DOE/NV/0003590-28

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Ronald L. Hershey

Submitted to

U.S. Department of Energy
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Nevada System of Higher Education

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The work upon which this report is based was supported by the U.S. Department of Energy under Contract #DE-NA0003590 and Contract #DE-NA0000939. Approved for public release; further dissemination unlimited.

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ABSTRACT

The Underground Test Area (UGTA) Activity uses a variety of methods to collect groundwater samples to identify radionuclide migration from underground nuclear tests. These include depth-discrete bailing, pumping with low-volume rod pumps, and pumping with electrical submersible pumps. The Nevada National Security Site (NNSS) Integrated Groundwater Sampling Plan specifies that when sampling with a pump, a minimum of three effective well volumes are withdrawn and then samples are collected after water-quality parameters have stabilized. In locations where pumping is not feasible, depth-discrete bailing is used and purging prior to sampling is usually not required. A recent study evaluated three sampling technologies and recommended that historical tritium results be evaluated where both pumped and bailed samples are available to identify preferred sampling protocols for the collection of tritium samples.

The tritium (^{3}H) activities were obtained from the UGTA chemistry data base. Wells were identified with known ^{3}H activities above method detection limits, and then evaluated if both bailed and pumped samples had been collected. Twenty two wells and piezometers with bailed samples, pumped samples, and ^{3}H activities above background were identified for further consideration.

The conclusions from this analysis are:

- Bailed samples collected for ^{3}H analysis near the water surface in a well are lower in ^{3}H activity than bailed samples from within screened intervals and pumped samples.
- Depth-discrete bailed samples from within the screened intervals are generally in good agreement with pumped samples from developed wells and piezometers.
- Depth-discrete bailed samples from undeveloped wells and piezometers are in good agreement with the first pumped samples. However, the next pumped samples increased in ^{3}H activity, resulting in a greater percent difference between the undeveloped bailed samples and later pumped samples.
- Continuous pumping over extended periods removing large purge volumes from wells can perturbate the surrounding groundwater system for long periods of time. These perturbations can cause large changes in ^{3}H activities in the aquifer near the well because of the mixing of groundwater with variable ^{3}H activities.

Recommendations include:

- Bailed samples for ^{3}H should not be collected near the water surface in the well.
- Bailed samples should be collected from within the well screen.
- Logs of temperature, chemistry, and thermal flow should be evaluated to identify optimal depths within the well screen to collect depth-discrete bailer samples.
- Purging of large volumes of water from the well over extended periods of time should be avoided when collecting ^{3}H samples.
- Sufficient time should be allowed after pumping large volumes of water from the well (e.g., after well development) for the surrounding aquifer and ^{3}H activities to return to ambient conditions.

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LIST OF ACRONYMS

bgs	below ground surface
DRI	Desert Research Institute
ESP	electrical submersible pump
ft	feet
gal	gallons
gpm	gallons per minute
^1H	hydrogen
^3H	tritium
L	liters
lpm	liters per minute
m	meters

NNSS	Nevada National Security Site
pCi/L	picocuries per liter
TCA	Tiva Canyon Aquifer
TFM	thermal flow meter
UGTA	Underground Test Area

INTRODUCTION

The Underground Test Area (UGTA) Activity uses a variety of methods to collect groundwater samples to identify radionuclide migration from underground nuclear tests. These methods include depth-discrete bailing, pumping with low-volume rod pumps, and pumping with electrical submersible pumps (ESP). The Nevada National Security Site (NNSS) Integrated Groundwater Sampling Plan defines data collection criteria for groundwater sampling and identifies tritium (^3H) as the contaminant of concern (U.S. DOE/EM NV, 2018). Depending on the type of sample location, analytical detection limits for ^3H range from low level (<10 picocuries per liter [pCi/L]) at early detection locations to standard detection (>300 pCi/L) at source/plume locations.

The NNSS Integrated Groundwater Sampling Plan specifies that when sampling with a pump, a minimum of three effective well volumes are withdrawn, and then samples are collected after water-quality parameters have stabilized (U.S. DOE/EM NV, 2018). In locations where pumping is not feasible, depth-discrete bailing is used to collect samples and purging water from the well prior to sampling is usually not required. A recent study by Navarro (2015a) evaluating three sampling technologies recommended that historical results from wells at the NNSS where both pumped and bailed samples are available should be evaluated with respect to sampling technology type and aquifer sampled. This report examined the differences in ^3H activity between samples collected by pumping and samples collected by depth-discrete bailing to evaluate whether one method is preferential to the other in terms of data quality and representativeness of ^3H activities in groundwater. This report does not address the ^3H analytical results with respect to the aquifer sampled, but does consider sampling depths for depth-discrete bailers as compared to samples collected near the water surface. Additionally, some comparisons were made between samples collected using bailing or pumping at different times (some were several years apart). However, these comparisons may not always be valid because they neglect ^3H decay, analytical variability, and changes in ^3H activity resulting from plume migration.

The ^3H activity results were obtained from the UGTA chemistry data base. Twenty-two wells and piezometers with bailed samples, pumped samples, and ^3H activities above background were identified for this analysis. All of these wells have unique completion configurations, which are described below. Well completion diagrams are provided in the Appendix.

RESULTS AND DISCUSSION

Comparisons are listed from lowest to highest measured ^3H activities.

ER-EC-6_m4

Well ER-EC-6 has four different completion zones in the main string that have been sampled with different zones open at different times since 2000. Only the most recent samples collected from the m4 zone allow comparison between bailed and pumped samples. Zone m4 was developed along with the other three zones (all four zones open) in 2000. At the end of well development in 2000, a bridge plug was installed to isolate the lowest zone, m1, from the rest of the well. In 2003 and 2009, zones m2, m3, and m4 were open and pumped at the same time to collect water samples. After sampling, piezometers and hydraulic packers were installed in the well to isolate zones m2, m3, and m4 from each other (shown in Figure A-1 in the Appendix). One purge volume for m4 is 8,642 liters (L) (2,283 gallons [gal]) (Navarro-Intera, 2014a).

On January 7, 2015, pumping from m4 began with a rod pump driven with a surface pump jack (hereafter referred to as a rod pump) at approximately 9.5 liters per minute (lpm) (2.5 gallons per minute [gpm]). The ^{3}H samples were collected on January 12, 2015, after approximately 61,700 L (16,300 gal) were purged (7.1 well volumes) (Navarro-Intera, 2015a). These two samples had ^{3}H activities of 4.4 and 5.2 pCi/L. Another sample collected the next day after approximately 76,000 L (20,000 gal) were purged (8.8 well volumes) (Navarro-Intera, 2015b) had a ^{3}H activity of 4.2 pCi/L. An average of the three samples is a ^{3}H activity of 4.6 pCi/L (Table 1 and Figure 1). In August 2017, two samples were bailed from the p3 piezometer, which samples the open interval in zone m4 in the main string. One sample had an activity of 6.6 pCi/L, whereas another was 3.8 pCi/L. The average for these two samples is 5.3 pCi/L. Table 2 lists the pertinent well information for the bailed samples. The percent difference between the 2015 pumped samples and the 2017 bailed samples is 13 percent (Table 1).

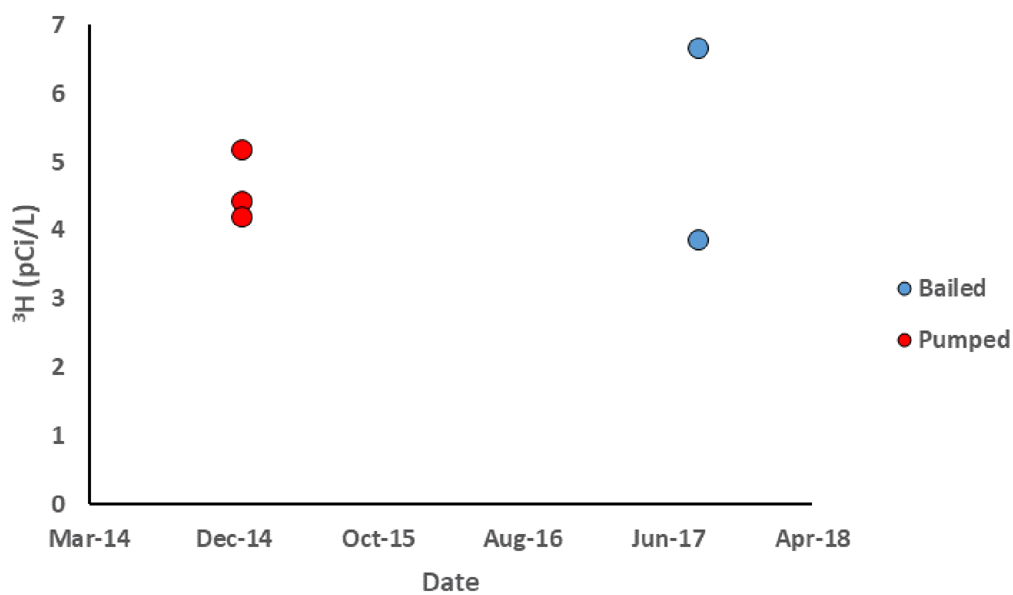

Figure 1. Bailed (2017) versus rod-pump (2015) ^{3}H sample results for well ER-EC-6_m4.

Table 1. Summary of ^{3}H sampling events and results. Wells are listed from lowest to highest ^{3}H activity.

Well	Date	^{3}H Activity Average (pCi/L)		Percent Difference Average Samples[*]	Bailed Depth (m bgs)	Pump Intake Depth (m bgs)	Purge Volume (L)	One Well Volume[+] (L)	Number of Well Volumes
		Bailed	Pumped						
ER-EC-6_m4	January 15, 2015	-	4.6	-	-	458.4	75,700	8,642	8.8
	August 17, 2017	5.3	-	13	451.1		-	-	-
ER-EC-11_p1	July 15 and 16, 2014	6.5	-	-	1,176.5		-	-	-
	July 21-24, 2014	-	6.9	5.6	-	476.6	48,500	12,931	3.7
	July 25, 2014	-	10.9	50	-	476.6	64,000	12,931	5.0
	October 2, 2017	-	10.9	50	-	528.4	59,000	12,931	4.6
ER-EC-11_p2	July 30, 2014	11.6	-	-	1,021.1		-	-	-
	August 7, 2014	-	29.0	-	-	453.5	38	6,602	0.006
	August 7-8, 2014	-	5.3	74	-	453.5	24,760	6,602	3.8
	August 11-12, 2104	-	11.3	2.8	-	453.5	75,700	6,602	12
ER-EC-11_m2	September 26, 2017	-	10.8	7.3	-	481.4	147,600	7,893	18.7
ER-12-3_p1	July 26, 2016	22.1	-	-	449.6		-	-	-
	September 7, 2016	-	23.6	6.4	-	429.6	16,350	757	21.6
Comment: ER-12-3_p1 not developed before bailed samples collected.									
PM-3_p1	July 20 and 22, 2011	28.5	-		604.7		-	-	-
	March 12, 2012	46.0	-		607.5		-	-	-
	July 30, 2013	13.8	-		448.4		-	-	-
	August 11, 2013	-	40.4		-	509.9	91,600	7,117	12.9
	August 12, 2013	-	87.8			509.9	109,216	7,117	15.3
	June 11, 2014	77.8	-		448.4		-	-	-
	June 11, 2014	39.0	-		604.4		-	-	-
	September 13, 2016	124	-		606.6		-	-	-
	September 13, 2016	34.2	-		606.6		-	-	-

* Percent difference = (|(x-y)|/((x+y)/2))*100

\+ Source of well volumes are described in text.

Table 1. Summary of ^{3}H sampling events and results. Wells are listed from lowest to highest ^{3}H activity (continued).

Well	Date	^{3}H Activity Average (pCi/L)		Percent Difference Bailed vs. Pumped*	Bailed Depth (m bgs)	Pump Intake Depth (m bgs)	Purge Volume (L)	One Well Volume+ (L)	Number of Well Volumes
		Bailed	Pumped						
ER-20-8_m1	August 8, 2011	-	267	-	-	557.5	WD	WD	WD
ER-20-8_p1	September 3, 2014	121.5	-	75	966.2		-	-	-
	September 27, 2017	192.3	-	33	981.8		-	-	-
PM-3_p2	September 25, 2000	10.7	-	-	475.5		-	-	-
	October 12, 2000	-	12.1	12.3	-	unknown	unknown	9,021	-
	May 18, 2010	47.6	-	-	475.5		-	-	-
	July 20 and 22, 2011	60.6	-	-	475.5		-	-	-
	March 13, 2012	69.0	-	-	475.5		-	-	-
	July 31, 2013	<2.0	-	-	448.4		-	-	-
	August 15, 2013	-	150	-	-	445.4	163	9,022	0.02
	August 22, 2013 12:35	-	237	-	-	445.4	121,100	9,022	13.4
	August 22, 2013 15:32	-	355	-	-	445.4	123,000	9,022	13.6
	June 11, 2014	130	-	-	447.8		-	-	-
	June 11, 2014	227	-	-	475.5		-	-	-
-	September 13, 2016	190	-	-	475.5		-	-	-
ER-20-8-2_m1	December 18, 2009	-	1,067	82	-	575.1	WD	WD	WD
ER-20-8-2_p1	September 17, 2014	2555	-	-	640.1		-	-	-
	September 30-October 7, 2014	-	2,426	5.2	-	515.8	98,400	15,709	6.3
ER-20-8-2_m1	October 14-17, 2014	-	2,712	6.0	-	534.6	420,000	15,709	26.7
	September 19, 2017	-	3,615	34	-	534.6	170,300	15,709	11
ER-20-8_m2	June 27, 2011		2,856	99	-	557.4	WD	WD	WD
ER-20-8_p2	October 21, 2014	8,500	-	-	853.4		-	-	-
ER-20-8_m2	March 5, 2015 10:17	-	445	-	-	537.1	114	9,486	0.012
	March 5, 2015 11:01	-	8,200	3.6	-	537.1	4,540	9,486	0.48
	March 5, 2015 14:41	-	6,300	30	-	537.1	28,390	9,486	3.0
	March 5, 2015 15:25	-	6,100	33	-	537.1	29,930	9,486	3.5
	March 8, 2015 10:35	-	4,038	71	-	537.1	435,000	9,486	46
	September 4, 2017	-	6,500	27	-	537.1	138,900	9,486	15

* Percent difference = (|(x-y)|/((x+y)/2))*100

+ Source of well volumes are described in text.

WD = Well Development

Table 1. Summary of ^{3}H sampling events and results. Wells are listed from lowest to highest ^{3}H activity (continued).

Well	Date	^{3}H Activity Average (pCi/L)		Percent Difference Bailed vs. Pumped*	Bailed Depth (m bgs)	Pump Intake Depth (m bgs)	Purge Volume (L)	One Well Volume+ (L)	Number of Well Volumes
		Bailed	Pumped						
ER-EC-11_p3	August 14, 2014	12,400	-	-	838.2		-	-	-
	August 19-15, 2014	-	16,200	27	-	477.4	90,721	34,663	2.6
	October 12, 2017	-	18,250	38	-	532.4	105,632	34,663	3.0
	Comment: ER-EC-11_p3 not developed before bailed samples collected.								
ER-20-12_p1	June 9, 2016	19,800	-	-	1,051.6		-	-	-
	July 6, 2016	-	18,750	5.4	-	614.9	89,241	15,641	5.7
	July 17, 2017	-	25,250	24	-	603.3	38,509	15,641	2.5
	Comment: ER-20-12_p1 not developed before bailed samples collected.								
ER-20-12_m1	June 10, 2016	30,200	-	-	1,249.7		-	-	-
	August 19, 2016	-	33,800	11.3	-	668.0	114,209	32,888	3.5
	July 12, 2017	-	41,400	31	-	658.2	223,740	32,888	6.8
	Comment: ER-20-12_m1 not developed before bailed samples collected.								
UE-5n_m1	June 2, 2014	1.53E+05	-	-	216.0		-	-	-
	June 12, 2014	--	1.54E+05	1.0	-	258.2	75,700	12,617	6.0
ER-20-11_m1	August 5, 2013	-	186,667	-	-	620.9	WD	WD	WD
	October 18, 2017	-	202,000	-	-	534.4	149,667	10,332	14.5
UE-2ce_m1	August 25, 1993	139,000	-	-	445		-	-	-
	August 22, 2001	147,500	-	11.3	472.4		-	-	-
	July 12, 2005	93,000	-	-	481		-	-	-
	July 2, 2008	-	261,875	56	-	477.2	115,106	4,542	25.3
	December 14, 2016	-	132,750	10.5	-	477.2	221,624	4,542	48.8

* Percent difference = (|(x-y)|/((x+y)/2))*100

+ Source of well volumes are described in text.

WD = Well Development

Table 2. Bailed sample collection depths and screened interval information for select wells.

Well Name	Bailed Sample Date	Bailed Sample Depth (m bgs)	Bailed Sample Depth (ft bgs)	Depth to Water (m bgs)	Depth to Water (ft bgs)	Depth to Water Date	Top of Screen (m bgs)	Top of Screen (ft bgs)	Bottom of Screen (m bgs)	Bottom of Screen (ft bgs)	Middle of Screen (m bgs)	Middle of Screen (ft bgs)	Comments
ER-EC-6_m4	8/17/2017	451.1	1,480	434.53	1,425.62	8/16/2017	496.34	1,628.42	570.13	1,870.49	533.23	1,749.46	Sampled from p3
ER-EC-11_p1	7/15/2014	1,176.5	3,860	450.21	1,477.08	7/15/2014	1,109.72	3,640.82	1,247.80	4,093.83	1,178.76	3,867.33	
ER-EC-11_p1	7/15/2014	1,176.5	3,860	450.21	1,477.08	7/15/2014	1,109.72	3,640.82	1,247.80	4,093.83	1,178.76	3,867.33	
ER-EC-11_p2	7/30/2014	1,021.1	3,350	449.91	1,476.07	7/29/2014	962.74	3,158.61	1,029.49	3,377.58	996.12	3,268.10	
ER-12-3_p1	7/26/2016	449.6	1,475	379.01	1,243.48	7/26/2016	431.15	1,414.53	467.10	1,532.49	449.13	1,473.51	
PM-3_p1	7/20/2011	604.7	1,984	444.00	1,456.70	7/22/2011	585.22	1,920	653.49	2,144	619.35	2,032	
PM-3_p1	7/22/2011	604.4	1,983	444.00	1,456.70	7/22/2011	585.22	1,920	653.49	2,144	619.35	2,032	
PM-3_p1	3/13/2012	607.4	1,993	443.90	1,456.38	3/12/2012	585.22	1,920	653.49	2,144	619.35	2,032	
PM-3_p1	7/30/2013	448.4	1,471	444.03	1,456.78	7/30/2013	585.22	1,920	653.49	2,144	619.35	2,032	Near water surface
PM-3_p1	7/30/2013	448.4	1,471	444.03	1,456.78	7/30/2013	585.22	1,920	653.49	2,144	619.35	2,032	Near water surface
PM-3_p1	6/11/2014	448.4	1,471	444.62	1,458.73	6/11/2014	585.22	1,920	653.49	2,144	619.35	2,032	Near water surface
PM-3_p1	6/11/2014	604.4	1,983	444.62	1,458.73	6/11/2014	585.22	1,920	653.49	2,144	619.35	2,032	
PM-3_p1	9/13/2016	606.6	1,990	444.05	1,456.85	9/13/2016	585.22	1,920	653.49	2,144	619.35	2,032	
ER-20-8_p1	9/3/2014	966.2	3,170	508.0	1,666.55	9/3/2014	957.4	3,140.94	1,006.5	3,302.18	981.9	3,222	
ER-20-8_p1	9/27/2017	981.8	3,221	508.2	1,667.21	9/20/2017	957.4	3,140.94	1,006.5	3,302.18	981.9	3,222	
PM-3_p2	1/5/2000	475.5	1,560	443.71	1,455.73	12/6/1999	439.52	1,442	508.10	1,667	473.81	1,555	
PM-3_p2	9/25/2000	473.7	1,554	443.69	1,455.66	9/11/2000	439.52	1,442	508.10	1,667	473.81	1,555	
PM-3_p2	5/25/2004	475.5	1,560	443.61	1,455.40	4/6/2004	439.52	1,442	508.10	1,667	473.81	1,555	
PM-3_p2	5/18/2010	475.5	1,560	443.40	1,454.72	5/4/2010	439.52	1,442	508.10	1,667	473.81	1,555	

Table 2. Bailed sample collection depths and screened interval information for select wells (continued).

Well Name	Bailed Sample Date	Bailed Sample Depth (m bgs)	Bailed Sample Depth (ft bgs)	Depth to Water (m bgs)	Depth to Water (ft bgs)	Depth to Water Date	Top of Screen (m bgs)	Top of Screen (ft bgs)	Bottom of Screen (m bgs)	Bottom of Screen (ft bgs)	Middle of Screen (m bgs)	Middle of Screen (ft bgs)	Comments
PM-3_p2	7/20/2011	475.5	1,560	443.42	1,454.80	7/22/2011	439.52	1,442	508.10	1,667	473.81	1,555	
PM-3_p2	7/22/2011	475.5	1,560	443.42	1,454.80	7/22/2011	439.52	1,442	508.10	1,667	473.81	1,555	
PM-3_p2	3/13/2012	475.5	1,560	443.36	1,454.59	3/12/2012	439.52	1,442	508.10	1,667	473.81	1,555	
PM-3_p2	7/31/2013	448.4	1,471	443.44	1,454.85	7/31/2013	439.52	1,442	508.10	1,667	473.81	1,555	Near water surface
PM-3_p2	6/11/2014	447.8	1,469	443.96	1,456.57	6/11/2014	439.52	1,442	508.10	1,667	473.81	1,555	Near water surface
PM-3_p2	6/11/2014	475.5	1,560	443.96	1,456.57	6/11/2014	439.52	1,442	508.10	1,667	473.81	1,555	
PM-3_p2	9/13/2016	475.5	1,560	444.04	1,456.81	9/13/2016	439.52	1,442	508.10	1,667	473.81	1,555	
ER-20-8-2_p1	9/17/2014	640.1	2,100	508.22	1,667.40	9/17/2014	506.39	1,661.37	681.00	2,234.26	593.69	1,947.82	
ER-20-8_p2	10/21/2014	853.4	2,800	507.88	1,666.27	10/20/2014	761.45	2,498.19	886.72	2,909.18	824.08	2,703.69	
ER-EC-11_p3	8/14/2014	838.2	2,750	450.15	1,476.86	8/13/2014	816.11	2,677.51	911.72	2,991.20	836.91	2,834.36	
ER-20-12_p1	6/9/2016	1,051.6	3,450	566.77	1,859.48	6/6/2016	1,043.69	3,424.18	1,116.70	3,663.73	1,080.20	3,543.96	
ER-20-12_m1	6/10/2016	1,249.7	4,100	563.75	1,849.57	6/6/2016	1,216.70	3,991.81	1,349.94	4,428.95	1,283.32	4,210.38	

ER-EC-11_p1

Well ER-EC-11 has two screened intervals (m1 and m2) in the main well, two piezometers (p1 and p2) screened at the same depths as the main well, and two piezometers outside the well casing with no gravel packs (p3 and p4). ER-EC-11_m1 and m2 were developed in 2010, and therefore p1 and p2 were also developed. After well development, a retrievable bridge plug was installed in the main well between m1 and m2, which isolated them from each other (shown in Figure A-2 in the Appendix). ER-EC-11_p4 has never been sampled. All samples collected during well development were below detection for standard ^{3}H analysis except for one sample collected from the combined screen intervals from m1 and m2 that was analyzed by low-level ^{3}H analysis (31 pCi/L).

Samples were collected with a depth-discrete bailer from ER-EC-11_p1 in July 2014 as part of a study evaluating different sampling technologies (Navarro, 2015a). These two samples have an average ^{3}H activity of 6.5 pCi/L ^{3}H (Table 1 and Figure 2A). Table 2 lists the pertinent well information for the bailed samples.

In July 2014, after samples were bailed, ER-EC-11_p1 was pumped and samples were collected as part of a study evaluating different sampling technologies (Navarro, 2015a). ER-EC-11_p1 was pumped continuously with a rod pump at approximately 10.2 lpm (2.7 gpm) for approximately four days. One well volume for ER-EC-11_p1 is 12,931 L (3,416 gal; Navarro, 2015a). During time-series sampling, approximately 48,500 L (12,800 gal) or 3.7 well volumes were purged from p1 after approximately three days of pumping. At the end of four days of pumping, over 64,000 L (17,000 gal) or 5.0 well volumes were purged from the piezometer. The ^{3}H activities ranged from 5.5 to 8.2 pCi/L during the four days of pumping with no trend in either increasing or decreasing ^{3}H activities (Figure 2A). The average ^{3}H activity during the four days of continuous pumping is 6.9 pCi/L, which is in good agreement (5.6 percent difference) with the bailed samples (Table 1 and Figure 2A). After 23 hours of pumping and after the end of the time-series sampling, two additional samples were collected. There was an increase in ^{3}H activity for these samples, with an average activity of 10.9 pCi/L (Table 1 and Figure 2A). In October 2017, a sample was collected by rod pump with a ^{3}H activity of 10.9 pCi/L (Table 1 and Figure 2B) after purging over 59,000 L (15,600 gal; 4.6 well volumes) (Navarro, 2018a). The two samples collected after 23 hours of pumping in 2014, and the rod-pump samples from 2017, are 50 percent different from the bailed samples in 2014 (Table 1).

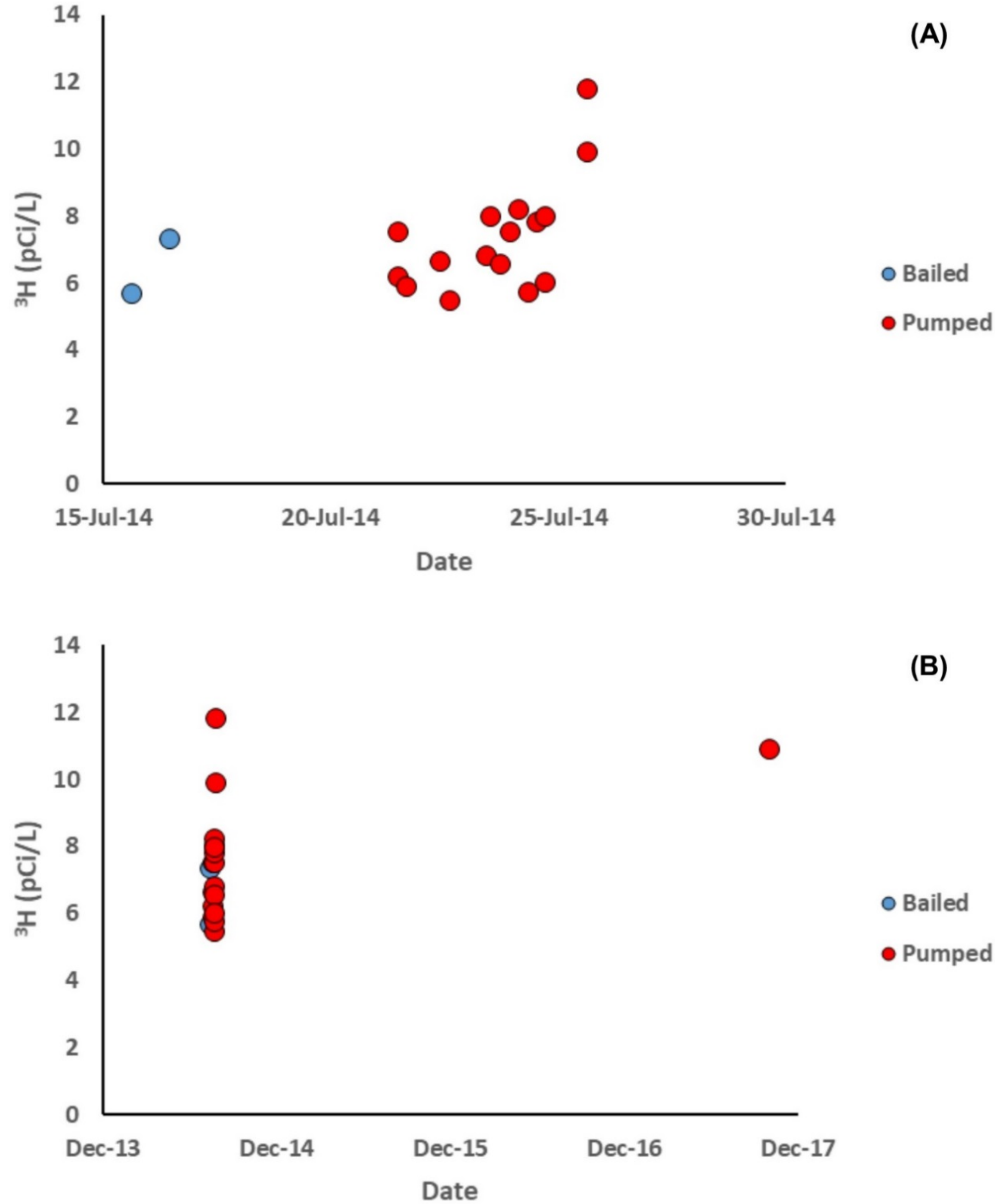

Figure 2. A) Bailed (July 2014) versus rod-pump (July 2014) ^{3}H sample results for ER-EC-11_p1; B) Bailed (July 2014) versus rod-pump (July 2014 and October 2017) ^{3}H sample results for ER-EC-11_p1.

ER-EC-11_m2 and ER-EC-11_p2

Well ER-EC-11 has two main screened intervals at two different depths and two piezometers that are screened adjacent to one of the main well screens, and two piezometers outside the well casing with no gravel packs (p3 and p4), as described above (shown in Figure A-2 in the Appendix). In July 2014, samples were collected from ER-EC-11_p2 with a depth-discrete bailer as part of a study evaluating sampling technologies (Navarro, 2015a). Table 2 lists the pertinent well information for the bailed samples. These two samples have an average ^{3}H activity of 11.6 pCi/L ^{3}H (Table 1 and Figure 3A).

In August 2014, after samples were bailed, ER-EC-11_p2 was pumped and samples were collected. ER-EC-11_p2 was pumped continuously with a rod pump at approximately 9.5 lpm (2.5 gpm) for approximately five days. One well volume for ER-EC-11_p2 is 6,602 L (1,744 gal; Navarro, 2015a). During time-series sampling, approximately 24,760 L (6,540 gal; 3.8 well volumes) were purged from p2 after approximately two days of pumping. At the end of five days of pumping, over 75,700 L (20,000 gal) or 12 well volumes were purged from the piezometer. The first two samples collected at the beginning of pumping after only 38 L (10 gal) were purged from the well have an average ^{3}H activity of 29.0 pCi/L. After these initial samples, ^{3}H activity ranged from 3.3 to 8.2 pCi/L during the two days of pumping, with no trend in either increasing or decreasing ^{3}H activities (Figure 3B). The average ^{3}H activity during the two days of continuous pumping (excluding the two initial samples) is 5.3 pCi/L, which is 74 percent different from the earlier bailed sample (Table 1 and Figure 3A).

Four samples were collected after another three days of pumping and after the end of the time-series sampling. There was an increase in ^{3}H activity for these samples, with an average activity of 11.3 pCi/L, which is in good agreement (2.8 percent difference) with the bailed samples (Table 1 and Figure 3A). Two samples were collected from ER-EC-11_m2 by pumping with an ESP in September 2017, with an average ^{3}H activity of 10.8 pCi/L (Table 1 and Figure 3B) after purging over 147,600 L (39,000 gal; 17.8 well volumes; Navarro, 2018a). These samples are 7.3 percent different from the bailed samples collected from p2 during 2014 (Table 1).

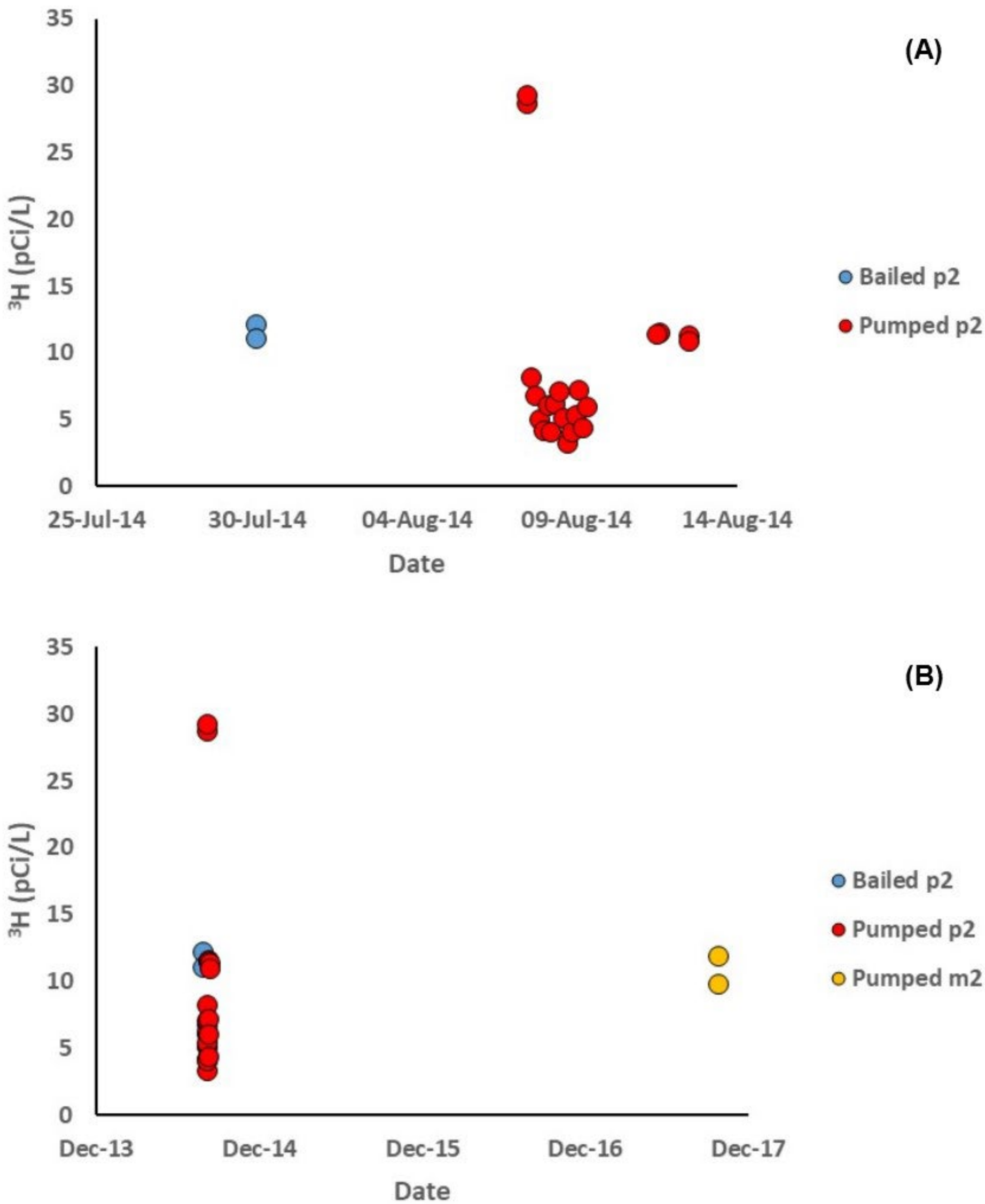

Figure 3. A) Bailed (July 2014) versus rod-pump (August 2014) ^3H sample results for ER-EC-11_p2; B) Bailed (July 2014) versus rod-pump (August 2014) ^3H sample results for ER-EC-11_p2 and ESP (September 2017) ^3H sample results for ER-EC-11_m2.

ER-12-3_p1

Well ER-12-3 consists of a main completion with two different screened intervals at two different depths (shown in Figure A-3 in the Appendix). Pumped samples were collected from the m1 completion in 2005, 2008, and 2015, but there are no bailed samples from m1.

In 2005, while the well was being drilled, piezometer p1 was installed near the water table. The piezometer, with a 36.0 m (118 ft) screened interval, was installed in the borehole outside the well casing. A gravel pack was not installed around the piezometer screen, which is open to approximately 239.4 m (785 ft) of geologic formation between the top of the screen and the top of the cement seal holding the main well casing in place in the well (Figure A-3 in the Appendix).

In July 2016, samples were bailed from the p1 piezometer. This piezometer was not developed or purged prior to bailer sampling in 2016. Table 2 lists the pertinent well information for the bailed samples. The first water bailed from p1 was described as "highly turbid with a dark green color" (Navarro, 2016a) and became less turbid and lighter in color as bailing continued. Four analyses from these samples have an average ^{3}H activity of 22.1 pCi/L (Table 1 and Figure 4).

In September 2016, a rod pump was installed in p1 and samples were collected over two days. One well volume for p1 is 757 L (220 gal; Navarro, 2016a). Sampling was initiated after approximately 16,350 L (4,320 gal; 21.6 well volumes) were purged. Four analyses from these samples have an average ^{3}H activity of 23.6 pCi/L (Table 1 and Figure 4). The ^{3}H activities between bailed and pumped samples are in good agreement at 6.4 percent difference between the average values (Table 1).

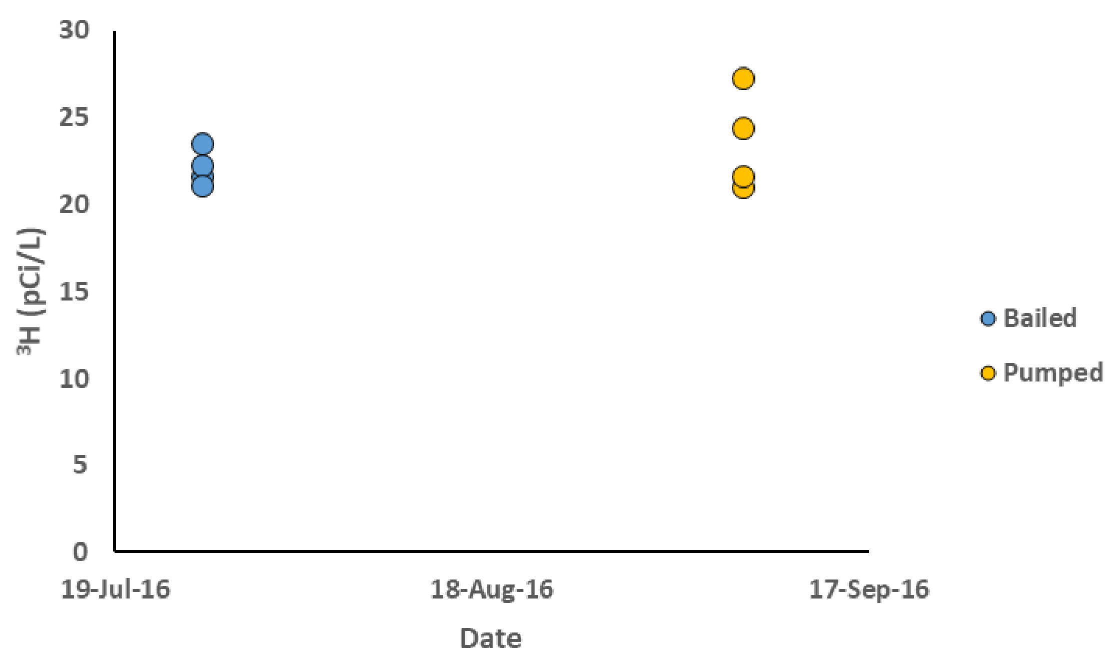

Figure 4. Bailed (July 2016) versus rod-pump (September 2016) ^{3}H sample results for ER-12-3_p1. ER-12-3_p1 was not developed prior to bailer sampling in 2016.

PM-3_p1

Well PM-3 was drilled and developed in 1988. The well was completed as an uncased, open borehole below 449.0 m bgs (1,473 ft bgs). In 1992, PM-3 was recompleted with two piezometers, PM-3_p1 (deep) and PM-3_p2 (shallow). During recompletion, approximately 397,500 L (105,000 gal) of drilling fluid (lithium bromide-tagged water) were lost downhole. During well development, approximately 64,000 L (16,900 gal) were swabbed from PM-3_p1 and 12,526 L (3,309 gal) from PM-3_p2, leaving most of the drilling fluid downhole. Table 2 lists the pertinent well information for the bailed samples and Figure A-4 in the Appendix shows the well completion diagram.

From 2000 through 2010, PM-3_p1 was bailed 11 times with all ^{3}H activities below detection. In July 2011, bailed samples were analyzed four times with one sample below detection (<28 pCi/L) and an average ^{3}H activity for the other three samples of 28.5 pCi/L. The detected activities ranged from 18.6 to 33.8 pCi/L. Bailed samples were also collected in 2012 with an average activity of 46.0 pCi/L (Table 1 and Figure 5).

On July 30, 2013, two bailed samples were collected with an average ^{3}H activity of 13.8 pCi/L (Table 1 and Figure 5). However, these were estimated values. These bailed samples were collected just below the surface of the water in the piezometer.

On August 6, 2013, pumping with a rod pump began at PM-3_p1. A sample was collected after 984 L (260 gal) or 0.1 well volumes were purged (Navarro-Intera, 2014b) with an activity of 37.2 pCi/L (estimated value). Pumping continued until August 11th, when two samples were collected after approximately 91,600 L (24,200 gal) or 12.9 well volumes were purged (Navarro-Intera, 2014b) with an average of 40.4 pCi/L. Another sample was collected on August 12, 2013, after approximately 109,216 L (28,852 gal) or 15.3 well volumes were purged (Navarro-Intera, 2014b) with an activity of 87.8 pCi/L (Table 1 and Figure 5). One well volume for PM-3_p1 is 7,117 L (1,880 gal) (Navarro-Intera, 2013b).

In 2014, two samples were bailed from PM-3_p1. The first sample was bailed from near the water surface with a ^{3}H activity of 77.8 pCi/L and the second sample was bailed from lower in the screened interval with an activity of 39.0 pCi/L. In 2016, two samples were bailed from PM-3_p1 that had a large difference in ^{3}H activities. The first sample had an activity of 124 pCi/L. The second sample was collected 40 minutes later and had an activity of 34.2 pCi/L (Table 1 and Figure 5).

The average ^{3}H activity from each sampling date suggest that ^{3}H activity is increasing with time. However, there is large variability in the analytical results of duplicate samples collected during pumping in August 2013 and in duplicate bailed samples in 2014 and 2016, making the increasing trend uncertain. The pumped sample ^{3}H activity from August 2013 increased with continued pumping, which suggests that pumping might be pulling higher ^{3}H activity water into the well. Bailed and pumped samples were collected in 2018 to better understand tritium activities at this location.

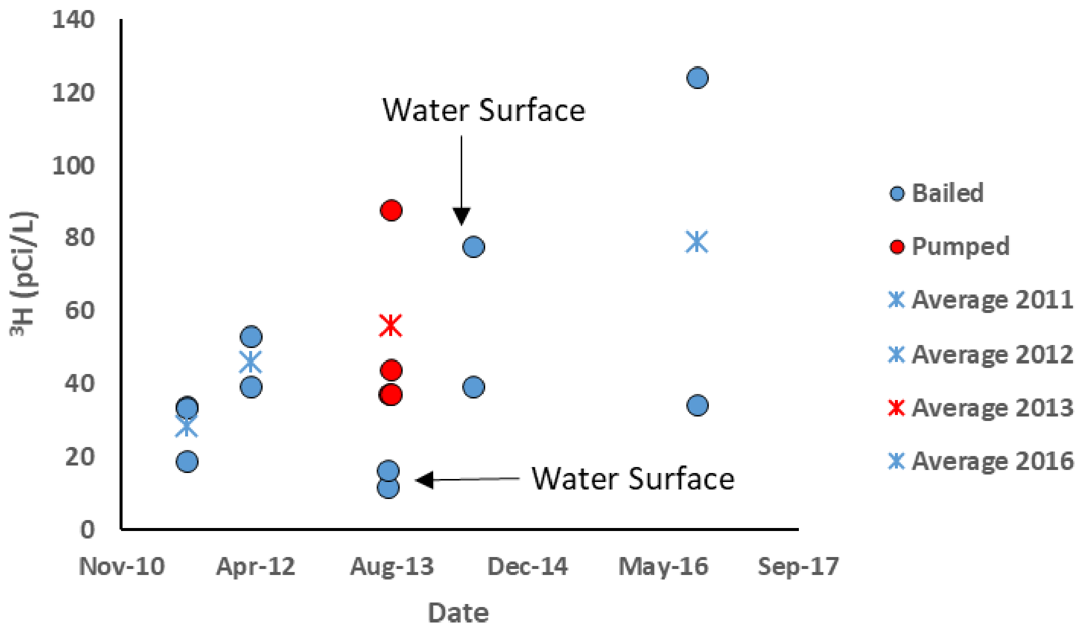

Figure 5. Bailed (2011, 2012, 2013, 2014, and 2016) versus rod-pump (2013) ^{3}H sample results for PM-3_p1. Samples collected near the water surface are identified.

Bailed samples collected from just below the water surface in the piezometer on July 30, 2013, had the lowest ^{3}H activity of any sample except for samples below detection. The lower activity seen at the water surface suggests that ^{3}H from the water near the surface may be exchanging with hydrogen (^{1}H) in the atmosphere in the piezometer above the water surface. The sample from near the water surface on June 2014 with higher ^{3}H activity could be left over from pumping in 2013 if the last sample collected during pumping (88.7 pCi/L) is accurate. If it is accurate, then the 10 months between pumping and bailing near the water surface provided time for the ^{3}H in the water near the surface to exchange isotopically with atmospheric ^{1}H, slowly reducing the ^{3}H activity in the near surface water (77.8 pCi/L).

In this instance, depth-discrete samples collected from areas of the screen identified by temperature and chemistry logging are likely more representative of ^{3}H in the formation, provided there is sufficient time after pumping to allow the well and surrounding groundwater to return to pre-pumping conditions. Again, because of the large variability in duplicate samples, it is difficult to ascertain which samples are most representative of ^{3}H activity in the aquifer.

ER-20-8_m1 and ER-20-8_p1

Well ER-20-8 has two main screened intervals at two different depths and two piezometers that are screened corresponding to one of the main well screens (shown in Figure A-5 in the Appendix). A third piezometer (ER-20-8_p3) is completed just below the water table outside of the 27.3 cm (10.75 inch) casing. ER-20-8_m1 and ER-20-8_p1 are the deeper completions, whereas ER-20-8_m2 and ER-20-8_p2 are the shallower completions. The main well completions are separated by a retrievable bridge plug, whereas the piezometers and gravel packs are separated by 39.6 m (130 ft) of cement.

During well development in 2011, one sample was bailed from p1 while m1 was being pumped. ER-20-8_m1 was pumped at approximately 488 lpm (129 gpm) and the sample collected from p1 while m1 was being pumped was below detection (<320 pCi/L). Five samples collected from m1 at the end of well development with the ESP were all below detection (<350 and <500 pCi/L) except for one sample with 267 pCi/L ^{3}H (Table 1 and Figure 6). There are no bailed samples from the m1 completion.

The samples collected at the end of well development do not provide representative contaminant concentrations (in this case, ^{3}H activities) because of the large volume of water removed during well development and the resulting perturbation to the aquifer. These samples are not directly comparable to samples collected during typical bailing or pumping sampling events at a later time after well development. The large volume of water removed by pumping during well development can either increase contaminant concentrations by inducing higher contaminant concentration parts of the plume toward well, or can dilute plume contaminant concentrations by inducing fresh water to the well from outside the contaminant plume depending on the location of the well relative to the contaminant plume. Samples collected from ER-20-8_m1 in 2011 at the end of well development are not directly comparable to samples collected at a later time after well development during typical bailing or pumping sampling events because of the large volume of water removed during well development (approximately 7,200,000 L [1,900,000 gal]) (Navarro-Intera, 2011). Bailed samples from ER-20-8_p1 collected while m1 was being pumped are also not directly comparable to samples collected at a later time after well development during typical bailing or pumping sampling events

Two bailed samples were collected from ER-20-8_p1 in September 2014 and in September 2017 (Figure 6). The average ^{3}H activity was 121.5 and 192 pCi/L for the two bailing events, respectively. Table 2 lists the pertinent well information for the bailed samples. The percent difference for the average activity for September 2014 bailed samples compared with the 2011 pumped samples at the end of well development is 75 percent (Table 1), whereas the difference for bailed samples from September 2017 and pumped samples from 2011 is 33 percent. The lower ^{3}H activity in bailed samples from p1 in September 2014 as compared to the pumped sample at the end of well development in 2011 suggests that the aquifer had time to recover to near ambient conditions after well development (more than three years). The increased ^{3}H activity in 2017 may indicate ^{3}H plume migration toward ER-20-8. Note that the half-life of ^{3}H is 12.3 years; the impact of radioactive decay for ^{3}H between well development and bailed samples was not estimated for this discussion.

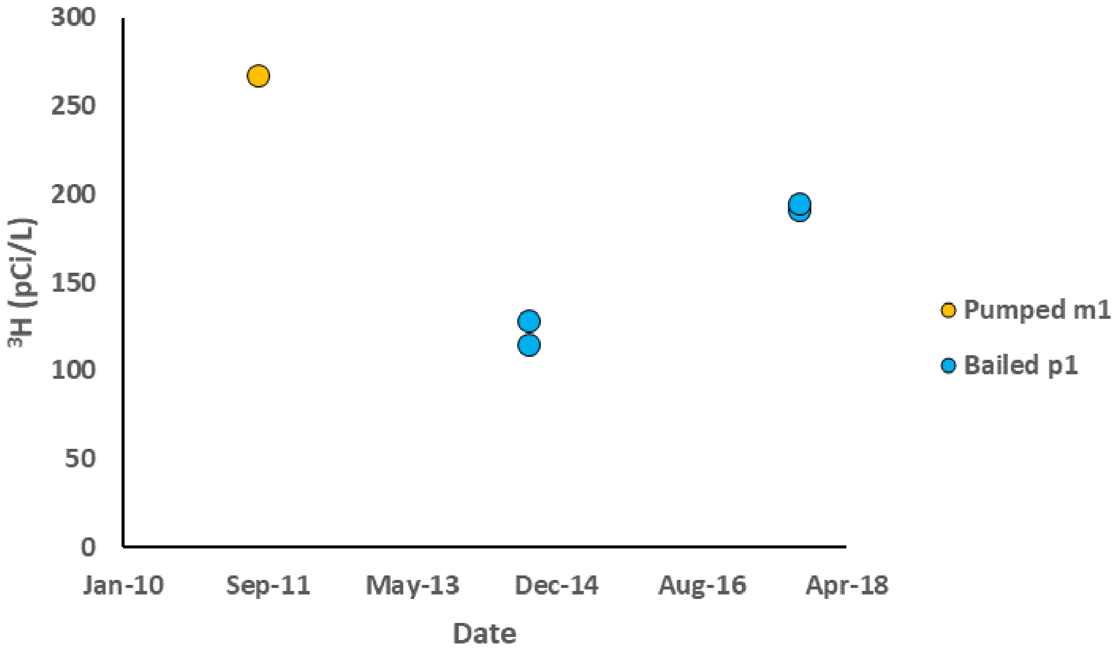

Figure 6. Bailed (September 2014 and September 2017) ^{3}H sample results for ER-20-8_p1 versus ESP (August 2011) ^{3}H sample results for ER-20-8_m1 collected at the end of well development.

PM-3_p2

Well PM-3 was drilled and developed in 1988. The well was completed as an uncased, open borehole below 449.0 m bgs (1,473 ft bgs). In 1992, PM-3 was recompleted with two piezometers, PM-3_p1 and PM-3_p2 (shown in Figure A-4 in the Appendix). During recompletion, approximately 397,500 L (105,000 gal) of drilling fluid (lithium bromide-tagged water) were lost downhole. During well development, approximately 64,000 L (16,900 gal) were swabbed from PM-3_p1 and 12,526 L (3,309 gal) were swabbed from PM-3_p2, leaving most of the drilling fluid downhole.

The next activity at PM-3_p2 was sample collection by bailing in January 2000. These samples were below detection at a detection limit of 280 pCi/L. In September 2000, a sample was bailed with a ^{3}H activity of 10.7 pCi/L reported as an estimated value that was biased high. In October 2000, samples were collected by Bennett pump; the purge volume for these samples is not known. These two samples have an average ^{3}H activity of 12.1 pCi/L. However, one of these samples was reported as an estimated value that was biased high.

Bailed samples were collected from PM-3_p2 from November 2000 through April 2009. All samples were below detection, with a range in detection limit from 18.5 to 28.1 pCi/L, except for one detectable value of 20.2 pCi/L in 2004, which was just above the detection limit. Bailed samples continued to be collected annually from 2010 to 2012 with increasing ^{3}H activities (Table 1 and Figure 7).

On July 31, 2013, two bailed samples from just below the water surface were both below the detection limit of 2.0 pCi/L. Samples collected near the water surface had much lower ^{3}H activity than samples collected from within the screened interval, which was also observed in PM-3_p1 (Figures 5 and 7). Table 2 lists pertinent well information for the bailed samples.

On August 15, 2013, pumping with a rod pump began at PM-3_p2. A sample collected after 163 L (43 gal) were purged showed an activity of 150 pCi/L. Pumping continued to August 22, 2013, when two samples were collected after approximately 121,100 L (32,000 gal) or 13.4 well volumes (Navarro-Intera, 2014b) were purged with an average ^{3}H activity of 237 pCi/L. Another sample was collected on August 22, 2013, approximately three hours later and after approximately 123,000 L (32,500 gal) or 13.6 well volumes (Navarro-Intera, 2013a had been purged). This sample had a ^{3}H activity of 355 pCi/L (Table 1 and Figure 7). One well volume for PM-3_p2 is 9,022 L (2,383 gal) (Navarro-Intera, 2013b). Two different laboratories analyzed these samples (237 versus 355 pCi/L), which is a possible explanation for the difference between the two samples.

In 2014, samples bailed from just below the water surface in PM-3_p2 had a ^{3}H activity of 130 pCi/L (447.8 m bgs [1,469 bgs]). Samples bailed from between the water surface and the bottom of the screen had an average activity of 227 pCi/L (475.5 m bgs [1,560 ft bgs]). Samples were bailed again in 2016 (475.5 m bgs [1,560 ft bgs]) that had an average activity of 190 pCi/L (Table 1 and Figure 7).

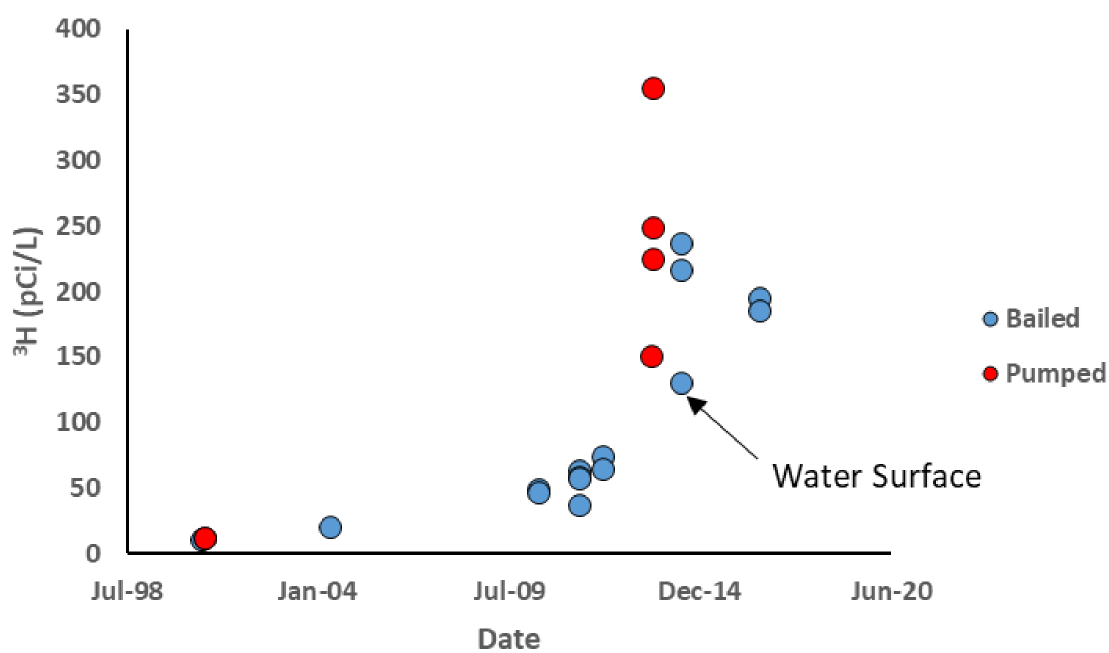

Figure 7. Bailed (September 2000, 2004, 2010, 2011, 2012, 2014, and 2016) versus Bennett pump (October 2000) and rod-pump (2013) ^{3}H sample results for PM-3_p2 that show an increasing trend in ^{3}H activity. The sample collected near the water surface is identified.

An increasing trend in ^3H activity over time is evident in Figure 7. Additionally, pumped ^3H activities appear to be dependent on pumped volume because ^3H activity increases as more water is pumped. This suggests that pumping during purging is pulling higher ^3H activities toward the well. The ^3H activities in bailed samples collected roughly one and three years later appear to be decreasing with time suggesting that ^3H activities in the aquifer near the well are slowly returning to ambient conditions prior to pumping/purging in 2013. Note, however, that radioactive decay was not considered.

Bailed samples collected from just below the water surface in the piezometer on July 30, 2013, had the lowest ^3H activity of any sample since ^3H was observed above detection limits. The lower activity seen at the water surface in PM-3_p2 from the bailed samples collected in 2013 and 2014 suggests that ^3H from the water near the surface may be exchanging with ^1H in the atmosphere in the piezometer above the water surface. Collecting depth-discrete samples within the screened interval are likely more representative of ^3H in the formation, provided there is sufficient time after pumping to allow the well and surrounding groundwater to return to pre-pumping conditions.

WW A_m1

The well construction diagram for WW A_m1 is presented in Figure A-6 in the Appendix. The analytical results from WW A_m1 indicate an increase in ^3H activities in ESP samples from 1978 through 1994. No samples were collected from 1994 until 2001 (Figure 8). In 2001, bailed samples showed more than a three-fold increase in ^3H activities from 1994 (170 to 570 pCi/L). Since 2001, bailed samples have decreased by roughly 200 pCi/L. The ^3H activity tends seen in WWA-m1 have been attributed to pumping induced transport of ^3H from the nearby HAYMAKER test (Lyles, 1990; Navarro, 2016b).

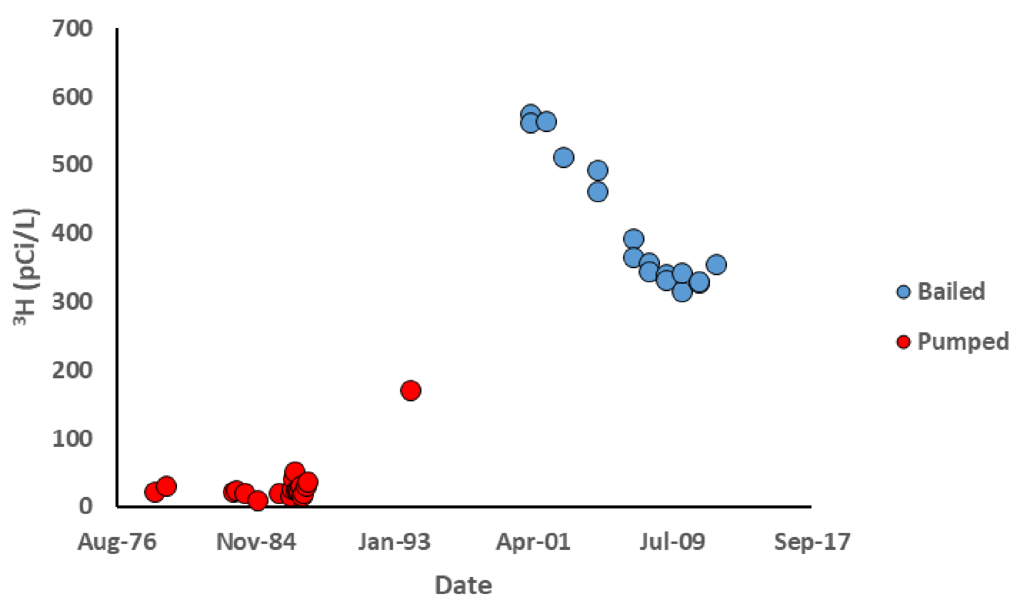

Figure 8. Bailed (2001-2012) versus ESP (1978-1994) ^3H sample results for well WWA_m1.

ER-20-8-2_m1 and ER-20-8-2_p1

Well ER-20-8-2 has one main screened interval and one piezometer that is screened in the same interval (shown in Figure A-7 in the Appendix). In September 2014, samples were bailed from ER-20-8-2_p1. Table 2 lists the pertinent well information for the bailed samples. The average ^{3}H activity for these two samples is 2,555 pCi/L (Table 1 and Figure 9).

In September and October 2014, after samples were bailed, ER-20-8-2_p1 was pumped and samples were collected as part of a study evaluating sampling technologies (Navarro, 2015a). ER-20-8-2_p1 was pumped continuously with a rod pump at approximately 8.7 lpm (2.3 gpm) for approximately nine days. One well volume for ER-20-8-2_m1 and p1 is 15,709 L (4,150 gal; Navarro, 2015a). During time-series sampling, approximately 62,800 L (16,600 gal) or 4.0 well volumes (Navarro, 2015a) were purged from p1 after approximately six days of pumping. At the end of nine days of pumping, over 98,400 L (26,000 gal) or 6.3 well volumes (Navarro, 2015b) were purged from the piezometer. The ^{3}H activities ranged from a low of 1,770 pCi/L (Figure 9) at the start of pumping, peaked at 2,720 pCi/L after approximately 21 hours of pumping, and then fluctuated between 2,100 and 2,600 pCi/L over the nine days of pumping.

In October 2014, after ER-20-8-2_p1 was pumped, ER-20-8-2_m1 was pumped continuously with an ESP at approximately 102 lpm (27 gpm) for approximately three days. During time-series sampling, approximately 62,800 L (16,600 gal) or 4.0 well volumes (Navarro, 2015a) were purged from m1 after approximately 9.5 hours of pumping. At the end of three days of pumping, over 420,000 L (111,000 gal) or 26.8 well volumes (Navarro, 2015b) were purged from the well. The ^{3}H activities ranged from a low of 2,060 pCi/L (average, shown in Table 1) at the start of pumping, peaked at 3,170 pCi/L after approximately 2.5 hours of pumping, and then fluctuated between 2,500 and 3,100 pCi/L over the three days of pumping (Figure 10A).

The bailed samples from ER-20-8-2_p1 in September 2014 at 2,555 pCi/L (average) are in good agreement with the average activities for the time-series and post-time-series samples for the rod pump in ER-20-8-2_p1 (average of samples after peak activity, 2,426 pCi/L, 5.2 percent difference [Figure 9 and Table 1]). The bailed samples from ER-20-8-2_p1 are also in good agreement with the average activities for the time-series and post-time-series samples for the ESP in ER-20-8-2_m1 (average of samples after peak activity, 2,712 pCi/L, 6.0 percent difference [Figure 10A and Table 1]).

ER-20-8-2_m1 was pumped again with an ESP at approximately 117 lpm (31 gpm) in September 2017. Samples were collected after approximately 25 hours of pumping and approximately 170,300 L (45,000 gal; approximately 10.8 well volumes) were purged from the well (Navarro, 2018b). The average of these samples is 3,600 pCi/L. This average activity is greater than the ^{3}H activity collected in the second half of the time-series sampling in 2014 by approximately 1,000 pCi/L (Table 1 and Figure 10B).

During well development in 2009, two samples were bailed from p1 while m1 was being pumped at approximately 488 lpm (129 gpm). The average ^{3}H activity for these two samples was 805 pCi/L. Three samples from m1 at the end of well development with the ESP averaged 1,067 pCi/L ^{3}H (Figure 10B). There are no bailed samples from the m1 completion. The samples collected from m1 and p1 in 2009 during well development likely are not directly comparable to samples collected during typical bailing or pumping sampling events at a later time after well development because of the large volume of water removed during well development and the resulting perturbation to the aquifer (approximately 6,900,000 L [1,800,000 gal]) (Navarro-Intera, 2010).

Bailed samples in 2014 from ER-20-8-2_p1 are in good agreement with low-volume rod-pump samples from p1 (5.2 percent difference, Table 1). Bailed samples from p1 are also in good agreement with high-volume ESP samples from m1 from 2014 (6.0 percent difference, Table 1). However, ESP samples on average are approximately 300 pCi/L higher than rod-pump samples. The ESP samples from 2017 from m1 are approximately 900 pCi/L higher than samples from 2014. This suggests that ^{3}H activities are increasing at ER-20-8-2 either because of contaminant migration by natural groundwater flow or because of pumping-induced flow to the well from groundwater with higher ^{3}H activity. The ESP samples from m1 at the end of well development are in poor agreement (82 percent difference, Table 1 and Figure 10B) with bailed samples from p1 in 2014. The impact of radioactive decay for ^{3}H between well development and more recent samples was not estimated for this discussion.

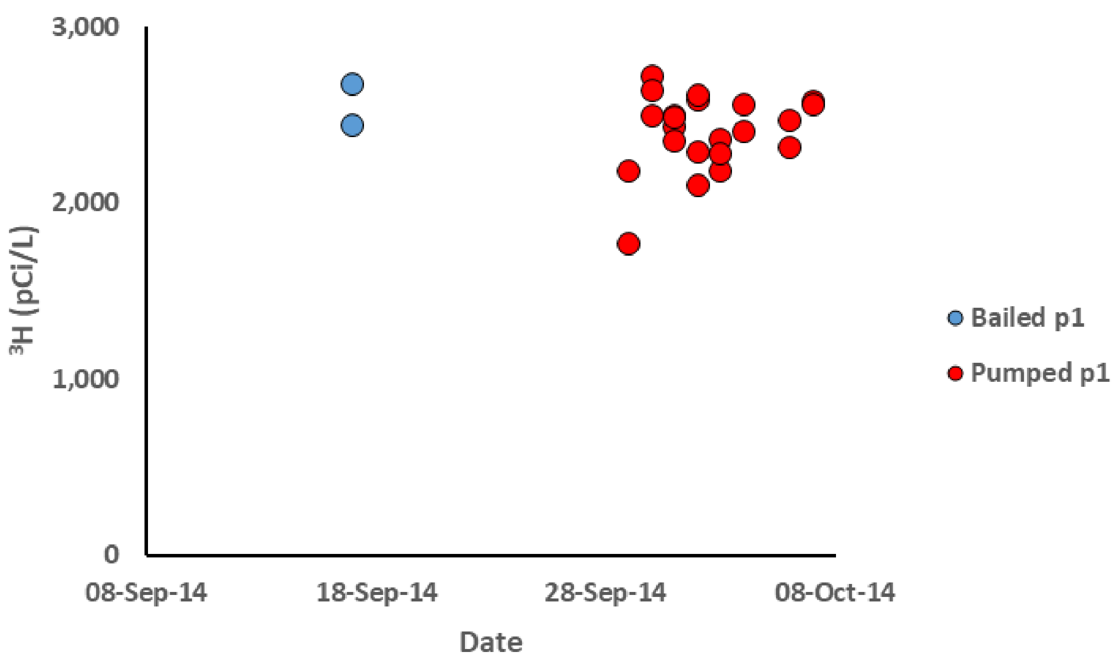

Figure 9. Bailed (September 2014) versus rod-pump (September and October 2014) ^{3}H sample results for ER-20-8-2_p1, including nine days of continuous pumping.

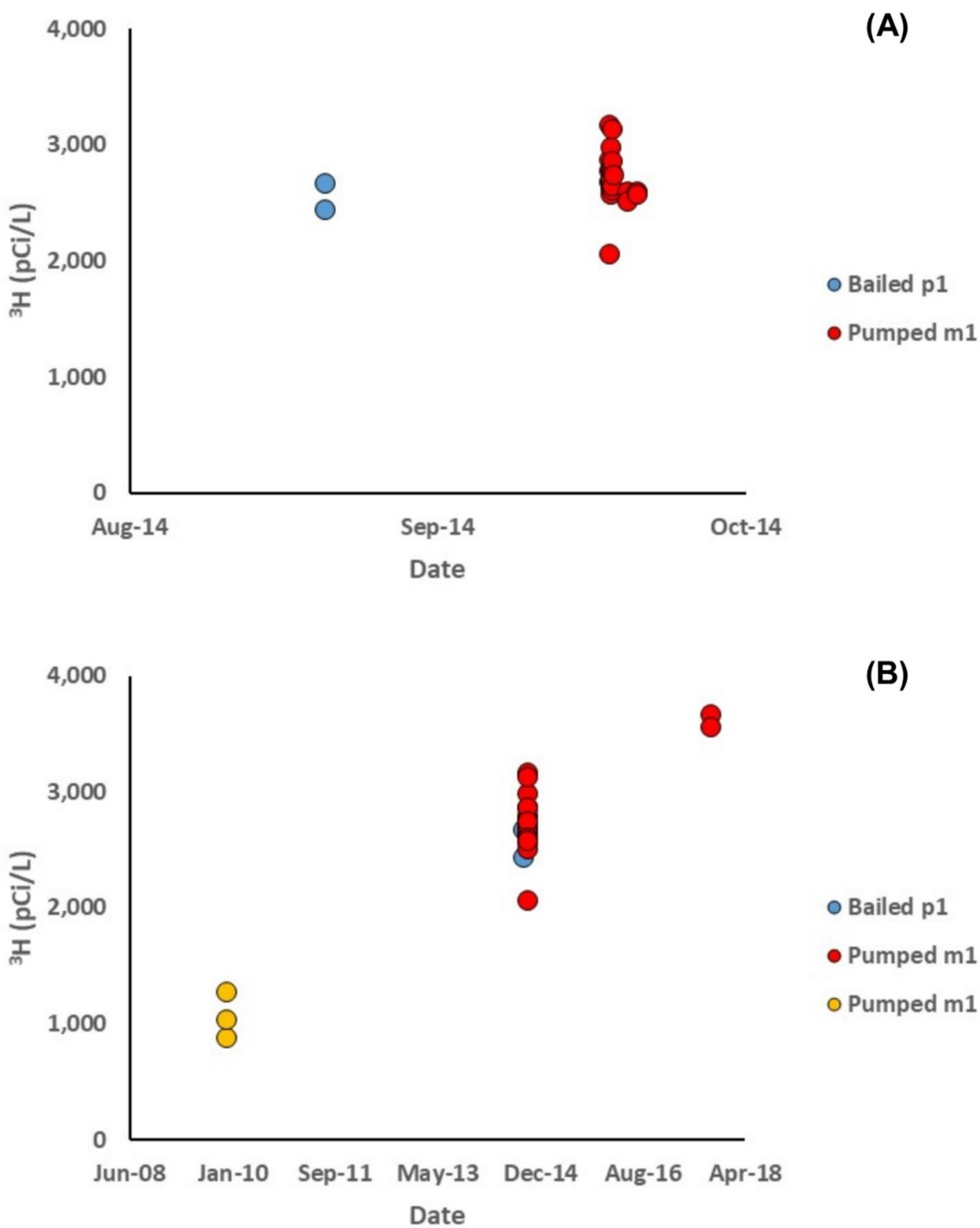

Figure 10. A) Bailed (September 2014) ^{3}H sample results for ER-20-8-2_p1 versus ESP ^{3}H sample results for well ER-20-8-2_m1 during time-series sampling over approximately nine hours of pumping in October 2014; B) Bailed (September 2014) ^{3}H sample results for ER-20-8-2_p1 versus ESP (October 2014 and September 2017) ^{3}H sample results for ER-20-8-2_m1 and ESP (December 2009) ^{3}H sample results for ER-20-8-2_m1 at the end of well development.

UE-7nS_m1

The well construction diagram for UE-7nS_m1 is presented in Figure A-8 in the Appendix. From 1977 to 1987, samples were collected by ESP. No samples were collected from 1987 through 1993. In 1993, samples were collected by bailing. There is a wide range in ^{3}H activity for both pumped and bailed samples (Figure 11) from 41 to 4,604 pCi/L. Because of this wide range in ^{3}H activity, and because there are no sampling events that paired pumped and bailed samples at approximately the same time, these data were not considered further. These data are presented here for completeness.

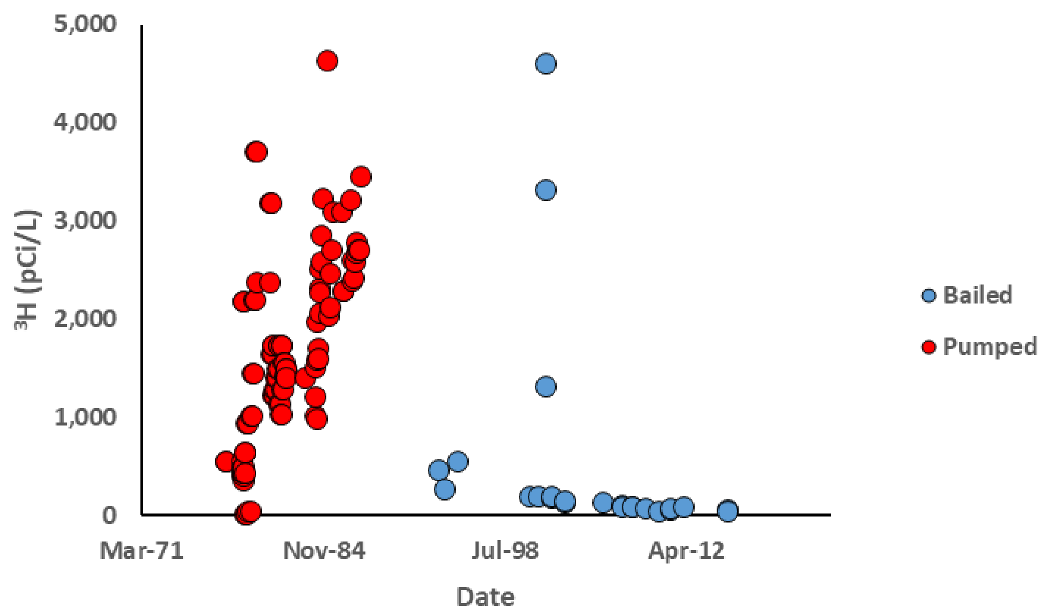

Figure 11. Bailed (1993-2015) versus ESP (1977-1987) ^{3}H sample results for UE-7nS_m1.

ER-20-8_m2 and ER-20-8_p2

Well ER-20-8 has two main screened intervals at two different depths and two piezometers that are screened adjacent to one of the main well screens, as described above (shown in Figure A-5 in the Appendix). During well development in 2011, two samples were bailed from p2 while m2 was being pumped at approximately 379 lpm (100 gpm). The average ^{3}H activity for these two samples was 2,090 pCi/L (not shown). Five samples from m2 at the end of well development with the ESP averaged 2,856 pCi/L ^{3}H (Figure 12A). There are no bailed samples from the m2 completion. The samples collected from m2 and p2 in 2011 during well development are likely not directly comparable to samples collected during typical bailing or pumping sampling events at a later time after well development because of the large volume of water removed during well development and the resulting perturbation to the aquifer (approximately 11,400,000 L [3,000,000 gal]) (Navarro-Intera, 2012). The impact of radioactive decay for ^{3}H between well development and bailed samples was not estimated for this discussion.

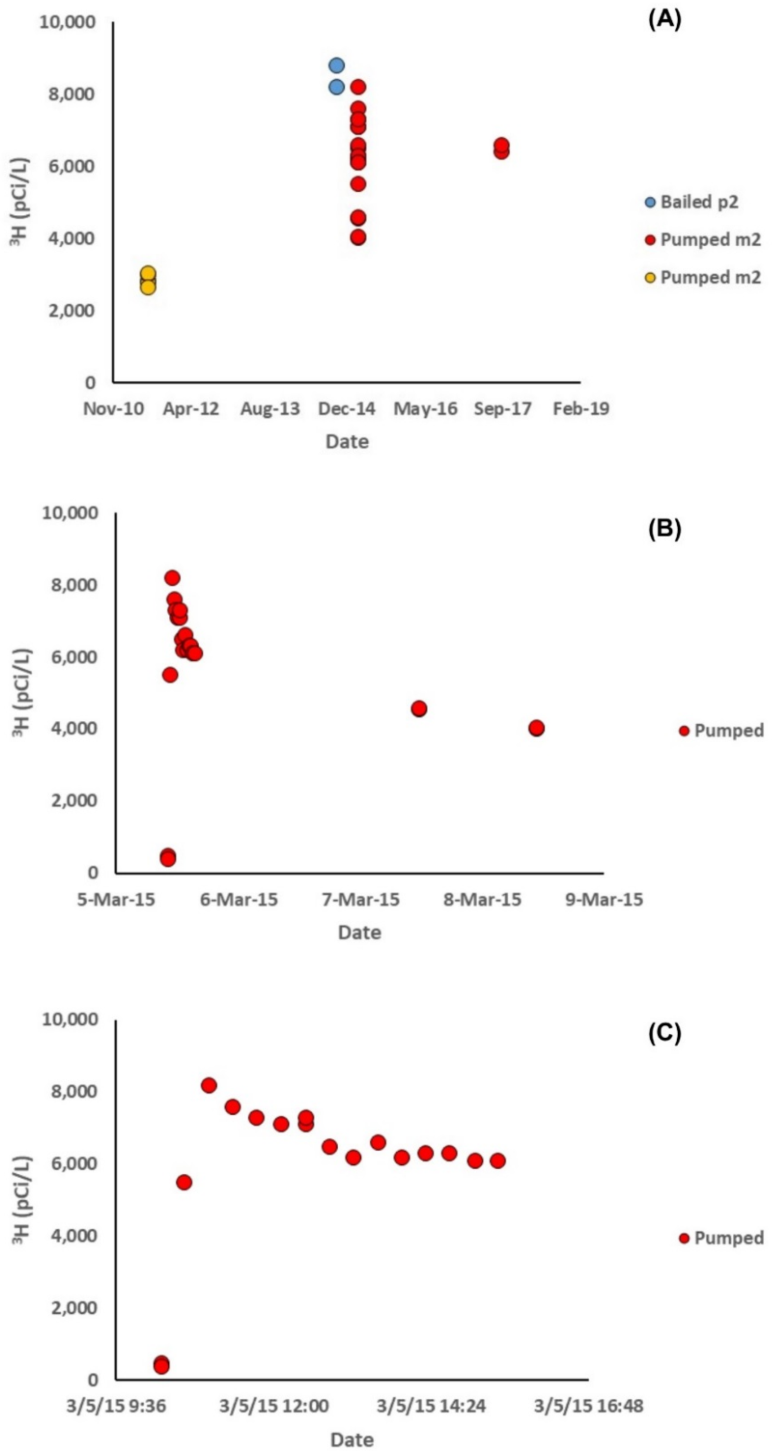

Figure 12. A) Bailed (October 2014) ^{3}H sample results for ER-20-8_p2 versus ESP (March 2015 and September 2017) ^{3}H sample results for well ER-20-8_m2 and ESP (June 2011) samples from ER-20-8_m2 at the end of well development; B) ESP ^{3}H sample results for ER-20-8_m2 over three days of continuous pumping in March 2015; C) ESP ^{3}H sample results for ER-20-8_m2 during time-series sampling over approximately five hours of pumping on March 5, 2015.

In October 2014, samples were bailed from ER-20-8_p2. Table 2 lists the pertinent well information for the bailed samples. The average ^3H activity for these two samples is 8,500 pCi/L (Table 1 and Figure 12A).

In March 2015, ER-20-8_m2 was pumped and samples were collected as part of a study evaluating sampling technologies (Navarro, 2015a). ER-20-8_m2 was pumped continuously with an ESP at approximately 98 lpm (26 gpm) for approximately three days. One well volume for ER-20-8_m2 is 9,486 L (2,506 gal; Navarro, 2015a). During time-series sampling, 33,175 L (8,764 gal) were purged from m2 after approximately 5.5 hours of pumping. At the end of three days of pumping, over 435,000 L (115,000 gal) were purged from the well. The ^3H activities ranged from a low of 445 pCi/L (average Table 1) at the start of pumping, peaked at 8,200 pCi/L after approximately an hour of pumping, and then decreased gradually to approximately 4,000 pCi/L at the end of pumping (Figures 12A and 12B).

Initial samples collected after only 114 L (30 gal) were purged averaged 445 pCi/L (Figure 12B and 12C), which is substantially less than later samples. This may be the result of water from near the water surface, which tends to have much lower ^3H activity than water from within the screened interval, entering the pump string during pump installation. The highest activity was 8,200 pCi/L observed after approximately 4,540 L (1,200 gal) had been purged, or approximately half of one well volume (Figure 12C). At approximately three well volumes, ^3H activity had decreased to 6,300 pCi/L (Figure 12C). The continued decrease in ^3H activity as pumping continued suggests that pumping with an ESP at this rate (approximately 95 lpm [25 gpm]), as opposed to pumping with a rod pump at a much lower rate (9.5 lpm [2.5 gpm]), was drawing in uncontaminated water and diluting the ^3H activity in the samples.

The bailed samples from ER-20-8_p2 in October 2014 at 8,500 pCi/L (average) are in good agreement (3.6 percent difference) with the 8,200 pCi/L measured after half of one well volume had been purged. ER-20-8_m2 was pumped again with an ESP at approximately 117 lpm (31 gpm) in September 2017. Samples were collected after approximately 20 hours of pumping and 138,900 L (36,700 gal; approximately 14.6 well volumes) were purged from the well. The average of these samples is 6,500 pCi/L (Figure 12A). This average activity is similar to the ^3H activity collected in the second half of the time-series sampling in 2015 (Table 1, Figure 12A), which both are approximately 30 percent different from bailed samples in October 2014.

ER-EC-11_p3

Well ER-EC-11 has two main screened intervals at two different depths and two piezometers that are screened adjacent to one of the main well screens, and two piezometers outside the well casing with no gravel packs (p3 and p4), as described above (shown in Figure A-2 in the Appendix). ER-EC-11_p3 was not developed prior to bailed samples being collected in August 2014, the average of these two samples was 12,400 pCi/L ^3H (Table 1 and Figure 13). Table 2 lists the pertinent well information for the bailed samples. Pumped samples were collected in August 2014 after bailed samples as part of a study evaluating sampling technologies (Navarro, 2015a). Rod-pump samples were collected over a seven-day period and after an initial sample at 8,400 pCi/L, samples ranged from 15,700 to 16,700 pCi/L with an average of approximately 16,200 pCi/L ^3H (Table 1 and Figure 13) with approximately 90,720 L (23,966 gal) or 2.6 well volumes purged from p1 by the end of sampling. One well volume for ER-EC-11_p3 is 34,663 L (9,157 gal) (Navarro, 2015). Two rod-pump samples were again collected from p3 in 2017 with an average of 18,250 pCi/L ^{3}H (Table 1 and Figure 13) after approximately 60,800 L (16,072 gal) or 1.8 well volumes were purged from the well. Average ^{3}H activities are increasing with time, the undeveloped bailed sample average is 27 percent different form the time-series rod-pump samples and 38 percent different from the rod-pump samples from 2017 (Table 1).

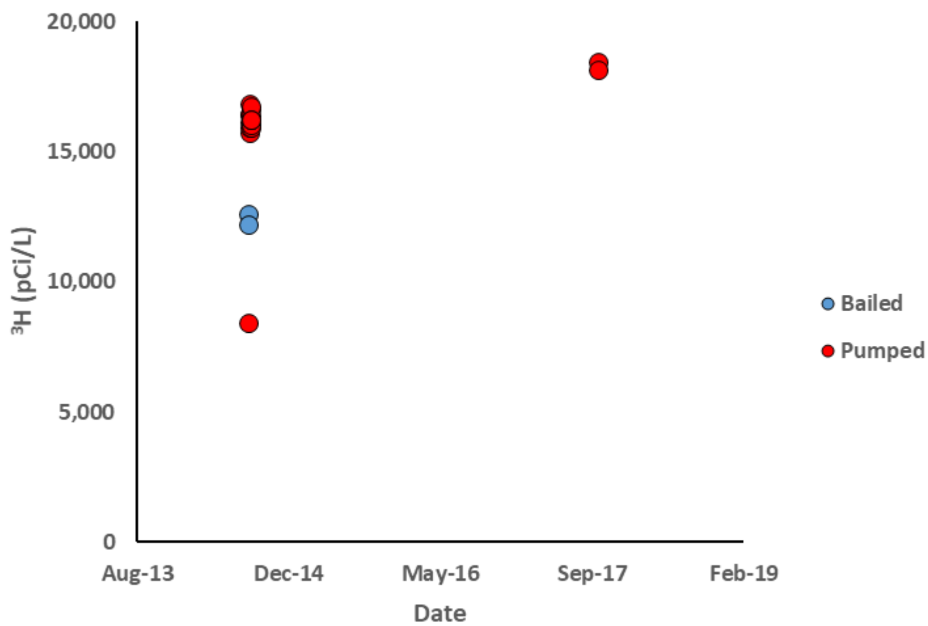

Figure 13. Bailed (August 2014) ^{3}H sample results versus rod-pump (August 2014 and October 2017) ^{3}H sample results for well ER-EC-11_p3. ER-EC-11_p3 was not developed prior to bailer sampling in 2014.

ER-20-12_p1

ER-20-12 has five different completion zones, each one samples a different hydrostratigraphic unit (shown in Figure A-9 in the Appendix). ER-20-12_p1 was not developed prior to bailed samples being collected in June 2016, one sample was 19,800 pCi/L ^{3}H (Table 1 and Figure 14). Table 2 lists the pertinent well information for the bailed samples. Rod-pump samples were collected on July 2016 with an average ^{3}H result of 18,750 pCi/L (Table 1 and Figure 14) after approximately 89,200 L (approximately 23,575 gal) or 5.7 well volumes were purged from the well. One well volume is 15,640 L (4.132 gal) (Navarro, 2018c). Rod-pump samples were again collected from p1 in July 2017 with an average of 25,250 pCi/L ^{3}H (Table 1 and Figure 14) after approximately 38,500 L (approximately 10,170 gal) or 2.5 well volumes were purged from the well. Average ^{3}H activities are increasing with time, the undeveloped bailed sample average from 2016 is 5.4 percent different form the rod-pump samples in 2016 and 24 percent different from the rod-pump samples from 2017 (Table 1).

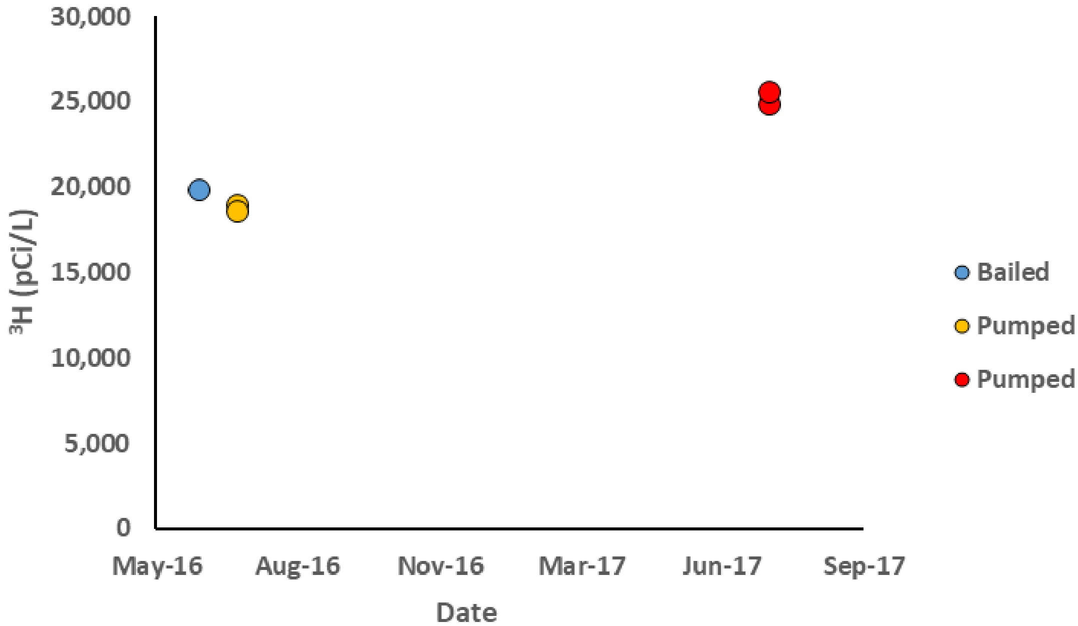

Figure 14. Bailed (June 2016) ^3H sample results versus rod-pump (July 2016 and July 2017) ^3H sample results for well ER-20-12_p1. ER-20-12_p1 was not developed prior to bailer sampling in 2016.

ER-20-12_m1

ER-20-12 has five different completion zones, each one samples a different hydrostratigraphic unit (shown in Figure A-9 in the Appendix). ER-20-12_m1 was not developed prior to bailed samples being collected in June 2016, the average for two bailed samples was 30,200 pCi/L ^3H (Table 1 and Figure 15). The ESP samples were collected on August 2016 with an average ^3H result of 33,800 pCi/L (Table 1 and Figure 15) after approximately 114,200 L (approximately 30,170 gal) or 3.5 well volumes were purged from the well (Navarro, 2018c). One well volume for ER-20-12_m1 is approximately 32,900 L (approximately 8,700 gal) (Navarro 2018d). The ESP samples were again collected from m1 in July 2017 with an average of 41,400 pCi/L ^3H (Table 1 and Figure 15) after approximately 223,700 L (approximately 59,100 gal) or 6.8 well volumes were purged from the well. The undeveloped bailed sample average from 2016 is 11 percent different form the ESP samples in 2016 and 31 percent different from the ESP samples from 2017 (Table 1). The ^3H activity in ER-20-12_m1 is increasing with time, but the large amount of water that is removed from m1 before samples are collected may be pulling higher ^3H activity water toward the well.

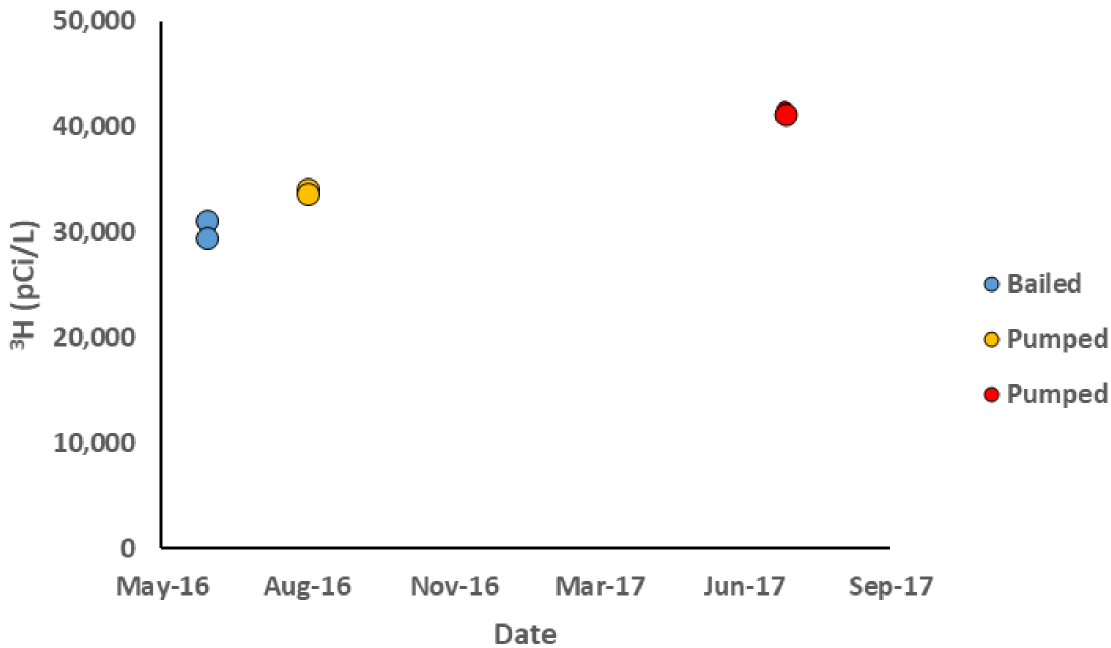

Figure 15. Bailed (June 2016) ^{3}H sample results versus ESP (August 2016 and July 2017) ^{3}H sample results for well ER-20-12_m1. ER-20-12_m1 was not developed prior to bailer sampling in 2016.

UE-5n_m1

UE-5n_m1 has perforated casing from 219.5 to 222.5 m bgs (720 to 730 ft bgs). There is no gravel pack in the well and the casing is hung in the open borehole and cemented at the bottom of the borehole (shown in Figure A-10 in the Appendix). Figure 16 shows the ^{3}H activities. Although records were not readily available at this time, the pump (type of pump used prior to 2004 is not known) was removed sometime after February 2004, which allowed samples to be bailed in 2007. A sample was collected in 2010, although it cannot be verified that the sample was pumped. In 2014, samples were bailed, and a dedicated ESP was then installed (NNSA 2016). Two bailed samples from June 2014 have an average ^{3}H activity of 152,500 pCi/L, and three pumped samples have an average activity of 154,100 pCi/L, which are in good agreement (Table 1 and Figure 16). One well volume for UE-5n_m1 is approximately 12,617 L (3,333 gal) (Navarro-Intera, 2014e).

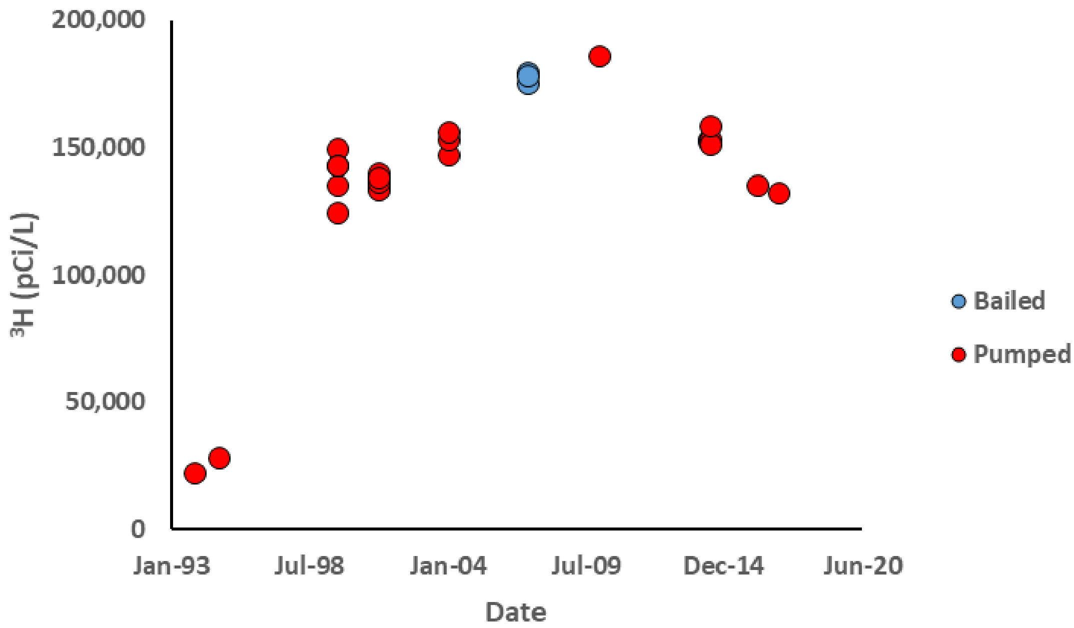

Figure 16. Bailed (2007 and 2014) versus pumped ^{3}H sample results for well UE-5n_m1.

ER-20-11_m1 and ER-20-11_p1

ER-20-11 has one main well completion, m1, and one piezometer, p1, both screened in the same interval. During well development in 2013, two samples were bailed from p1 while m1 was being pumped at approximately 693 lpm (183 gpm). The average ^{3}H activity for these two samples was 217,000 pCi/L (not shown). Three samples from m1 at the end of well development with the ESP averaged 186,667 pCi/L ^{3}H (Figure 17). There are no bailed samples from the m1 completion. The samples collected from m1 and p1 in 2013 during well development are likely not directly comparable to samples collected during typical bailing or pumping sampling events at a later time after well development because of the large volume of water removed during well development and the resulting perturbation to the aquifer (approximately 40,500,000 L (10,700,000 gal]) (Navarro-Intera, 2014f). The impact of radioactive decay for ^{3}H between well development and bailed samples was not estimated for this discussion.

One ESP sample was collected from m1 in October 2017 with a ^{3}H activity of 202,000 pCi/L after approximately 150,000 L (39,538 gal) or 14.5 well volumes were purged (Table 1 and Figure 17). One well volume for ER-20-11_m1 is 10,332 L (2,729 gal) (Navarro, 2018a).

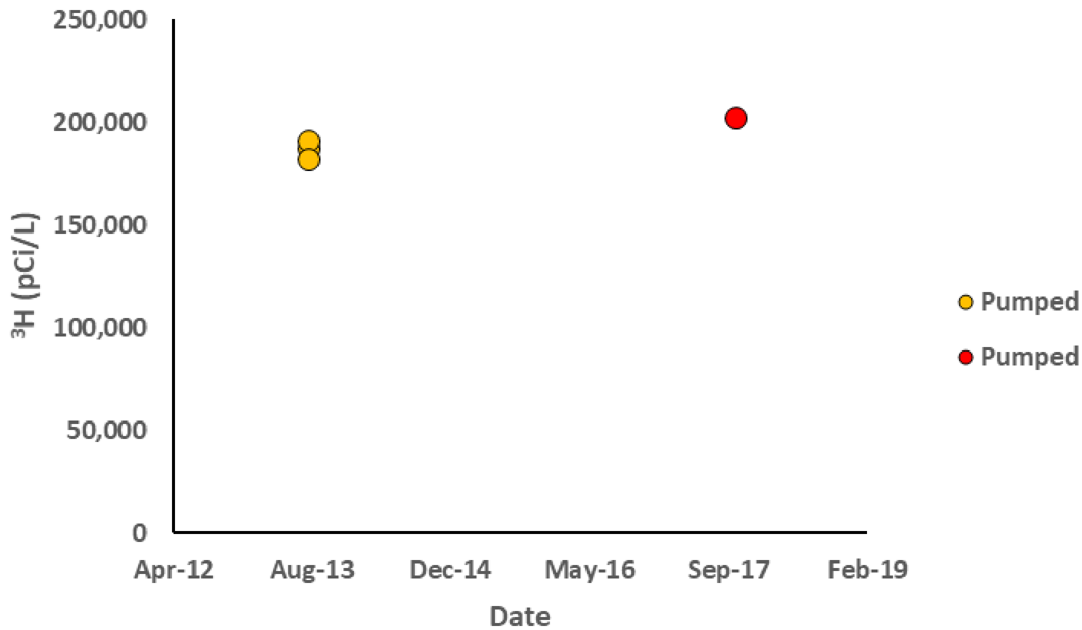

Figure 17. ESP (August 2013) ^3H sample results for well ER-20-11_m1 at the end of well development and ESP (October 2017) ^3H sample results for well ER-20-11_m1.

UE-2ce_m1

UE-2ce_m1 is screened from 420.0 to 495.0 m bgs (1,378 to 1,624 ft bgs). There is no gravel pack in the well and the casing is hung in the open borehole and cemented above the screen (shown in Figure A-12 in the Appendix). The depth to water was approximately 443.5 m bgs (1,455 ft bgs) (USGS, 2018) in November 2017. The well was sampled by pumping (the type of pump is not known) many times between 1977 and 1984 (LLNL, 2010) followed by a period from 1984 to 1993 when no samples were collected. Figure 18 shows the ^3H activity since 1993. Samples were collected by bailing in 1993 (445 m bgs), 2001 (472.4 m bgs), and 2005 (481 m bgs). An ESP was installed in 2008 (Navarro, 2016c) and samples were collected (Table 1 and Figure 18). Pumped samples were also collected in 2016. Tritium activities during pumping in 2016 increased over approximately three days suggesting that ^3H may have been pulled into the well from a ^3H plume. One well volume for UE-2ce_m1 is 4,542 L (1,200 gal; Navarro, 2017). There is good agreement between bailed samples in 1993 and 2001, poor agreement between bailed samples in 2001 and pumped samples in 2008, and good agreement between bailed samples in 2001 and pumped samples in 2016 (Table 1 and Figure 18). The impact of radioactive decay for ^3H between well development and bailed samples was not estimated for this discussion.

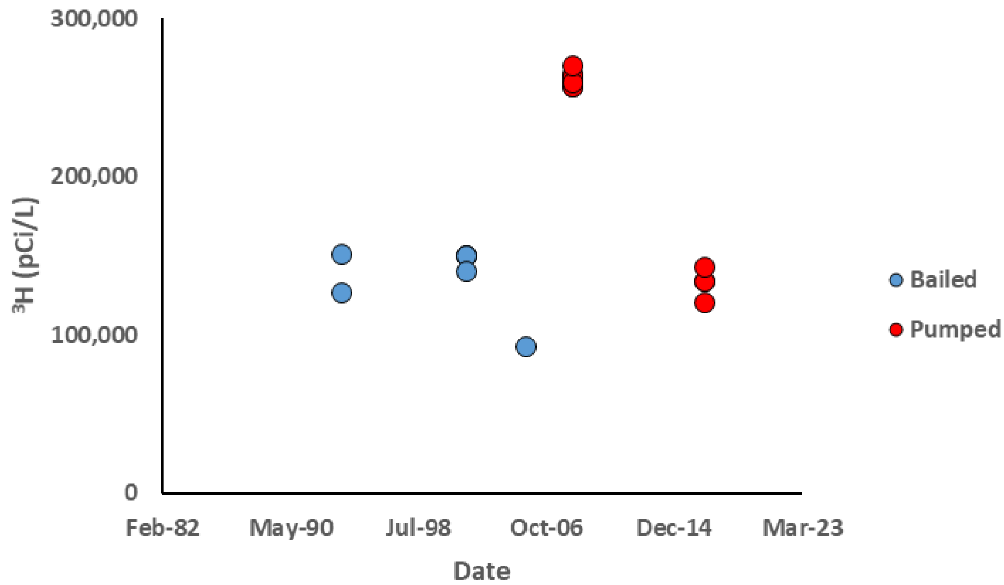

Figure 18. Bailed (1993, 2001, and 2005) versus ESP (2008 and 2016) ^3H sample results for UE-2ce_m1.

UE-20n 1_o2

The well construction diagram for UE-20n_o2 is presented in Figure A-11 in the Appendix. Although both pumped and bailed samples are available from UE-20n 1_o2 from 1987, bailed samples were collected while the ESP was operating. Therefore, the available data from UE-20n 1_o2 are not directly comparable to typical bailed and purged samples.

Identification of Sampling Zones

To obtain a representative and repeatable ^3H activity, depth-discrete bailed samples should be collected at depths that take advantage of active groundwater flow zone. Appropriate depths can be identified by examining logging data under both stressed and ambient conditions. For example, logs at ER-20-8_p2 can be used to identify an optimal sampling depth in the Tiva Canyon Aquifer (TCA).

Examinations of temperature logs and thermal flow logs (TFM) under stressed conditions (Figure 19), bailed ^3H activity under stressed conditions (Figure 20), and temperature logs and thermal flow logs under non-stressed conditions (Figure 21) are used to identify the origination of flow into the well at discrete depths. From these logs, a change in temperature at approximately 868.7 m bgs (2,850 ft bgs; Figure 19) indicates flow into the well, which corresponds to the lowest measured ^3H activity. From there, the flow is upward with approximately one half of the flow at approximately 853.4 m bgs (2,800 ft bgs) and ^3H activity increases from roughly 600 pCi/L at 868.7 m bgs (2,850 ft bgs) to approximately 1,800 pCi/L at 853.4 m bgs (2,800 ft bgs). Above 853.4 m bgs (2,800 ft bgs), the ^3H activity is relatively uniform. An appropriate place to collect depth-discrete samples in ER-20-8_p2 to obtain consistent ^3H activity results is at 853.4 m bgs (2,800 ft). Review of these types of logs while planning bailing activities will increase confidence that samples for ^3H activity are collected at appropriate depths that take advantage of borehole flow.

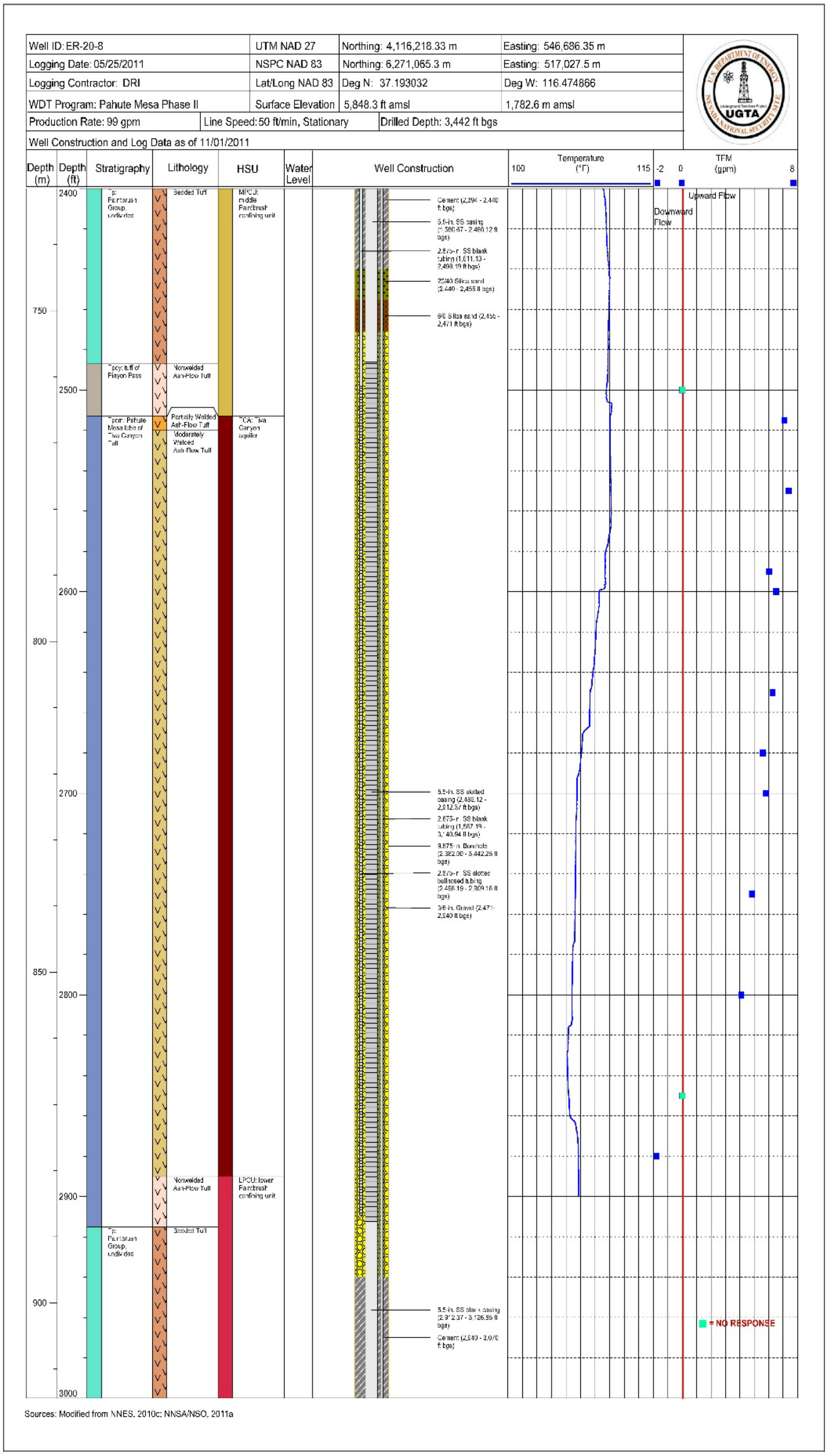

Figure 19. Desert Research Institute (DRI) TFM and temperature logs at ER-20-8 on May 25, 2011, under stressed conditions (375 lpm [99 gpm]).

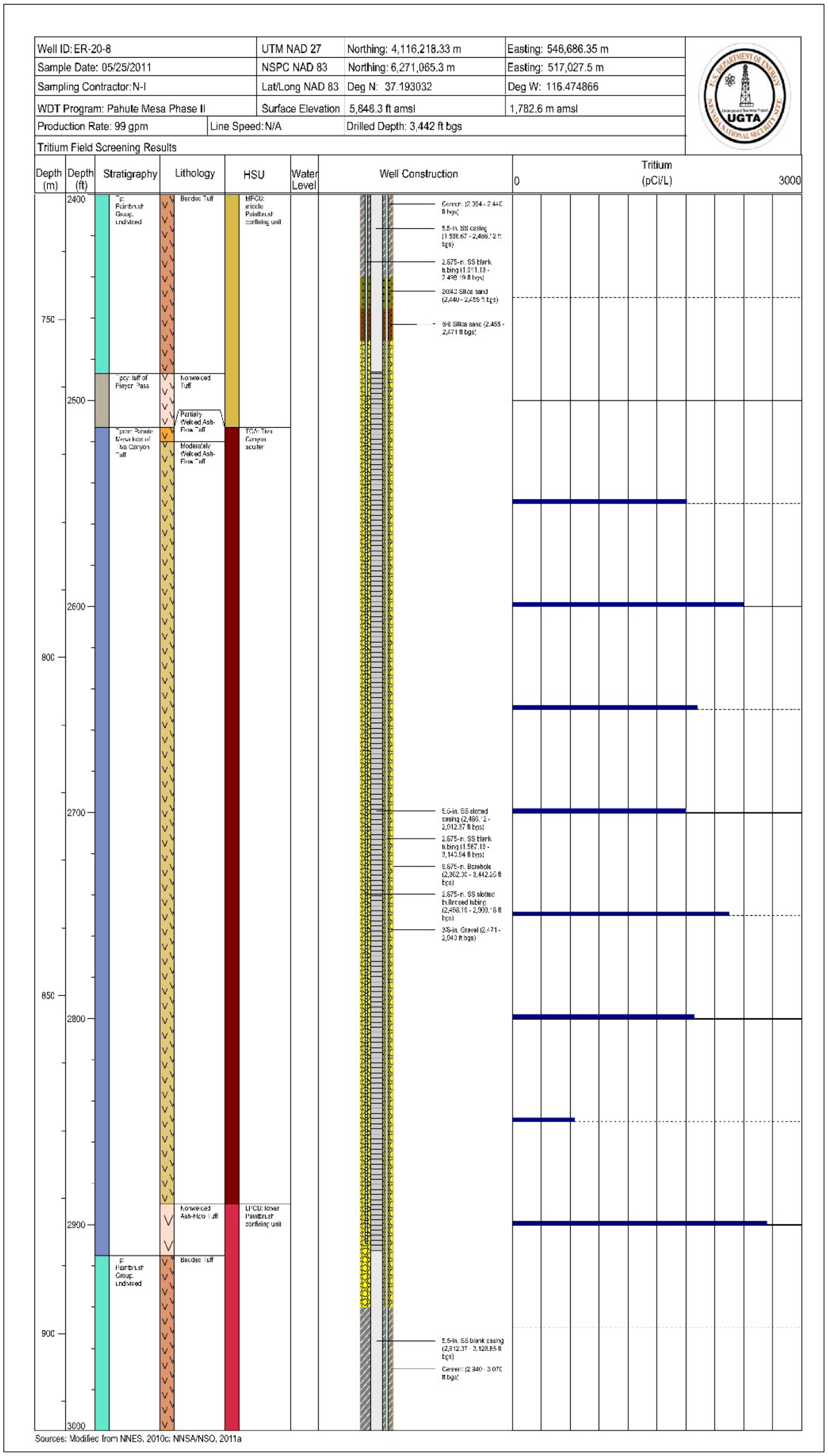

Figure 20. Tritium activity with depth in the TCA at ER-20-8 under stressed conditions (375 lpm [99 gpm]).

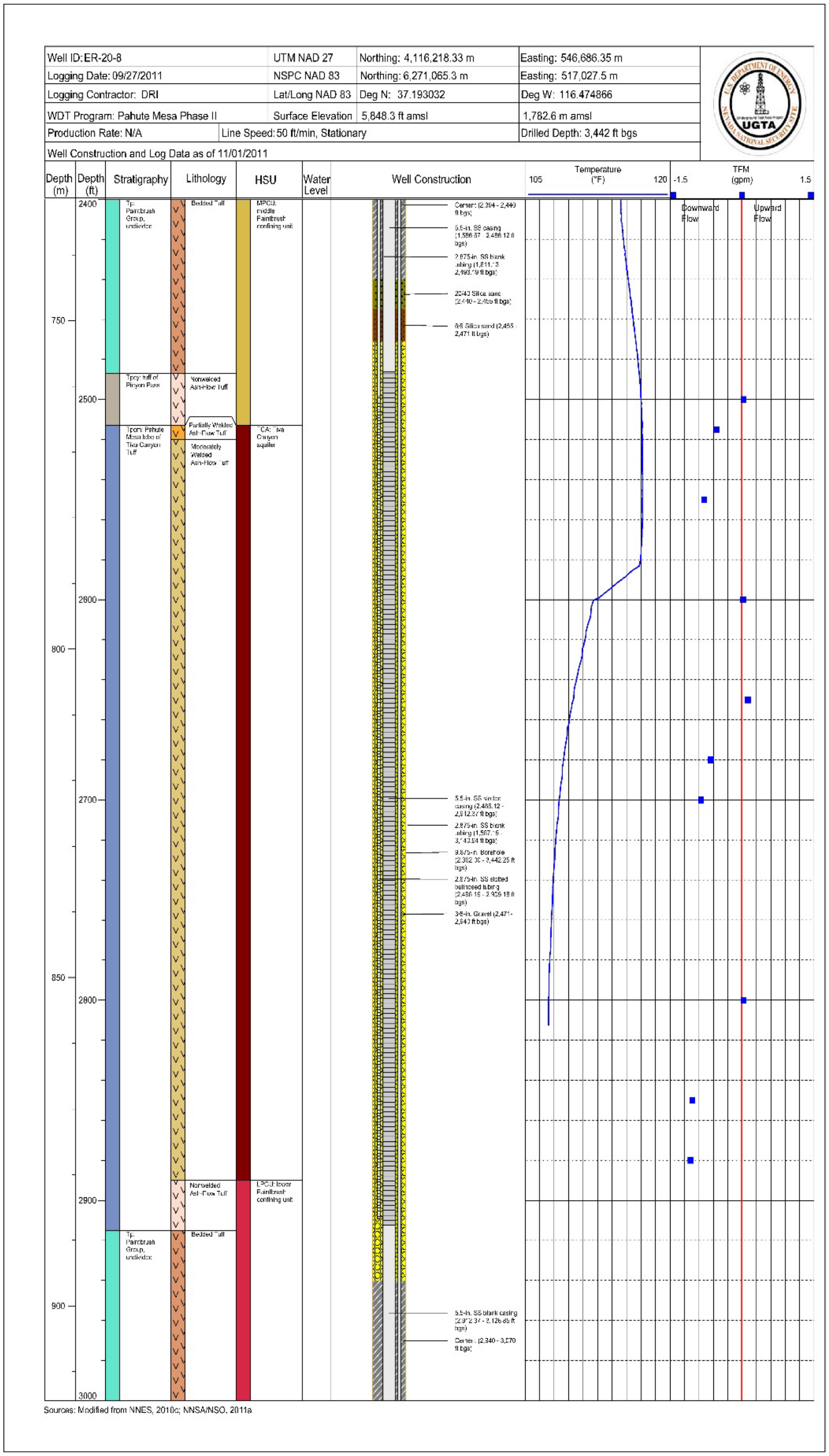

Figure 21. DRI TFM and temperature logs in the TCA at ER-20-8 under static conditions.

Summary of Wells Evaluated

The wells evaluated have a wide range in ^3H activity from approximately 5 pCi/L at ER-EC-6_m4 to 264,000 pCi/L at UE-2ce_m1. Samples collected by bailing generally are not purged of stagnant water in the well prior to sampling. Rod pumps withdraw water at a low rate (approximately 9.5 lpm [2.5 gpm]), but they can purge multiple well volumes over several days of pumping. The ESPs remove water at a higher rate (greater than 95 lpm [25 gpm]) and can purge large volumes in a short time. The important points from the analysis of each well include:

- ER-EC-6_m4 may have an increasing trend in ^3H activity. Bailed and pumped samples were collected two-and-a-half years apart, so a direct comparison between the two methods at this well may not be valid.
- ER-EC-11_p1 was bailed and pumped as part of a sampling technology study in 2014. A low-volume rod pump was used to pump the well. There was no trend of increasing or decreasing ^3H activities during time-series sampling. There is a 7.5 percent difference between bailed (6.5 pCi/L) and pumped time-series samples (6.9 pCi/L) after 3.7 well volumes were purged. Continued pumping after time-series sampling increased ^3H activity to 10.9 pCi/L after 5.0 well volumes were purged. Rod-pump samples from 2017 were also higher, at 10.9 pCi/L, after 4.6 well volumes were purged. Purging multiple well volumes may be drawing higher ^3H activity water into well from a nearby ^3H plume.
- ER-EC-11_p2 was bailed and pumped as part of sampling technology study in 2014. Bailed samples had 11.6 pCi/L prior to pumping. At the beginning of pumping, after only 10 gal purged (0.006 well volumes), the ^3H activity of 29.0 pCi/L. After that, rod-pump time-series samples ranged from 3.3 to 8.2 pCi/L (average = 5.3 pCi/L), with no increasing or decreasing trend in ^3H activities after 3.8 well volumes were purged. Continued pumping after time-series sampling increased ^3H activity to 11.3 pCi/L after 12 well volumes were purged, which is in good agreement with bailed samples. The ESP samples from m2 collected in 2017 had an activity of 10.8 pCi/L after 22 well volumes were purged, which is in good agreement with the bailed samples from p2. The variation between bailed samples, an initial high-activity pumped sample, lower activity during time-series sampling, and similar activity between bailed samples and longer time-pumping samples (low and high volume) makes any conclusions uncertain.
- ER-12-3_p1 was not developed prior to samples being bailed, these samples had an average ^3H activity of 22.1 pCi/L. Rod-pump samples were 23.6 pCi/L after pumping 21.6 well volumes, which is in good agreement with bailed samples. However, because p1 was not developed prior to bailing and pumping, these results may not be representative of ^3H activity in the aquifer.
- PM-3_p1 had minimal well development prior to bailing. There appears to be an increasing trend in ^3H activity over time, but large variability in duplicate samples since 2013 make this increasing trend uncertain. Large volumes of water were purged in 2013 (110,961 L [29,313 gal]; 16 well volumes). The increasing trend could be caused by pumping drawing higher ^3H activity water from the aquifer into the well when large volumes are purged. The ^3H near the surface of the water in the well is

likely exchanging with ^{1}H in the atmosphere in the well above the water surface. Depth-discrete bailed samples from within the screened interval are more likely to be representative of ^{3}H activity in the aquifer than samples collected near the water surface. Sufficient time after pumping is required to allow wells and the surrounding aquifers to return to ambient conditions before bailing more samples. The amount of time needed for a well and the surrounding aquifers to return to ambient conditions after pumping should be determined for each well.

- The only pumped sample from ER-20-8_m1 and p1 was collected from m1 at the end of well development after approximately 7,200,000 L (1,900,000 gal) were purged from the well. Two sets of bailed samples from p1 three and eight years after well development are lower in ^{3}H activity than the pumped sample.
- PM-3_p2 pumped ^{3}H activities appear to be dependent on pumped volume because the ^{3}H activity increases as more water is pumped. Large volumes of water were purged in 2013 (approximately 123,000 L [32,500 gal]; 14 well volumes). This suggests that pumping during purging is pulling higher ^{3}H activities toward the well. Overall, there is an increasing trend with time. However, ^{3}H activities in bailed samples roughly one and three years later appear to be decreasing with time, which suggests that ^{3}H activities in the aquifer are slowly returning to ambient conditions prior to pumping and purging in 2013. Samples were bailed at the water table in 2013 and the ^{3}H activity was <2 pCi/L, which was much less than other samples of all types. This is likely the result of ^{3}H near the water surface exchanging with ^{1}H in the atmosphere within the well. Depth-discrete samples collected from within the screened interval are likely more representative of ^{3}H in the aquifer, provided that there is sufficient time after pumping to allow the well and surrounding aquifer to return to pre-pumping conditions.
- WW A ^{3}H activities in pumped samples from 1978 to 1994 were lower than bailed samples from 2001 to 2012. Bailed sample ^{3}H activities have been decreasing since 2001.
- ER-20-8-2 ^{3}H activities are increasing either because of contaminant migration by natural groundwater flow or because of pumping-induced flow to the well from groundwater with higher ^{3}H activity. Large volumes of water were purged in 2014 (27 well volumes) and 2017 (11 well volumes).
- UE-7nS ^{3}H activities in pumped samples from 1997 to 1987 varied widely from below detection to over 4,000 pCi/L. Bailed samples from 1993 to 2015 were less than 500 pCi/L and decreased with time except for one set of samples from 2001. Tritium in bailed samples is lower in general than in pumped samples.
- ER-20-8 ^{3}H activities decreased with continuous pumping, which suggests that water with lower ^{3}H activity is being pulled to the well. Large volumes of water were purged in 2015 (46 well volumes) and 2017 (15 well volumes). The interaction between the deeper ER-20-8 and the shallower ER-20-8-2 was not considered for this report, but the short distance between the wells and the timing of pumping is likely important for understanding the changes in ^{3}H in this well complex.

- ER-EC-11_p3 ^{3}H activity of bailed samples prior to any pumping was 12,400 pCi/L in 2014. Time-series samples collected by pumping after bailing in 2014 were higher in ^{3}H (16,200 pCi/L). Tritium activities continued to increase in pumped samples in 2017 (18,250 pCi/L).
- ER-20-12_p1 ^{3}H activity of bailed samples prior to any pumping was 19,800 pCi/L in 2016. Pumped samples collected after well development had a similar ^{3}H activity (18,750 pCi/L). Pumped samples collected in 2017 were higher in ^{3}H at 25,250 pCi/L.
- ER-20-12_m1 ^{3}H activity of bailed samples prior to any pumping was 30,200 pCi/L in 2016. Pumped samples collected after well development had higher ^{3}H activity at 33,800 pCi/L. Pumped samples collected in 2017 increased in ^{3}H activity at 41,400 pCi/L.
- UE-5n bailed and pumped samples from 2014 are in good agreement at over 150,000 pCi/L ^{3}H.
- ER-20-11 does not have any directly comparable bailed and pumped sample. A pumped sample in 2017 at 202,000 pCi/L was higher than pumped samples collected at the end of well development in 2013 at 187,000 pCi/L ^{3}H.
- UE-2ce had good agreement between bailed samples in 1993 and 2001, poor agreement between bailed samples in 2001 and pumped samples in 2008, and good agreement between bailed samples in 2001 and pumped samples in 2016. The impact of radioactive decay for ^{3}H between well development and bailed samples and possible ^{3}H migration was not considered.
- UE-20n does not have any directly comparable bailed and pumped samples.

CONCLUSIONS AND RECOMMENDATIONS

Several conclusions can be drawn from the observations made during this study.

- Bailed samples collected for ^{3}H analysis near the water surface in a well are lower in ^{3}H activity than bailed samples from screened intervals and pumped samples. The ^{3}H in water near the interface with the atmosphere in the well is likely isotopically exchanging with ^{1}H in the atmosphere. This was observed in bailed samples from PM-3_p1 and PM-3_p2.
- Depth-discrete bailed samples from within well screens are generally in good agreement with pumped samples from developed wells and piezometers at ER-EC-11_p1, ER-20-8-2_p1, UE-5n_m1, and UE-2e_m1.
- Depth-discrete bailed samples from undeveloped wells and piezometers are in good agreement with the first pumped samples at ER-12-3_p1, ER-EC-11_p3, ER-20-12_p1, and ER-20-11_m1. However, the next pumped samples increased in ^{3}H activity, resulting in greater percent difference between the undeveloped bailed samples and later pumped samples at ER-EC-11_p3, ER-20-12_p1, and ER-20-11_m1.

- Continuous pumping over extended periods (i.e., days for low-volume rod pumps, hours for high-volume ESPs) removing large purge volumes from wells can perturbate the surrounding groundwater system for long periods of time (i.e., months to years). This was observed at ER-EC-11_p1, ER-EC-11_p2, PM-3_p1, PM-3_p2, ER-20-8-2_p1, ER-20-8_m1, ER-20-8_p2, ER-20-8_m2, ER-EC-11_p3, ER-20-12_p1, and ER-20-12_m1. This should not be an issue for most naturally occurring chemical constituents under long-term equilibrium conditions, such as major ions, trace metals, and environmental isotopes. However, these perturbations can cause large changes in ^{3}H activities (and possibly other radionuclides and other contaminants) in the aquifer near the well because ^{3}H activities are of limited extent and are variable within the aquifer.

Recommendations based on the study's observations and conclusions include:

- Bailed samples for ^{3}H should not be collected near the water surface in the well.
- Bailed samples should be collected from within the well screen.
- Ideally, logs of temperature, chemistry, and thermal flow should be evaluated to identify optimal depths within the well screen to collect depth-discrete bailer samples.
- Bailing can be used to detect the presence of a ^{3}H plume edge in early detection wells.
- Bailing can be used to monitor ^{3}H in distal and community wells when samples are analyzed by low-level ^{3}H analytical methods.
- Purging of large volumes of water from the well (many well volumes) over extended periods of time should be avoided when collecting samples for ^{3}H analyses.
- Care should be taken to replicate purging and sampling conditions at any given well so that ^{3}H activities between sampling events are directly comparable.
- Sufficient time should be allowed after pumping large volumes of water from the well (e.g., after well development) for the surrounding aquifer and ^{3}H activities to return to ambient conditions.
- The amount of time needed after pumping to allow a well and the surrounding aquifer to return to ambient conditions should be determined for each well.

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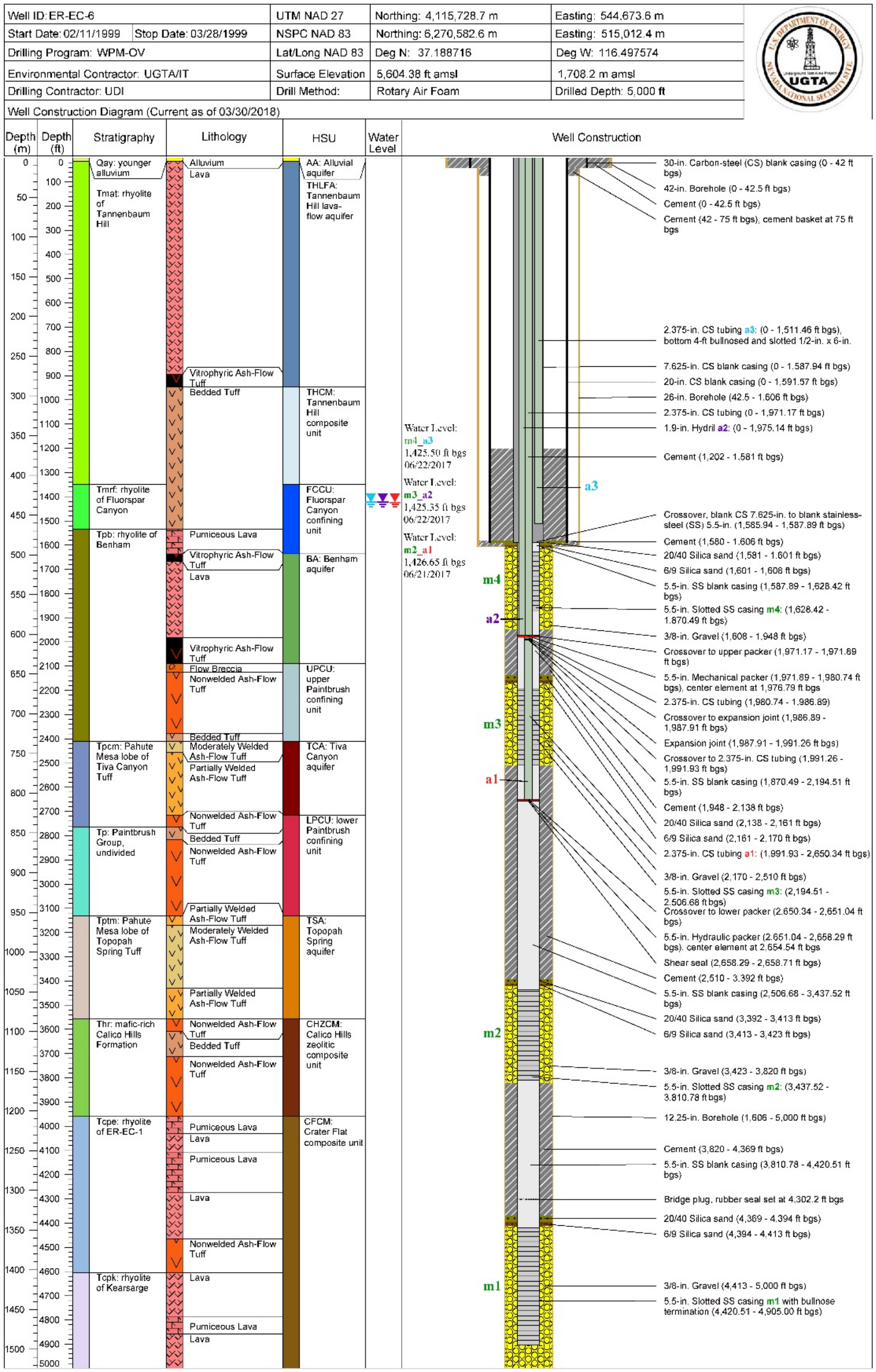
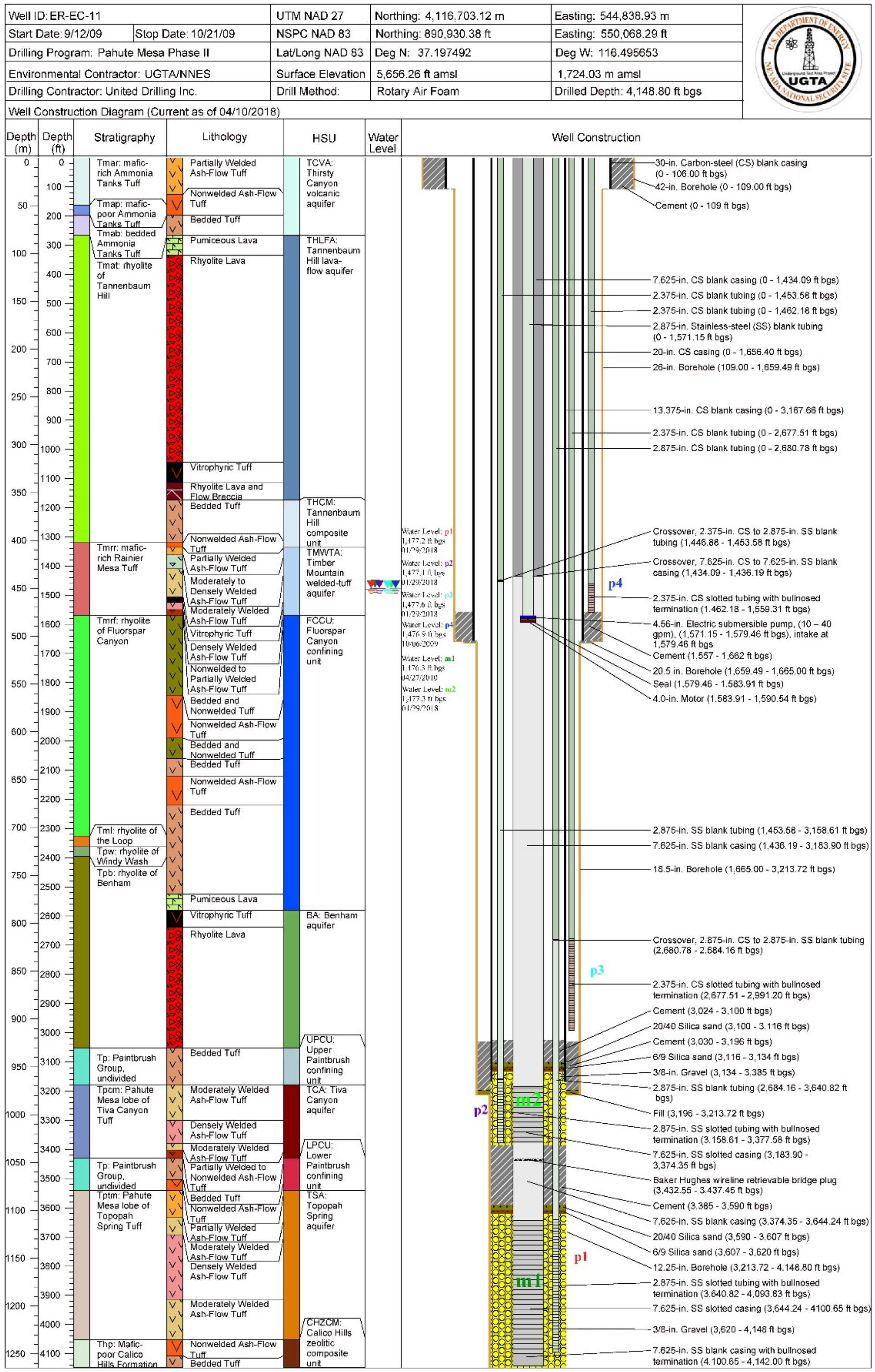
APPENDIX: Well Completion Diagrams



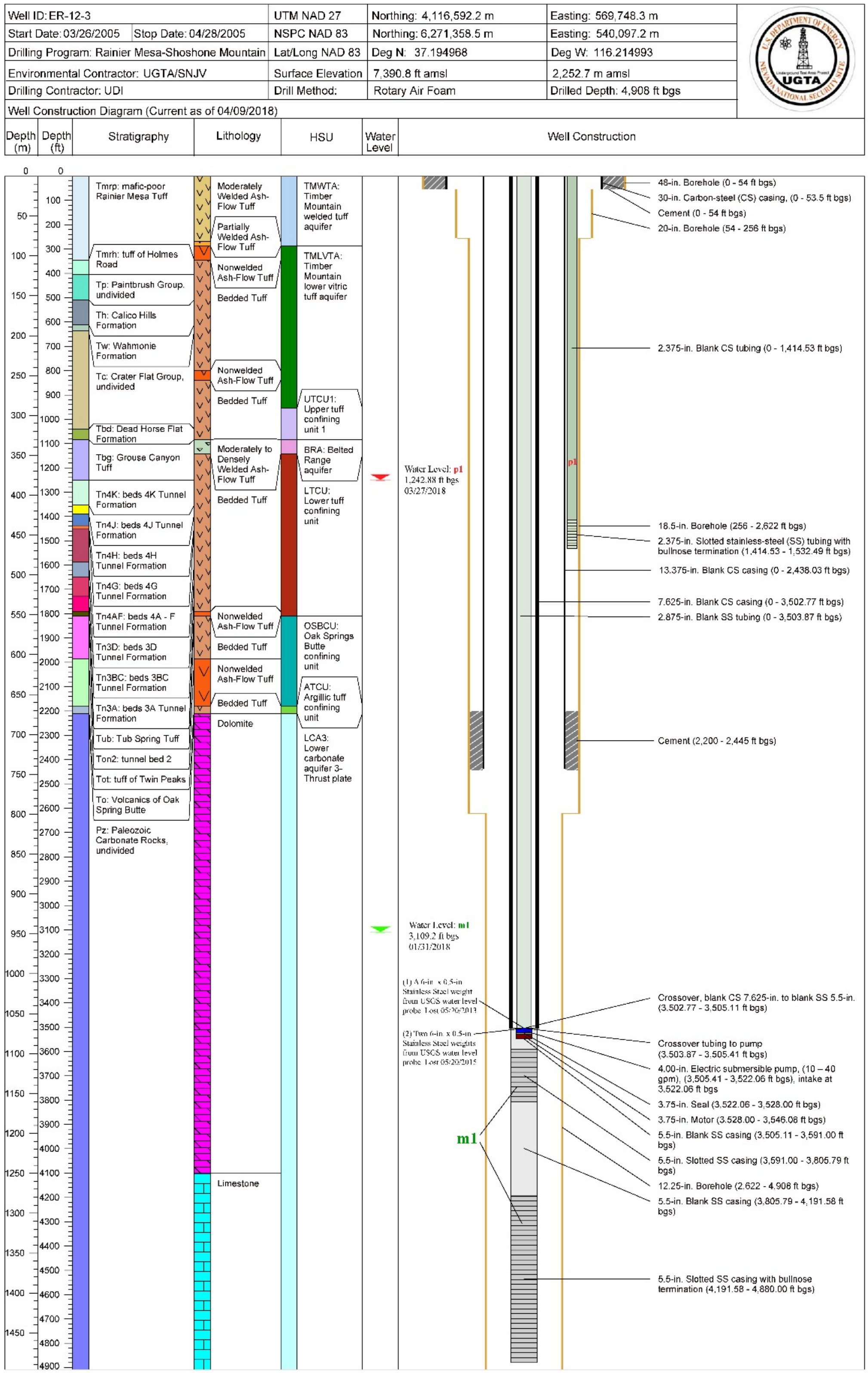
Source: Modified from Western Pahute Mesa - Oasis Valley Well ER-EC-6 Data Report for Development and Hydraulic Testing, IT, 2000; Completion Report for Well ER-EC-6, U.S. Department of Energy, National Nuclear Security Administration Nevada Site Office, 2000.; Int. Samp. Plan ID's (ISPIDS) - https://extranet.nv.doe.gov/Boreholes/ISPIDS.xlsx accessed on 03/30/2018; Phase II Pahute Mesa/Oasis Valley Model, N-I, 11/27/2013.

Figure A-1. ER-EC-6 well completion diagram.



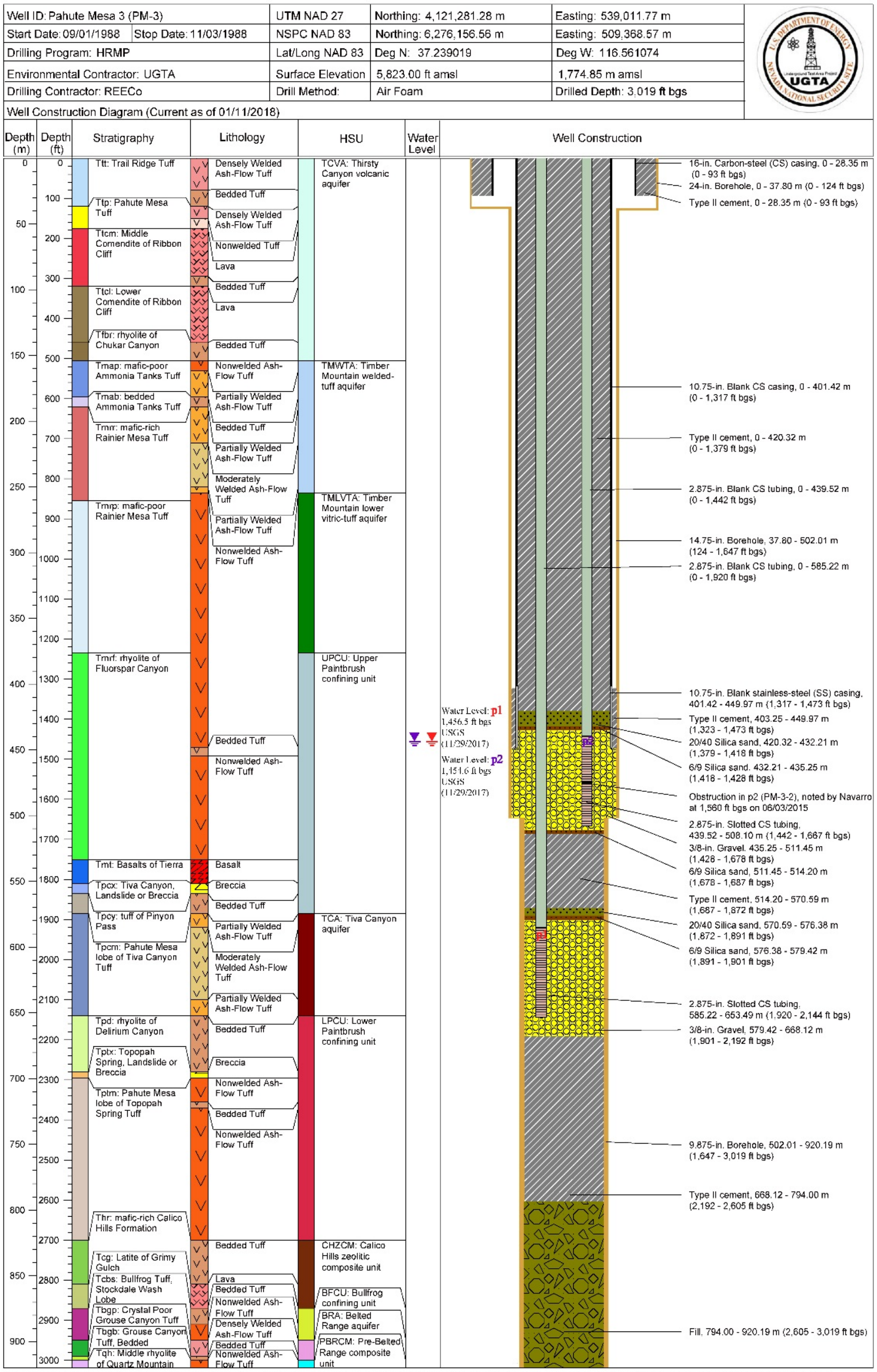
Source: Modified from Pahute Mesa Phase II ER-EC-11 Well Development, Testing, and Sampling Data Report, N-I, 2010; Completion Report for Well ER-EC-11, U.S. Department of Energy, National Nuclear Security Administration Nevada Site Office, 2010.; Phase II Pahute Mesa/Oasis Valley Model, N-I, 11/27/2013; Int. Samp. Plan ID's (ISPIDS)- https://extranet.nv.doe.gov/Boreholes/ISPIDS.xlsx accessed on 04/10/2018; Water Levels from USGS NWIS and Navarro 04/10/2018

Figure A-2. ER-EC-11 well completion diagram.



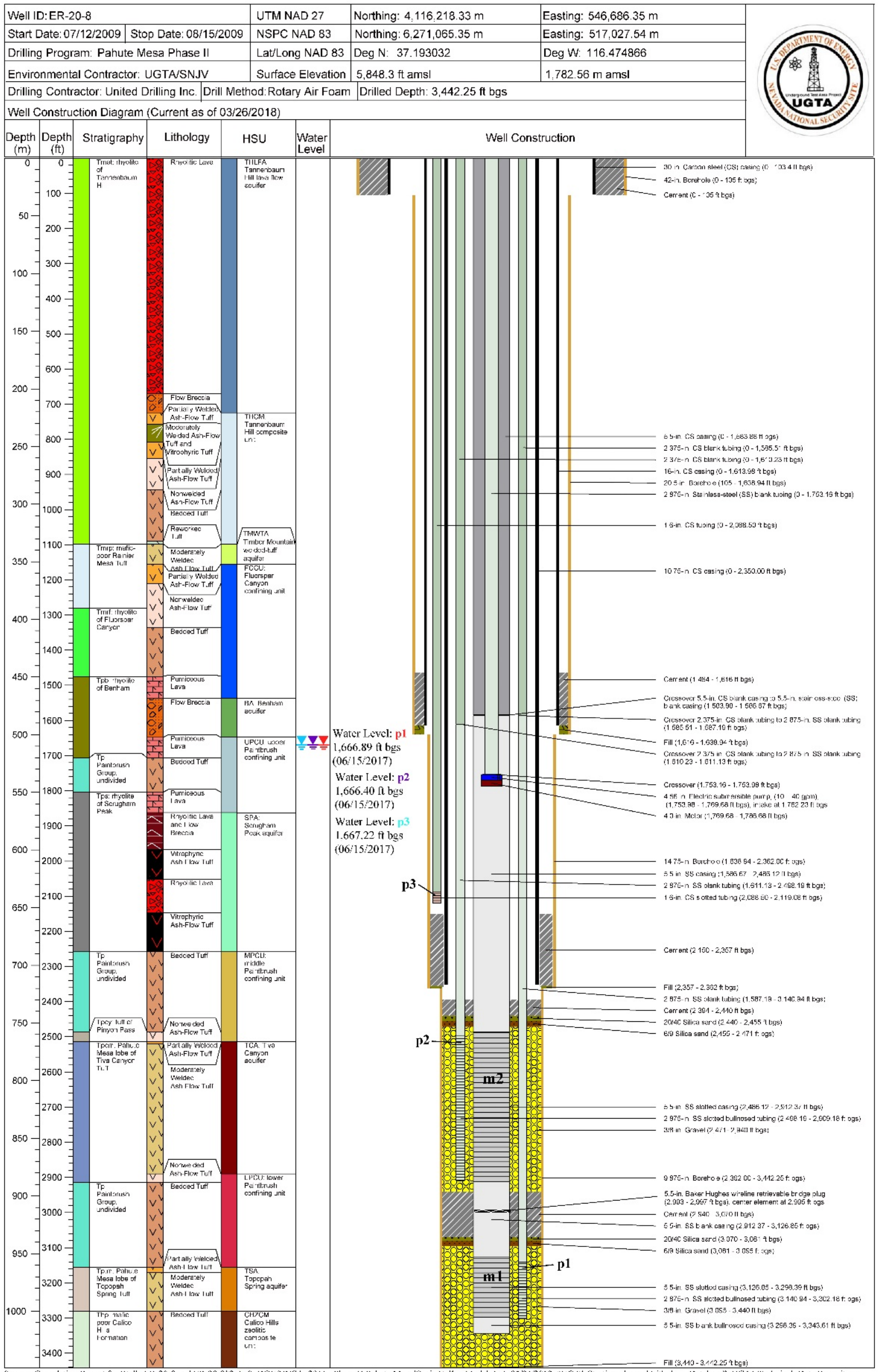
Source: Modified from Rainier Mesa Well ER-12-3 Data Report for Well Development and Hydraulic Testing, SNJV, 2006; Completion Report for Well ER-12-3, U.S. Department of Energy, National Nuclear Security Administration, Nevada Site Office, 2005; Stratigraphy / Lithology from "UGTA Stratigraphy and Lithology Database," UGTA Technical Data Repository Database Identification Number UGTA-4-134, Navarro, 2017; Water Levels from USGS-NWIS and Navarro 04/09/2018.

Figure A-3. ER-12-3 well completion diagram.



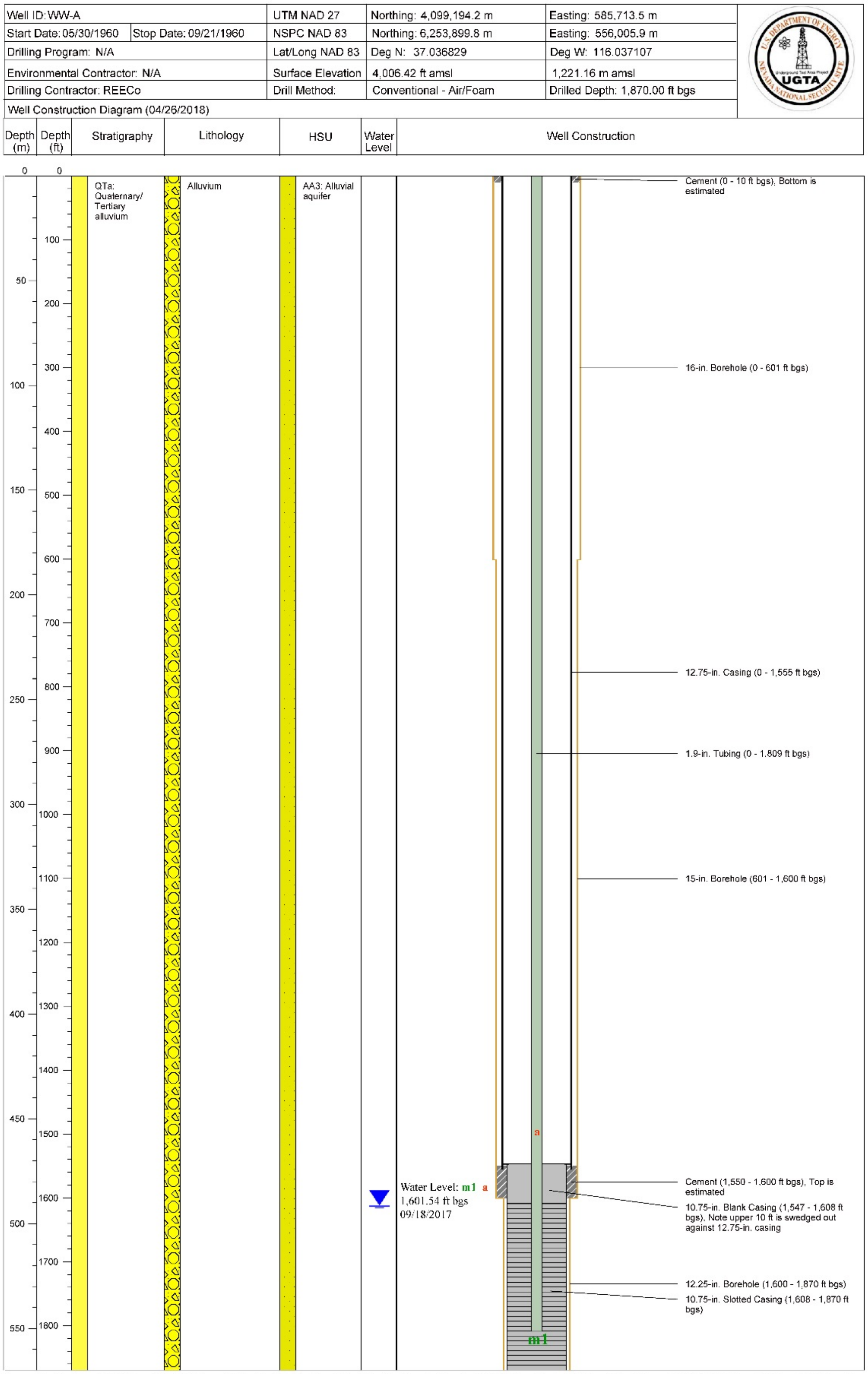
Source: Modified from Recompletion Report and Summary of Well History for Well PM-3, U.S. Department of Energy, Nevada Operations Office, 1996.; Int. Samp. Plan ID's (ISPIDS) - https://extranet.nv.doe.gov/Boreholes/ISPIDS.xlsx accessed on 01/11/2018. Stratigraphic, Lithologic, and HSU information from "UGTA Stratigraphy and Lithology Database", UGTA Technical Data Repository Database Identification No. UGTA-4-134, Navarro 2017

Figure A-4. PM-3 well completion diagram.



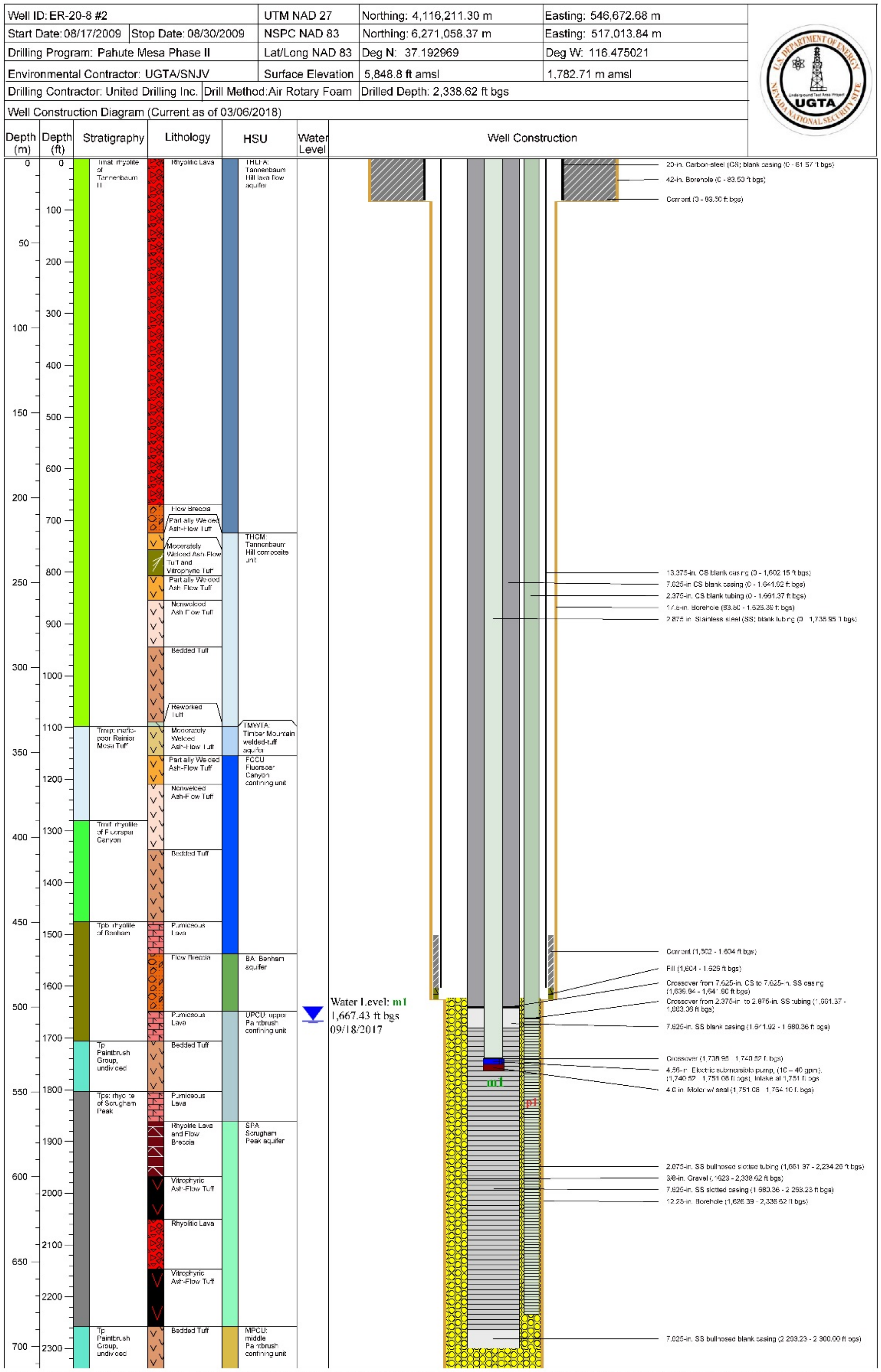
Source: Completion Report for Wells ER-20-8 and ER-20-8#2, U.S. DOE/NNSA, 2011; Phase II Pahute Mesa/Oasis Valley Model, N-I, 05/24/2012, "UGTA Stratigraphy and Lithology Database", UGTA Technical Data Repository Database Identification No. UGTA-4-134, Navarro 2017; Int. Samp. Plan ID's (ISPIDS)- https://extranet.nv.doe.gov/Boreholes/ISPIDS.xlsx accessed on 03/26/2018.

Figure A-5. ER-20-8 well completion diagram.



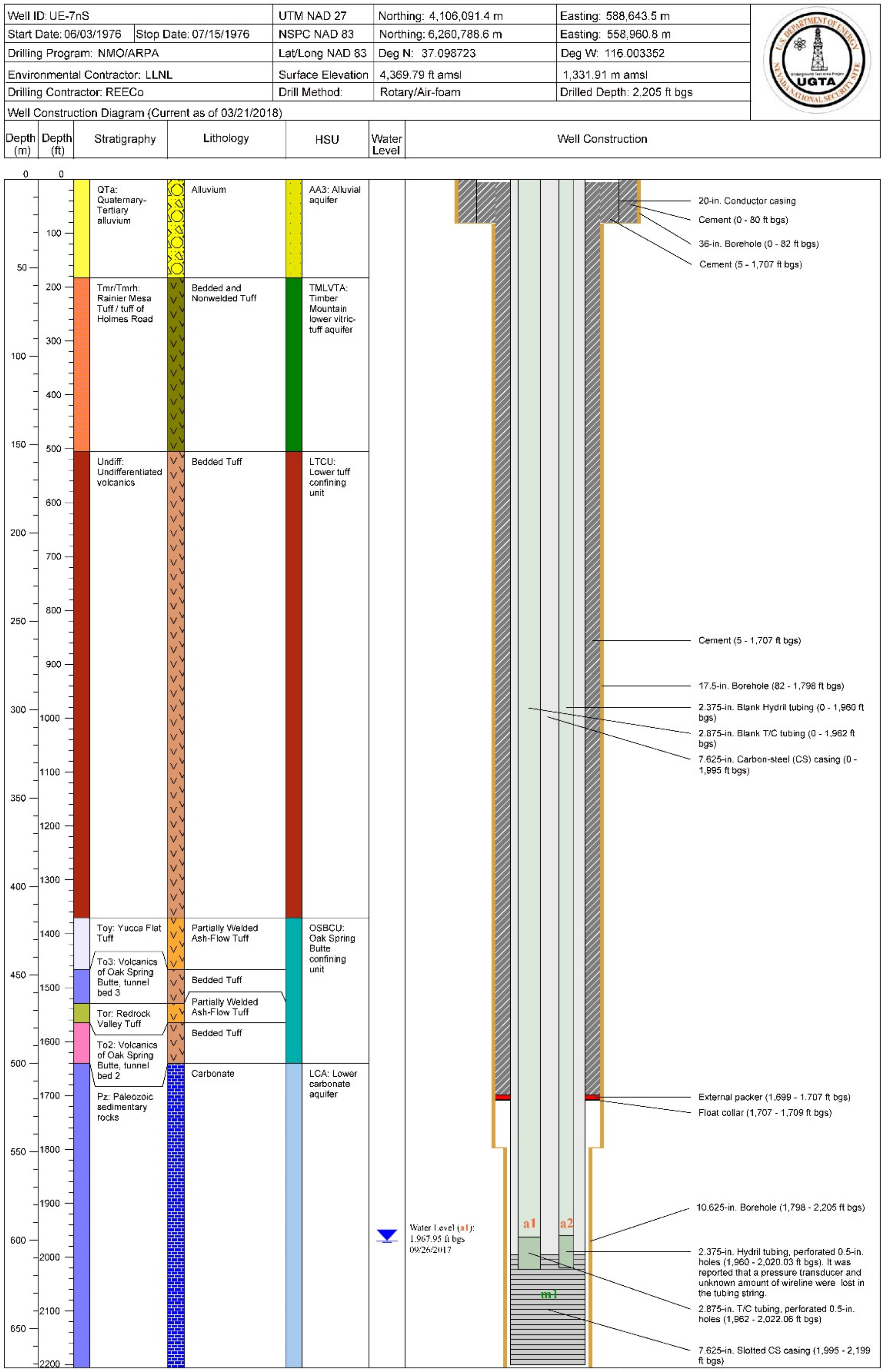
Source: Modified from USGS Report TEI-800, Ground Water Test Well A, Nevada Test Site, Nye County, Nevada, 01/17/1962 and Fenix & Scisson Hole History: UGTA-4-320, Yucca Flat Phase I EV Base Case Hydrostratigraphic (geologic) Model Rev 1; Int. Samp. Plan ID's (ISPIDS) - https://extranet.nv.doe.gov/Boreholes/ISPIDS.xlsx, accessed on 04/26/2018

Figure A-6. WW A well completion diagram.



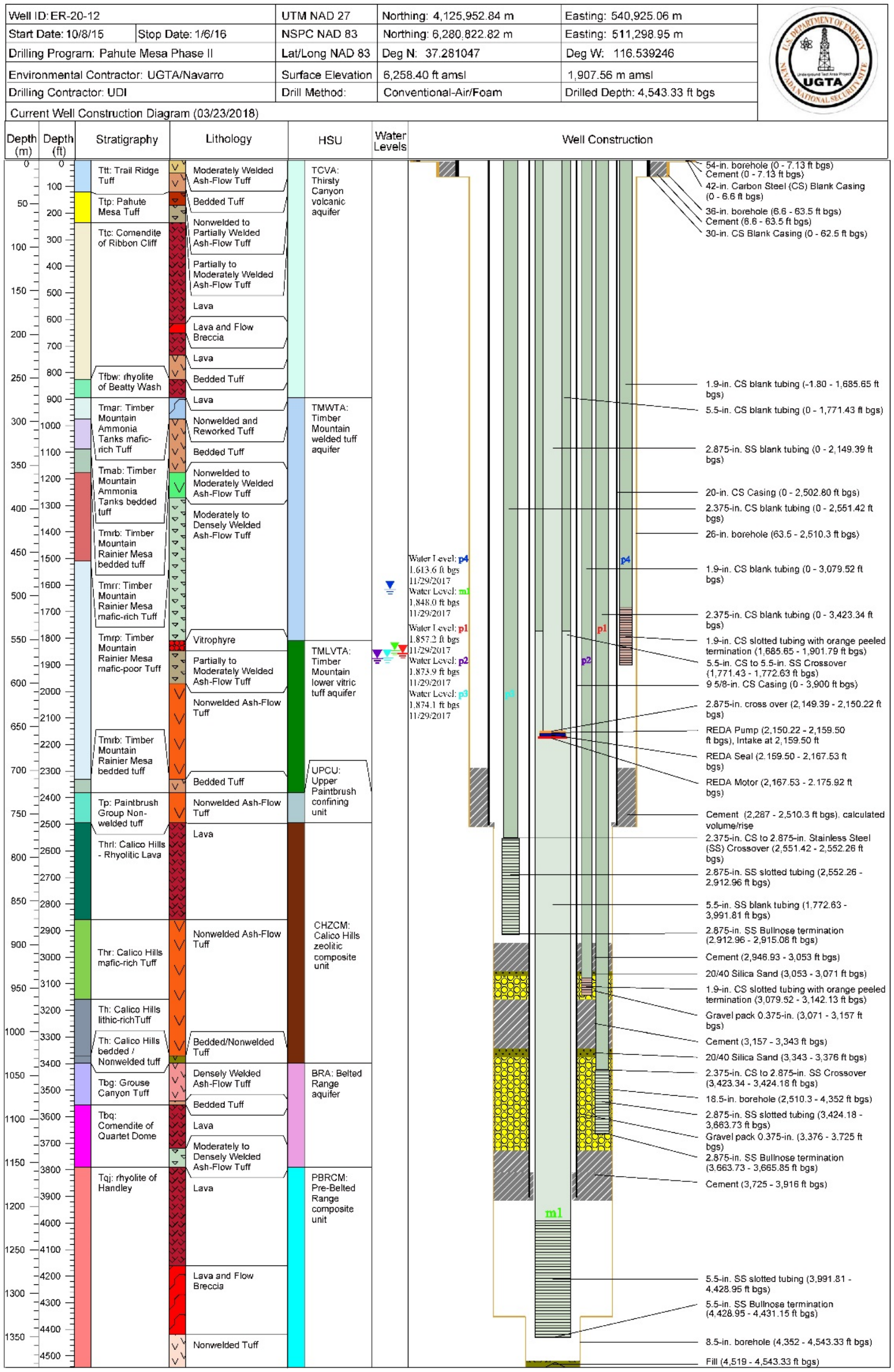
Source: Modified from Pahute Mesa Phase II ER-20-8 #2 Well Development, Testing, and Sampling Data Report, N-I, 2010, Completion Report for Wells ER-20-8 and ER-20-8#2, U.S. Department of Energy, National Nuclear Security Administration Nevada Site Office, 2011.; Phase II Pahute Mesa/Oasis Valley Model, N-I, 06/04/2012, Int. Samp. Plan ID's (ISPIDS) - https://extranet.nv.doe.gov/Boreholes/ISPIDS.xlsx accessed on 03/06/2018.

Figure A-7. ER-20-8-2 well completion diagram.



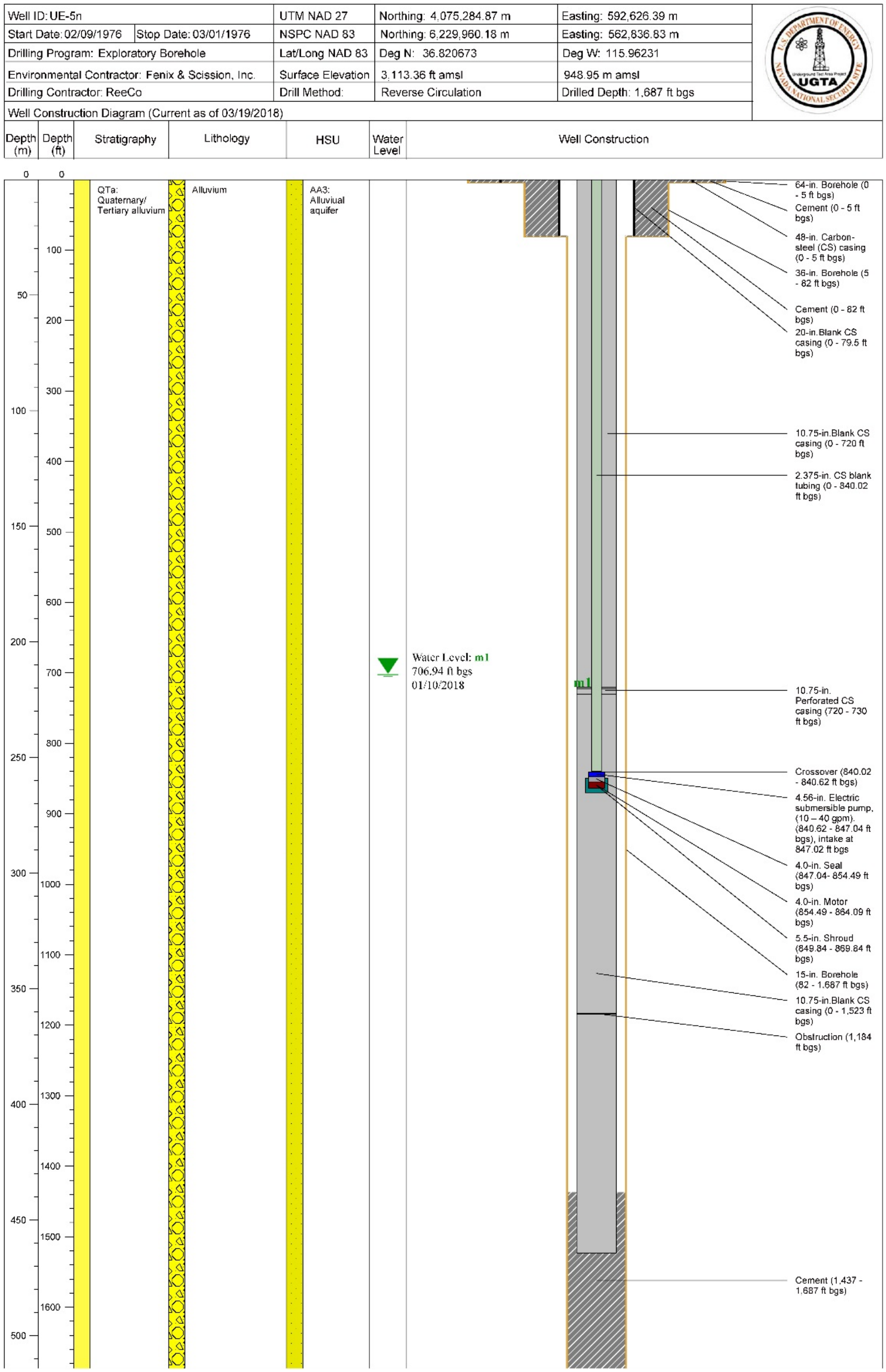
Source: Modified from Preliminary Data Drilling Report UE-7nS, 05/05/1990; Int. Samp. Plan ID's (ISPIDS) - https://extranet.nv.doe.gov/Boreholes/ISPIDS.xlsx accessed on 03/21/2018. Stratigraphic, Lithologic, and HSU information from "UGTA Stratigraphy and Lithology Database", UGTA Technical Data Repository Database Identification No. UGTA-4-134, Navarro 2017

Figure A-8. UE-7nS well completion diagram.



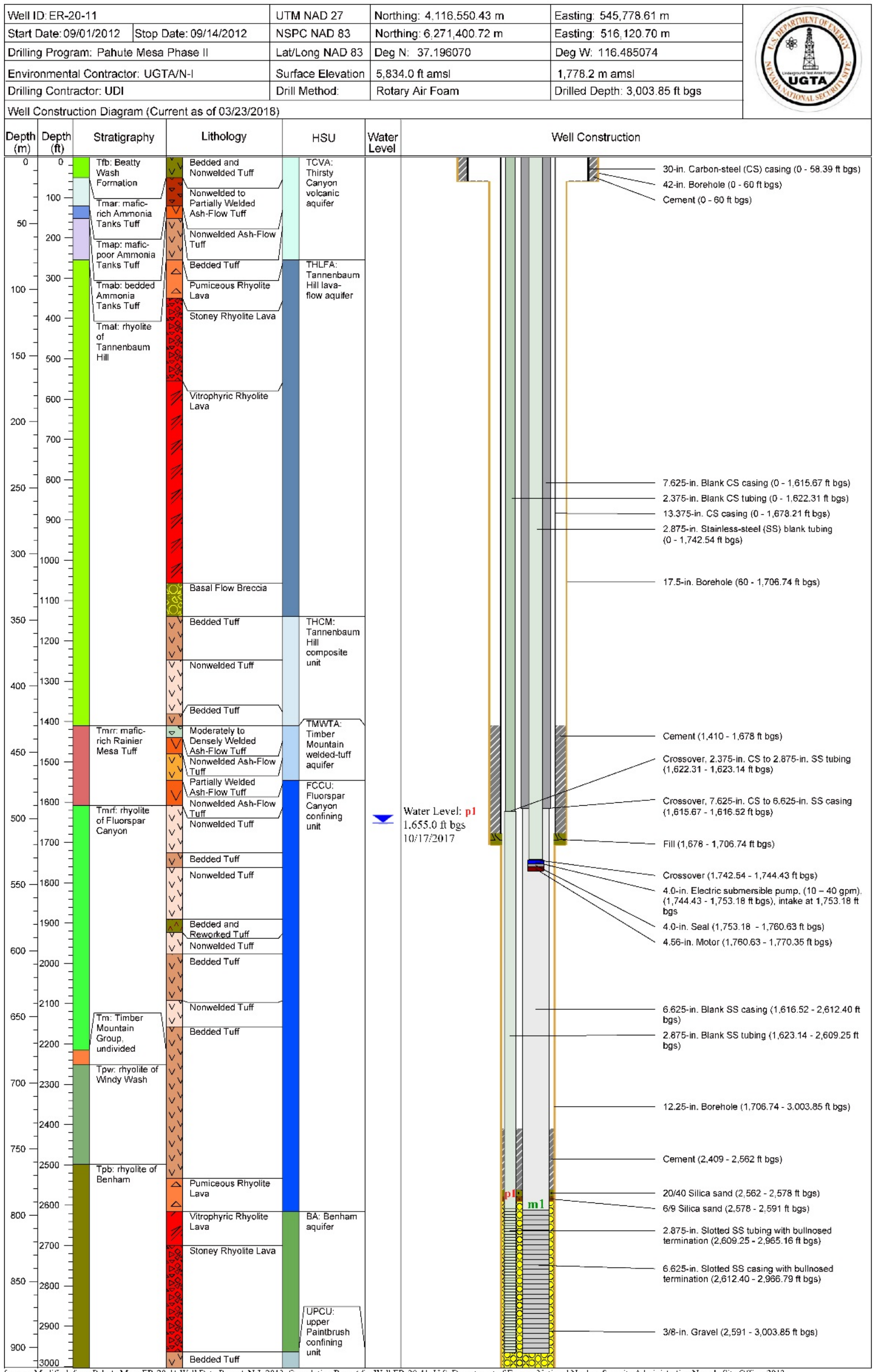
Source: Modified from Completion Report for Well ER-20-12, Navarro 2016; U.S. Department of Energy, National Nuclear Security Administration, Nevada Field Office, 2016. Water Levels from USGS NWIS 03/23/2018
Int. Samp. Plan ID's (ISPIDS)- https://extranet.nv.doe.gov/Boreholes/ISPIDS.xlsx accessed on 03/23/2018

Figure A-9. ER-20-12 well completion diagram.



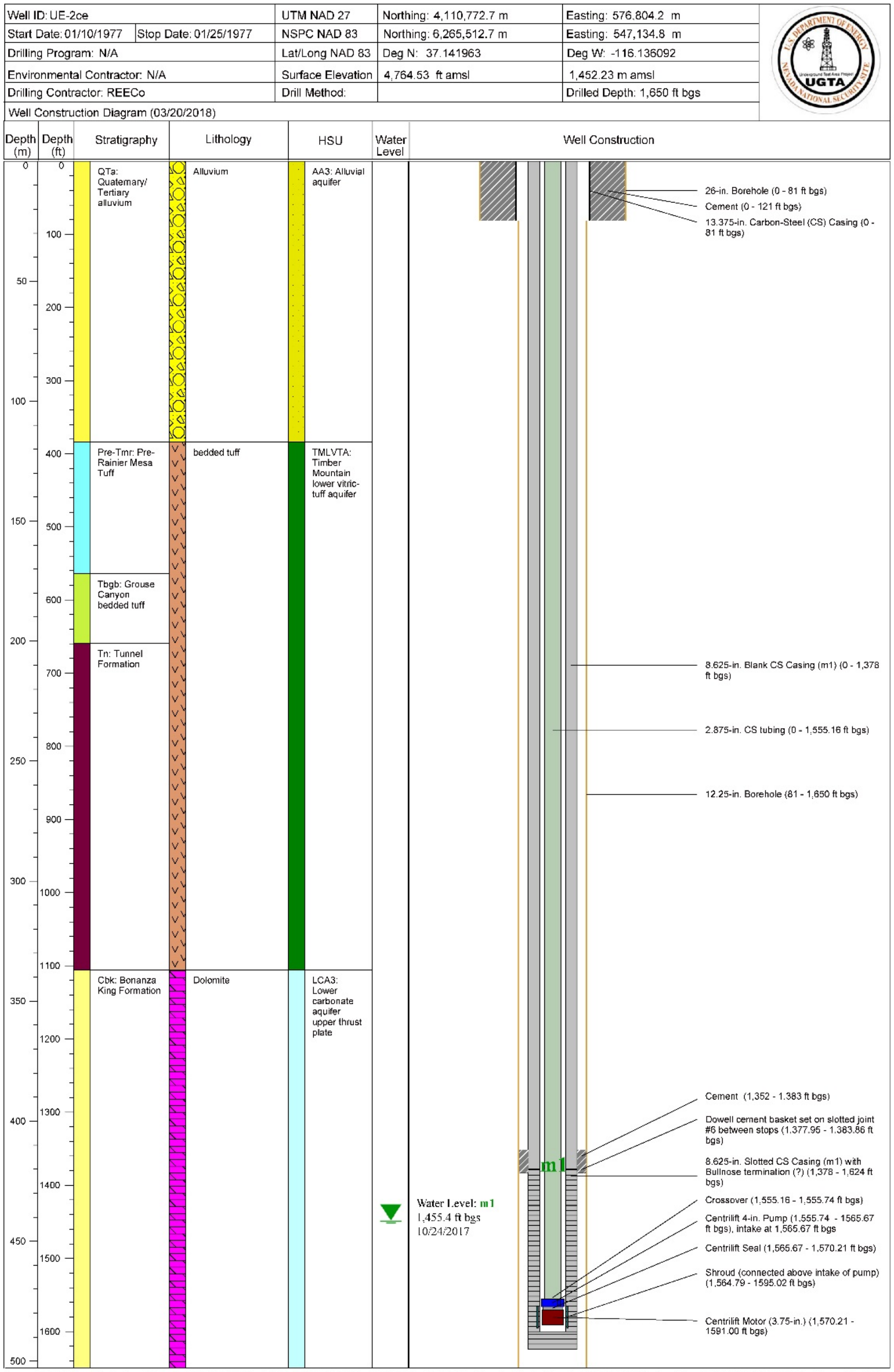
Source: Modified from Evaluation of Existing Wells at the Nevada Test Site for Plugging and Abandonment or for Recompletion as Monitoring Wells, U.S. Department of Energy, Nevada Operations Office, Sept. 1996 Navarro and NSTec records; Int. Samp. Plan ID's (ISPIDS) - https://extranet.nv.doe.gov/Boreholes/ISPIDS.xlsx, accessed on 11/16/2017. Stratigraphic, Lithologic, and HSU information from "UGTA Stratigraphy and Lithology Database", UGTA Technical Data Repository Database Identification No. UGTA-4-134, Navarro 2017

Figure A-10. UE-5n well completion diagram.



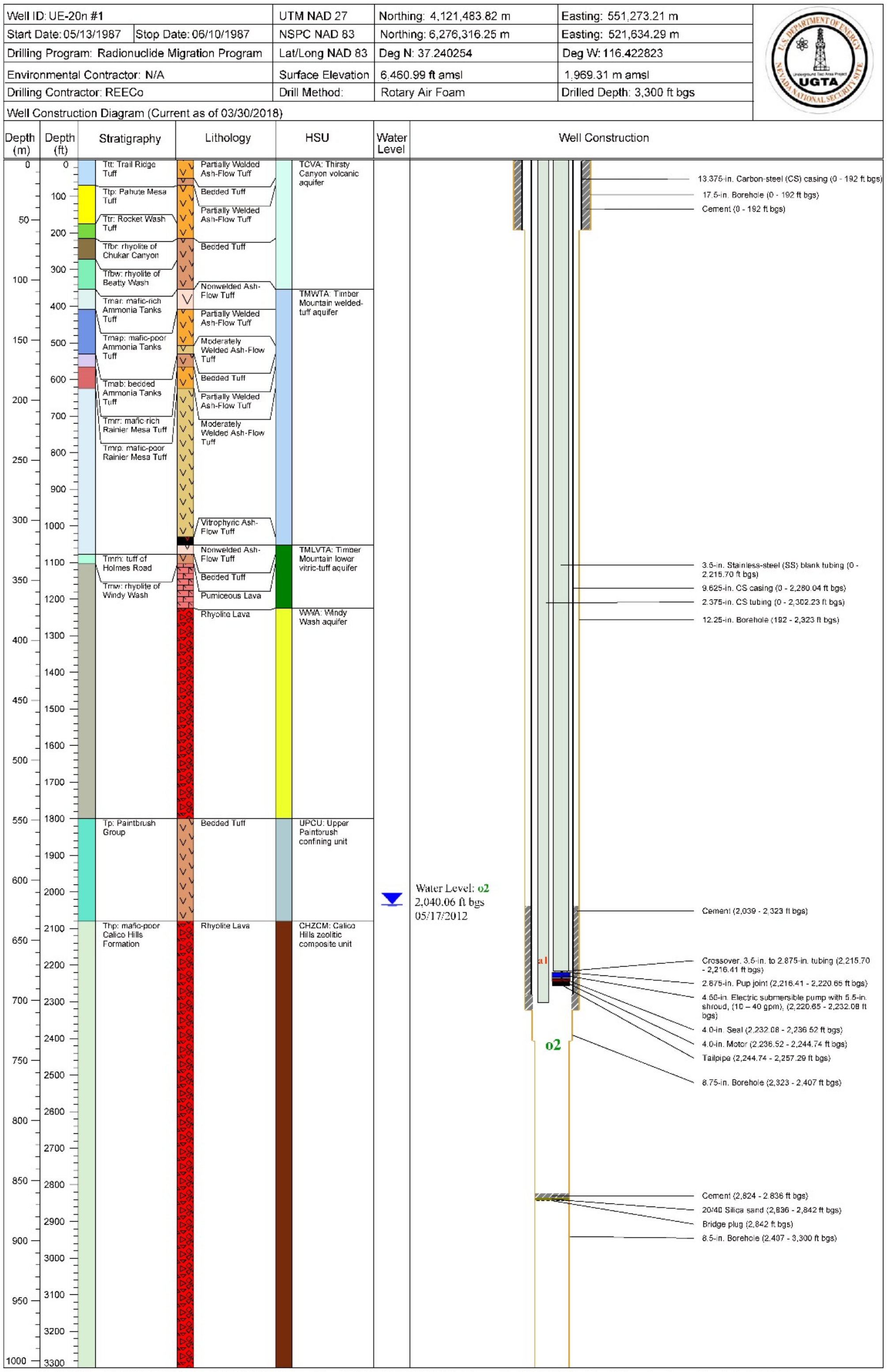
Source: Modified from Pahute Mesa ER-20-11 Well Data Report. N-I, 2013; Completion Report for Well ER-20-11, U.S. Department of Energy, National Nuclear Security Administration Nevada Site Office, 2013. Phase II Pahute Mesa/Oasis Valley Model, N-I, 06/05/2012. Int. Samp. Plan ID's (ISPIDS)- https://extranet.nv.doe.gov/Boreholes/ISPIDS.xlsx accessed on 03/23/2018

Figure A11. ER-20-11 well completion diagram.



Source: Modified from Results from Exploratory Drill Hole UE-2ce, LLNL: UCID-19324, March 1982; UE-2ce WW NSTec Pump Installation Records (06/24/2008); Water Levels from USGS NWIS 03/19/2018; Int. Samp. Plan ID's (ISPIDS) - https://extranet.nv.doe.gov/Boreholes/ISPIDS.xlsx accessed on 03/19/2018. Stratigraphic, Lithologic, and HSU information from "UGTA Stratigraphy and Lithology Database", UGTA Technical Data Repository Database Identification No. UGTA-4-134, Navarro 2017

Figure A-12. UE-2ce well completion diagram.



Source: Fenix & Scisson UE-20 #1 Hole History, 01/06/1988; Water Level from USGS NWIS 03/30/2018; Int. Samp. Plan ID's (ISPIDS) - https://extranet.nv.doe.gov/Boreholes/ISPIDS.xlsx accessed on 03/30/2018; Stratigraphic, Lithologic, and HSU information from "UGTA Stratigraphy and Lithology Database", UGTA Technical Data Repository Database Identification No. UGTA-4-134, Navarro 2017

Figure A-13. UE-20n well completion diagram.

DISTRIBUTION LIST

Wilhelm Wilborn
UGTA Activity Lead
U.S. Department of Energy
Environmental Management Nevada Program
P.O. Box 98518
Las Vegas, NV 89193-8518
Bill.Wilborn@emcbc.doe.gov

Chuck Russell
Division of Hydrologic Sciences
Desert Research Institute
755 E. Flamingo Road
Las Vegas, NV 89119-7363
Chuck.Russell@dri.edu

Jenny Chapman
DOE Program Manager
Division of Hydrologic Sciences
Desert Research Institute
755 E. Flamingo Road
Las Vegas, NV 89119-7363
Jenny.Chapman@dri.edu

Irene Farnham
Navarro
P.O. Box 98952
M/S NSF167
Las Vegas, NV 89193-8952
Irene.Farnham@nv.doe.gov

Ed Kwicklis
Los Alamos National Laboratory
P.O. Box 1663
Los Alamos, NM 87544
kwicklis@lanl.gov

P.K. Ortego
Mission Support and Test Services, LLC
P.O. Box 98521
M/S NLV082
Las Vegas, NV 89193-8521
ortegopk@nv.doe.gov

Andy Tompson
Lawrence Livermore National Laboratory
P.O. Box 808, L-231
Livermore, CA 94551-0808
Tompson1@llnl.gov

Jeffrey Sanders
U.S. Geological Survey
Nevada Water Science Center
160 N. Stephanie St.
Henderson, NV 89074-8829
jvsanders@usgs.gov

Ken Rehfeldt
Navarro
P.O. Box 98952
M/S NSF 167
Las Vegas, NV 89193-8952
Ken.Rehfeldt@nv.doe.gov

Brian Haight
Navarro
P.O. Box 98952
M/S NSF 167
Las Vegas, NV 89193-8952
Brian.Haight@nv.doe.gov

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