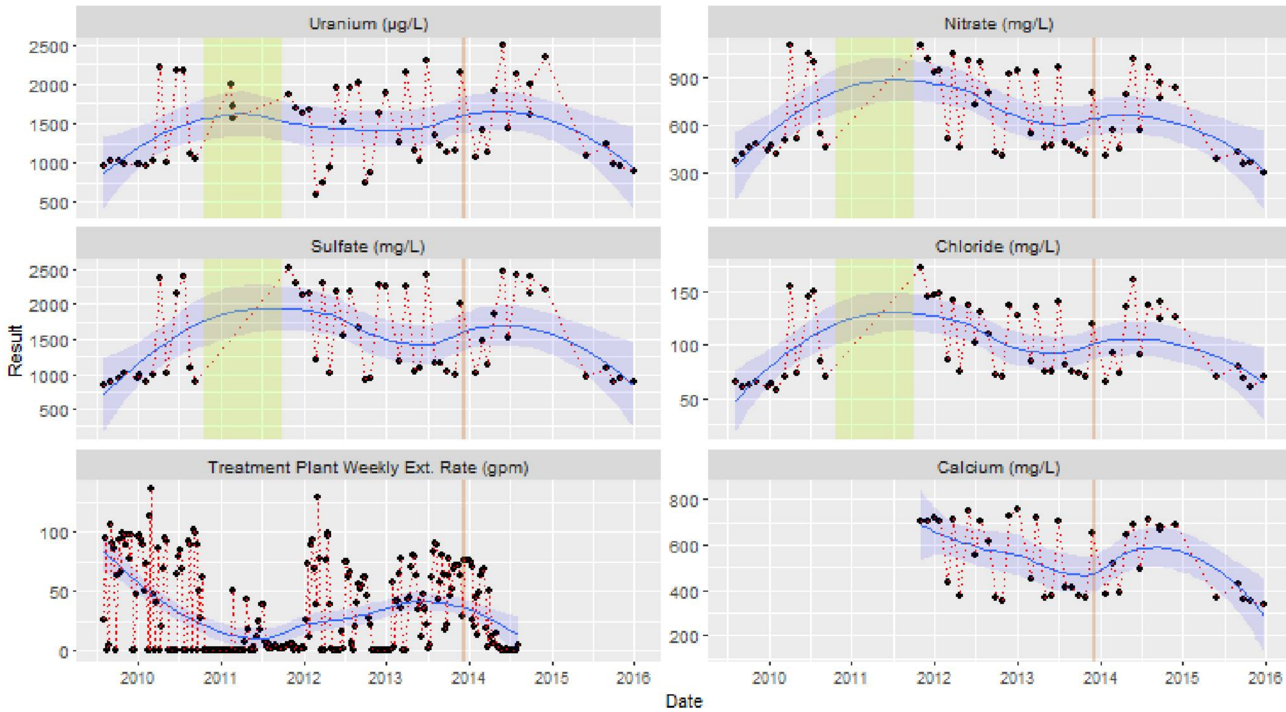


Figure 13. Time-Concentration Plots of Constituents in Tuba City Site Extraction Well 1105, 2009–2016

Data plotted are monthly sample results (analyzed at ESL). | denotes December 2013 well redevelopment.
Green shaded area denotes interim period (2010–2011) when groundwater extraction and treatment was suspended.
Active remediation resumed intermittently until March 2014.

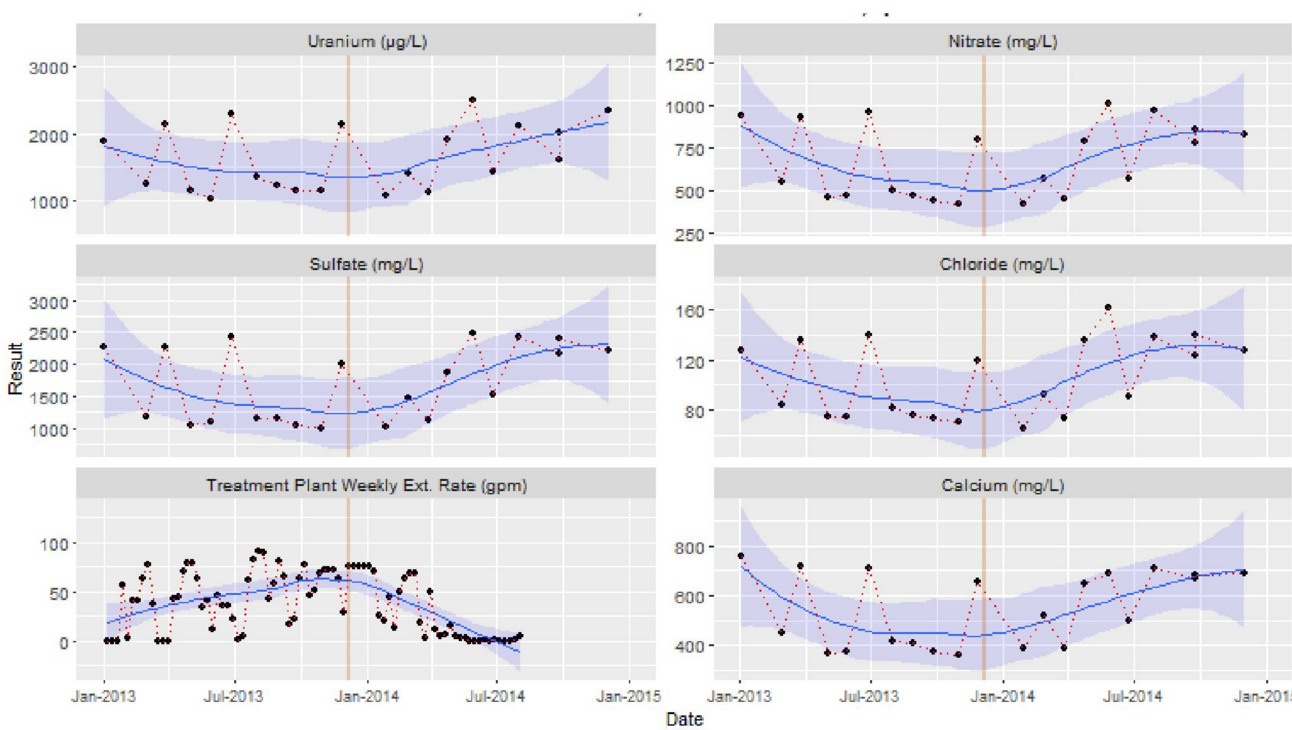


Figure 14. Zoom View of Well 1105 Time-Concentration Plots, 2013–2015

| denotes December 2013 well redevelopment

Figure 15 and Figure 16 plot monthly uranium concentrations for extraction wells redeveloped in December 2013 and January 2014, respectively. Monthly data were insufficient to plot concentration trends for the five wells redeveloped in October 2014 (0936, 0938, 0942, 1126, and 1127). For comparison, Appendix C, Figure C-10 shows time-concentration plots of uranium based on annual sampling results for all redeveloped wells. Consistent with conclusions drawn for well 1105, there are no apparent impacts of well redevelopment on uranium trends in these wells. Extraction (pumping) rates and fluctuations in groundwater elevation would be more important factors influencing contaminant concentrations.

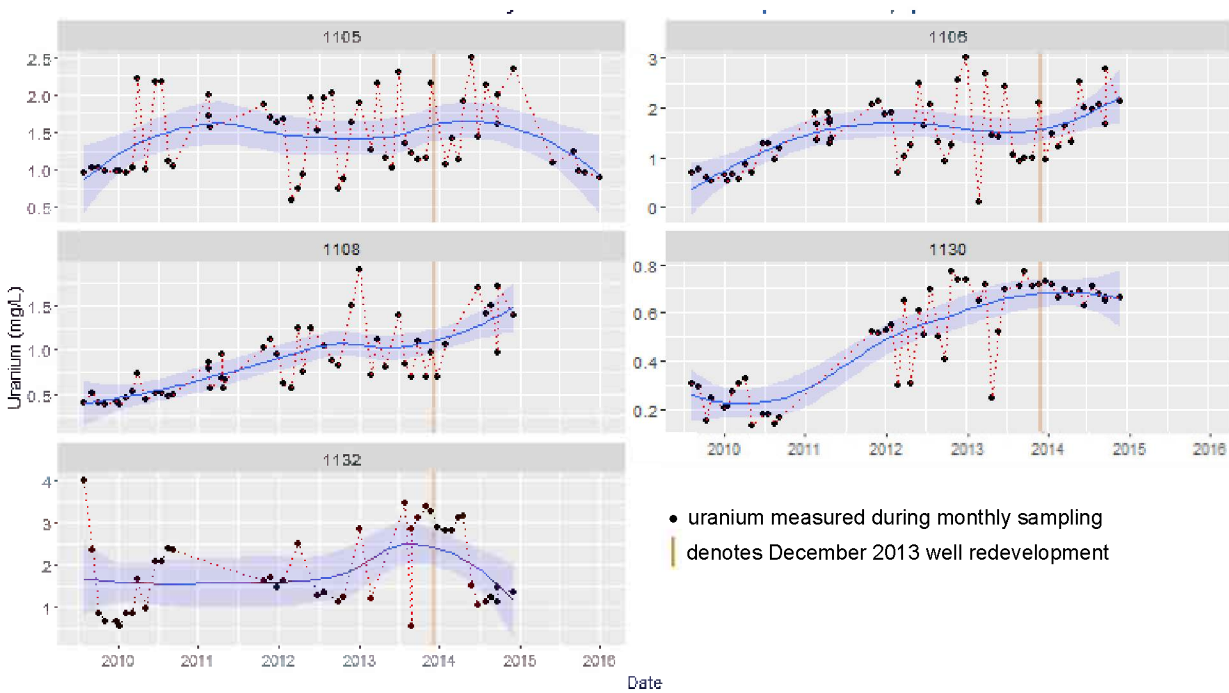
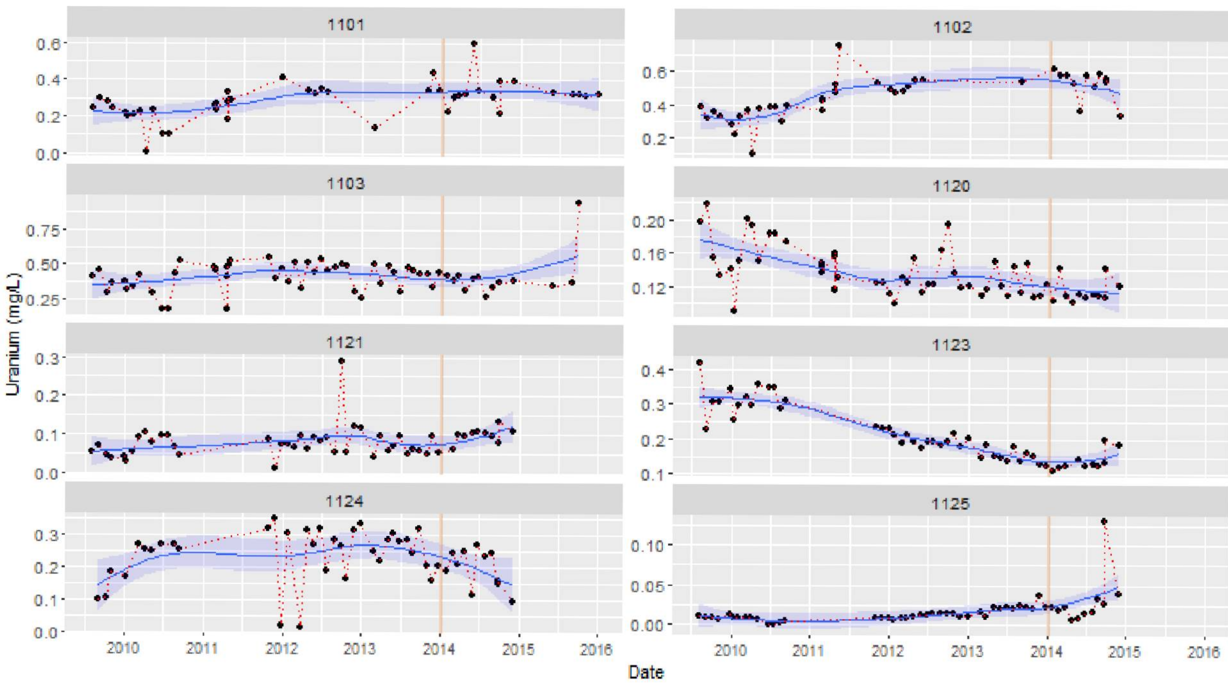


Figure 15. Monthly Uranium Measurements in Tuba City Extraction Wells Redeveloped December 2013

Wells were redeveloped December 2–5, 2013.
Uranium plot for well 1105 duplicates that shown in upper left plot of Figure 13.

a. Extraction Wells Redeveloped January 6–10, 2014



b. Extraction Wells Redeveloped January 13–17, 2014

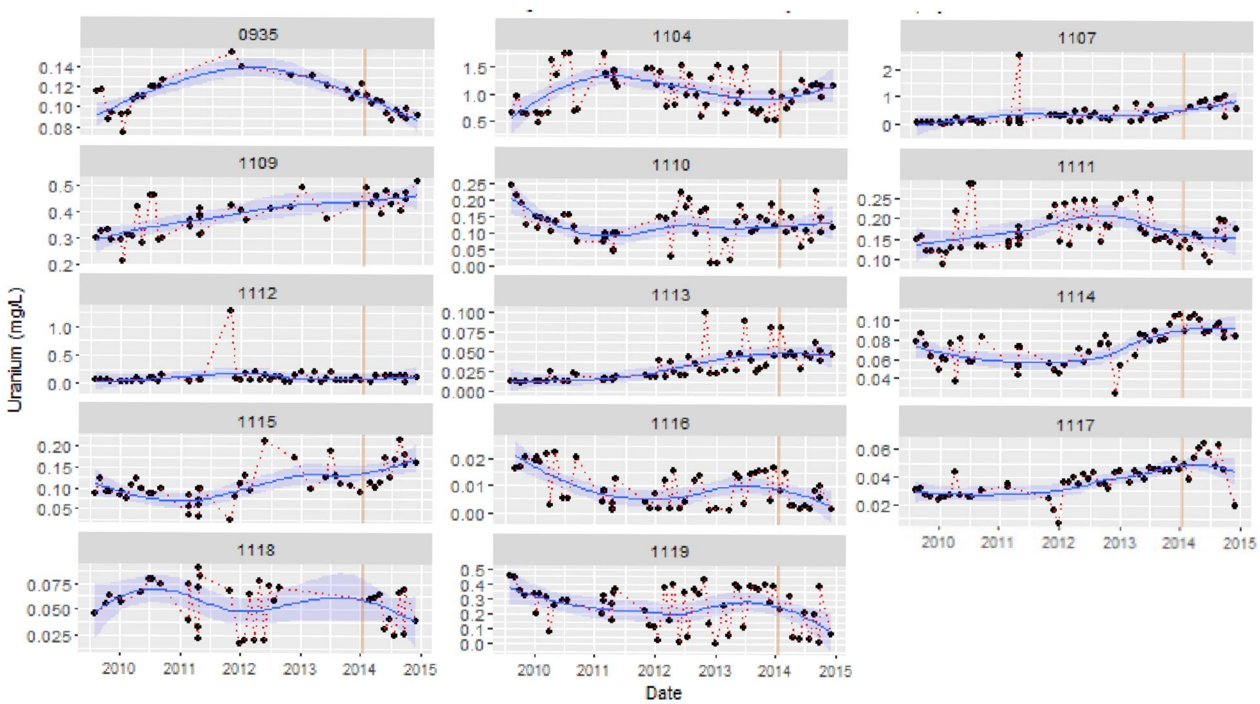


Figure 16. Monthly Uranium Measurements in Tuba City Extraction Wells Redeveloped in January 2014

| denotes January 2014 well redevelopment

6.4 Shiprock Disposal Site Floodplain—July 2013 Profiling Event

The material addressed in this section falls into a distinct category, as the results apply to a site-specific evaluation undertaken by AS&T in support of the Shiprock site. These findings are documented here because they are directly relevant to this study. In July 2013, AS&T conducted fieldwork to examine pre- and post-well-redevelopment SC and chemical profiles in a subset of wells on the central portion of the Shiprock floodplain near the San Juan River: 0857, 1136, 1137, 1138, and 1139. A catalyst for this effort was observed increases in contaminant concentrations in these but not in other wells nearby. Uranium concentrations in the near-river wells had more than doubled between 2010 and 2013, and similar trends were apparent for other COCs (nitrate, sulfate, and selenium). The remainder of this section summarizes the methods and results of that investigation.[7]

6.4.1 Methods

Fieldwork was conducted July 22–26, 2013. SC profiles were taken by slowly lowering a sonde down the well's water column and stopping at each 0.5 ft interval; the sonde was left at the target depth until SC and temperature readings were stable. Each well was developed in accordance with standard LMS practices until the turbidity in the well water was less than 10 NTU. SC profiles and chemical samples were taken at 0.5 ft intervals both before and after well development; the time lag between these events was about 48 hours. Samples for chemical analysis were pumped from each 0.5 ft interval at about 100–150 milliliters per minute and analyzed in the ESL for uranium, nitrate, selenium, sulfate, and chloride.

6.4.2 Results

No consistent differences in pre- vs. post-development SC and chemical profiles were found for this well subset. The box plots in Figure 17 indicate differences in pre- and post-well-redevelopment profiles for some constituents—for example, selenium in well 0857, and chloride, SC, and sulfate in well 1137. However, each box plot represents the entire SC or chemical profile, encompassing a range of sample depths. Individual pre- and post-redevelopment profiles (shown in Figures 18 through 23) indicate that, for the portions of the well most typically sampled, post-redevelopment profiles are generally similar to pre-redevelopment profiles. For example, although pre- and post-redevelopment selenium profiles differed markedly in the upper (non-screened) portion of well 0857, profiles within the screened interval were similar.

Whatever short-term impacts well redevelopment had on these wells, no long-term impacts are apparent based on semiannual monitoring results for uranium (Figure 24). Fluctuations in uranium concentrations in well 1136 appear to be correlated with seasonal changes in groundwater elevations (Figure 25). Changes in COC concentrations in wells 1137, 1138, and 1139 would also likely be influenced by variable pumping rates at nearby wells 1089 and 1104. The most important finding of this investigation is not whether or not pre- and post-well-redevelopment samples differ in terms of representativeness or quality. Rather, the marked vertical stratification found in these wells highlights the importance of considering sample depth when interpreting results: sampling of different strata can yield variable and inconsistent results.

[7] The full report is posted on the AS&T SharePoint site: https://projects.lm.doe.gov/AST/The%20MEMO/Forms/AllItems.aspx

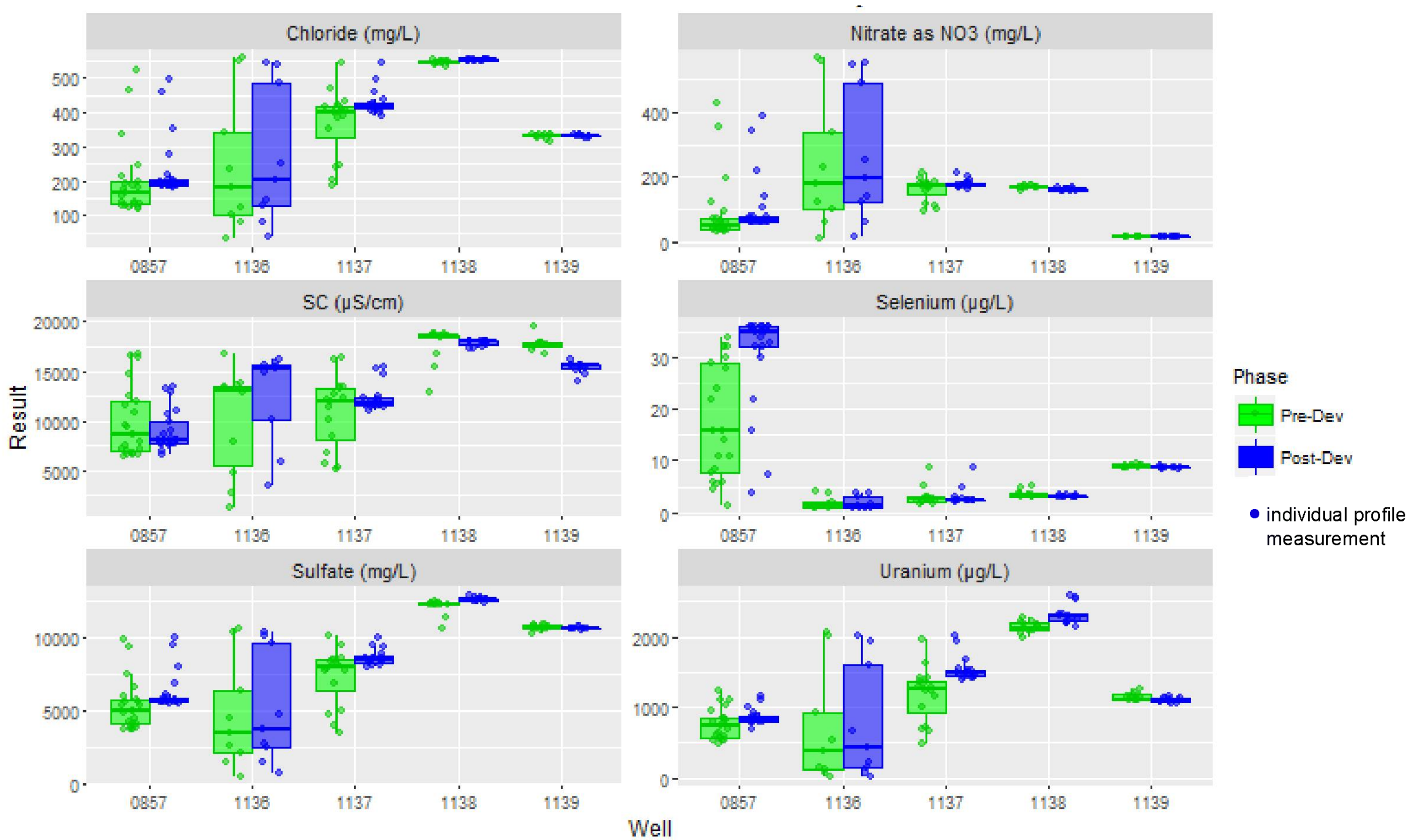


Figure 17. Box Plots of Pre- and Post-Well-Redevelopment SC and Chemical Concentrations in Near-River Shiprock Floodplain Wells

Data from July 2013 independent evaluation of Shiprock near-river wells.
Each box plot includes measurements at different depths, corresponding to the well profiles plotted in Figures 18 through 23.
The time lag between pre- and post-redevelopment measurements was approximately 48 hours.

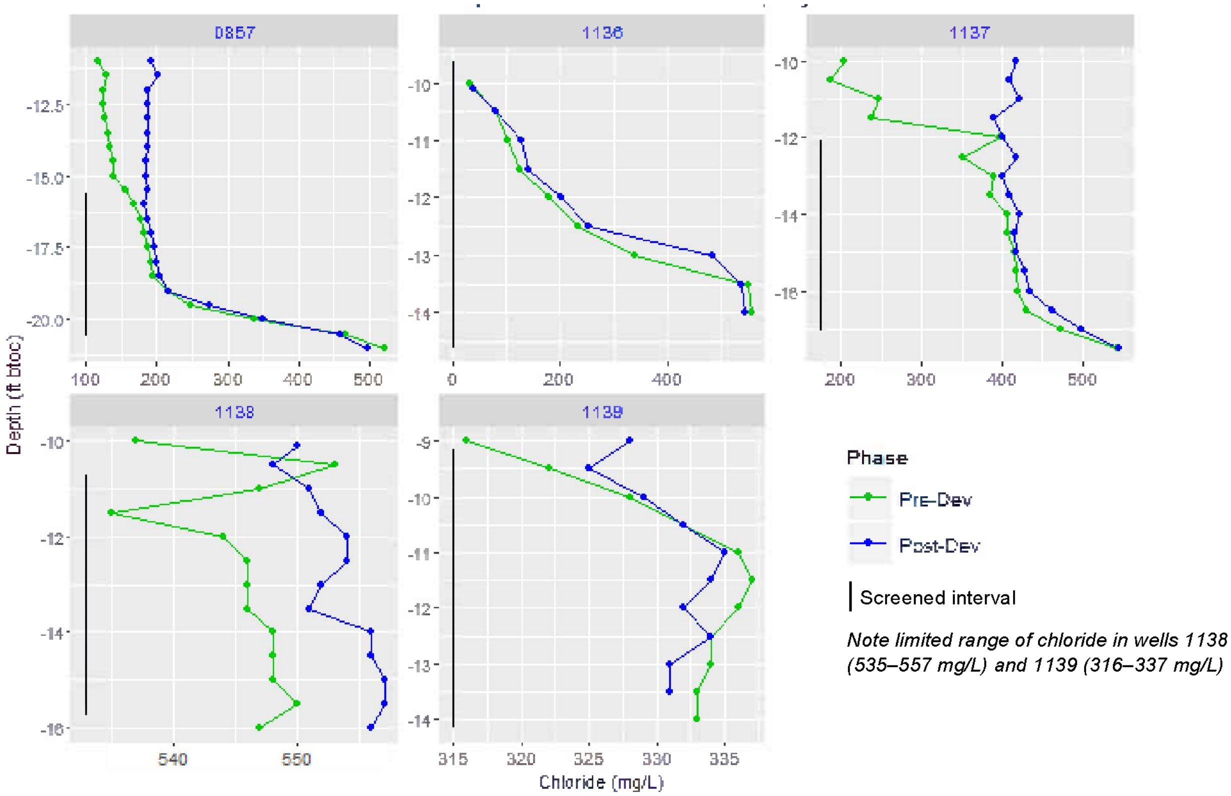


Figure 18. Chloride Profiles in Shiprock Near-River Wells: Pre- and Post-Redevelopment, July 2013

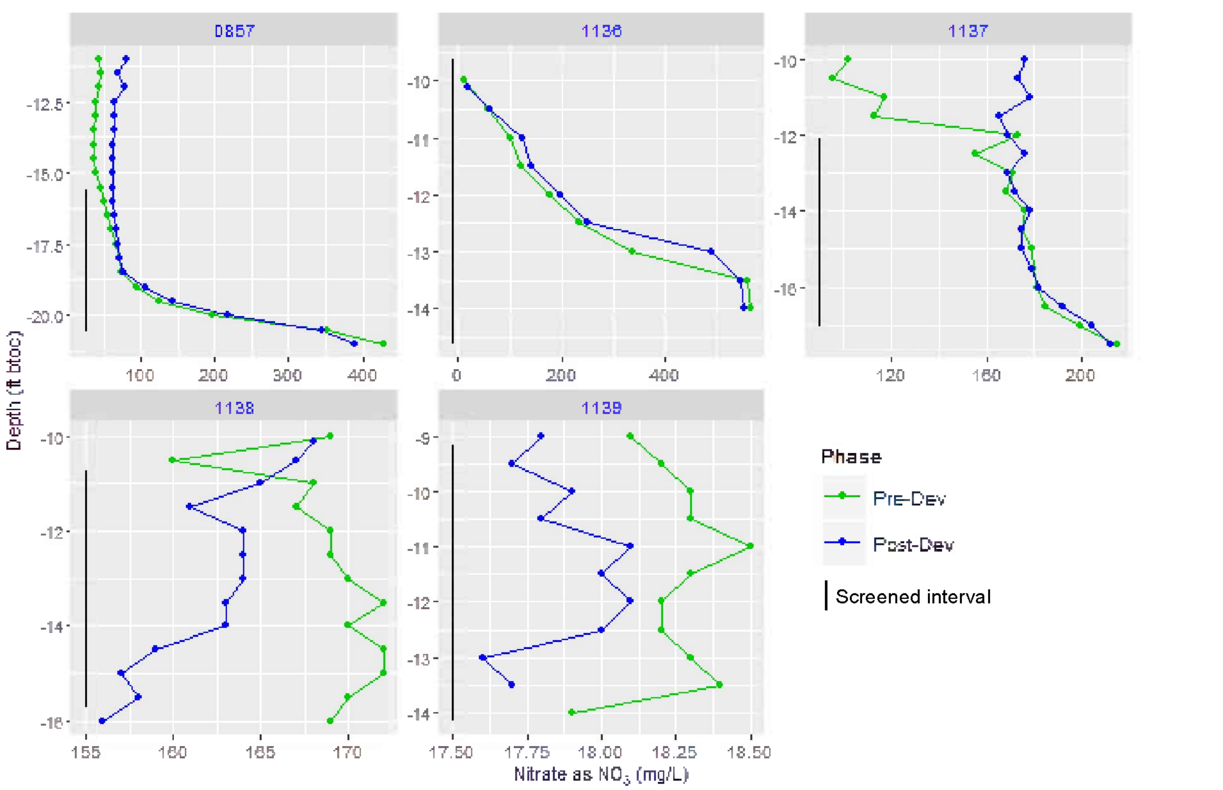


Figure 19. Nitrate Profiles in Shiprock Near-River Wells: Pre- and Post-Redevelopment, July 2013

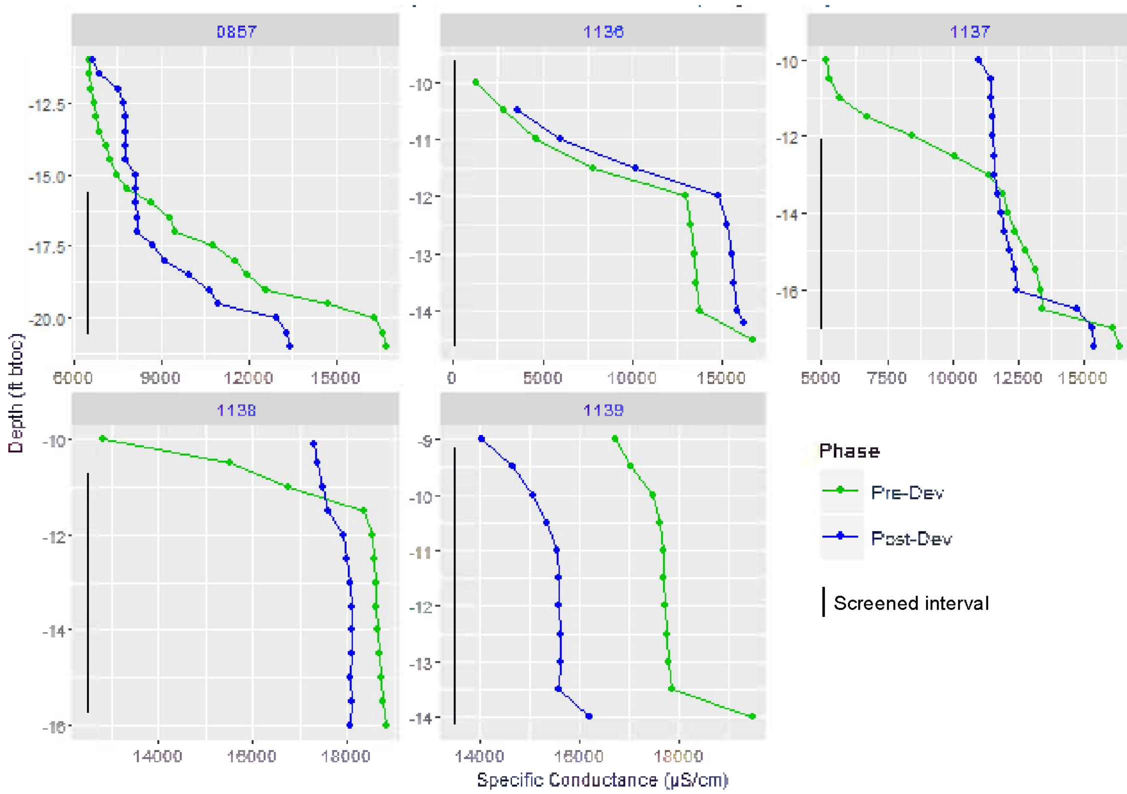


Figure 20. SC Profiles in Shiprock Near-River Wells: Pre- and Post-Redevelopment, July 2013

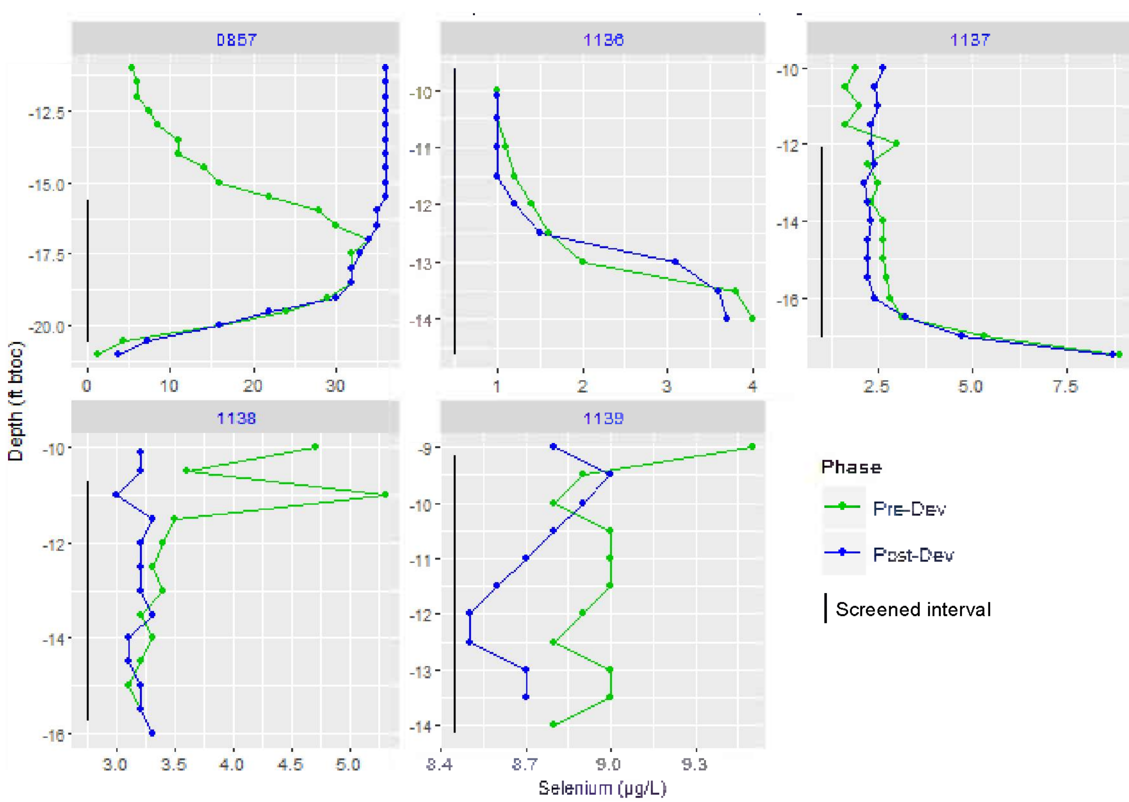


Figure 21. Selenium Profiles in Shiprock Near-River Wells: Pre- and Post-Redevelopment, July 2013

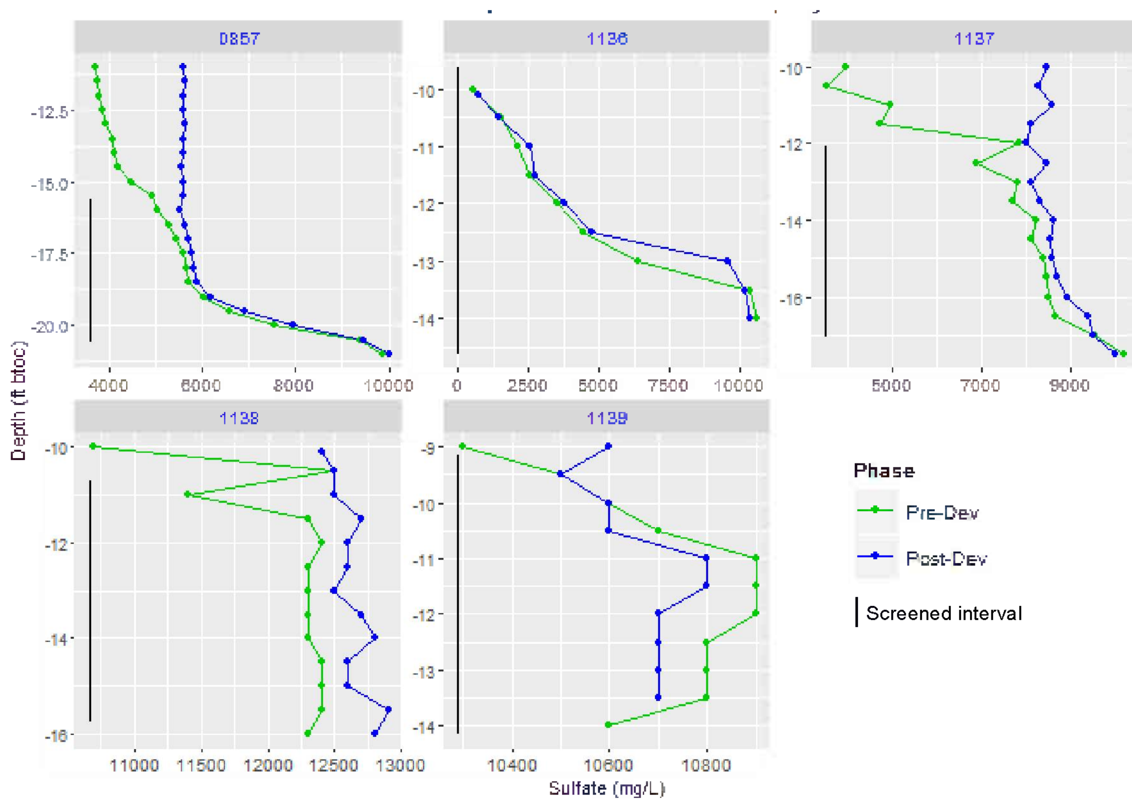


Figure 22. Sulfate Profiles in Shiprock Near-River Wells: Pre- and Post-Redevelopment, July 2013

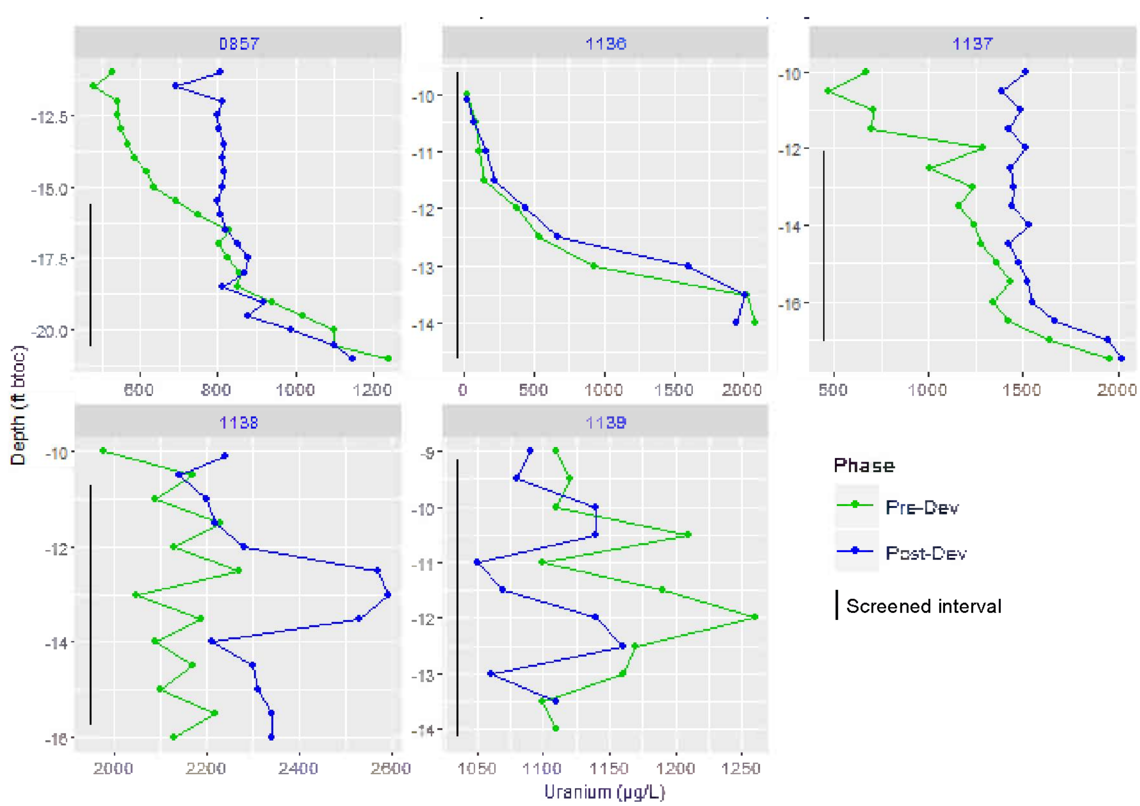


Figure 23. Uranium Profiles in Shiprock Near-River Wells: Pre- and Post- Redevelopment, July 2013

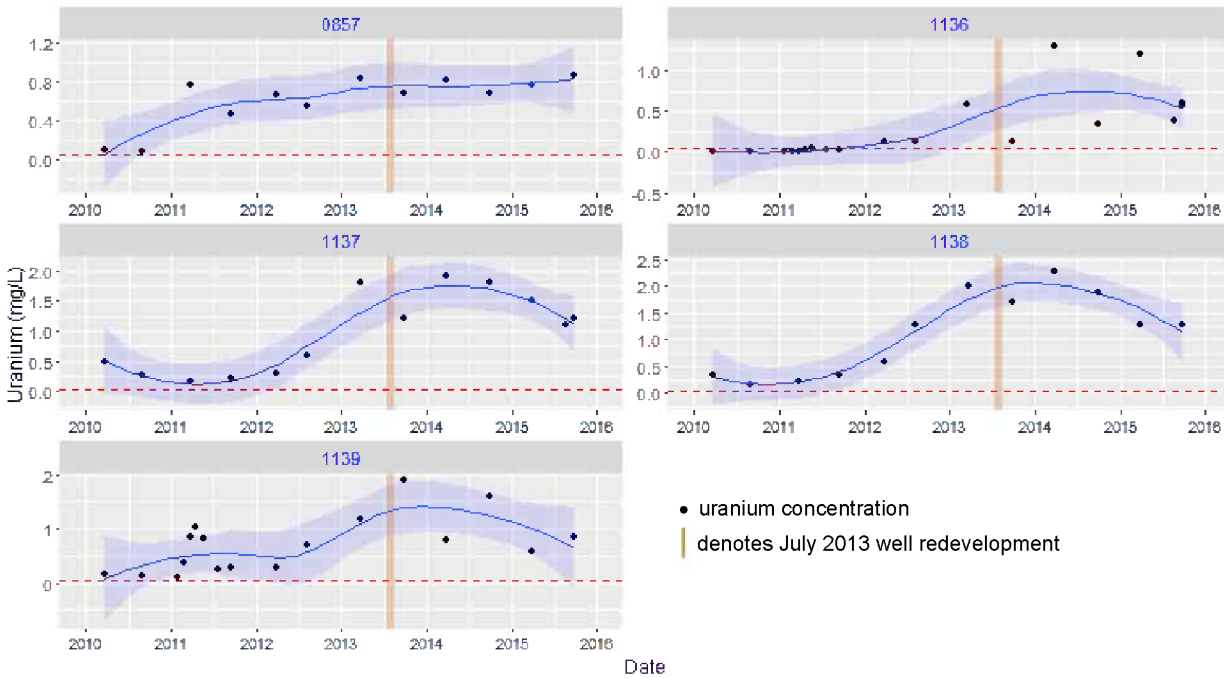


Figure 24. Time-Concentration Plots of Uranium in Shiprock Floodplain Near-River Wells

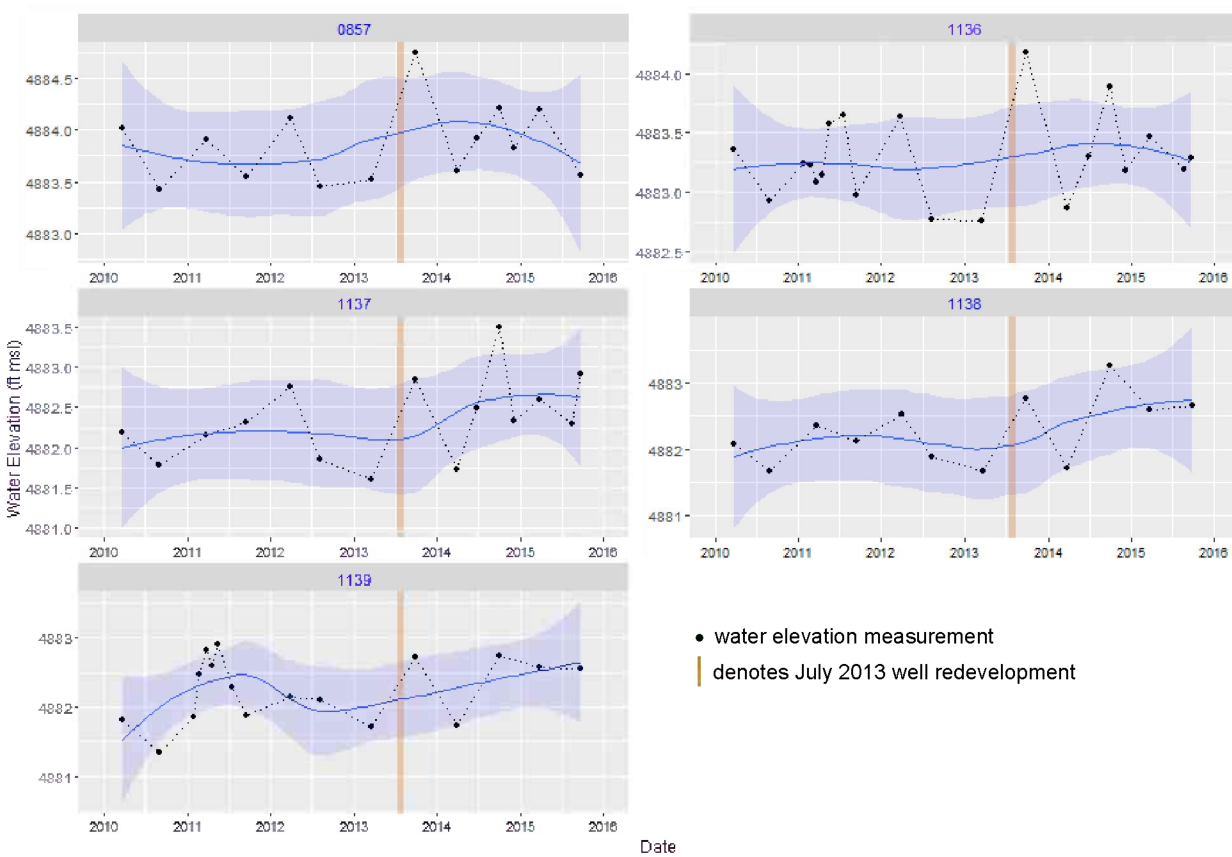


Figure 25. Groundwater Elevations in Shiprock Near-River Wells

6.5 Sites with Recent Detailed Redevelopment Information

This section addresses the sites where recent (2015) well redevelopments were more comprehensive in terms of both pre- and post-redevelopment field measurements taken and the associated level of documentation. At these sites, turbidity, SC, pH, and temperature were continuously measured before and after well redevelopment and documented using the EDGE form described in Section 3.0. The sites addressed in this section are:

- Grand Junction office site
- Gunnison processing site
- Naturita processing site
- Riverton processing site
- Slick Rock East processing site

Except for the Naturita processing site (only the August 2015 redevelopment is on record), wells at all other sites had been redeveloped previously but documented with varying levels of detail.

6.5.1 Grand Junction Office Site

Well redevelopment has been a routine practice at the Grand Junction office site. EMO records show that site wells have been redeveloped almost annually since 2005. As shown in Figure 26, uranium trends in these wells have been generally stable. A few deviations are apparent for wells in a formerly contaminated soils area near the Gunnison River, 8-4S and 11-1S. Although uranium concentrations measured in late February 2015 are higher than most preceding measurements, these deviations cannot necessarily be attributed to the preceding mid-January well redevelopment event. Other factors, such as Gunnison River flows, groundwater elevations, and precipitation potentially influence contaminant trends.

Evaluation of SC Trends in SOARS Well 8-4S

One site well, 8-4S, has been instrumented with a SOARS water level transducer and SCT probe since March 2013 and has an interesting history. Figure 27, which plots SC over time since 2013, shows decreases in SC that appear to correlate with each redevelopment event. Two of the four well redevelopments coincide closely with intense storm events, defined as producing more than 0.5 inch of rain within 4 hours. LMS staff examined the relationship between intense storms and groundwater salinity in this well; investigation findings are summarized below.

The SOARS SC sensor in well 8-4S is positioned in the sump beneath the screened zone. During the intense storms, infiltrating rain water collects dissolved salt and uranium prior to entering the well. The density contrast causes the water to flow downward through the well bore and collect in the sump. SC rapidly increases and is maintained for up to several months following the storm event. Well redevelopment removes this saline water and causes the SC to decrease back to pre-storm levels. Thus, redevelopment is not necessarily mitigating a deteriorating well, but rather is simply flushing out stratified borehole water.

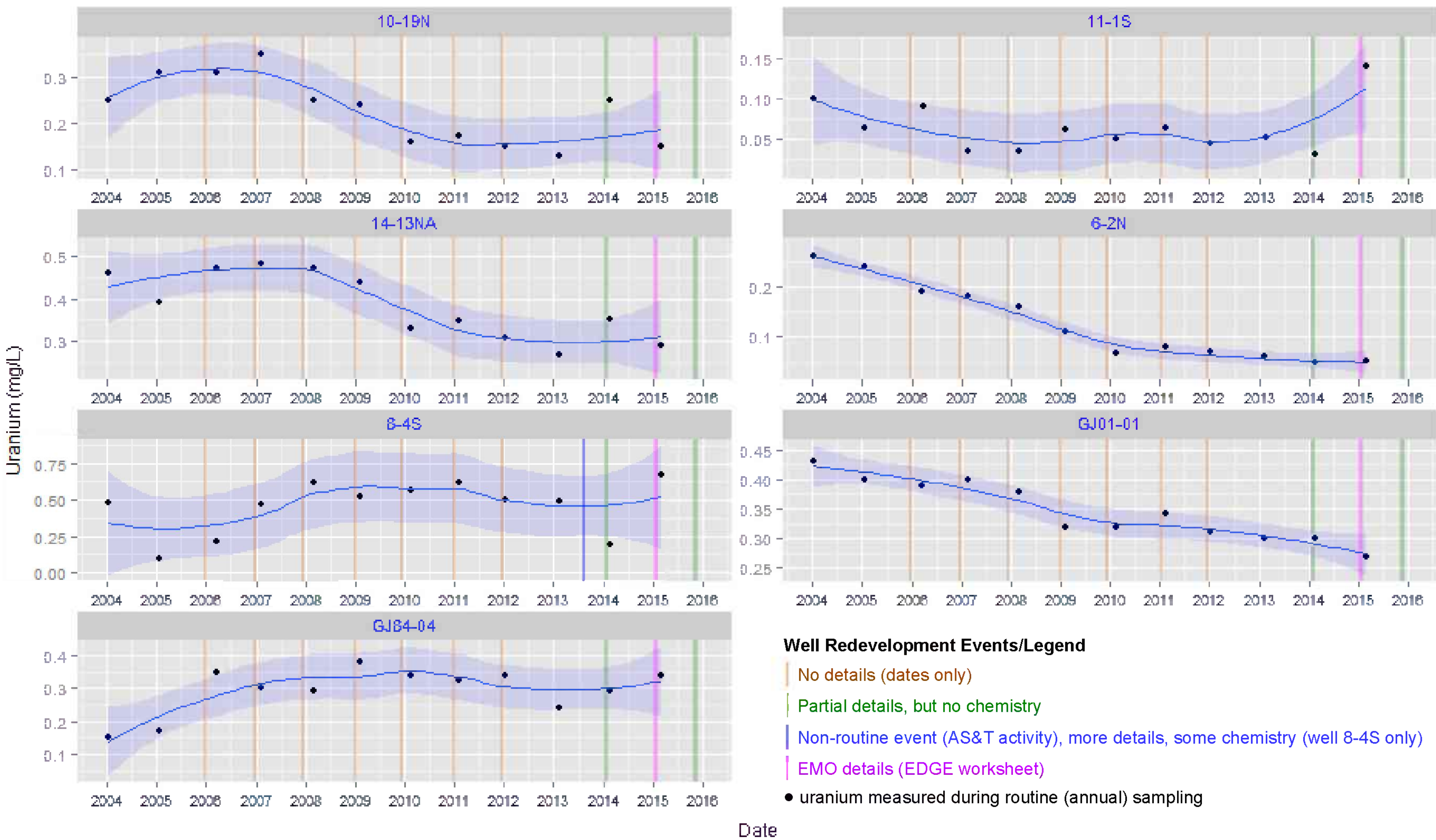


Figure 26. Time-Concentration Plots of Uranium in Grand Junction Office Site Redeveloped Wells

Data for well GJ01-02 (redeveloped in December 2005 and January 2014) are not shown, as this well has been sampled only twice since 2005.

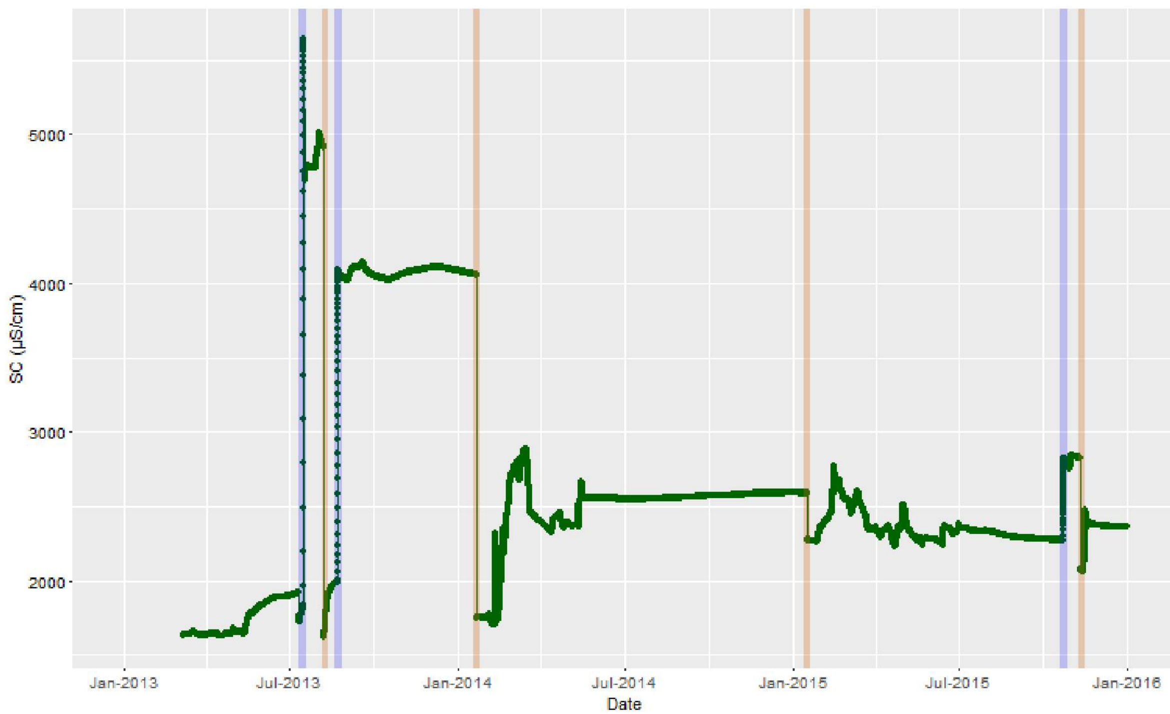


Figure 27. SC Data from SOARS, Grand Junction Office Site Well 8-4S, 2013–2016

| denotes redevelopment events | denotes storm events

Storm events correspond to periods when rainfall equaled or exceeded 0.5 inch within a 4-hour period.

Evaluation of Pre- and Post-Redevelopment Field Measurements

Seven Grand Junction office site wells were redeveloped in January 2015. At each well, redevelopment was conducted and recorded using EMO's enhanced documentation protocol. Temperature, SC, pH, and turbidity were recorded before and after redevelopment (see Figure 3 example). Additional information—including flow rates, the volume of water purged, the number of surges, and the number of times the screen was brushed—was also documented. The amount of time that elapsed between pre-redevelopment measurements and final post-redevelopment measurements ranged from 52 minutes (well 11-1S) to 160 minutes (well 6-2N).

Figure 28 plots the initial pre-redevelopment and final post-redevelopment measurements for all four field parameters. Turbidity increased after redevelopment in all but two wells—these results are not surprising given the short period of time that elapsed between pre- and post-redevelopment measurements. Post-redevelopment SC was about 10 percent lower in well 10-19N (4773 to 4139 µS/cm). However, this difference is comparable to the degree of change found in SC vertically in this well during the August 2013 profiling effort (DOE 2015a). In remaining wells, pre- and post-redevelopment SC measurements were essentially equal. There were also nominal changes in pH. The slight increases in temperature in groundwater within the well would be expected given effects of mechanical surging.

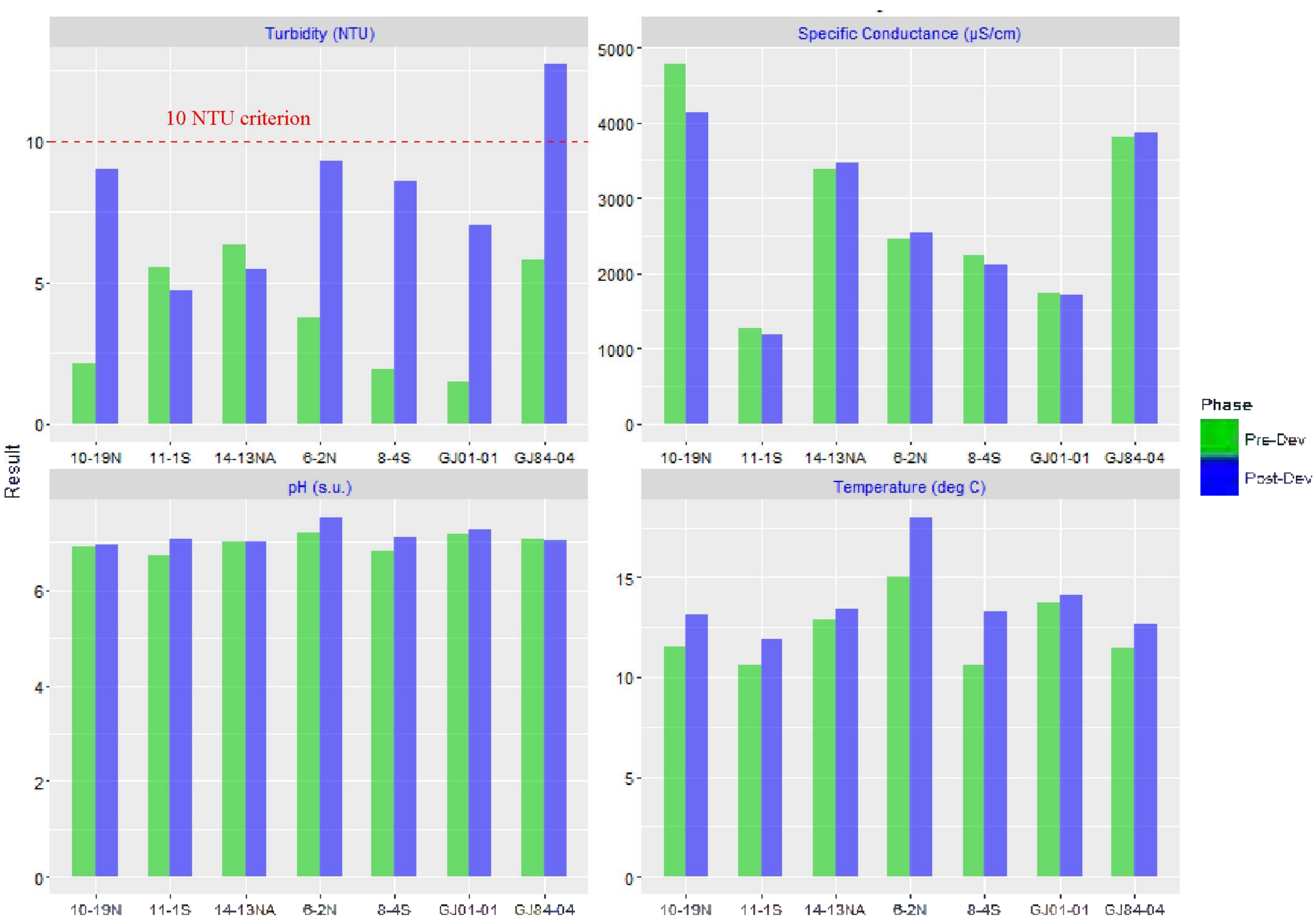


Figure 28. Pre- and Post-Redevelopment Field Measurements in Grand Junction Office Site Wells January 2015 Redevelopment Event

6.5.2 Gunnison Processing Site

Since 2009, Gunnison processing site wells have been redeveloped every year except 2013 (Figure 5). For the five redevelopment efforts between 2009 and 2014 (when 23 to 28 wells were redeveloped depending on the event), only dates were recorded. However, in 2015, redevelopment was conducted and recorded using EMO's enhanced documentation protocol. Seventeen of the 28 wells were redeveloped in July 2015; the remaining 11 wells were redeveloped in October.

Figure 29 and Figure 30 plot pre-redevelopment and post-redevelopment turbidity and SC measurements taken during the 2015 redevelopment effort. The box plots in these figures demonstrate the range in measurements as pumping progressed both before and after well redevelopment. At least three measurements of these and other field parameters were taken during each event. The bar charts in Figure 31 show the initial pre-redevelopment and final post-redevelopment results.

For most Gunnison processing site wells, post-redevelopment turbidity was lower than the initial pre-redevelopment reading. In the few cases where turbidity increased, post-redevelopment results were ≤10 NTU (Figure 29, Figure 31). The initial pre-redevelopment turbidity measured in well 12R, 152 NTU (Figure 31), was the highest measured of all wells addressed in this study except Slick Rock East processing site well 0310 (Figure 38). After redevelopment, the turbidity was 9.2 NTU, within the range measured during previous annual monitoring events (1.7–9.7 NTU). No observations were documented in the field log explaining potential causes of the high pre-development turbidity in well 12R, a shallow alluvial well located within the former mill area.

Pre- and post-redevelopment SCs measured in Gunnison processing site wells were generally similar (Figure 30, Figure 31). Two exceptions were found: SC halved in well 0013 (from 821-392 µS/cm) and decreased by 40 percent in well 0186 (from 1200 to 720 µS/cm). The field sheet noted a white precipitate at the bottom well 0186 (a 60 ft deep well), and the samples had an unusually high initial pre-development pH of 11.9 (Figure 32). This reading is much higher than the historical range based on annual monitoring results (6.95–8.23). Potential causes of the initially high pH in this well (e.g., grout contamination), and the reproducibility of the results, warrants further investigation. Pre- and post-redevelopment pH measurements in most remaining site wells were comparable (Figure 32).

Uranium trends in Gunnison processing site wells are shown in Figure 33; for most wells, no impact of the five previous well redevelopment events (2009–2014) is apparent. Uranium levels in well 0012R, with the initially high turbidity, have been fairly stable and elevated since 2008 (0.21-0.37 mg/L). Uranium concentrations in a few wells near the Gunnison River—for example, wells 0066 (Figure 33a) and 0183 (Figure 33b)—appear to fluctuate seasonally. In both of these wells, a slight spike in uranium following the April 9, 2014, redevelopment event (the wells were sampled on April 15, 2014) are potentially related to the preceding well redevelopment. Whether this is the case (if there is any cause and effect relationship) cannot be determined from the available data. These apparent spikes could be random variation or related solely or partly to changes in groundwater elevations. Based on a brief examination of historical data, there is an apparent correlation between groundwater levels and uranium in well 0066 but not in well 0183.

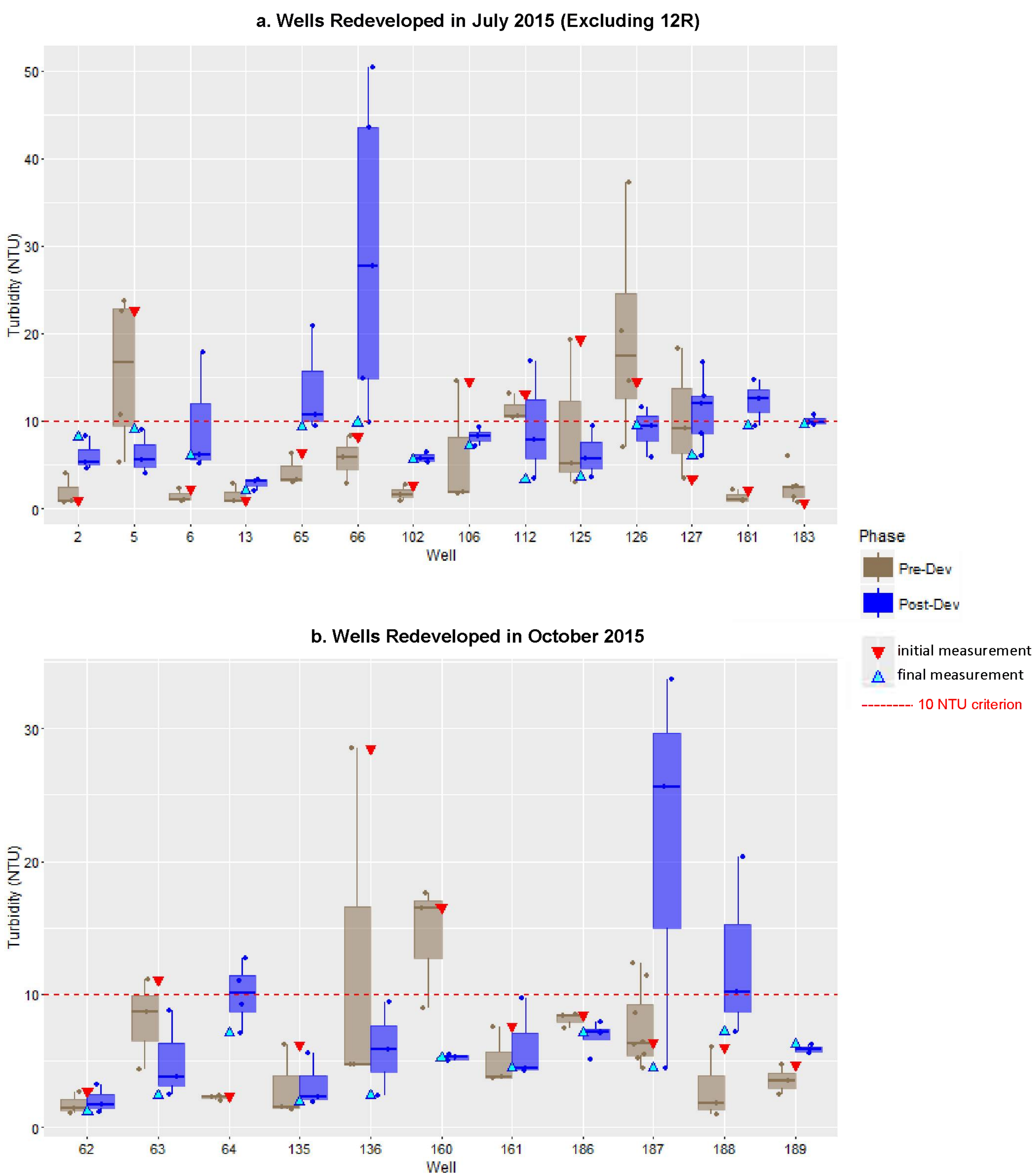


Figure 29. Box Plots of Pre- and Post-Well-Redevelopment Turbidity, Gunnison Processing Site Wells

Results for well 12R excluded from plot (a) given high magnitude: 83.7–152 NTU pre-redevelopment versus 9.2–25.1 NTU post- redevelopment (final measurement was 9.2 NTU). Refer to upper left plot in Figure 31.

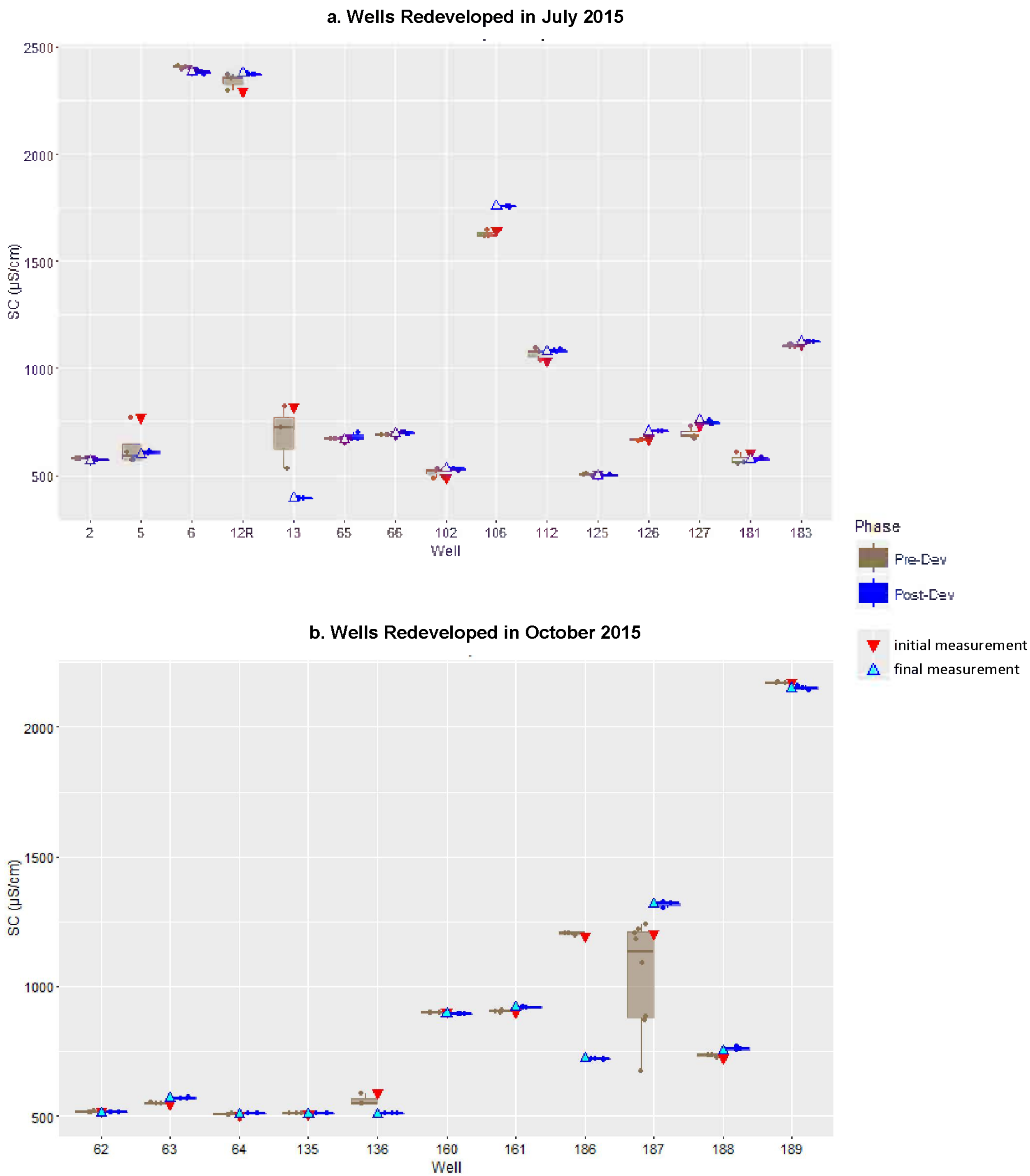


Figure 30. Box Plots of Pre- and Post-Well-Redevelopment SC, Gunnison Processing Site Wells

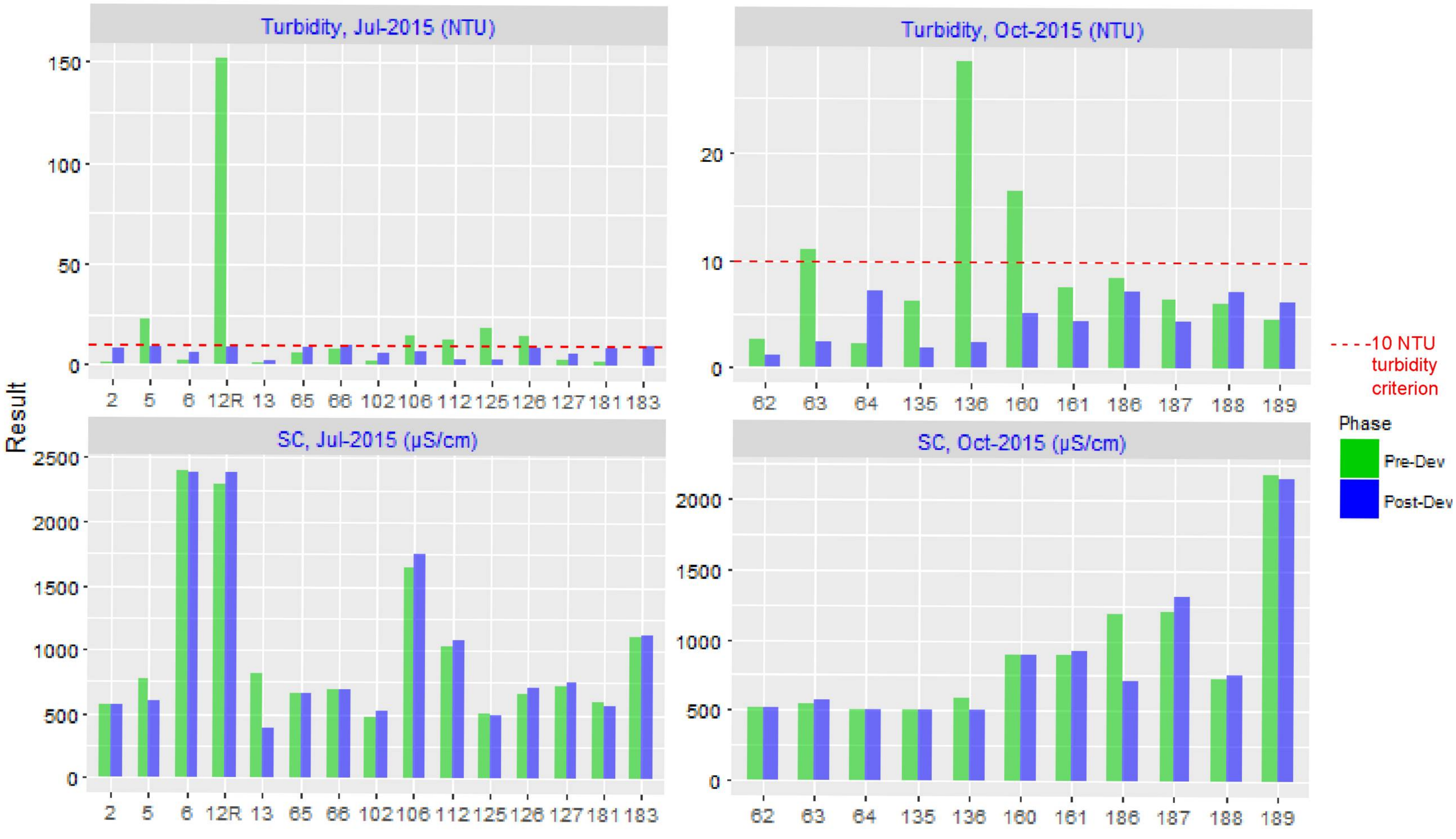


Figure 31. Bar Charts of Pre- and Post-Redevelopment Turbidity and SC in Gunnison Processing Site Wells

The turbidity scale for wells redeveloped in July 2015 is driven by the well 12R outlier;
for better resolution on these results, refer to box plots in Figure 29.

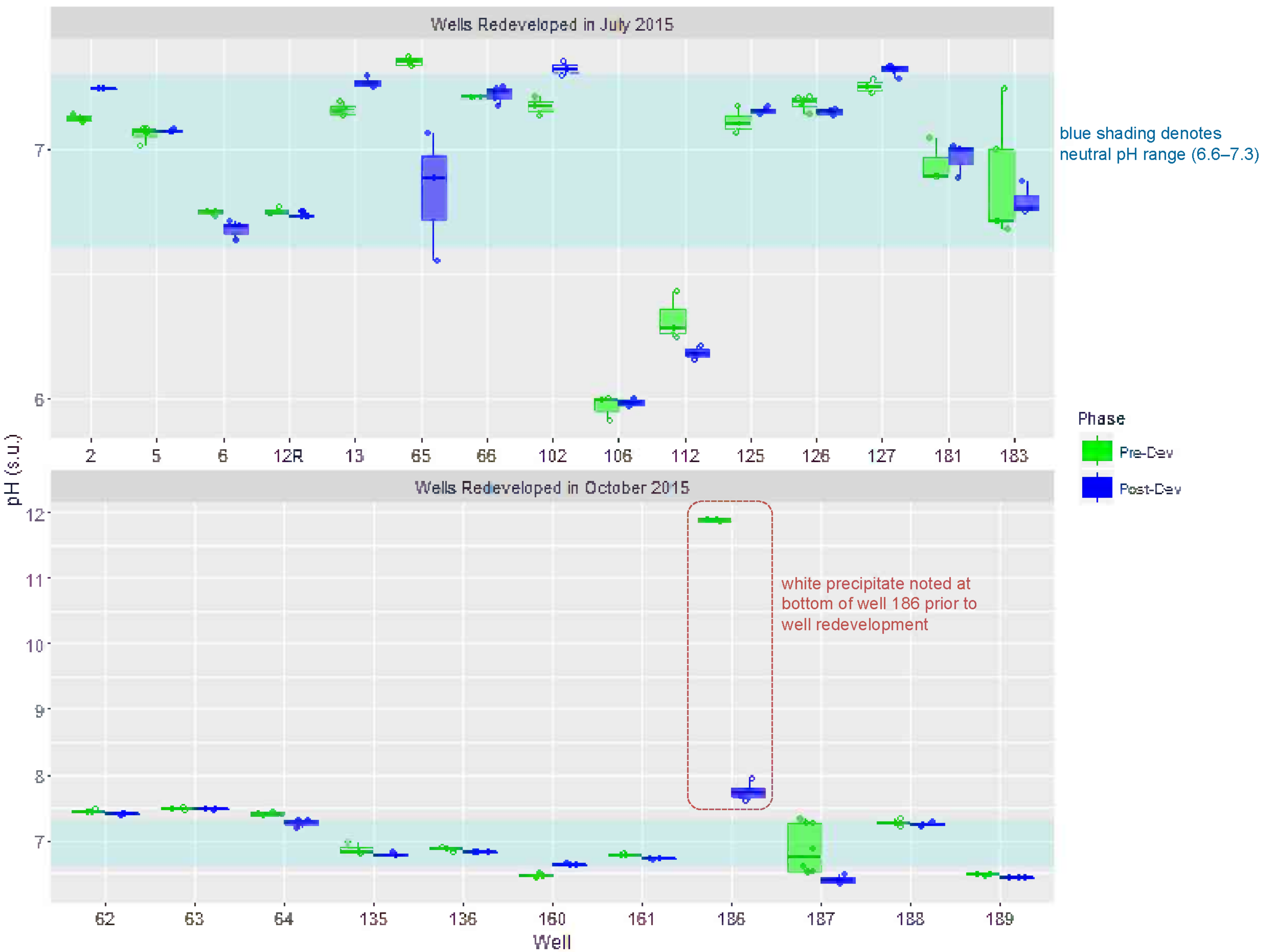
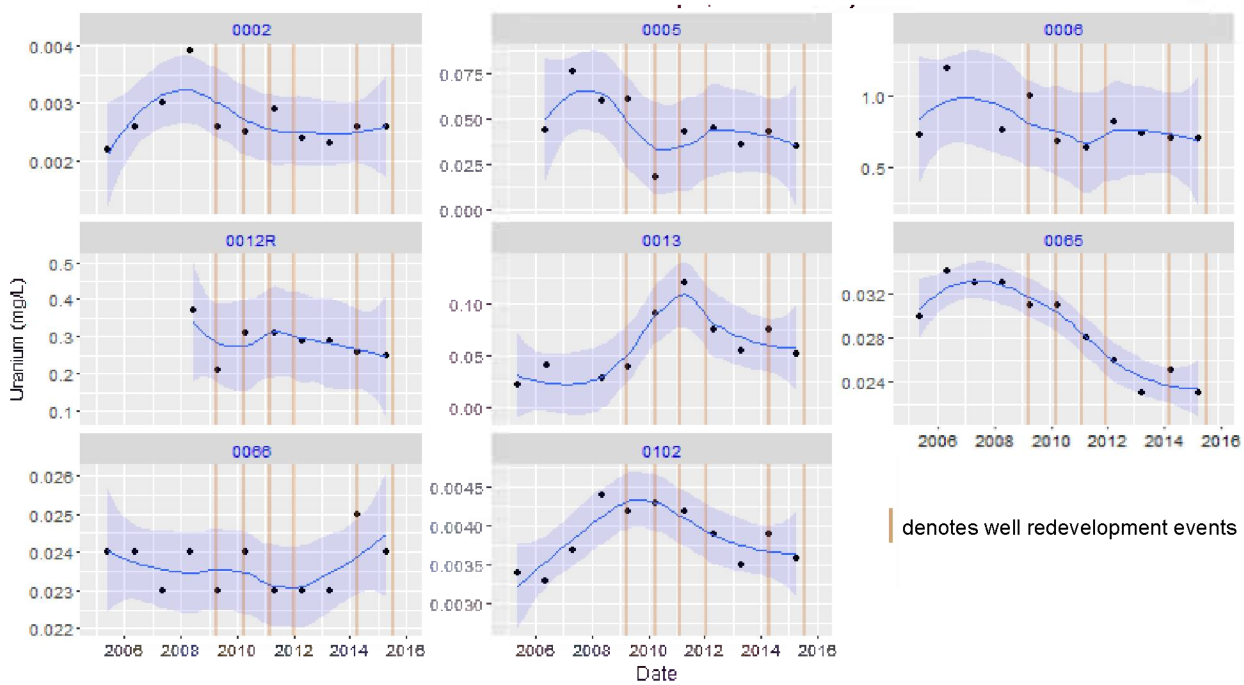


Figure 32. Box Plots of Pre- and Post-Redevelopment pH in Gunnison Processing Site Wells

a. Wells Last Redeveloped in July 2015



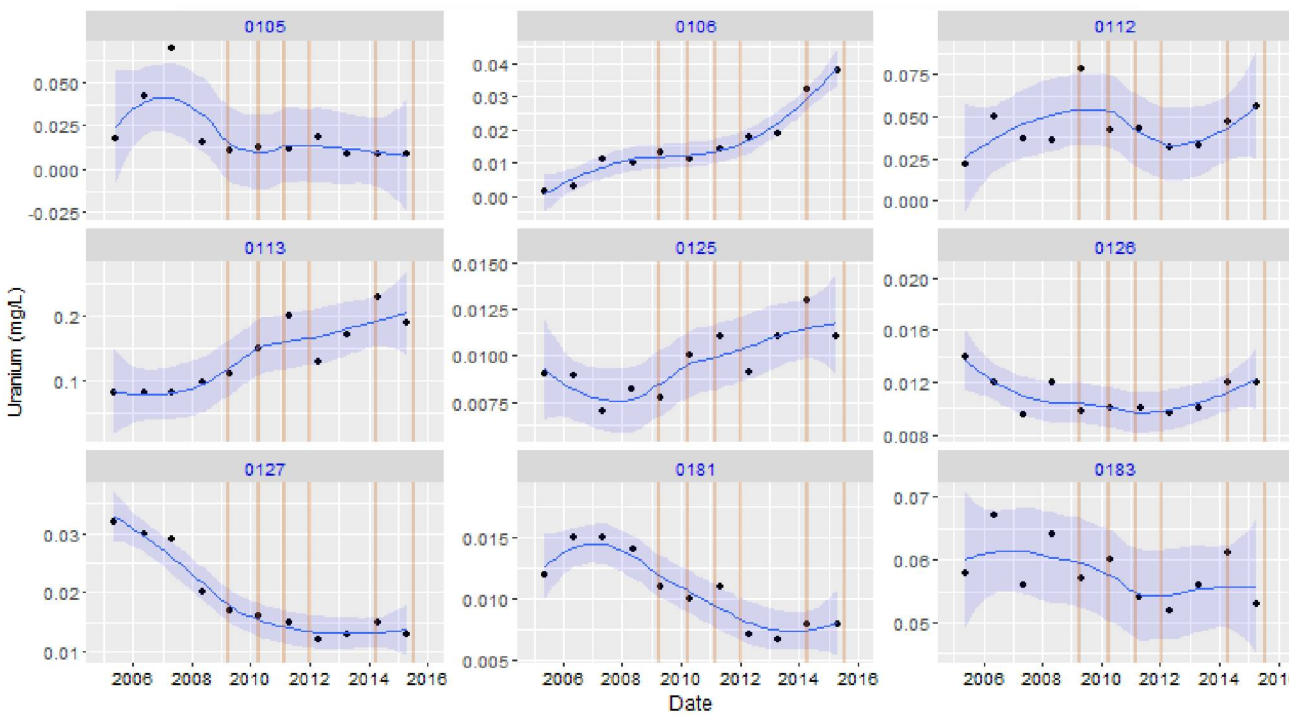


Figure 33. Time-Concentration Plots of Uranium in Gunnison Site Wells

b. Wells Last Redeveloped in October 2015

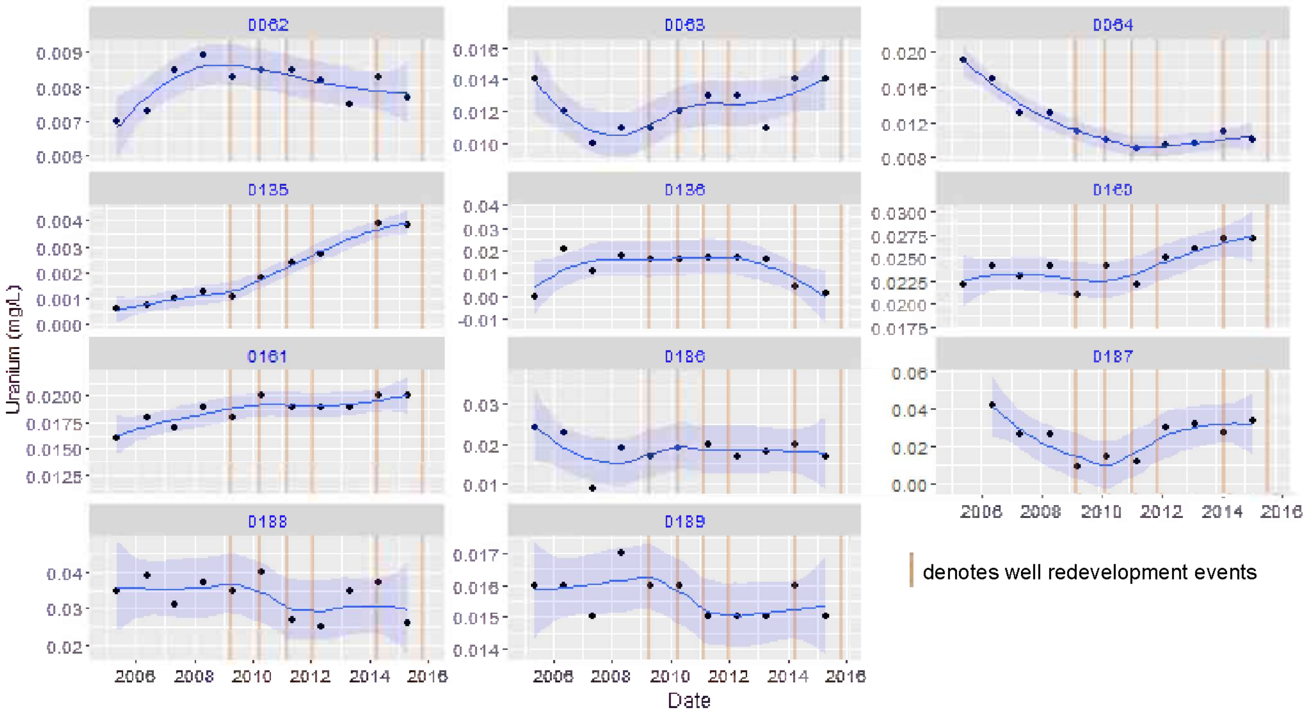


Figure 33 (continued). Time-Concentration Plots of Uranium in Gunnison Processing Site Wells

6.5.3 Naturita Processing Site

Only one well redevelopment event is on record for the Naturita processing site (Figure 5). In July 2015, EMO redeveloped seven site wells and recorded the event using the enhanced documentation protocol. Figure 34 plots the initial pre- and final post-redevelopment turbidity and SC measurements for these wells. Redevelopment was effective in reducing turbidity in wells NAT-01 and NAT-08 (initially 15 and 19 NTU, respectively) to below the 10 NTU criterion. However, pre- and post-redevelopment SCs were essentially equal and changes in pH were also nominal (data are not plotted here).

With the possible exception of well NAT-26, there is no apparent impact of the July well redevelopment on uranium trends (Figure 35). Uranium concentrations in well NAT-26 increased slightly between 2014 and 2015, from 1.1 to 1.5 mg/L (the well was sampled 3 weeks after the July redevelopment). Although it is possible that redevelopment influenced groundwater chemistry in this well, the increase could also be explained by the corresponding drop in water levels (0.76 ft) within that time frame. Based on examination of the long-term trend (2000–2015), the increase could also be attributed to random variation. Of the wells that were redeveloped, the greatest fluctuations in uranium are found in the subset closest to the San Miguel River: wells 0718, DM-1, and MAU-07 (Figure 35).

Figure 34. Pre- and Post-Redevelopment Turbidity and SC in Naturita Processing Site Wells

Pre-redevelopment measurements were not taken at downgradient-most well 0718.

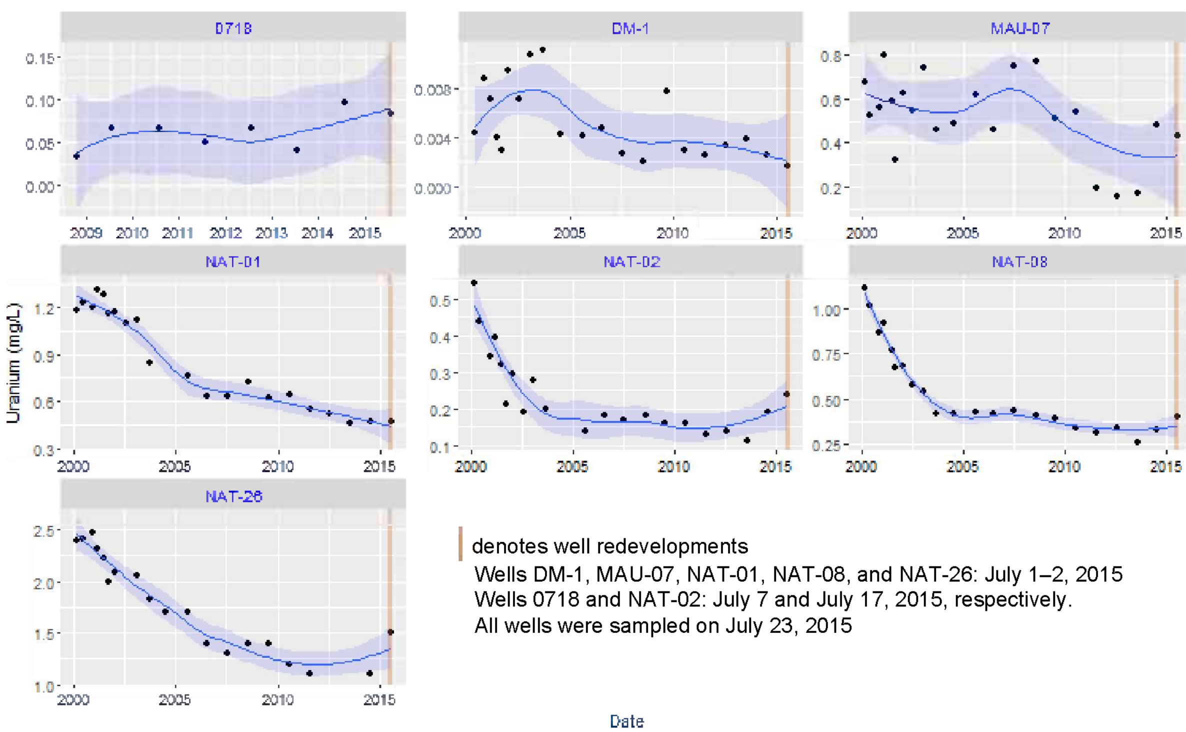


Figure 35. Time-Concentration Plots of Uranium in Naturita Processing Site Redeveloped Wells

6.5.4 Riverton Processing Site

Between 2009 and 2014, Riverton processing site wells were redeveloped four times—in May 2009, April 2010, April 2012, and May 2013 (Table 2). In May 2015, redevelopment at a subset of those wells (9 of the 20 wells redeveloped in previous years) was recorded in greater detail using EMO's enhanced documentation protocol. Figure 36 plots initial and final turbidity and SC measurements taken as part of that effort. As found for other sites, there are no compelling differences between pre- and post-redevelopment turbidity measurements. Although post-redevelopment turbidities were higher than pre-redevelopment measurements in most (7/9) wells, this is not unexpected given the short time (in most cases less than 1 hour) between well surging and post-redevelopment measurements. Except for well 0719 (pre- and post-redevelopment measurements were 1435 and 2380 µS/cm), pre- and post-redevelopment SCs were similar. Changes in pH were also nominal; the average absolute difference in pre- vs. post-redevelopment measurements was 0.07 (data are not plotted here).

Figure 36. Pre- and Post-Redevelopment Turbidity and SC in Riverton Site Redeveloped Wells

Figure 37 plots uranium versus time in the Riverton processing site wells with a redevelopment history. This figure is divided into two segments. Figure 37a shows uranium trends in the subset of wells last redeveloped in May 2015 (with more detailed documentation). Figure 37b plots trends for remaining wells, last redeveloped in May 2013. The most interesting cause and effect relationship shown in this figure is not the influence of well redevelopments, but rather the effects of the June 2010 flooding of the Little Wind River on uranium concentrations in site wells. At that time, overbank flow observed within a large area downgradient of the former mill site resulted in the mobilization of residual contamination in the unsaturated zone (DOE 2013).

If the data shown in Figure 37 were evaluated ignoring all potential influences or factors *except* well redevelopments (i.e., if the blue line denoting the flood event was excluded from the plots), increases in uranium concentrations in near-river alluvial wells 0707, 0788, 0789, and 0826 might be attributed to the April 2010 well redevelopment event. But that would be a spurious conclusion. The available data give no indication that well redevelopment influenced uranium trends in Riverton site wells. Even if redevelopment did influence uranium presence in the well, other factors potentially affecting changes in contaminant concentrations (precipitation, Little Wind River flows) might make any effect of well redevelopment difficult to decipher.

a. Subset of Wells Last Redeveloped in May 2015

Figure 37. Time-Concentration Plots of Uranium in Riverton Processing Site Redeveloped Wells

| denotes well redevelopment events; | denotes June 2010 Little Wind River flood event

SF = surficial aquifer well; SE = semiconfined aquifer well; ** denotes wells closest to the Little Wind River

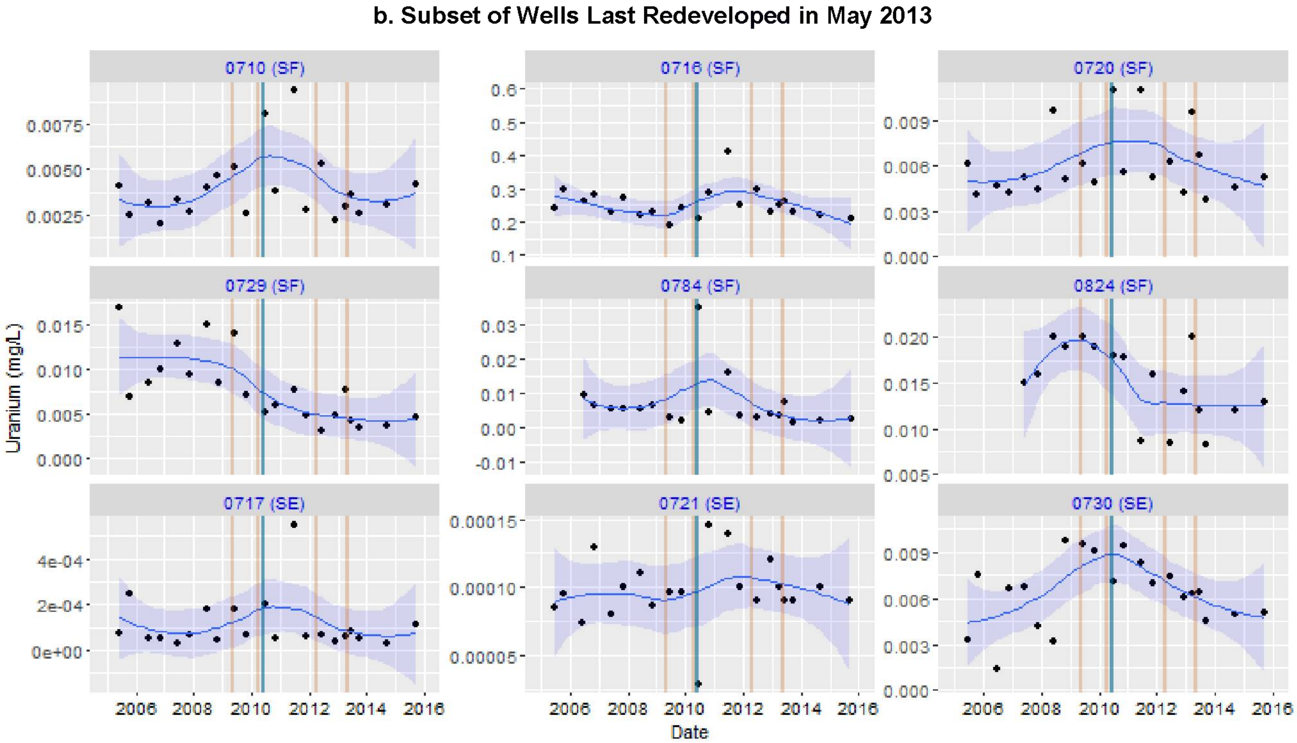


Figure 37 (continued). Time-Concentration Plots of Uranium in Riverton Processing Site Redeveloped Wells

| denotes well redevelopment events; | denotes June 2010 Little Wind River flood event

SF = surficial aquifer well; SE = semiconfined aquifer well

Unlike wells in plot (a), most of these wells are outside of the near-river uranium plume

Time-trend plots for wells 0732, 0735, 0736, and 0809, redeveloped at the same frequency as shown for other wells above, are not provided, as these are not sampled regularly and there are insufficient data to plot. Wells 0732 and 0736 have been sampled only 1–2 times since 2005; wells 0735 and 0809 have not been sampled since 2008–2009.

6.5.5 Slick Rock East Processing Site

Two redevelopment events have been documented for the Slick Rock East (SRE) processing site. The first occurred in December 2012 (eight wells), and the second in August 2015, when redevelopment of six site wells was conducted and recorded using EMO's enhanced documentation protocol. The most recent redevelopment was done at the request of the LMS site lead, in part due to increases in uranium concentrations in a background well (0300) that had not been regularly sampled (DOE 2015b). Figure 38 plots the initial and final turbidity and SC measurements for site wells obtained during the August 2015 redevelopment event. All turbidity measurements were approximate, and all were greater than 10 NTU. The initial turbidity in offsite well 0310, across the Dolores River and outside of the former mill area, ~500 NTU, was the highest measured of all wells addressed in this study. All final post-redevelopment turbidity measurements were recorded as ≥20 NTU (Figure 38). No observations were documented in the field log explaining potential causes of the high pre- and post-redevelopment turbidity readings.

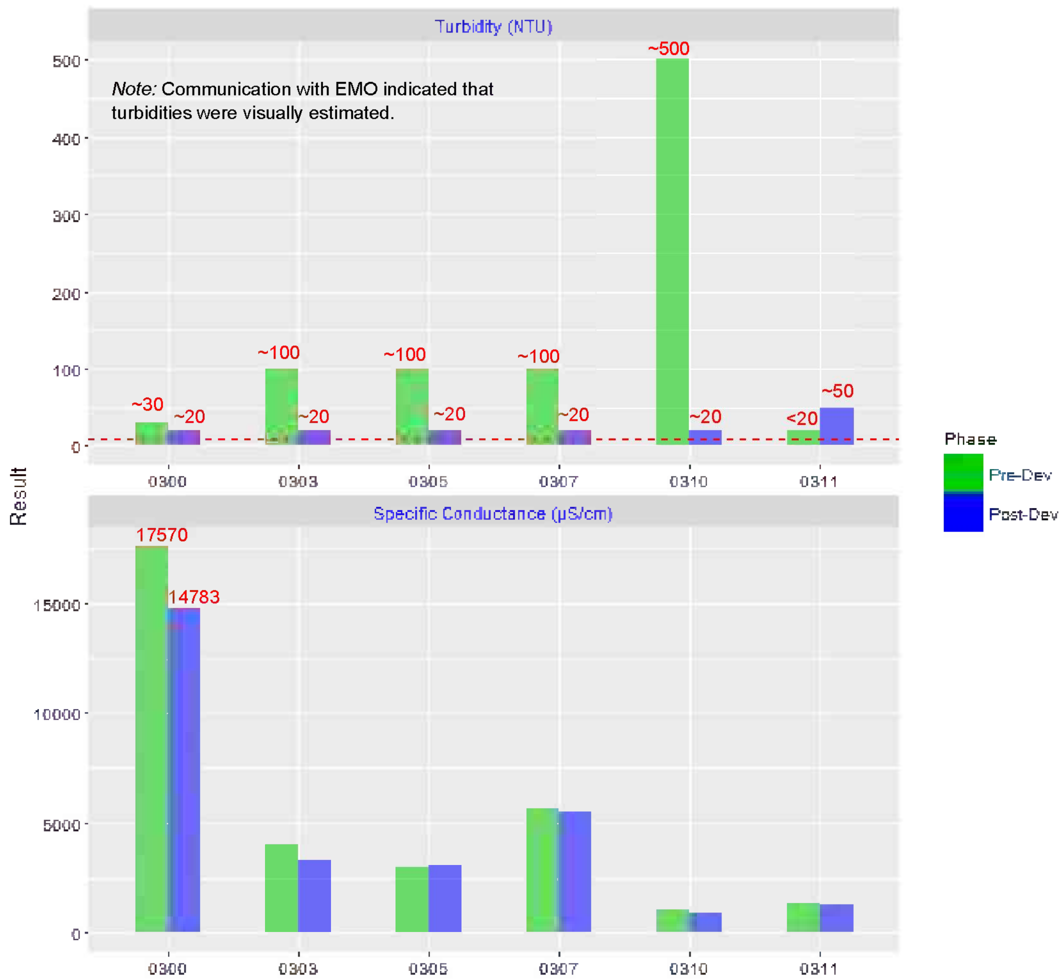
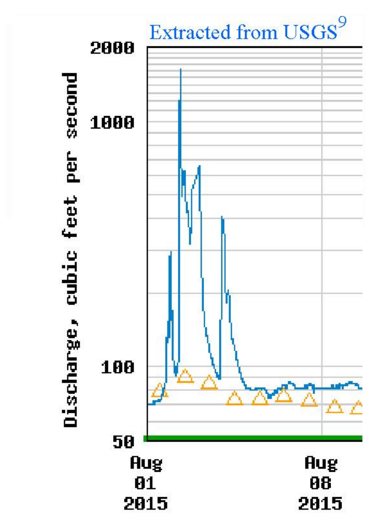


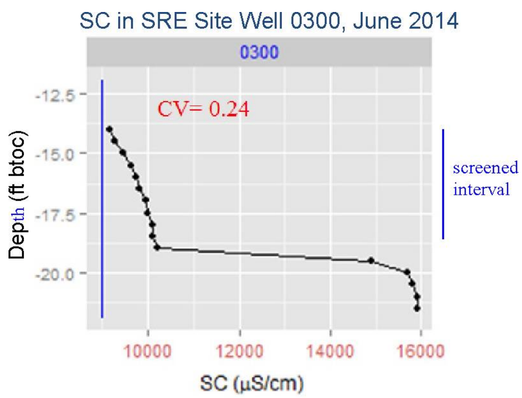
Figure 38. Pre- and Post-Redevelopment Turbidity and SC in Slick Rock East Site Wells, August 2015

To explore potential causes of the high turbidity in site wells, Dolores River flow data from the U.S. Geological Survey (USGS) and regional historical precipitation data were accessed. Well redevelopment at the SRE site took place August 4–5, 2015. Precipitation measured on August 3, 2015, was the second highest on record for 2015: 0.77 inch for Naturita, the closest town for which historical rainfall data were available (0.11 inch was recorded on August 2).[8] As shown in the inset to the right, USGS flow data indicate marked increases in Dolores River flows during this time period.[9] The extent to which the heavy rainfall affected turbidity in site wells cannot be determined, but it is a possible explanation.



[8] Data for Slick Rock and nearby Dove Creek were unavailable, so rainfall data for Naturita were used: http://www.usclimatedata.com/climate/naturita/colorado/united-states/usco0651/2015/8
[9] http://nwis.waterdata.usgs.gov/co/nwis/uv?cb_00060=on&cb_00065=on&format=gif_default&site_no=09168730&period=&begin_date=2015-08-01&end_date=2015-08-31

Pre- and post-redevelopment SCs measured in SRE processing site wells were generally similar (Figure 38). The single exception was found in upgradient (background) well 0300, with pre- and post-redevelopment SCs of 17,570 and 14,783 µS/cm, respectively (~15 percent reduction). This change might be explained by the chemical stratification measured in this well in a previous study (DOE 2015a). As shown in the inset below, SC ranged from 9168 to 15,900 µS/cm over the 7.5 ft saturated screened interval. Thus, the change in SC after well redevelopment could be a result of mixing of the stratified well water. A comparison of pre- versus post-redevelopment pH results (data not plotted here) showed nominal changes in pH; the mean absolute difference was 0.06 (maximum difference of 0.1).



Inset adapted from Figure 71 in the Variation Project Report (DOE 2015a). Based on the coefficient of variation (CV, = standard deviation divided by the mean) of 0.24, well 0300 had one of the most variable SC profiles of the 19 SRE wells profiled for the Variation Project.

Based on examination of uranium trends for most wells (Figure 39), there is no apparent impact of the two well redevelopment events. Data are insufficient to determine whether redevelopment influenced the recent reduction in uranium in well 0300—from the maximum of 0.045 mg/L (9/8/2014) to 0.013 mg/L (9/28/2015).

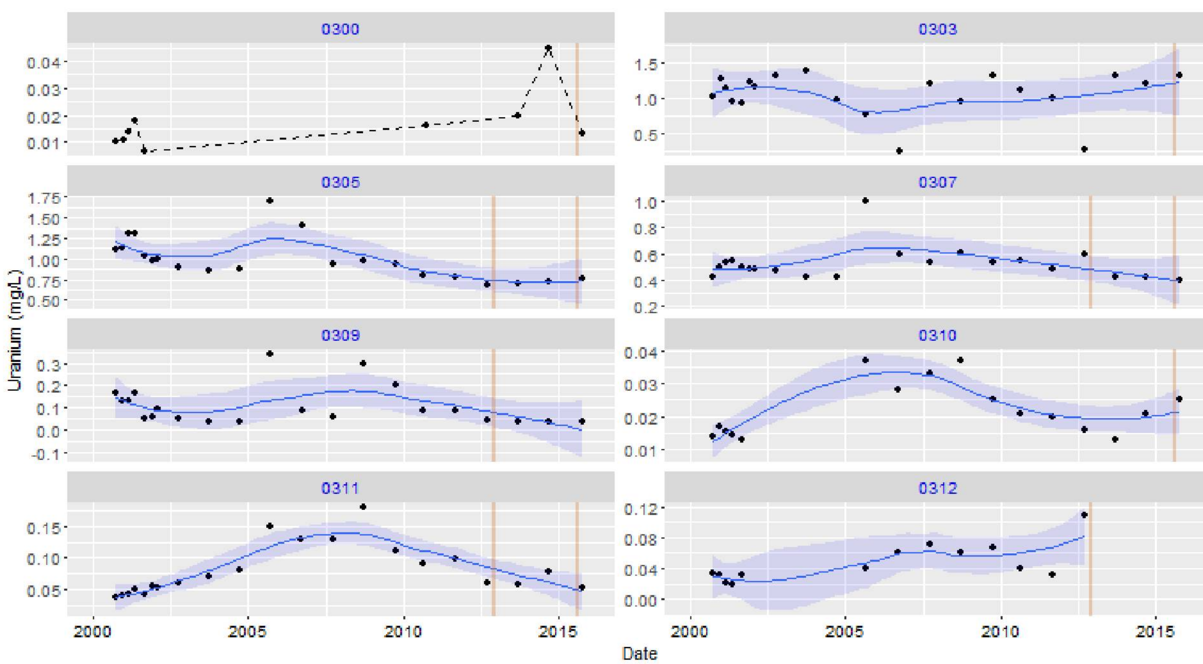


Figure 39. Time-Concentration Plots of Uranium in Slick Rock East Site Redeveloped Wells

| denotes December 5, 2012, and August 4–5, 2015, well redevelopments

7.0 Conclusions

Well redevelopment records and historical monitoring data from 16 LM UMTRCA sites were evaluated to assess potential impacts of monitoring well redevelopments on chemical signatures in groundwater. A catalyst for this evaluation was LMS's self-identification of inconsistencies in the level of documentation recorded for each redevelopment event. Until late 2014, the onset of this project, there was no standard procedure for documenting field measurements during well redevelopments. For many sites, the only information on record was the date wells were redeveloped. As a result, in 2015 EMO began collecting and documenting additional field measurements other than turbidity during well redevelopment events. At the same time, EMO developed a data capture methodology (EDGE form) to create an accessible data repository for all well redevelopments that would be compatible with the LM EQuIS database.

The independent evaluation documented in this report entailed compiling an inventory of nearly 500 previous well redevelopment events, searching the literature for impacts of well redevelopment on groundwater sample quality, and—the focus of this report—evaluating the impacts of well redevelopment on field measurements and sample analytical results.

7.1 Summary of Findings

Although literature discussions parallel the prevailing industry-wide assumption that well redevelopment is necessary to increase production or to extend the life of a well, no data in the literature indicate that redevelopment affects chemical signatures in monitoring wells. The comprehensive evaluation undertaken for this study also yielded no evidence that redevelopment has any quantifiable or predictable effect on groundwater sample quality. Both short- term and long-term changes in groundwater chemistry were assessed relative to preceding and subsequent well redevelopment events.

Short-Term Changes

Short-term impacts were evaluated for seven LM sites: two with relevant information from other sources and five sites with a detailed record of pre- and post-redevelopment field measurements, as recently implemented by EMO. Overall, there were nominal changes in pH and SC in a comparison of pre- versus post-redevelopment results. Although short-term changes in SC or contaminant concentrations likely attributable to well redevelopment were found at some sites, these cases were generally limited to wells in which chemical stratification had been observed. Redevelopment causes mixing of the well water, resulting in short-term impacts, but not in a consistent (increasing or decreasing) direction.

Turbidity, an indicator of suspended solids in the vicinity of the well bore, typically decreases following well development. Exceptions were found in wells where initial turbidity was less than the 10 NTU criterion. In these cases, slight increases in turbidity were a result of the mechanical disruption of sediments that occurs during redevelopment. Although turbidity is the best indicator of removal of particulates isolated during redevelopment, it is not a good indicator of the groundwater chemical signature.

Long-Term Changes

Long-term trends of uranium in groundwater were evaluated for all 16 sites addressed in this study, including sites with routine redevelopments (e.g., the Grand Junction office site) and—the majority—sites with only one or two well redevelopments on record (e.g., the Tuba City site). Based on the data evaluated, there are no apparent impacts of well redevelopment on uranium concentration trends in LM site wells. In most cases where deviations in trends were found, these could be attributed to water level fluctuations or other factors. A few exceptions were found where spikes or marked decreases in uranium concentrations could potentially be related to the preceding well redevelopment (e.g., at a few Green River site wells), but apparent impacts were neither predictable nor quantifiable.

7.2 Recommendations

Until late 2014, the onset of this project, there was no standard procedure for documenting well redevelopment events; some (perhaps many) had not been captured in the historical record. EMO has made notable progress in this regard since 2015, having established a format for documenting well redevelopment events and associated field measurements, as well as a data repository for capturing those records. This policy should be continued to ensure that all well redevelopment events and associated field observations are recorded and easily tracked. Additional recommendations are as follows:

- *Continue to improve record-keeping*. Areas for improvement pertain mostly to the recording of qualitative information, such as identifying field variances (e.g., turbidity not met) or atypical field conditions (examples provided in Table 4). A tracking system similar to that used in SOARS, which captures field notes coupled to a database, may be useful.
- *Recommended parameters to record on the EDGE form.* Continue documenting redevelopment information, such as elapsed time, flow rates, number of surges, and brushing of screens in accordance with current EMO policy. Measurement of SC, pH, and temperature as pumping progresses both before and after well redevelopment may not be necessary (Table 4).

In general, the literature supports redevelopment of monitoring and municipal wells if signs of reduced productivity, biofouling, sediment buildup, or other condition potentially affecting long-term well integrity are observed (e.g., Korte 2001, Schnieders 2003). However, based on the data sets examined for this study, there is no evidence that well redevelopment is needed in order to obtain samples that have the same chemical concentrations as those in the groundwater. To conclusively demonstrate that point—that is, to define chemical effects, the underlying mechanisms have to be understood. For example, if biofouling is observed in a well and is considered a potential cause of spurious or invalid chemical data, appropriate hypothesis-testing methodology should be used to test the validity of this claim. In these cases, use of a downhole camera to examine the condition of the well screen and casing may be helpful.

Table 4. Current and Recommended Well Redevelopment EDGE Form Inputs

<table>
<tr><th colspan="5">Current Edge Inputs</th><th>Comments and Recommendations</th></tr>
<tr><td colspan="6">General Information</td></tr>
<tr><td colspan="5">• Site
• Well ID
• Date
• Well Diameter
• Well Depth
• Screen Interval[10]
• Well Type
• Formation Type
• Technicians
• Equipment Used/Redevelopment Method</td><td>No changes recommended.[10]</td></tr>
<tr><td colspan="6">Quantitative Inputs by Stage of Redevelopment Effort</td></tr>
<tr><td></td><td>EDGE Inputs</td><td>Pre-</td><td>During</td><td>Post-</td><td></td></tr>
<tr><td>1</td><td>Well ID, Date</td><td>x</td><td>x</td><td>x</td><td></td></tr>
<tr><td>2</td><td>Start Time</td><td>x</td><td>x</td><td>x</td><td rowspan="8">Continue to document elapsed time, flow rates, number of surges, brushing of screens, etc. during the well redevelopment effort.

Documentation of flow rates corresponding to pre- and post-redevelopment field measurements may not be necessary (see comments below).</td></tr>
<tr><td>3</td><td>Reading Time or Stop Time</td><td>x</td><td>x</td><td>x</td></tr>
<tr><td>4</td><td>Elapsed Time or Total Time</td><td>x</td><td>x</td><td>x</td></tr>
<tr><td>5</td><td>Interval Volume</td><td></td><td>x</td><td></td></tr>
<tr><td>6</td><td>Total Volume</td><td>x</td><td>x</td><td>x</td></tr>
<tr><td>7</td><td>Flow Rate (mL/min or gal/min)</td><td>x</td><td>x</td><td>x</td></tr>
<tr><td>8</td><td>Brush Screen</td><td></td><td>x</td><td></td></tr>
<tr><td>9</td><td>Surge Well/No. of Surges</td><td></td><td>x</td><td></td></tr>
<tr><td>10</td><td>Temperature</td><td>x</td><td></td><td>x</td><td rowspan="3">Consider eliminating measurement of pH, SC, and temperature as pumping progresses before and after well redevelopment. In most cases, there were nominal changes in SC and temperature when comparing pre- and post-redevelopment measurements. (The temperature of groundwater within the well would change as a function of mechanical surging.)</td></tr>
<tr><td>11</td><td>Specific Conductance</td><td>x</td><td></td><td>x</td></tr>
<tr><td>12</td><td>pH</td><td>x</td><td></td><td>x</td></tr>
<tr><td>13</td><td>Turbidity</td><td>x</td><td>x</td><td>x</td><td>Measure and document turbidity as done historically both during and upon completion of well redevelopment. Note or flag cases when the 10 NTU criterion is not met.</td></tr>
<tr><td>14</td><td>Notes/Comments</td><td>x</td><td>x</td><td>x</td><td>This field is underutilized. At the least, it should be populated to identify field variances—e.g., cases when turbidity is not met or other anomalies are encountered. Relevant ambient conditions such as rainfall or ground saturation should also be noted.</td></tr>
</table>

Table based on current EDGE form and well redevelopment spreadsheets for the five sites for which EMO collected and documented additional field measurements during recent (2015) well redevelopment events.

[10] Although not directly relevant to this study, a recommendation for the sampling counterpart to the well redevelopment EDGE form would be documentation of the sample collection depth along with screen interval information. As discussed in Sections 6.3.1, 6.4, and 6.5.5 (and DOE 2015a), stratification of SC or chemical concentrations has been observed in some LM site wells. For these sites in particular, and as a general rule, sample depth should be recorded for all groundwater samples.

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Appendix A

Well Redevelopment at LM Sites: July 2014 Draft EMO White Paper

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Well Redevelopment at LM Sites
Discussion and Recommendations

Introduction

This paper provides information on monitoring well redevelopment, current redevelopment procedures and practices, and recommendations for a programmatic approach to monitoring well redevelopment as part of the quality assurance component of a long-term groundwater monitoring program.

Background

Numerous publications, including internal U. S. Department of Energy (DOE) documents, indicate the importance of a properly developed monitoring well. Examples of these publications documenting the importance include:

- American Society for Testing and Materials (ASTM) *Standard Guide for Development of Groundwater Monitoring Wells in Granular Aquifers* (ASTM 2013): "The importance of well development in monitoring wells cannot be overestimated; all too often development is not performed or is carried out inadequately. Proper and careful well development will improve the ability of most monitoring wells to provide representative, unbiased chemical and hydraulic data."

- Ohio Environmental Protection Agency *Technical Guidance Manual for Ground Water Investigations* (OEPA 2009): "The goal of ground water sampling is to obtain a sample that represents the current ground water conditions. Well development, well maintenance, and re-development (as needed) are critical to any ground water sampling program."

- The *Sampling and Analysis Plan for U. S. Department of Energy Office of Legacy Management Sites* (SAP) (DOE 2014): "Because of natural processes and human activities, the condition of groundwater monitoring wells deteriorate with time, and a routine monitoring well inspection and maintenance program is necessary to mitigate deterioration. As a quality assurance component of a comprehensive groundwater monitoring program, a routine inspection and maintenance program should be in place that includes periodic monitoring well redevelopment in order to promote collection of representative samples, especially when using low-flow purging and sampling techniques."

- Environmental Procedures Catalog *Standard Practice for the Inspection and Maintenance of Groundwater Monitoring Wells* (LMS/POL/S04325): "Monitoring wells should be redeveloped periodically as part of a regular maintenance program to enhance collection of high-quality samples that are representative of the subsurface environment and to minimize localized well affects. Low-flow sampling does not provide flow rates or purge volumes necessary to remove build-up of fine-grained sediment in the filter pack and well sump, or to provide removal of biological build-up in the well; therefore, routine redevelopment is an essential component of a low-flow sampling program."

Methodology

As detailed in the *Standard Practice for the Inspection and Maintenance of Groundwater Monitoring Wells* (LMS/POL/S04325): there are several methods for redeveloping monitoring wells, but the most common method used at LM sites is the surge block and pumping method. A surge block is a round disk or cylinder with a diameter close to the inside diameter of the well casing that is used to surge the well. Surging is the process of forcing water in and out of the formation and filter pack by moving the surge block up and down in the water column of a well. The surging action loosens sediment and biological material entrained in the filter pack and screen. Liberated debris is then removed from the well by pumping. Alternate cycles of surging and pumping continue until well-development completion-criteria are met. In addition to pumping and surging, well brushes are commonly used to brush the screen of a well in order to removed adhered mineral and biological build-up on the screen.

Target Indicator Parameter

Because the goal of redevelopment is to loosen and remove accumulated sediment and biological build-up in a well, turbidity (measurement of water clarity) is the best indicator parameter to determine the progress and completion of redevelopment. A turbidity criterion of 10 nepholometric turbidity units (NTUs) or less is used to determine the completion of redevelopment; the 10 NTUs criterion is used because it is the purge criterion specified in the SAP that must be met prior to groundwater-sample collection. In addition to determining the completion of well redevelopment, measurement of turbidity during sampling provides an indication of the "condition" of the well. If the 10 NTUs criterion cannot be met, or is difficult to meet (greater than 30 minutes of purge time) during groundwater sampling, then redevelopment of the well is warranted.

Current Practice

Monitoring well redevelopment has been conducted consistently at several LM sites (e. g. Gunnison, Riverton, and Grand Junction) in recent years. Extraction wells have been redeveloped consistently at the Fernald Preserve for many years, but, until the recent work at Tuba City, extraction well redevelopment at other LM sites has not been conducted consistently or per an agreed upon schedule. Table 1shows where and how often monitoring well redevelopment has been conducted at western LM sites.

Table 1. Well Development at Western LM Sites

Site	Year									
	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Bluewater									X	
Grand Junction (Office)	X	X	X	X	X	X	X	X		X
Gunnison (Processing)					X	X	X	X		X
Lakeview (Processing)								X		
Rifle (New/Old)							X	X	X	X
Riverton					X	X	X	X	X	
Monticello									X	
Shiprock										X
Slick Rock								X		
Tuba City									X	X
Shirley Basin South										X

Proposed Programmatic Approach

A consistent, programmatic approach to well redevelopment will be developed and implemented at LM sites using a graded approach to determine the frequency of well redevelopment on the basis of site-specific and/or well specific factors. A proposed programmatic-approach to determine the frequency of well redevelopment is shown in Figure 1.

The division of wells in Figure 1 is based on the following considerations:

Extraction Wells: These wells typically are larger diameter than monitoring wells to accommodate large pumps and higher flow rates. The larger diameter makes the wells more difficult to surge and develop. These types of wells typically have accelerated mineral build-up and biological growth compared to monitoring wells because continuous pumping brings a constant supply of nutrients and dissolved solids into the well. These wells typically are required to have pumping rates maximized to optimize the treatment remedy. Because of these factors, extraction wells require consistent redevelopment; therefore, a site-specific program is recommended for this type of well based on down-hole camera surveys and well yield.

Bedrock Monitoring Wells: These wells tend to have less sediment accumulation than alluvial wells, and, therefore, may require less frequent redevelopment. Targeted well redevelopment is recommended for this type of well.

Targeted well redevelopment is defined as redeveloping a well when any of the following occur:

- Sample turbidity criterion of 10 NTUs is not obtained or is difficult to obtain (greater than 30 minute purge time) during sampling.
- Significant sediment accumulation has occurred in the well, which is defined as 20 percent or more of the screen is occluded with sediment (OEPA 2009).

Sediment accumulation will be assessed by measuring the total depth of the well and comparing the measured depth to the actual depth.

- Evidence of biological growth is observed during groundwater sampling.
- Well yield has diminished to the point where a well has to be reclassified from a Category I to a Category II or III. Well categories are defined in the SAP.
- A down-hole camera survey, which will be conducted every five years, indicates significant mineral and/or biological build-up on the screen.

Deep Alluvial Monitoring Wells: Because of their depth (greater than 50 feet), these wells are more difficult to surge and develop than shallow alluvial wells due to the volume of water in the well. Targeted well redevelopment is proposed for these wells using the targeted well development criteria listed above.

Shallow Alluvial Monitoring Wells: This category of wells constitutes the majority of monitoring wells at small, unoccupied LM sites, and because of their depth (less than 50 feet) these wells are relatively easy to redevelop. Shallow wells can have an additional issue of plant roots growing into the screen (e.g. wells at Green River, Shirpock, Grand Junction disposal), which requires more frequent redevelopment.

Redevelopment work at several LM sites has demonstrated that annual redevelopment maintains shallow alluvial wells in good condition. For example, turbidity values measured at the Riverton site during sampling events conducted after monitoring well redevelopment in April 2012 are displayed in Table 2. As shown in the table, most initial turbidities measured during the purging process met the turbidity criterion of 10 NTUs, and all final turbidities met the turbidity criterion. In wells where the turbidity was not met on the first measurement, the turbidity criterion was met within five measurements or approximately 15 minutes of purge time. The low turbidity values and the short time-frame to obtain acceptable turbidity are indicators of the good condition of the wells and the effectiveness of the annual well-redevelopment. Therefore, two rounds of well redevelopment are recommended for shallow alluvial monitoring wells to get the wells in good condition followed by targeted well development protocol.

Table 2. Post-Redevelopment Turbidities at the Riverton Site.

Well Location	June 2012			December 2012			March 2013		
	Initial Turbidity[1]	Final Turbidity	N[2]	Initial Turbidity	Final Turbidity	N	Initial Turbidity	Final Turbidity	N
0707	16.5	6.37	2	6.68	3.42	1	4.18	1.72	1
0710	9.69	5.9	1	8.58	1.45	1	14.1	1.73	2
0716	8.93	5.34	1	6.39	0.88	1	4.35	5.7	1
0718	8.78	6.57	1	3.55	2.94	1	1.67	2.02	1
0720	1.53	1.74	1	2.86	2.27	1	4.95	0.84	1
0722R	2.56	1.17	1	2.06	0.84	1	2.03	1.06	1
0729	3.68	2.18	1	2.03	9.23	1	1.67	1.09	1
0784	4.89	3.2	1	8.27	2.38	1	3.97	2.41	1
0788	9.64	5.74	1	19.2	6.29	5	7.97	3.56	1
0789	20.3	4.02	2	6.02	1.76	1	67.2	9.83	5
0824	55.1	8.17	5	5.95	2.06	1	11.7	9.05	3
0826	7.65	4.25	1	4.67	4.45	1	32.2	8.61	3

[1]Turbidity units are in NTUs.
[2]Number of measurements required during monitoring-well purging to achieve turbidity criterion.

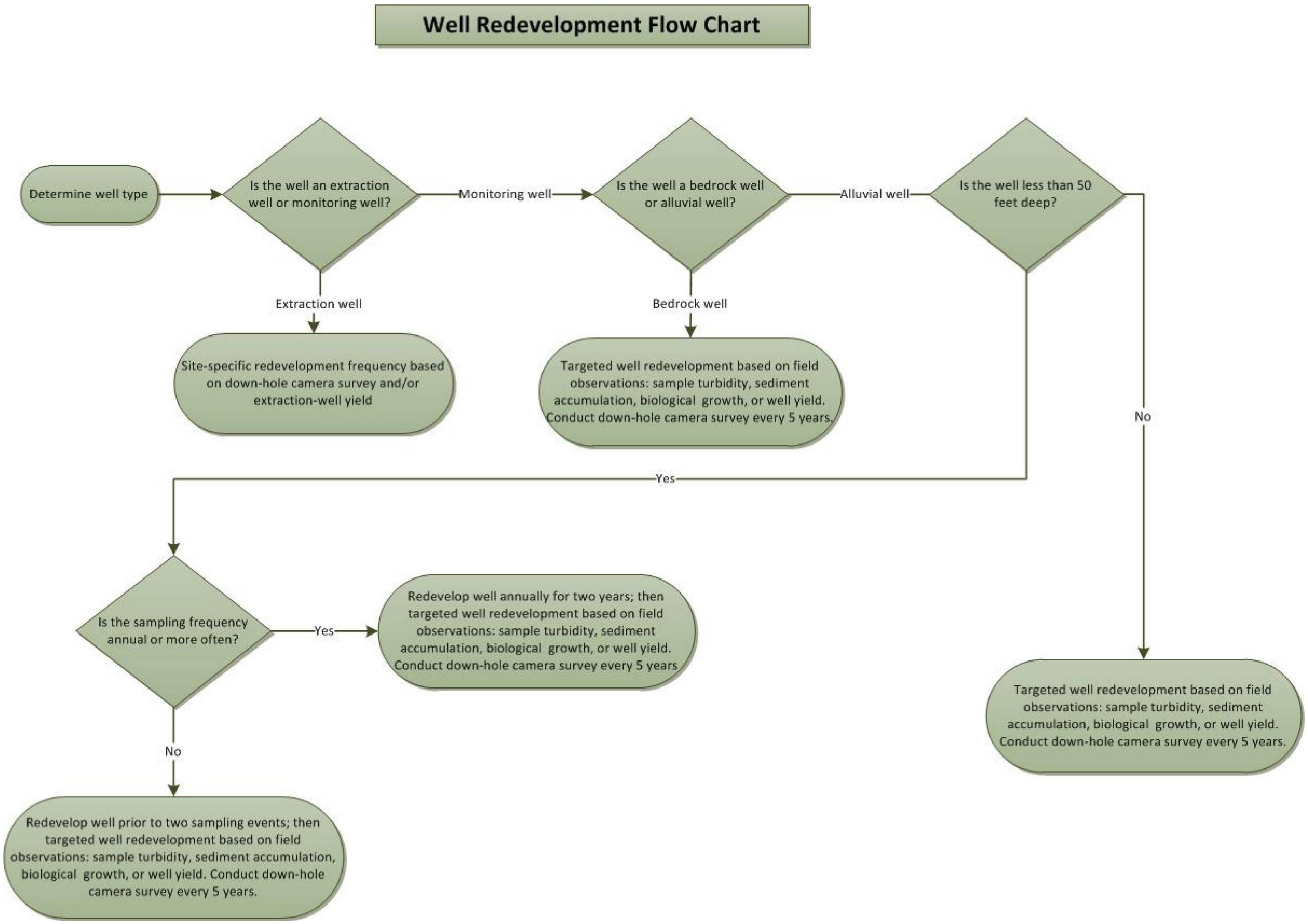

Figure 1. Well Redevelopment Flow Chart.

Post-Redevelopment Equilibrium

According to the OEPA, a sufficient time should be allowed for equilibration with the formation between well redevelopment and groundwater sampling; however, there is no rigorous scientific analysis to substantiate a time frame (OEPA 2009). OEPA suggests a "rule of thumb" of one week between well redevelopment and sampling, but could be several weeks in low permeability formations. Because the time frame for equilibration depends on the permeability of the formation, the time-frame between well redevelopment and sampling should be based on the yield of the well and the time required for water level recovery after well redevelopment. Following is the proposed minimum time-frame between well redevelopment and sampling for LM wells.

- Category I wells. Category I wells are wells that will maintain a stable water level during groundwater sampling; therefore, these wells have sufficient yield/formation permeability to use the minimum time-frame between redevelopment and sampling.
  Minimum time-frame: one week.

- Category II or III wells. Category II and III wells are wells that will not maintain a stable water level during groundwater sampling; therefore, these well have low yield/formation permeability and a longer time-frame between redevelopment and sampling is warranted. Some of these wells may have extremely low yield/permeability and some may take a week or more for full water-level recovery after redevelopment.
  Minimum time-frame: 10 times the amount of time required for full water-level recovery after redevelopment or one week, whichever is greater.

Conclusions and Recommendations

An LM-wide program for well redevelopment will be implemented as part of a comprehensive quality assurance program to collect representative samples and provide defensible data of known quality. General guidance presented in this paper associated with well redevelopment includes:

- Redevelopment frequency is based on well type:
  - Extraction wells – site-specific program based on site-specific conditions
  - Monitoring wells
    - Bedrock wells – targeted well redevelopment based on well-specific observations.
    - Alluvial wells greater than 50 feet deep – targeted well redevelopment based on well-specific observations.
    - Alluvial wells less than 50 feet deep – redevelop annually for two years or prior to two sampling events (if sampling frequency is greater than annual) followed by targeted well development.
- Allow at least one week between redevelopment and sampling for wells that produce sufficient water.

- Allow more time between redevelopment and sampling for low-producing wells – the time-frame will be dependent upon water level recovery after redevelopment is complete.

Specific actions to implement a LM-wide well redevelopment program include:

- After review and approval from DOE, this programmatic approach will be documented in an update to the *Standard Practice for the Inspection and Maintenance of Groundwater Monitoring Wells*, which is found in the Environmental Procedures Catalog as a Level 2 document on the intranet. Complete by August 30, 2014.
- Implement and complete a data call from all LMS Site Leads to document an inventory of well types that are currently monitored at all LM sites. Complete by October 15, 2014.
- Based on the results from the inventory of well types, plan and execute a base-line well quality survey to document well-condition status per the redevelopment criteria defined for each well type. Complete by June 30, 2015.
- Develop an EDGE input form so that well redevelopment activities will be captured and well redevelopment data will be stored in the new EQuIS database. Complete by March 2, 2015.
- Based on the results of the well-quality survey, develop and cost a program-wide well redevelopment schedule for consideration by DOE for inclusion in the Life-cycle baseline. Track and implement well redevelopment activities the same as sampling events by having the well redevelopment schedule for each site listed in the site-specific information in Appendix D of the SAP. Complete by August 30, 2015.

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Appendix B

Well Redevelopment Assessment Literature Search Results

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B.1 Reviews of Selected Literature

ASTM (American Society for Testing and Materials), 2011. *Standard Guide for Maintenance and Rehabilitation of Groundwater Monitoring Wells*, D5978-96.

ASTM (American Society for Testing and Materials), 2013. *Standard Guide for Development of Groundwater Monitoring Wells in Granular Aquifers*, D5521/D5521M-13, August.

Barber, C., and G.B. Davis, 1987. "Representative sampling of ground water from short-screened boreholes," *Ground Water* 25(5): 581–587.

Barcelona, M.J., and J.A. Helfrich, 1986. "Well construction and purging effects on ground-water samples," *Environmental Science & Technology* 20(11): 1179–1184.

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Schnieders, J.H., 2003. *Chemical Cleaning, Disinfection & Decontamination of Water Wells*, Johnson Screens Inc., St. Paul, Minnesota.

B.2 Detailed Bibliography and Interpretations

ASTM (American Society for Testing and Materials), 2011. "Standard Guide for Maintenance and Rehabilitation of Groundwater Monitoring Wells, D5978-96."

Review:

Like the related ASTM D5521 (*Standard Guide for Development of Groundwater Monitoring Wells in Granular Aquifers*), this is a procedural paper only. However, unlike ASTM D5521, which makes no reference to well redevelopment, this ASTM guide does address redevelopment and also references the literature (D5521 only cites other ASTM procedures). Section 3.2.5 of this guide defines well redevelopment as follows:

> any preventive or rehabilitative well maintenance action, taken after start-up, for the purpose of mitigating or correcting deterioration of the filter pack or adjacent geologic formations, or both, due to the well's presence and operation over time, usually involving physical development procedures, applied in reaction to deterioration.

The rationale underlying the guidance is presented as follows:

> The process of operating any engineered system, such as monitoring wells, includes active maintenance to prevent, mitigate, or reverse deterioration. Lack of or improper maintenance can lead to well performance deficiencies (physical problems) or sample quality degradation (chemical problems). These problems are intrinsic to monitoring wells, which are often left idle for long periods of time (as long as a year), installed in non-aquifer materials, and installed to evaluate contamination that can cause locally anomalous hydrogeochemical conditions.

In this guide, well redevelopment falls within the realm of well rehabilitation, considered synonymous with restorative maintenance:

> [Well rehabilitation] Methods include redevelopment to remove fine-grained materials from the well and to remove materials clogging the well screen.

According to this guidance, there are two primary sets of factors that would indicate the need for restorative maintenance (i.e., well redevelopment): well performance deficiencies (e.g., sand, silt, and clay infiltration, low yield, slow responses to changes in groundwater elevations, and loss of production) and sample quality degradation. Physical indicators of sample quality degradation include (1) chemical encrustation (e.g., $CaCO_3$ precipitation), (2) biofouling, (3) corrosion, (4) turbidity, and (5) change in sand/silt content or particle counts. Chemical indicators of sample quality degradation include changes in the following parameters: Fe, Mn, sulfur, redox potential (Eh), pH, conductivity, and various gases (e.g., DO, CO_2, and H_2S). Guide D5978-96 does not address the extent to which changes in these parameters can be attributed to sample quality degradation (catalyst for well maintenance) versus sitewide or local changes in hydrogeochemistry. Nor does it provide any data to substantiate these qualitative guidelines.

Section 10.3 of the guide specifically addresses well redevelopment:

> Redevelopment can be accomplished using pumps, surge blocks, compressed air (for example, air lift method), or water jetting, or combination thereof. In certain conditions, chemicals and steam may be used for redevelopment for bacterial problems. The reader should consult Guide D5521 for appropriate methods. It is noted that the goals for redevelopment are the same as the goals identified in Guide D5521.

ASTM (American Society for Testing and Materials), 2013. *Standard Guide for Development of Groundwater Monitoring Wells in Granular Aquifers*, D5521/D5521M-13, August.

Review:

This is a procedural paper addressing well development only. Redevelopment may be implied in some cases but, as found in much of the literature related to this topic, the procedures are focused on well development in the context of well completion or post-well-installation procedures—not redevelopment. Section 4.3 of this guide states:

> The importance of well development in monitoring wells cannot be overestimated; all too often development is not performed or is carried out inadequately. Proper and careful well development will improve the ability of most monitoring wells to provide representative, unbiased chemical and hydraulic data.

The discussion of well development techniques or processes (Section 8, p. 5) begins with the following general statement:

> Of the various methods available for use in developing wells in general, mechanical surging, overpumping and backwashing, and high-velocity hydraulic jetting with pumping (or combinations of two or more of these methods) are best suited for use in developing groundwater monitoring wells. The method most appropriate for use in a given situation depends on a variety of factors...

Examples of the factors involved include well construction, borehole drilling method, depth to static water level, and height of the water column in the well. Overpumping is referred to as:

> the simplest method of removing formation fines...However, five important limitations to overpumping include: overpumping by itself will not adequately develop a well because water flow is in only one direction...

Remaining limitations discussed seem to apply to the context of post-installation well development, not necessarily well redevelopment. Much is said about removing fines and also infiltration of drilling fluids. (Drilling fluid invasion is not typically important to LM wells because many are drilled without the use of drilling fluids.) No data or references are provided to support or quantify any of the statements provided in this guidance (the only documents referenced are other ASTM standards).

Barber, C. and G.B. Davis, 1987. "Representative sampling of ground water from short-screened boreholes," *Ground Water* 25(5): 581–587.

Review:

This article is potentially relevant to the issue of sample quality or representativeness in relation to well redevelopment given the following preface/abstract:

> Boreholes terminated with a short (1-3 m) length of screen are often used in ground-water quality monitoring, although to obtain representative samples, pumping is often required to overcome the effects of stagnant casing storage.

However, it is not directly relevant to this issue, and there is no mention of well development, redevelopment, or maintenance. According to the authors, pumping 2–3 casing volumes is necessary to meet mass balance requirements (to overcome stagnant well storage effects). The article mostly discusses modeling but also has some laboratory and field specific conductance and bromide data. The entire thesis is built around the time needed to stabilize purged concentrations (due to different chemical signatures in the stagnant casing). As with many other papers of this generation, the conclusion seems to be that if the concentrations stabilize, it is a 'good' sample.

Barcelona, M.J., and J.A. Helfrich, 1986. "Well construction and purging effects on ground-water samples," *Environmental Science & Technology* 20(11): 1179–1184.

Review:

This article addresses variability in sample results due to well casing material and purging methods. The authors considered mostly volatile organic compounds (VOCs), examining chemical differences in purged vs. stagnant water, PVC vs. stainless steel casing, and grout- vs. non-grout-contaminated well water. The logic used in the article seems to be as follows: authors sample wells in proximity, one constructed with PVC, and the other with stainless steel. Their conclusion is based on the implicit assumption that no other effects exist. That is, if the nearby well had been made of the same material it would have given comparable results.

However, based on experience at LM UMTRCA sites, this statement is not always true, because well chemistry often varies even in closely spaced wells. Authors seem to infer that a comparison of purged to stagnant samples can be used to conclude that the stagnant samples were affected by redox processes or increased interaction with well materials. It could, however, simply be that the purging is drawing water from a different part of a stratified formation within the screened interval. The first sentence in the authors' conclusions states:

> The purging of stagnant water from monitoring wells is essential to the collection of reliable ground-water quality data.

However, the data presented in the article do not conclusively demonstrate this point. Furthermore, so many combinations of variables are assessed—stainless steel vs. PVC casing, purging vs. stagnant water, contaminated groundwater vs. grout-contaminated-groundwater—that conclusions are somewhat muddied and difficult to interpret. Although differences were found in the chemical composition of some purged vs. non-purged samples, there was no apparent consistency in either the magnitude or direction (positive or negative) of those differences. Again, the focus was on volatile constituents rather than on inorganics typically monitored under the LM UMTRCA program.

The underlying logic of the authors' (Barcelona is a known proponent of low-flow sampling) appears to be: If purging a well yields sample results that are different from the non-purge results, then purging is essential. Regarding rationales supporting "to purge" or "not to purge" sampling approaches, the more logical conclusion would be that it depends on a variety of factors. Perhaps more important factors influencing whether or not groundwater quality data are "reliable" would be: sample depth in the water column (screened vs. non-screened interval, and consistency in sample depth over time), the sample collection technique, preservation, packaging, handling, and analysis.

In this article, well "redevelopment" was specifically mentioned only once, as it related to the authors' examination of wells at a site with consistently high pH (>12) and apparent grout contamination:

> The apparent cement contamination problem persisted more than 18 months after construction, despite at least 10 redevelopment attempts.

Barcelona, M.J., H.A. Wehrmann, M.D. Varljen, et al., 1994. "Reproducible well-purging procedures and VOC stabilization criteria for ground-water sampling," *Ground Water* 32(1): 12–22.

Review:

In this article, the first two sentences in the abstract state:

> Recent research has confirmed that low flow rate purging (i.e., ~1 l/min) is a valid technique for 2" (5 cm) diameter monitoring wells with short screened intervals. The use of low flow, dedicated pumping devices for purging and sampling minimizes both the disturbance of stagnant water in the well casing and the potential for mobilization of particulate or colloidal matter which could lead to sampling artifacts.

This study attempts to advocate the use of low-flow sampling using small 2-inch wells with 5-ft screens in glacial outwash at an NPL site near Rockford Illinois. The contaminants were trichloroethene and other VOCs. Samples were collected using a bladder pump and a purge rate of 1 liter/minute. Dissolved oxygen, pH, and specific conductance (SC) were the stabilization indicators (the highest SC was 859 µS/cm). Samples were collected quarterly from 13 wells. The main concern was obtaining stable values for VOC concentrations that had "degassed" in the well bore. The entire thesis has to do with the stabilization of dissolved oxygen, SC, and VOC concentrations; if these parameters stabilize, then the sample is good. Well development is mentioned only in the context of standard post-well-installation procedures, as reflected in the following excerpt from the article conclusions:

> Consistent well purging and sampling procedures must be carefully chosen to meet the purposes of investigations, the hydrogeologic setting, and the hydraulic performance of sampling points. Proper well development to remove fines created during drilling is a necessary first step to avoid excess turbidity and particulate artifacts.

DOE (U.S. Department of Energy), 1995. *UMTRA Ground Water Sampling Techniques: Comparison of the Traditional and Low Flow Methods*, DOE/AL/62350-193, Rev. 0.

Review:

Although not directly relevant to the rationale for well redevelopment, this methods paper is somewhat related in that it appears to have served as a springboard for conversion to low-flow sampling methods. The text presents case histories and literature review of work by Kearl, Shanklin (Fernald, OH, Site) and others. Section 5.2 (Recommendations) states:

> The literature reviewed in this paper suggests that conversion to low-flow sampling will cause no systematic, uniform, or predictable shift in analytical results. The shifts that are documented in the literature appear to be the result of factors such as lowering the turbidity in the sample, hydrogeology, oxidation-reduction state of the ground water, or other site-specific conditions. Of the six papers reviewed, none demonstrated any statistically significant analytical shift for filtered ground water samples. Based on the

> current literature, the impact of low-flow sampling overall appears to be minimal, with a few different results that are site-specific and unpredictable.

The need for well maintenance or redevelopment when using low-flow sampling is not mentioned in this paper.

Environmental Procedures Catalog, LMS/POL/S04325, continually updated, prepared by Navarro Research and Engineering, Inc., for the U.S. Department of Energy Office of Legacy Management.

Review:

Well Development/Redevelopment Procedures are addressed in Section 24.5.2, which states:

> Monitoring wells should be redeveloped periodically as part of a regular maintenance program to enhance collection of high-quality samples that are representative of the subsurface environment and to minimize localized well affects [sic]. Low-flow sampling does not provide flow rates or purge volumes necessary to remove build-up of fine-grained sediment in the filter pack and well sump, or to provide removal of biological build-up in the well; therefore, routine redevelopment is an essential component of a low-flow sampling program.

However, as is true for the general literature on this topic, no data or references are provided to support this statement. Page 201 also states:

> In addition to routine redevelopment, monitoring wells should be redeveloped if the following conditions are encountered.
>
> - The well-inspection process indicates that excessive sedimentation is occurring.
> - The capacity of the well appears to have significantly declined during the course of a sampling program. (i.e., low-yield criterion)
> - There is evidence of excessive biological growth in the well.

Three development/redevelopment techniques are discussed: (1) compressed-nitrogen jetting and air-lift pumping, (2) surge block and pumping or bailing, (3) pumping only. Although the procedures don't mandate or specify the use of one particular technique, the implicit recommendation seems to be that use of a surge block is the best approach (following quoted from p. 201, para. 3):

> Successful development/redevelopment requires that water be forced (or surged) from the well screen interval into the filter pack and formation, and from the formation and filter pack into the well screen interval. This is best accomplished through the use of a surge block or a bailer as a surging tool. Compressed-nitrogen jetting can also accomplish this flow reversal to some extent. Pumping only is not as effective in achieving flow reversal (although reversing the pump can be effective) and is, therefore, best used in conjunction with nitrogen jetting or surge blocking.

The well development/redevelopment section of the *Environmental Procedures Catalogue* concludes with the following recommendations regarding documentation (p. 203):

> Documentation of well development should include the following information: site, well identification, date, start and stop time of pump cycles, volume of water removed during each pump cycle, number of times surged, turbidity, water levels, and persons performing the work.

Sampling and Analysis Plan for U. S. Department of Energy Office of Legacy Management Sites, LMS/PRO/S04351, continually updated, prepared by Navarro Research and Engineering, Inc., for the U.S. Department of Energy Office of Legacy Management.

Review:

Much of the material in this plan duplicates that already cited in the *Environmental Procedures Catalog*. Some additional information is provided regarding specific well maintenance, development, and redevelopment approaches, but apart from the reference to Korte (2001), there is no discussion of documented impacts of well redevelopment on sample analytical results. Well redevelopment is addressed specifically in Section 5.1.4 of this Sampling and Analysis Plan:

> Because of natural processes and human activities, the condition of groundwater monitoring wells deteriorate[s] with time, and a routine monitoring well inspection and maintenance program is necessary to mitigate deterioration. As a quality assurance component of a comprehensive groundwater monitoring program, a routine inspection and maintenance program should be in place that includes periodic monitoring well redevelopment in order to promote collection of representative samples, especially when using low-flow purging and sampling techniques (Korte 2001). Inspection and maintenance activities will be conducted according to the 'Standard Practice for the Inspection and Maintenance of Groundwater Monitoring Wells … The frequency of monitoring well inspection and maintenance will be determined on a site-specific basis.

Driscoll, F.G., 1986. *Groundwater and Wells,* Johnson Division, St Paul, MN, pp. 1–1089.

Review:

This classic book on groundwater wells devotes an entire chapter (15) to well development. However, the discussion is focused almost completely on well development for the purpose of increasing well production (yield). We were unable to find any text relating well development or maintenance to the quality of groundwater samples collected. The discussion includes drilling methods and the infiltration of drilling fluids/drilling muds into the permeable zones of the formation. There are no data; rather (like many), the text is based strictly on experience and opinion (although data probably do exist to support the assertion that well development can result in increased yields). Chapter 15 (p. 497) begins with the following statements:

> Procedures designed to maximize well yield are included in the term 'well development.' Development has two broad objectives: (1) repair damage done to the formation by the drilling operation so that the natural hydraulic properties are restored, and (2) alter the basic physical characteristics of the aquifer near the borehole so that water will flow more freely to a well.

Although the focus of the chapter is on development coinciding with/immediately following well installation, the author states:

> In addition, older wells often require periodic redevelopment to maintain or even improve the original yield or drawdown conditions.

There is no mention of redevelopment in the context of groundwater sample quality, thus implying that the need for redevelopment has to deal with well yield. Driscoll also states (p. 499) that:

> Techniques described below are applicable for all types of common aquifer materials, but the benefits are generally more substantial for unconsolidated sediments.

Keely, J.F. and K. Boateng, 1987. "Monitoring well installation, purging, and sampling techniques—Part 1: Conceptualizations," *Ground Water* 25(3): 300–313.

Review:

This article consists mostly of a review of various drilling and well development methods and is for the most part not germane to the questions posted in this report. Of interest is the authors' view on well development procedures:

> Of the methods available for well development, overpumping is probably the most desirable for monitoring wells.

This view is counter to recent ASTM (2013) guidelines, which cite various limitations to overpumping.

Korte, N., 2001. *Application of Low-Flow Purging to the UMTRA Ground Water Project,* Consultant Report: pp, 1–24.

Review:

This white paper is relevant to the well redevelopment topic as it is the only reference cited by EMO as the basis for redeveloping monitoring wells to ensure sample quality and representativeness (following quoted from Section 5.1.4 of LM Sampling and Analysis Plan):

> Because of natural processes and human activities, the condition of groundwater monitoring wells deteriorate[s] with time, and a routine monitoring well inspection and maintenance program is necessary to mitigate deterioration. As a quality assurance component of a comprehensive groundwater monitoring program, a routine inspection and maintenance program should be in place that includes periodic monitoring well redevelopment in order to promote collection of representative samples, especially when using low-flow purging and sampling techniques (Korte 2001).

This white paper provides recommendations for the UMTRA sampling program. It references the authors most prolific in the areas of low-flow sampling (Barcelona, Puls and Powell, etc.), but no citations or data are provided that support the assertion that well redevelopment is required to ensure sample quality. Discussions suggesting the need for well maintenance are largely based on professional judgment rather than data. The only mention of well redevelopment in this paper is made in the discussion of "High Pumping Rates" (Section 2.3.1):

> High pumping rates are clearly deleterious to the collection of representative samples. Nevertheless, high pumping rates are often necessary to remove water from deep wells within a reasonable time period. The problems caused by a high rate of pumping are: turbulence, redevelopment of the well, mixing of chemically distinct zones, and aeration, all of which might affect the chemistry of the system (Puls and Powell 1992).

The discussion of well development (Section 2.3.3) states:

> Well development is also a critical issue. Poorly-developed wells yield extraneous particles irrespective of the sampling procedure. Thus, an appropriate well maintenance schedule is necessary.

The citation in the LM SAP seems to be based on the following discussion in Korte's paper:

> A problem with infrequent sampling was recently encountered at one site that extensively uses micropurging. It was determined that the dedicated tubing and/or pumps provide a substrate for microbial attachment which, in turn, contributed to spurious metal contamination (Korte 2000). Thus, the use of micropurging is not necessarily low maintenance because the sampling apparatus and wells have to be cleaned periodically. Problems with microbial growth are typically more likely when the well is infrequently used.

With regard to well maintenance (Section 5.2.5), Korte states:

> An appropriate well maintenance schedule is necessary. ...Nevertheless, there is reason to be especially vigilant because many of the wells are not sampled very often (DOE 2000). Thus, there is ample opportunity for microbial activity. Thus, the well maintenance program should be reviewed. Well development (ensuring that the well and the formation have a good hydraulic connection) is critical to getting a representative sample (Barcelona et al. 1994).

Korte's recommendations regarding well maintenance parallel those offered by others in the industry but, once again, no data are presented that substantiate these conclusions.

Ohio EPA (Ohio Environmental Protection Agency), 2009. *Technical Guidance Manual for Groundwater Investigations*, Chapter 8, "Monitoring Well Development, Maintenance, and Redevelopment."

Review:

The following statement from this (OEPA) guidance is cited in EMO's draft white paper (*Well Redevelopment at LM Sites, Discussion and Recommendations)* to demonstrate that redevelopment is needed to obtain representative groundwater samples:

> The goal of ground water sampling is to obtain a sample that represents the current ground water conditions. Well development, well maintenance, and re-development (as needed) are critical to any ground water sampling program.

This guidance is largely a procedural document that primarily addresses well development (e.g., as a necessary post-well-installation procedure). Discussion of redevelopment is limited to the final chapter titled "Well Maintenance Checks and Redevelopment" (pg. 8-13). There are many practical suggestions (quoted below in indented text) that support periodic well redevelopment as a good management practice, but no data are provided that indicate that the water in the well is any less representative with or without redevelopment.

> During the course of their active lives, monitoring wells should be checked to confirm that the well is still intact and fine particles have not accumulated. Unlike water supply wells, monitoring wells remain predominantly unpumped. There is no continuous removal of fines over an extended period. According to Kraemer et al. (1991), no matter how complete development appears to be, there is a high probability (especially for wells completed in fine-grained formations) that introduction of pumps or bailers will create a surge rendering the water somewhat turbid. In addition to sediments accumulating in the well, the casing and screen can become corroded or plugged by chemical or bio-chemical precipitates, and thus cause a loss of hydraulic connection. …A deteriorating well structure or a well that is "silting up" can cause a bias to the data that might be difficult to detect or might even be interpreted as trends in ground water quality. To provide a representative sample, these wells should be restored. Restoration typically involves redevelopment.

The underlined text in the quoted material above is an example of statements that, although perhaps true, have not been fully supported by the data. That said, the remainder of this chapter does include useful guidelines for determining the need for well redevelopment. These recommendations do not necessarily warrant a regular (e.g., annual) redevelopment frequency. Rather, frequency is determined by various factors, including yield and screen blockage.

> It is recommended that performance be evaluated during the life of a well. This may include, but not be limited to, noting a significant drop in yield during purging, noting increased turbidity, measuring total well depth to determine if sediments have been deposited, and using a camera to determine if incrustation of the screen or damage to the well casing has occurred. Comparison of water-level fluctuations over time in the well can indicate a possible change in hydraulic connection of the well to the aquifer. For example, a long-term decline in the water level in a well could indicate gradual plugging of the well screen.
>
> Well maintenance records should be kept including, but not limited to, periodic checks on depths; trends in water levels, yield changes and turbidity; the external physical condition of the well, its protective casing, the surface seal; and other criteria utilized to monitor the integrity of the well. At minimum, wells should be redeveloped when 20% of the well screen is occluded by sediments (U.S. EPA, 1988), or records indicate a change in yield and turbidity.

Schnieders, 2003. *Chemical Cleaning, Disinfection & Decontamination of Water Wells*, Johnson Screens Inc., St. Paul, Minnesota, pp. 1–227.

Review:

This book addresses practical considerations of well maintenance and development. According to the author:

> …well development is a very important part of well construction. It is designed to remove the mud from the borehole wall drawing it through the gravel into the well for removal from the well system… Redevelopment is necessary in wells due to the presence of blockage or fines from formation or geological changes rather than those due to biological and mineral deposits. Sand, clays, and particulate matter from the formation are usually considered in this category.

Although proper mud placement and well development during well construction is paramount, redevelopment

> may become necessary as the well ages and physical blockage begins to build up in the gravel pack and immediate formation in order to restore the well to its original formation structure and open flow areas.

Schnieders also discusses microbial-induced mineralization and contaminant accumulation:

> Both laboratory research and observation of operating well chemistry have shown that most of the time well water is fairly evenly balanced and may operate many years without significant mineral blockage. Once a biofilm develops in the well, however, mineral formation takes place and significant blockage occurs….The process of biofouling, mineralization, and/or a combination of both together with the intricate flow pathways that make up a well environment, offer considerable area for contaminant accumulation.

Appendix C

Supplementary Time-Concentration Plots of Uranium and Other COCs Relative to Well Redevelopment Events

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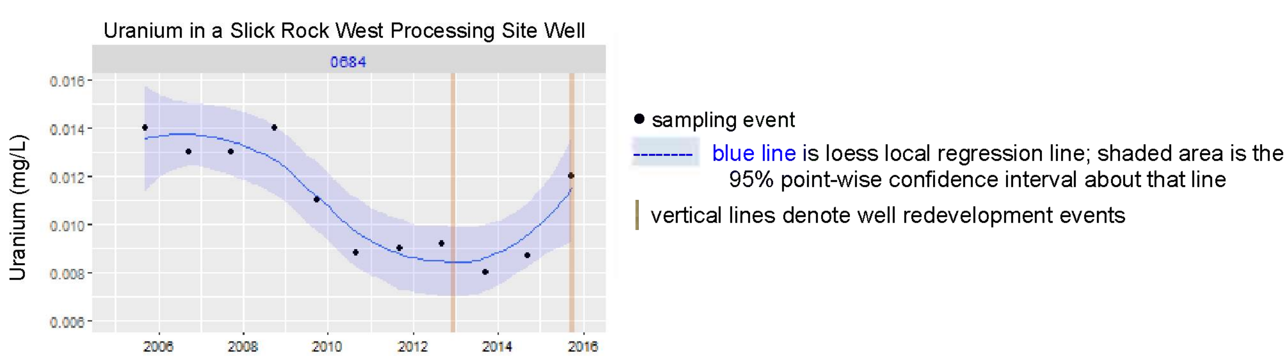
Appendix C Preface

This appendix includes supplementary time-concentration plots of uranium or other constituents of concern for LM site wells redeveloped between 2010 and 2015. Most of these figures (Figures C-1 through C-9) correspond to sites LM sites with limited redevelopment documentation (those addressed in Section 6.2 of this report). Figure C-10 includes time-concentration plots of semiannual uranium data for Tuba City site extraction wells (monthly data are presented in Section 6.3.2).

List of Figures

Global Legend for Time-Concentration Plots Used in this Appendix

In most of the time-concentration plots included in this appendix (most are for uranium), a non-parametric smoothing method or locally weighted regression—"loess" (not to be confused with the geologic term)—is used. With this approach, overall trends in the data are more apparent and not obscured by "noise." An example of this data presentation approach is shown in the inset below. For wells with only a few data points, the smoothing is not valid; in these cases, traditional line plots are used.



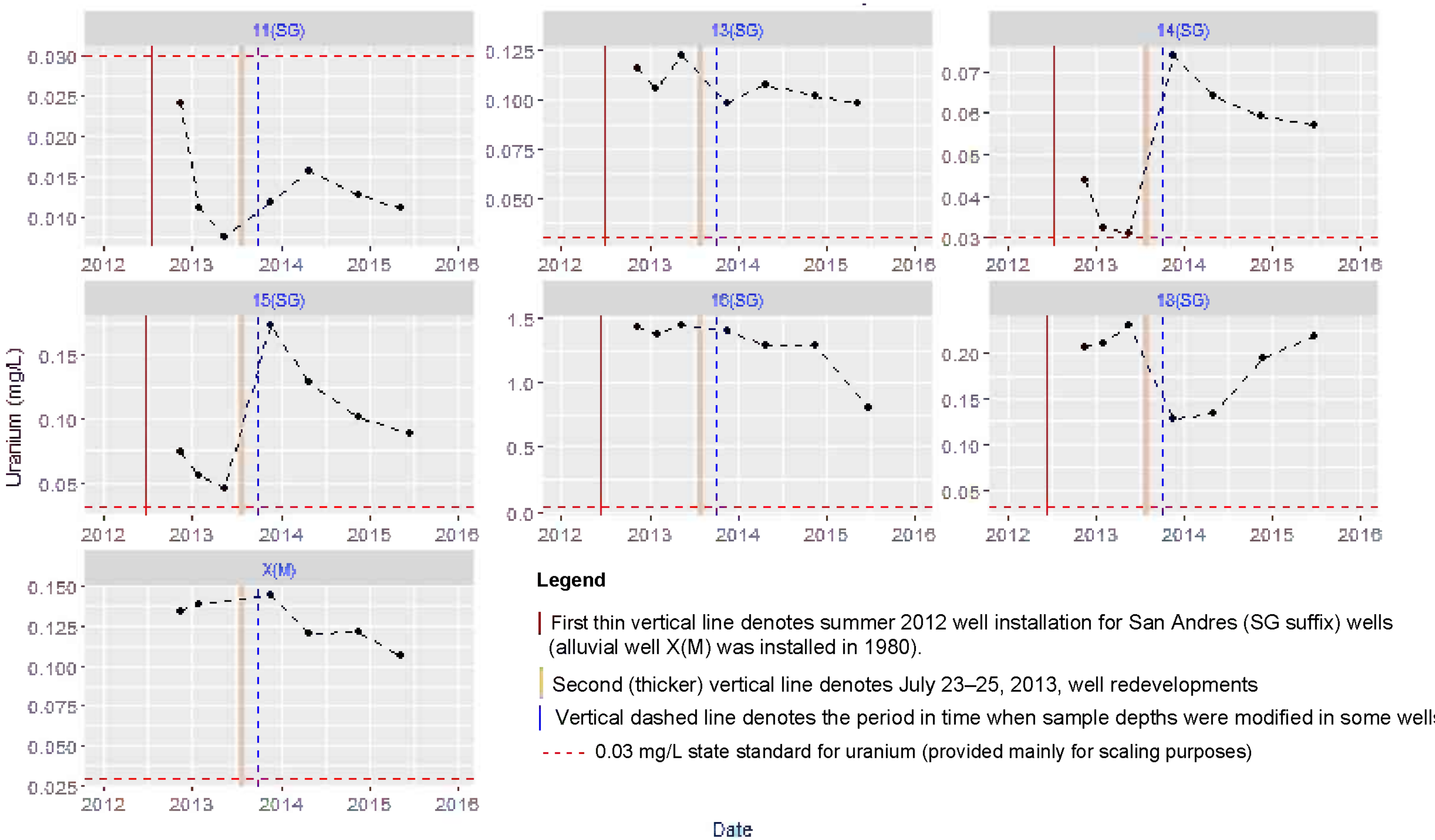


Figure C-1. Time-Concentration Plots of Uranium in Bluewater Disposal Site Wells Wells Redeveloped July 23–25, 2013

Only one redevelopment event has been documented for this site, based on information provided by EMO.
This figure is also included in the main text (Figure 6); supporting discussion provided in Section 6.2.1.

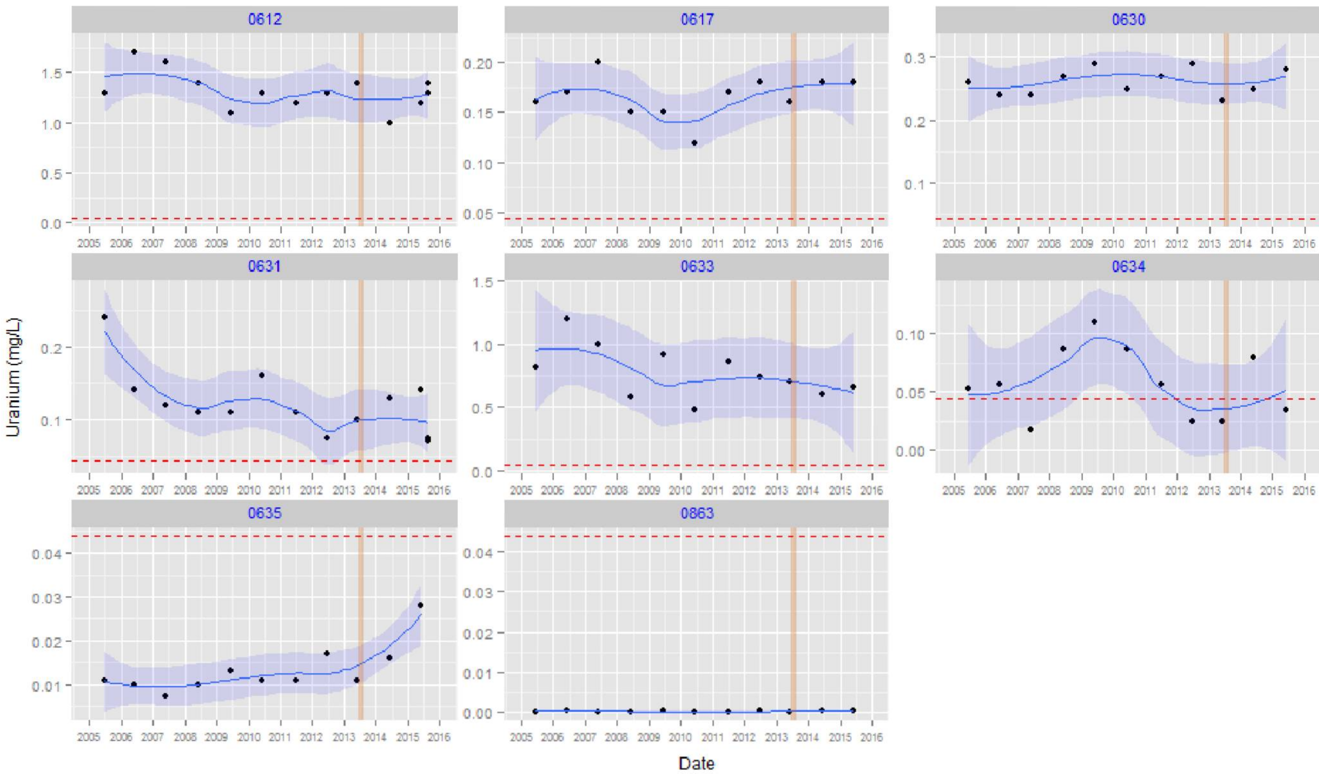


Figure C-2. Time-Concentration Plots of Uranium in Durango Mill Tailings Area Wells (Redeveloped July 2013)

Wells redeveloped July 15–17, 2013, about one month after the June 2013 routine sampling event (the following sampling event took place on June 5, 2014). Five additional wells—0605, 0607, 0608, 0618, and 0621—were also redeveloped but are no longer monitored.

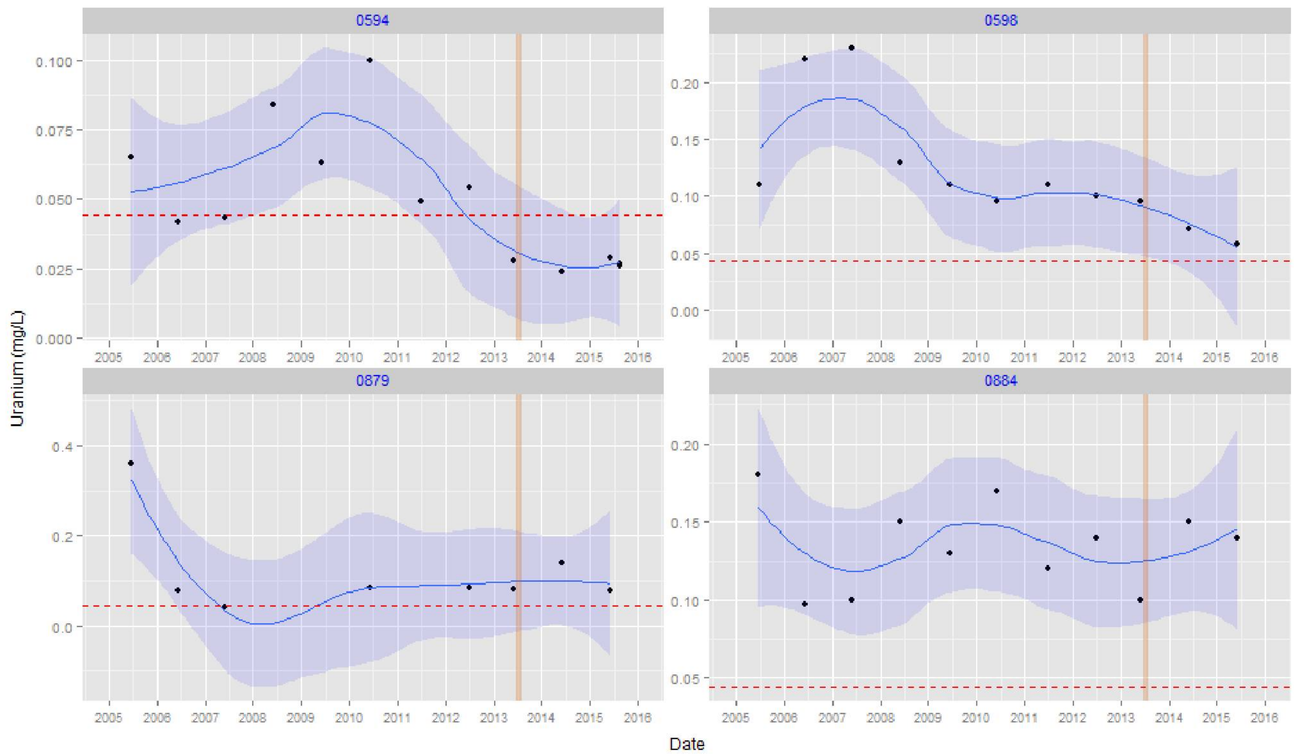
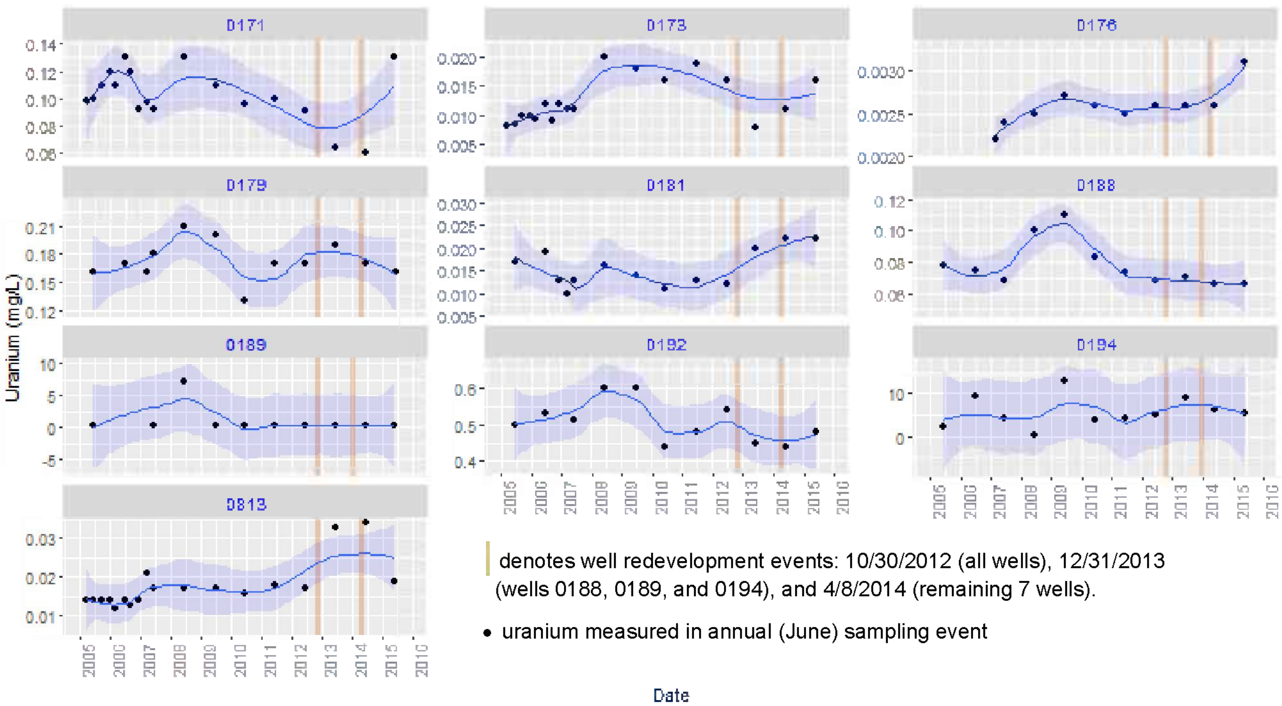


Figure C-3. Time-Concentration Plots of Uranium in Durango Raffinate Pond Area Wells (Wells Redeveloped July 2013)

Wells redeveloped July 16–17, 2013, about one month after the June 4, 2013 routine sampling event; the next annual sampling event took place June 2–4, 2014. One additional well—0623—was also apparently redeveloped but is no longer monitored.

a. Uranium in Routinely Monitored Green River Site Wells



b. Uranium in Green River Site Wells with Limited Historical Data

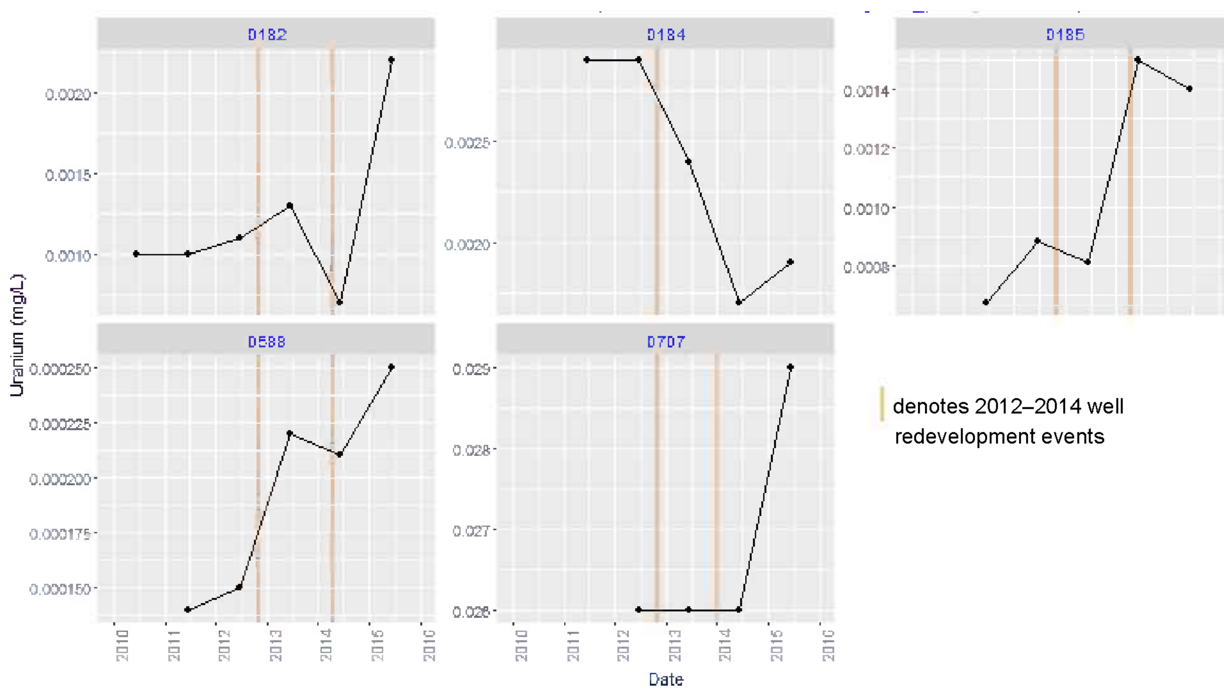


Figure C-4. Time-Concentration Plots of Uranium in Green River Disposal Site Wells

Upper plot plots uranium over time for the subset of wells with sufficient data to use smoothing method (this plot duplicated in Figure 7 of main text). Lowermost figure plots uranium vs. time in wells with limited sampling results.

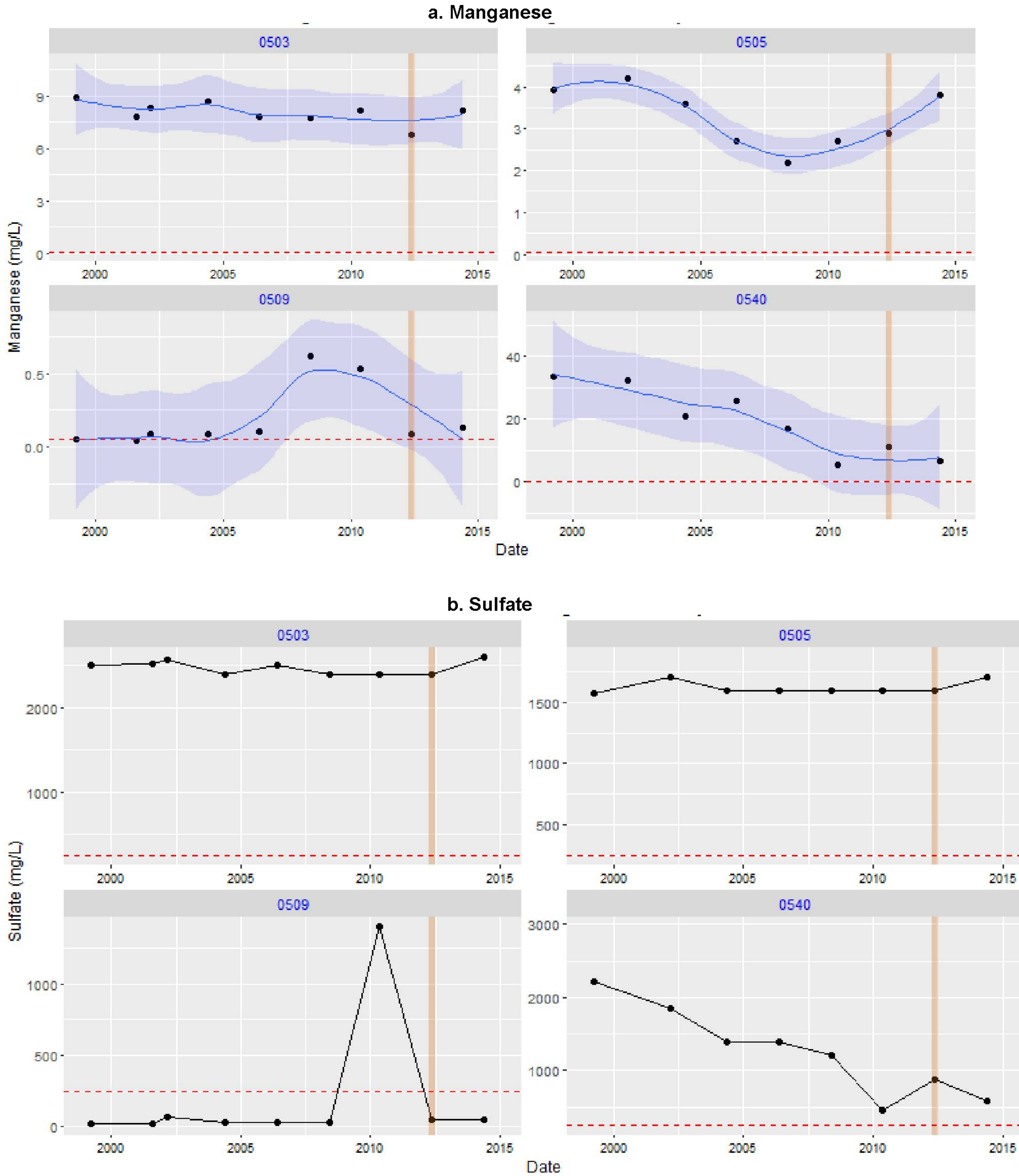


Figure C-5. Time-Concentration Plots of Manganese and Sulfate in Lakeview Processing Site Wells

| denotes May 15-16, 2012 redevelopment. Wells are sampled every two years—wells 0503, 0505, and 0509 were sampled one day after the 5/15/2012 redevelopment; well 0540 was sampled on the same day (5/16/2012). Manganese (a) and sulfate (b) are the primary COCs at this site. Uranium has generally not been detected in wells 0503, 0505, and 0509; uranium concentrations in well 0540 have varied but with one exception have been below the 0.044 mg/L UMTRCA MCL. *Note:* The May 2010 sulfate datum for well 0509 (1400 mg/L) was verified (i.e., the result was not rejected); remaining sulfate concentrations in this well ranged from 11–68 mg/L.

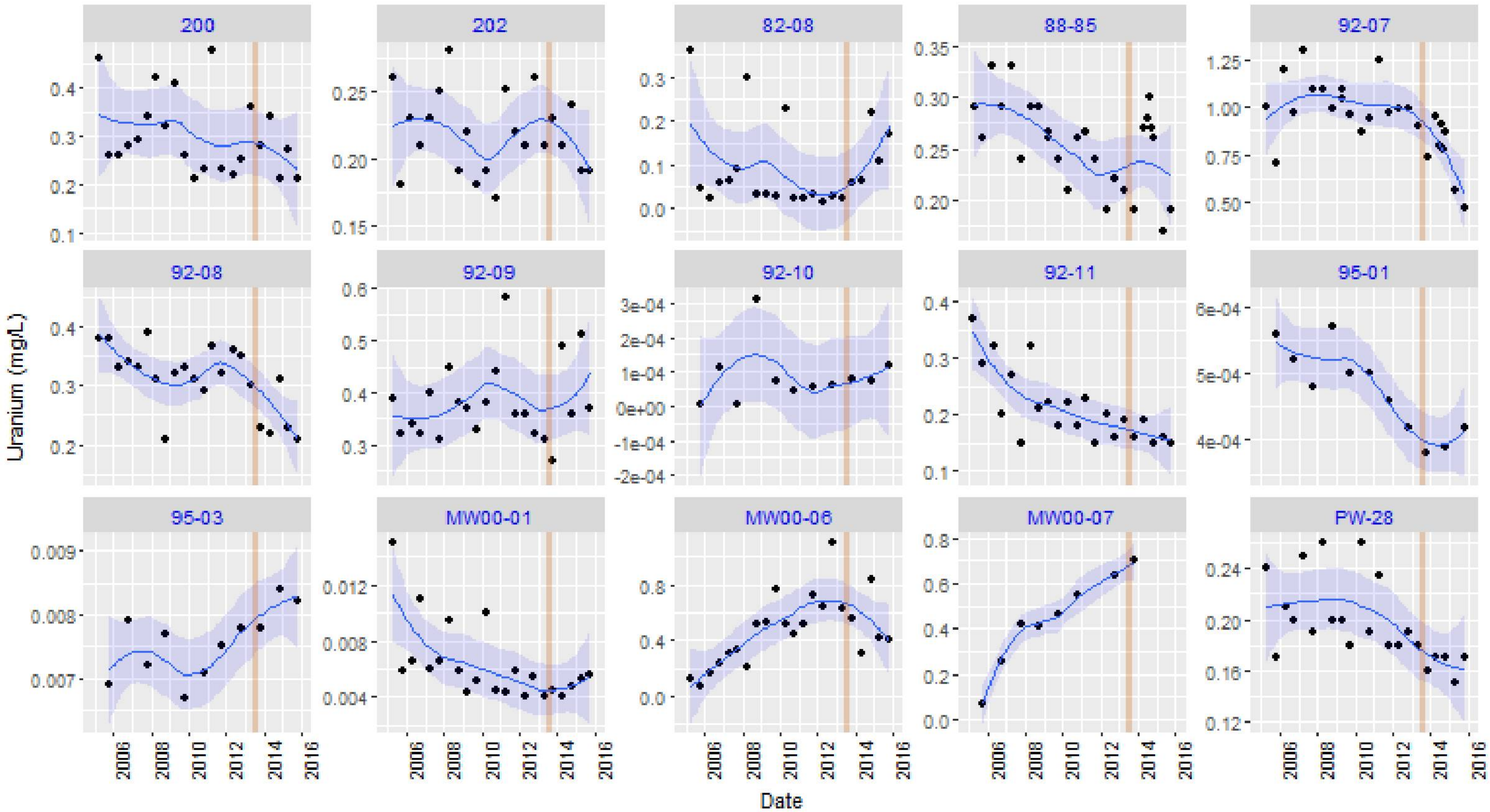


Figure C-6. Time-Concentration Plots of Uranium in Monticello Processing Site Wells: July 2013 Redevelopment page 1 of 2

well redevelopment event

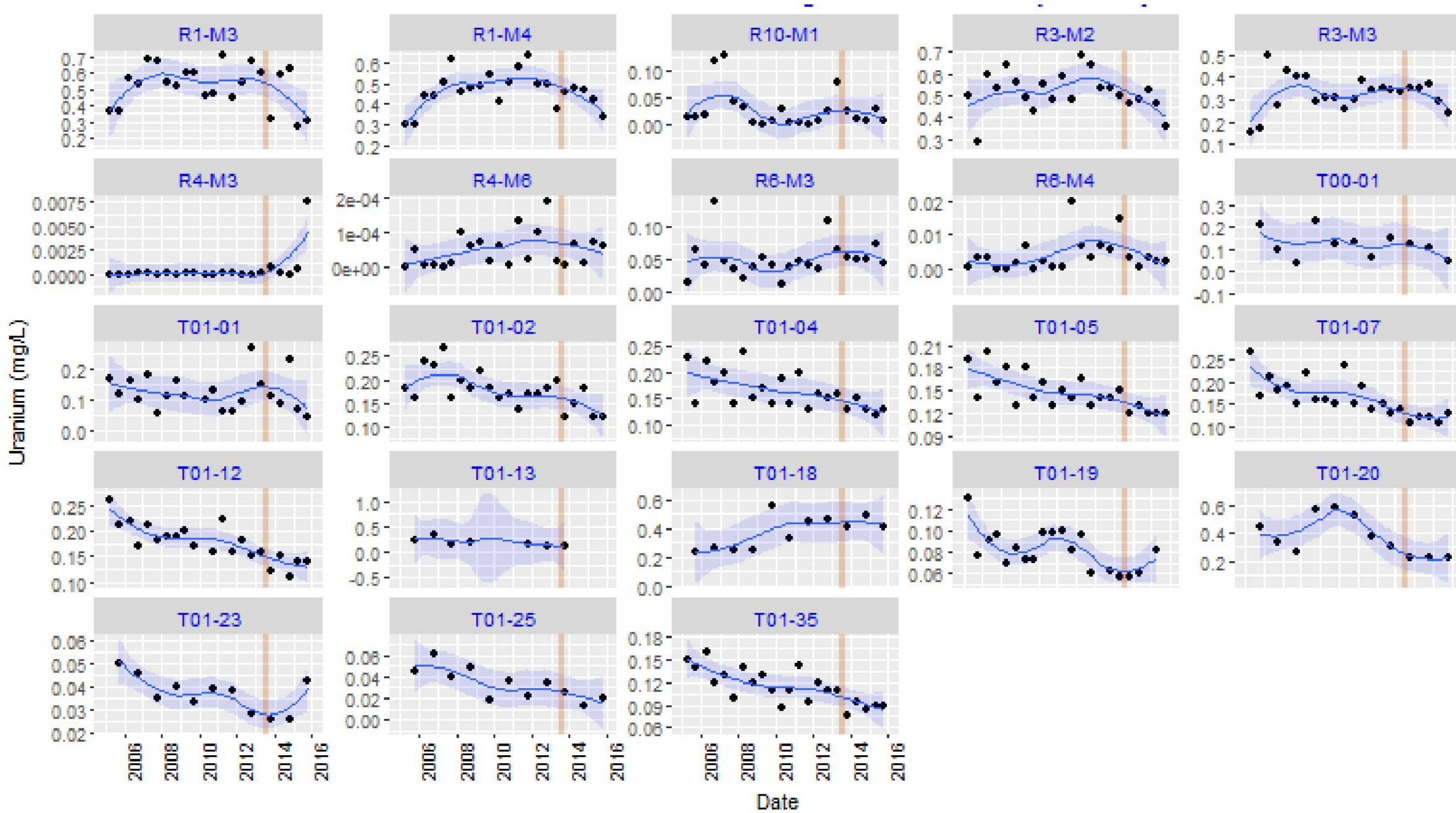


Figure C-6. Time-Concentration Plots of Uranium in Monticello Processing Site Wells: July 2013 Redevelopment page 2 of 2

well redevelopment event

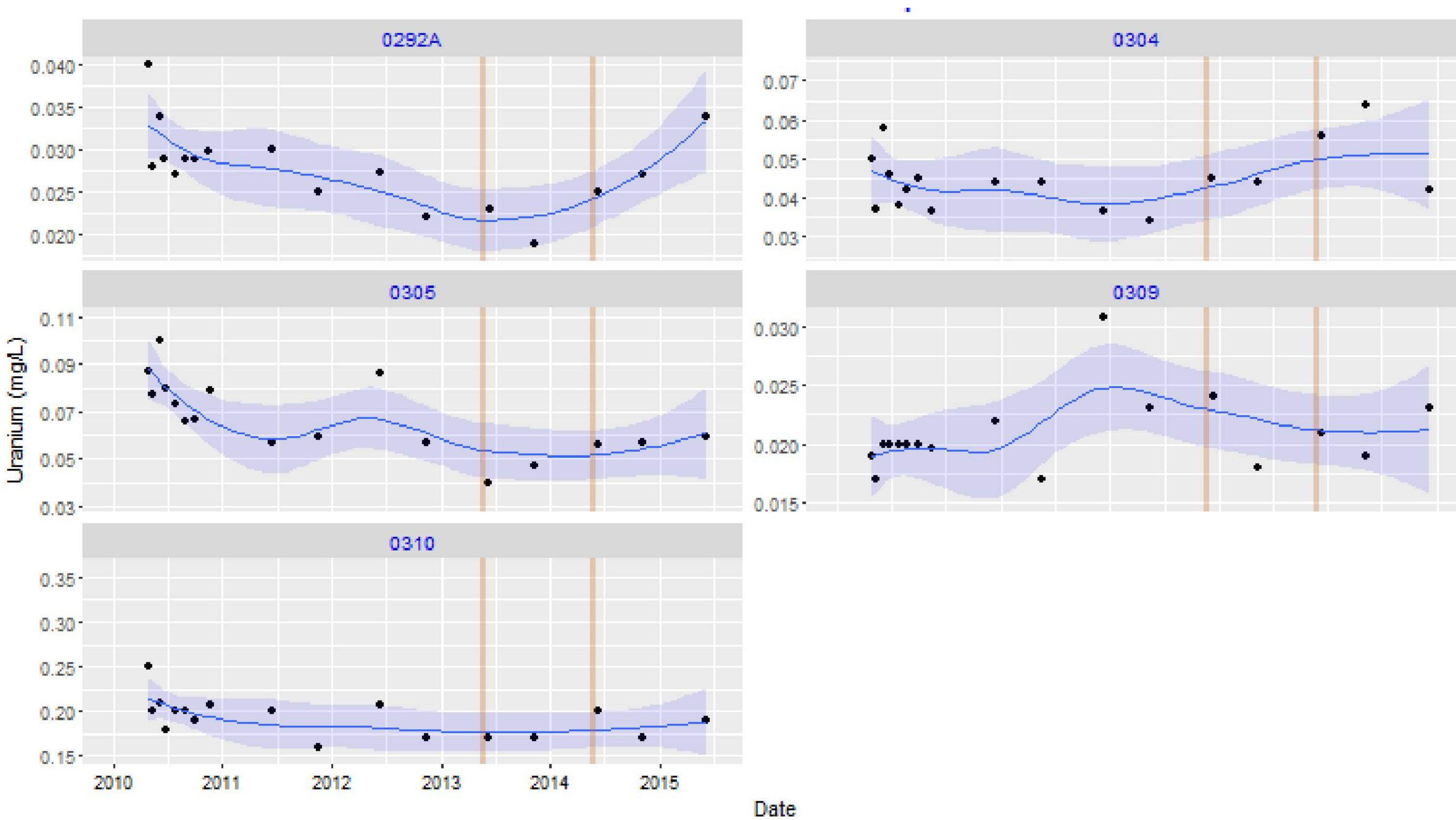


Figure C-7. Time-Concentration Plots of Uranium in Old Rifle Processing Site Wells

| denotes May 20–21, 2013 and May 19–20, 2014 well redevelopment events. Routine sampling coinciding with this period occurred June 11–12, 2013; November 12-13, 2013; and June 11–12, 2014.

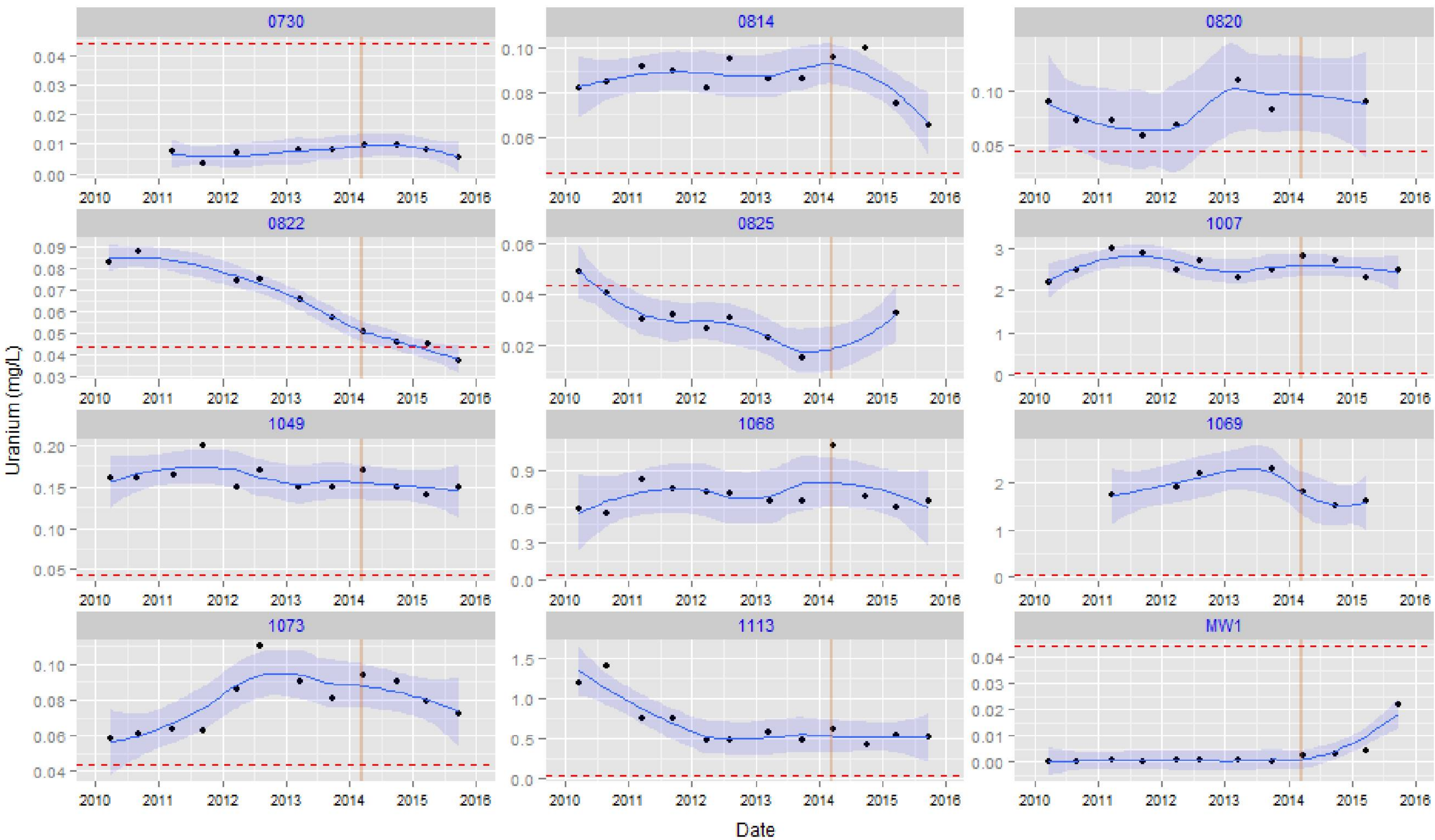


Figure C-8. Time-Concentration Plots of Uranium in Shiprock Disposal Site Wells

All wells are on the Shiprock terrace except well 1113, a floodplain well located at the base of the escarpment (directly below MW1).

| denotes the March 13, 2014 well redevelopment event, which occurred two weeks prior to the biannual sampling event.

a. SRW Wells with Sufficient Data for Loess Smoothing Method

Figure C-9. Time-Concentration Plots of Uranium in Slick Rock West Site Wells
page 1 of 2

| denotes the December 2012 and September 2015 redevelopment events. Nine wells were developed on December 5, 2012, and eight wells were redeveloped September 28–29, 2015. Plot a shows uranium trends for the subset of wells with data dating back to at least 2005; plot b (following page) shows trends for more recently installed wells. Time-trend plots for wells 0317 and 0319 are not shown as these wells have not been monitored for mill-tailings-related constituents since 2002; well 0319 is currently monitored for benzene. Well 0317 was developed in 2012 and 2015; well 0319 was redeveloped in 2012 only. No changes in benzene trends in well 0319 potentially attributable to the 2012 redevelopment event are apparent.

b. Recently Installed SRW Wells

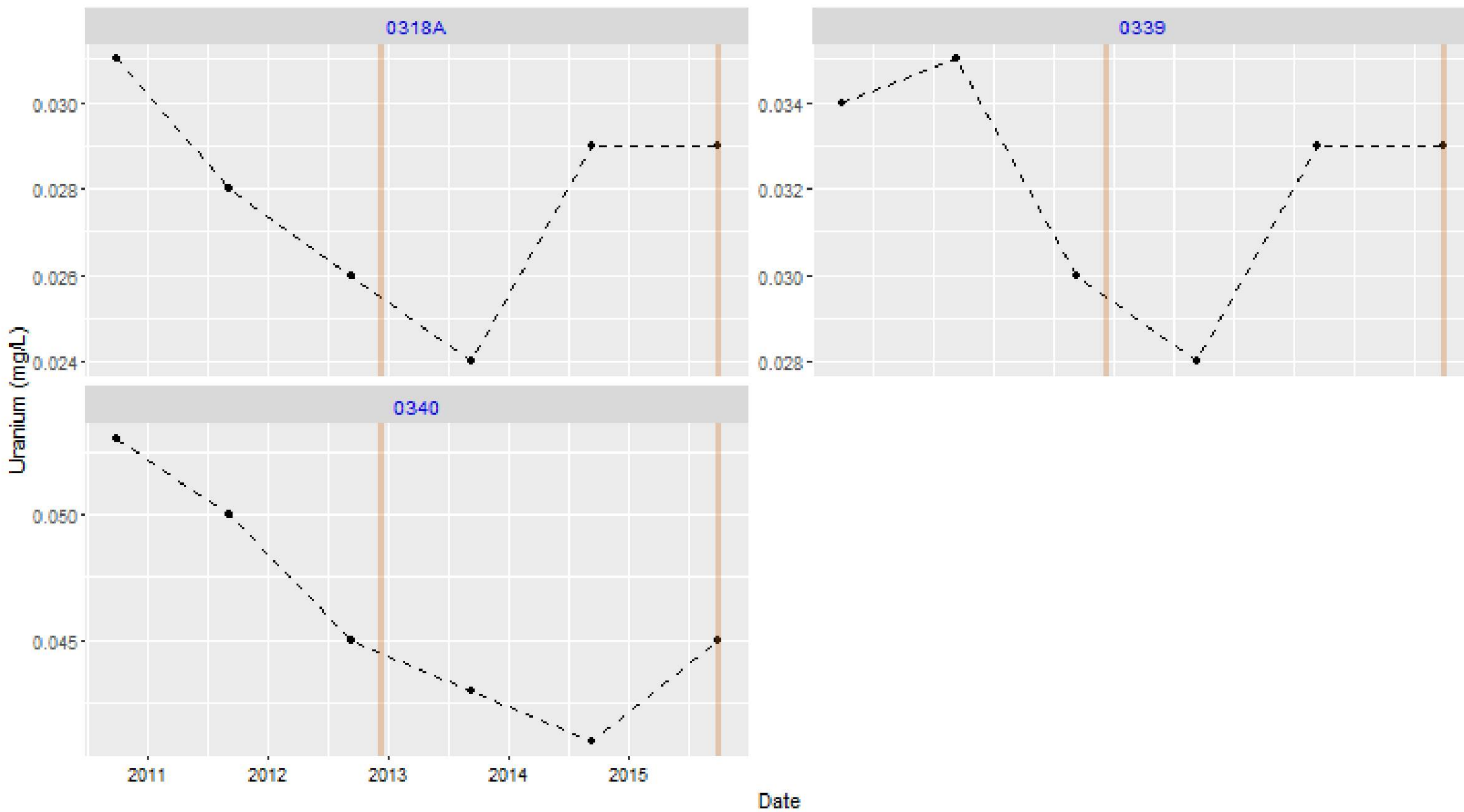


Figure C-9. Time-Concentration Plots of Uranium in Slick Rock West Site Wells

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denotes the December 2012 and September 2015 redevelopment events.

The wells in this subset were recently installed, so traditional line plots are used instead of the loess smoothing method.

a. Extraction Wells Redeveloped in December 2013

Figure C-10. Time-Concentration Plots of Uranium in Tuba City Disposal Site Extraction Wells

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| denotes December 5, 2013 well redevelopment event

b. Extraction Wells Redeveloped January 6–10, 2014

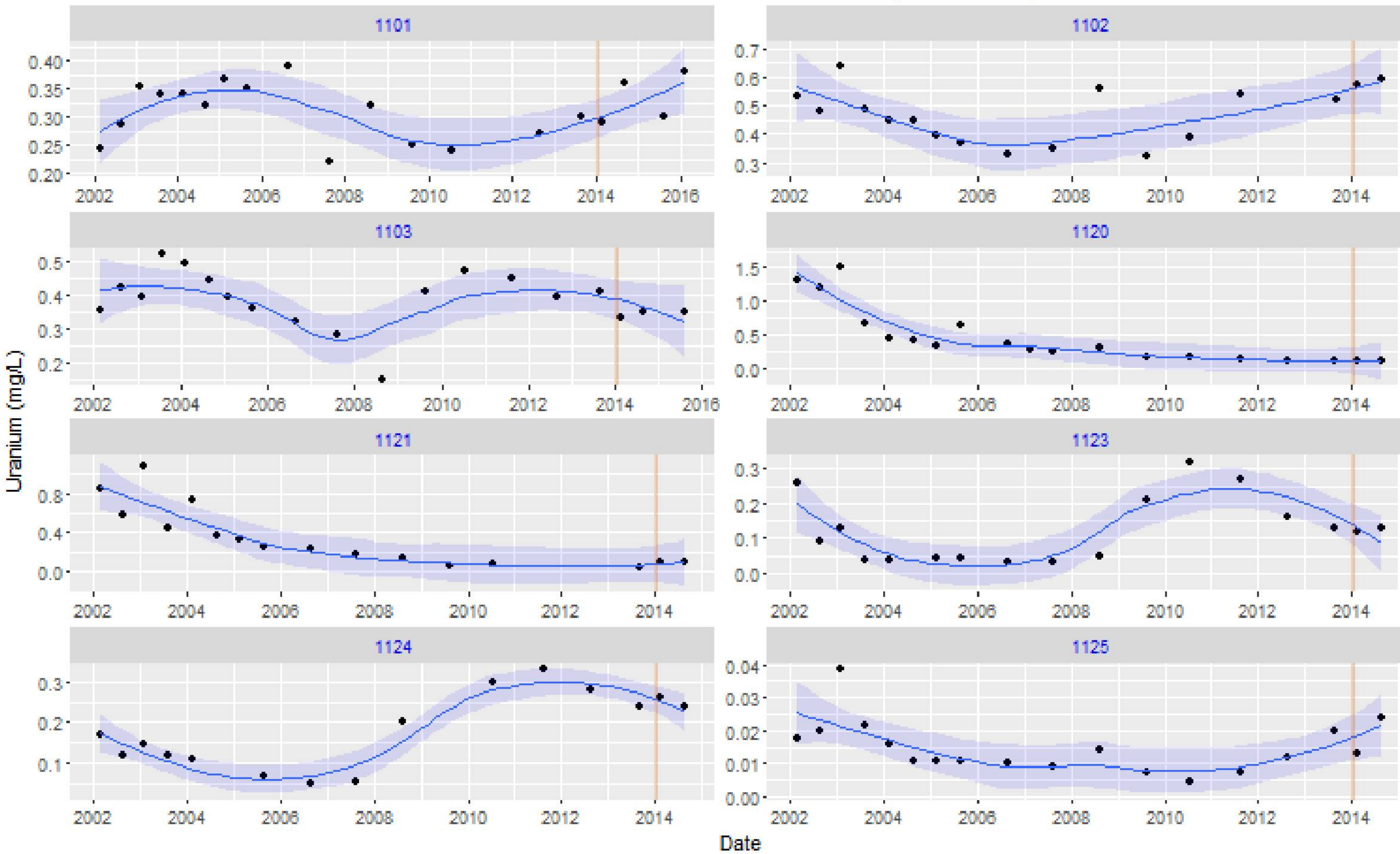

Figure C-10. Time-Concentration Plots of Uranium in Tuba City Disposal Site Extraction Wells

page 2 of 4

| denotes January 6–10, 2014 well redevelopment event

c. Extraction Wells Redeveloped January 13–17, 2014

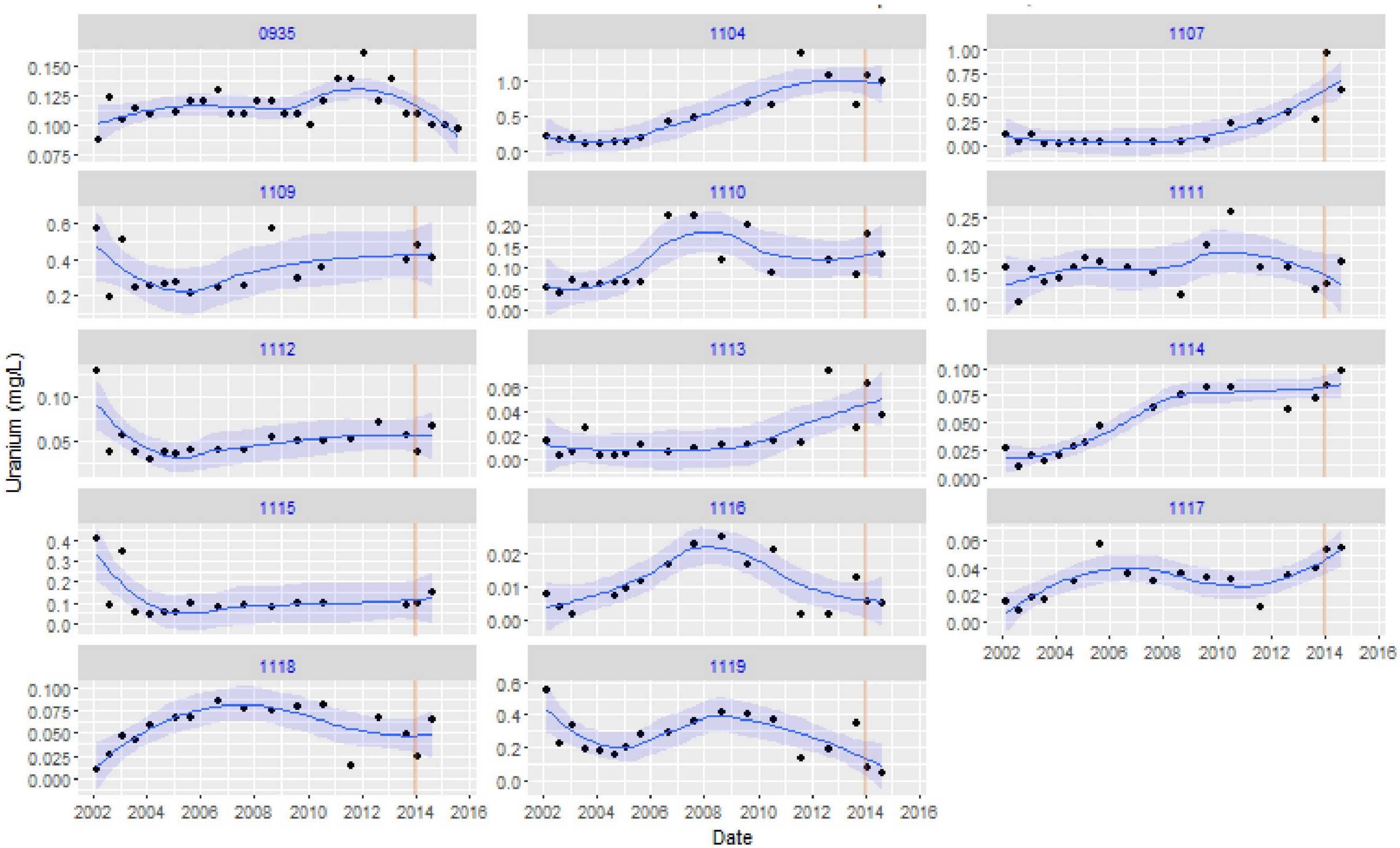

Figure C-10. Time-Concentration Plots of Uranium in Tuba City Disposal Site Extraction Wells

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denotes January 13–17, 2014 well redevelopment event

d. Extraction Wells Redeveloped October 2014

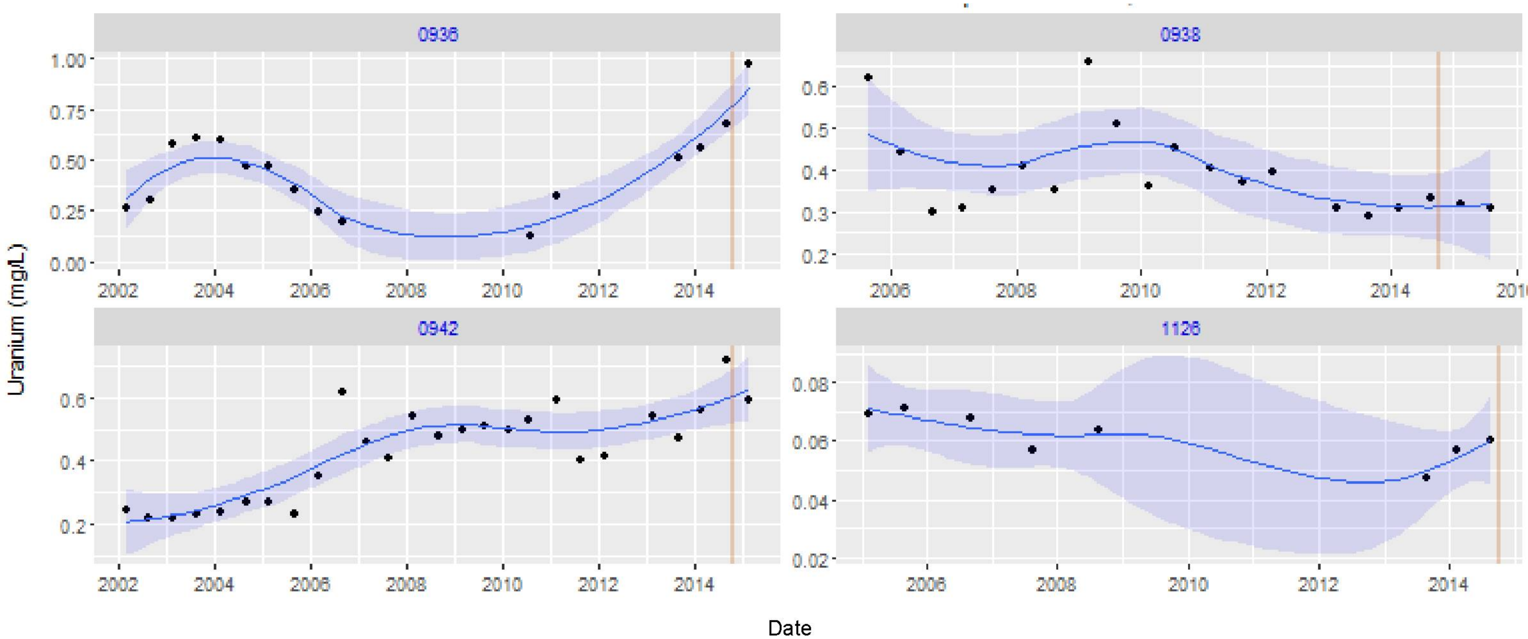

Figure C-10. Time-Concentration Plots of Uranium in Tuba City Disposal Site Extraction Wells

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denotes October 8, 2014 well redevelopment event; well 1127 excluded as insufficient data to plot