Appendix M

Flow and Injection Testing Summary

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Appendix M.
Flow and Injection Testing Summary

Ormat performed a 46-day flow and injection test from April 27 to June 11, 2017. Locations of test wells, observation wells, springs, and faults are shown in **Figure M0**. Plots of production rates over time and injection rates over time are provided in **Figure M1-M3**.

Water was pumped from Well 23A-8, with discharge rates decreasing over time from approximately 2,080 to 1,340 gpm, with an average production rate of approximately 1,600 gpm (**Figure M1**). Production Well 23A-8 was drilled through densely compacted and cemented alluvial materials extending to 3,400 ft bgs and is completed in Triassic slate and siltstone in the footwall of the range-front fault at 4,733 ft bgs (**Table M1**). Permeable fractures associated with an east-northeast-striking fault zone were recorded in 23A-8 at depths of approximately 4,580 and 4,640 ft bgs (Ormat Fault Model, 2017).

Discharge water was reinjected at Wells 24-8 and 75-4, which are completed in mineralized and fractured alluvium at depths 3,060 ft bgs and 2,493 ft bgs, respectively (**Table M1**). Injection rates decreased over time at Well 24-8 from approximately 2,500 to 1,300 gpm (**Figure M2**), while the injection rate was relatively constant at Well 75-4 at an average of 165 gpm (**Figure M3**). The average injection rate was approximately 1350 gpm, with the variance between pumping and injection being mostly due to evaporative losses from holding tanks and temperature changes.

M.1 PRESSURE AND POTENTIOMETRIC HEAD OBSERVATIONS

Observation wells 23-8, 24A-8, 42-9, 86-7, and 22-8B were monitored for hydraulic head responses during testing activities to determine the degree of hydraulic connectivity between bedrock and deep mineralized/cemented alluvial aquifer, and to qualitatively assess fault permeabilities. Observation well depths and lithologies are summarized in **Table M1**. Plots of pressure head versus time are also included in **Figure M4-M8** and maximum observed hydraulic responses are summarized in **Table M2**.

Observation wells 86-7 and 22-8B are completed in densely compacted and cemented basin-fill. Decreases in pressure head in wells 86-7 and 22-8B (**Figure M6** and **Figure M7**) during the flow test indicate a hydraulic interconnection between the Pre-Tertiary bedrock and deep consolidated/cemented basin-fill. The pressure response observed at 86-7 suggests that the range-front fault and east-northeast trending faults between 86-7 and 23A-8 are permeable. Pressure data at well 24A-8 (**Figure M8**) is unclear whether the small (~1.5 psi) reduction in pressure head at this observation well was a response to the flow test.

Well 42-9 exhibited the greatest reduction in absolute pressure during the flow test, decreasing from 118.4 to 104.95 psi, but then gradually recovering back to the initial pressure after approximately 30 days (**Figure M5**). Well 42-9 is separated from production well 23A-8 by the regional range-front Dixie Valley and Piedmont faults and associated intra-basin faults; the hydraulic response observed at 42-9 suggests that pressure responses occur across these fault structures, which may be indicative of deep permeability across the fault planes. The presence of an observed deep pressure response to the east of Dixie Meadows, in conjunction with the lack of spring responses, especially at the high temperature springs NDOWSS-1 and 5A-5B within Dixie Meadows (Section M.2) supports the conceptual hydrogeological model that the source of thermal spring discharge is from the shallow lateral flow system defined by temperature-gradient data, and not the hypothesized upwelling along the Piedmont Fault. The pressure differential deep beneath Dixie Meadows would have otherwise intercepted potentiometric head driving spring discharge at the thermal springs. The observation that pressures returned to near the pre-test levels during the pumping and injection suggests that the pumping and injection was in relative balance and reporting predominantly to the deep aquifer system, and not the shallow lateral flow system.

M.2 Spring Pool, Temperature and EC Observations

Five spring locations were monitored for temperature, electrical conductivity (EC), and spring pool stage during flow testing activities to assess the degree of hydraulic connectivity between the geothermal reservoir and springs in Dixie Meadows. Monitoring locations are shown in Figure 14B. Plots of data collected by Ormat for the flow testing are included in **Figure M9** to **M23**.

Spring 5A-5B is the nearest to the production well (24A-8) and primary injection well (24-8) used in the 2017 flow test, and is situated in Dixie Meadows Spring Complex 3. Spring 5A-5B did not display any significant variances in temperature, spring pool height, or EC outside of what appears to be normal variations recorded before and after testing (**Figure M9** to **M11**). The low temperature during the testing period was 123°F, and the high was 130°F, being within the range of 104.8 to 139.77°F that is observed in the 2015-2020 period of record. There were no apparent influences of pumping and injection actives observed at this spring location.

Monitoring of spring pool stage, temperature, and EC at spring sites USGS-101 and Site 2 (Downstream of USGS-101) also appeared to have remained stable during the flow test (M12-M14, and M21 to M23). These springs are both located in Complex 1A and are cold water springs. Temperature and EC remained relatively constant over time at Spring 2 (Downstream of USGS 101), while EC increased mildly in May and June, and continued to rise after the test. The EC increase is likely due to increased evaporation during the summer months (**Figure M14**). Pool depth decreased and EC increased during the test and post-test and is likely the result of increasing summer temperatures and evapotranspiration. Temperature remained stable at 68.5 to 69.8 °F, which is consistent with the 2015-2020 period of record data .

Temperature and spring pool increases recorded at NDOWSS-1, the hottest spring in the Dixie Meadows, were mildly increasing during the flow test (**Figure M16**). The increases during the flow test appear to have been associated with the flow testing. The temperatures observed during the flow test ranged from 137 to 144.5°F. The 2015 to 2020 period of record range of temperature is 130.82 to 160.54°F, and the temperatures observed during testing were very near to the period of record average temperature of 141.87°F. Down-stream of NDOWSS-1 near the confluence point for spring discharge in Spring Complex 2 (labeled Spring 4 in the flow testing), the water stage, temperature and EC remained relatively constant during the monitoring period (**Figures M18-M20**).

In summary, the observations made during the flow test indicate little to no observed changes in spring discharge conditions within Spring Complexes 1, 2 and 3 in Dixie Meadows as a result of production and injection during the 2017 flow testing.

M.3 TRACER OBSERVATIONS

Return curves of tracers 2-ns and 2,6-nds, which were introduced into Wells 24-8 and 75-4, respectively, during flow/injection testing operations, are included in **Figures M24** to **M25**. Well 24-8 was injecting return flows into compacted/cemented alluvial materials up to 3,060 ft bgs. Well 75-4 is completed in both dense compacted/cemented alluvium up to 2,493 ft bgs and granodiorite and gabbro to 5,000 ft bgs.

A valid tracer response typically maintains measurable concentrations for a period of time that depends on the amount and duration of tracer injected and the hydrogeologic conditions. The observed 2-ns returns at Production Well 23A-8 (**Figure M24**) indicate some injection fluid return to production due to a hydraulic connection between the deep cemented and fractured basin-fill and the underlying bedrock.

Isolated detections of very small quantities of tracer were observed at each spring, but these individual detections do not exhibit the appearance of a typical solute breakthrough curve, which would show sustained elevated concentrations following an initial rise. These individual detections may instead be the result of cross-contamination from tracer-laden injectate encountered while conducting pump test operations and monitoring. Tracer detections for both 2-ns and 2,6-nds at Spring 2 (Below USGS-101, **Figure M27** and **M33**) occurred near the end of the flow test, but decline back toward non-detect values prior to the cessation of injection rather than exhibiting sustained breakthrough. These tracer detections likewise may have resulted from cross contamination.

In summary, the tracers added to the injection water indicated hydraulic connection between the 24-8 injection well and 24A-8 production well, but did not indicate a hydraulic connection between injection wells and spring sources that were monitored. Isolated positive detections are not consistent with a sustained subsurface connection between the injection well and the monitoring points.

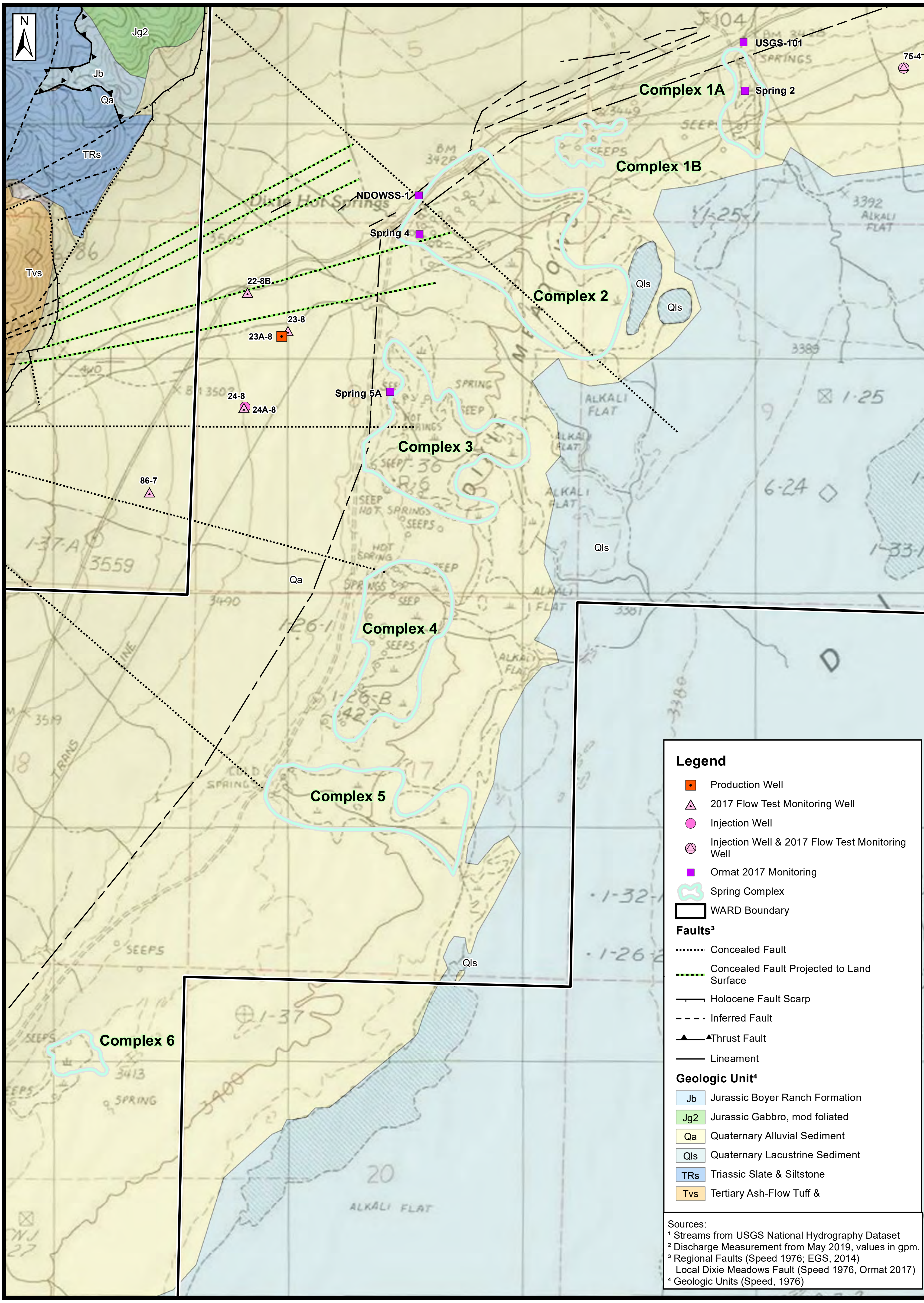

FIGURE M0

TITLE:

SITE MAP

-SHOWING-

MONITORING LOCATIONS DURING 2017 FLOW TEST

ORNI 32, LLC
DIXIE MEADOWS GEOTHERMAL PROJECT
CHURCHILL COUNTY, NV

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FILE: Fig 2 - Monitoring Locations During 2017 Flow Test

COORDINATE SYSTEM: NAD 1983 UTM Zone 11N

JOB NO.:	DATE:	REF.					REVISION:
ORM007	5/24/2021		DESIGNED	DS	CHECKED	DW	-
			DRAWN	HC	APPROVED	DW	

R:\Projects\GIS Data\ORM\007\Dixie Valley\Fig 14B - Monitoring Locations During 2017 Flow Test.mxd

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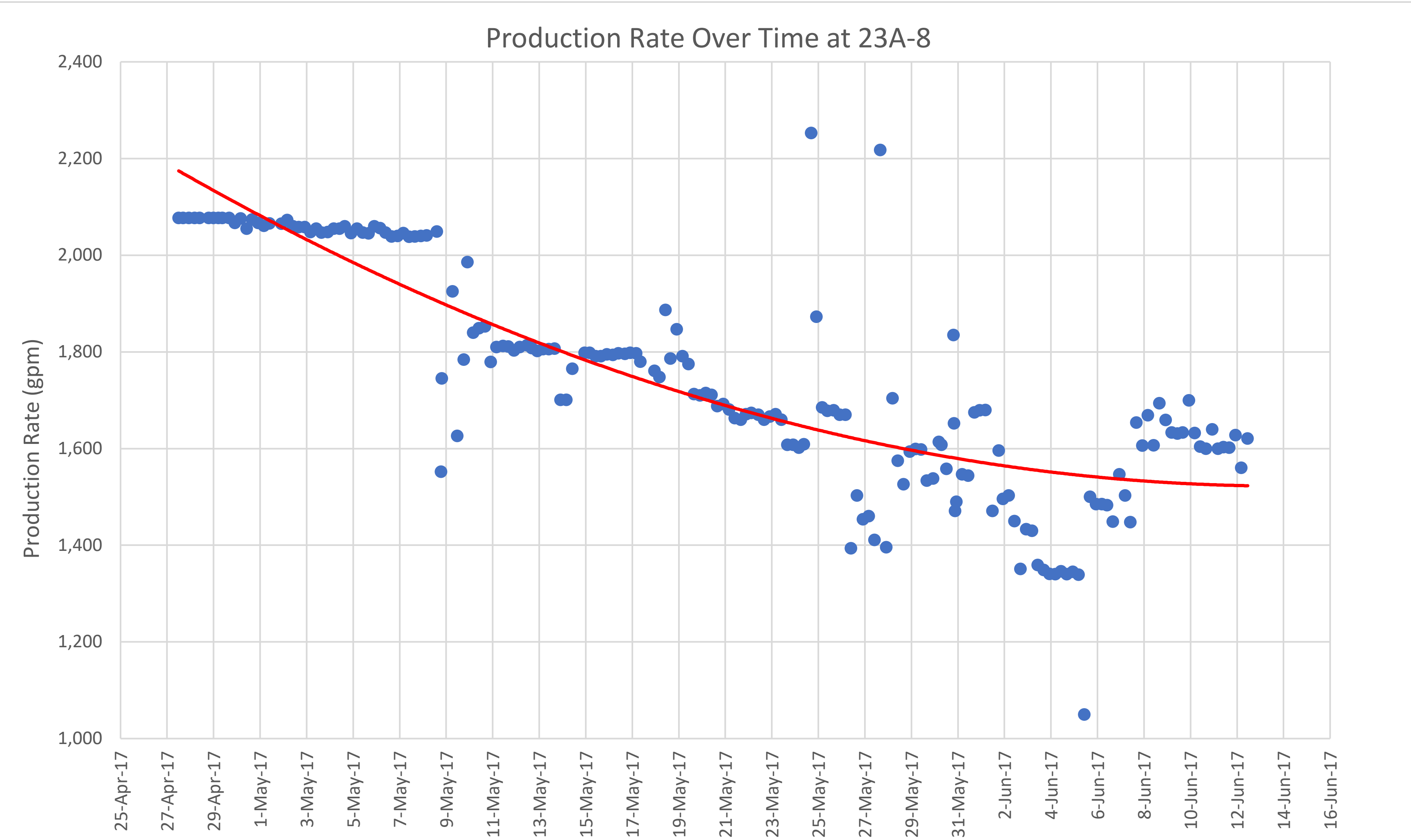

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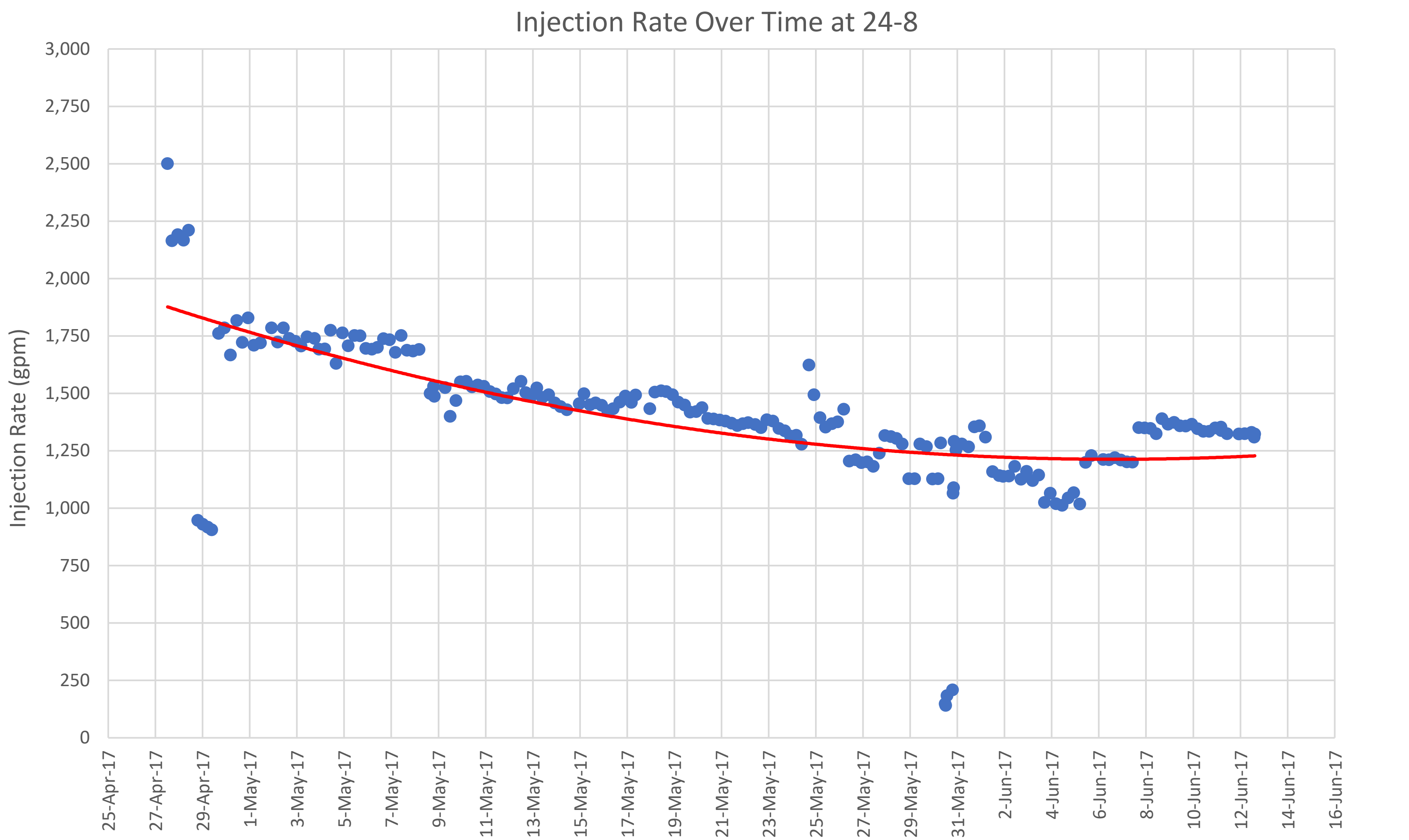
Title	Production Rate Over Time at 23A-8 During Flow Testing Operations
Project Name	Dixie Meadows
Project Number	ORM007
Client Name	Ormat
Date	7/19/201
Figure	M1



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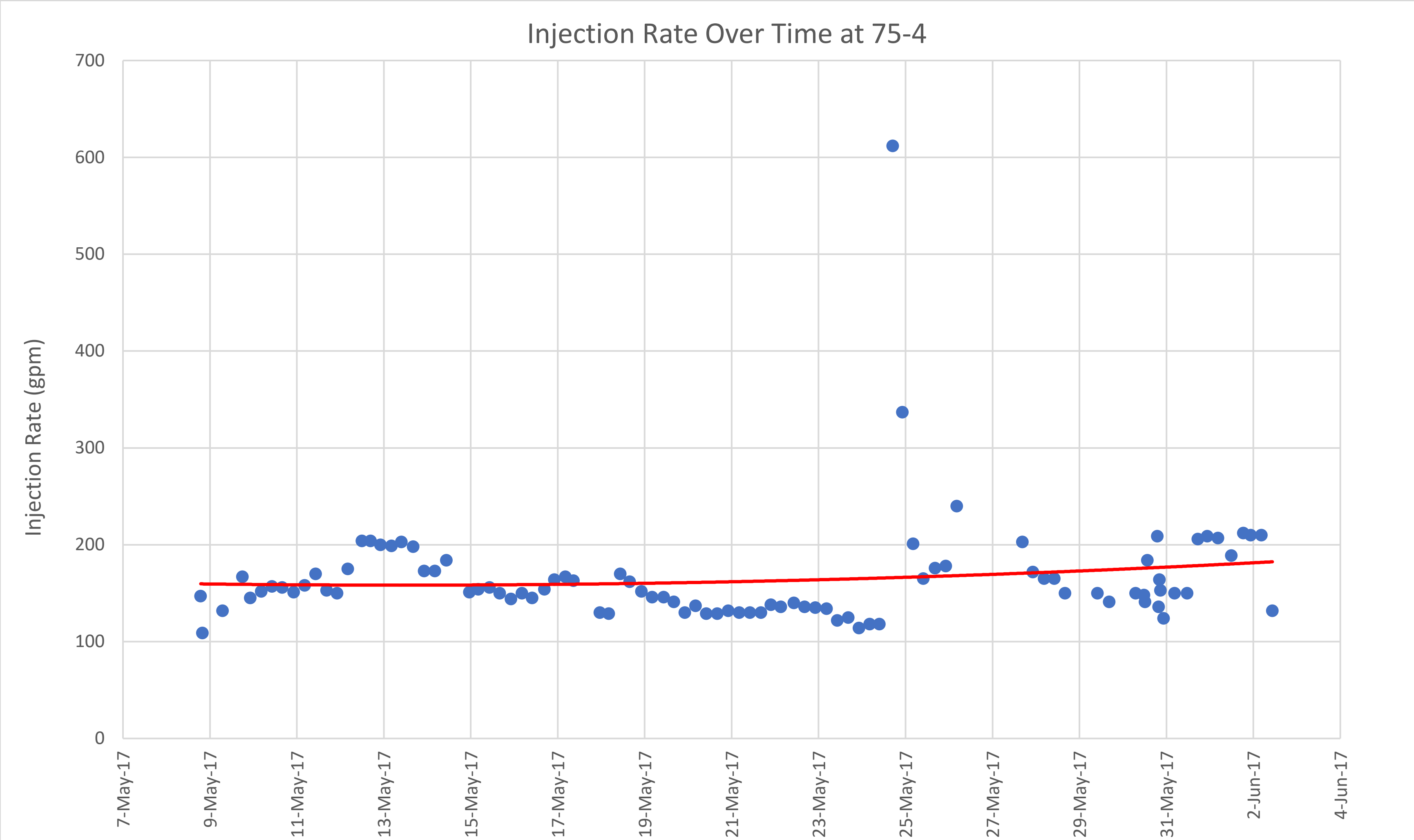
Title	Injection Rate Over Time at 24-8 During Flow Testing Operations			
Project Name	Dixie Meadows	Project Number	ORM007	Figure
Client Name	Ormat	Date	7/8/2019	M2



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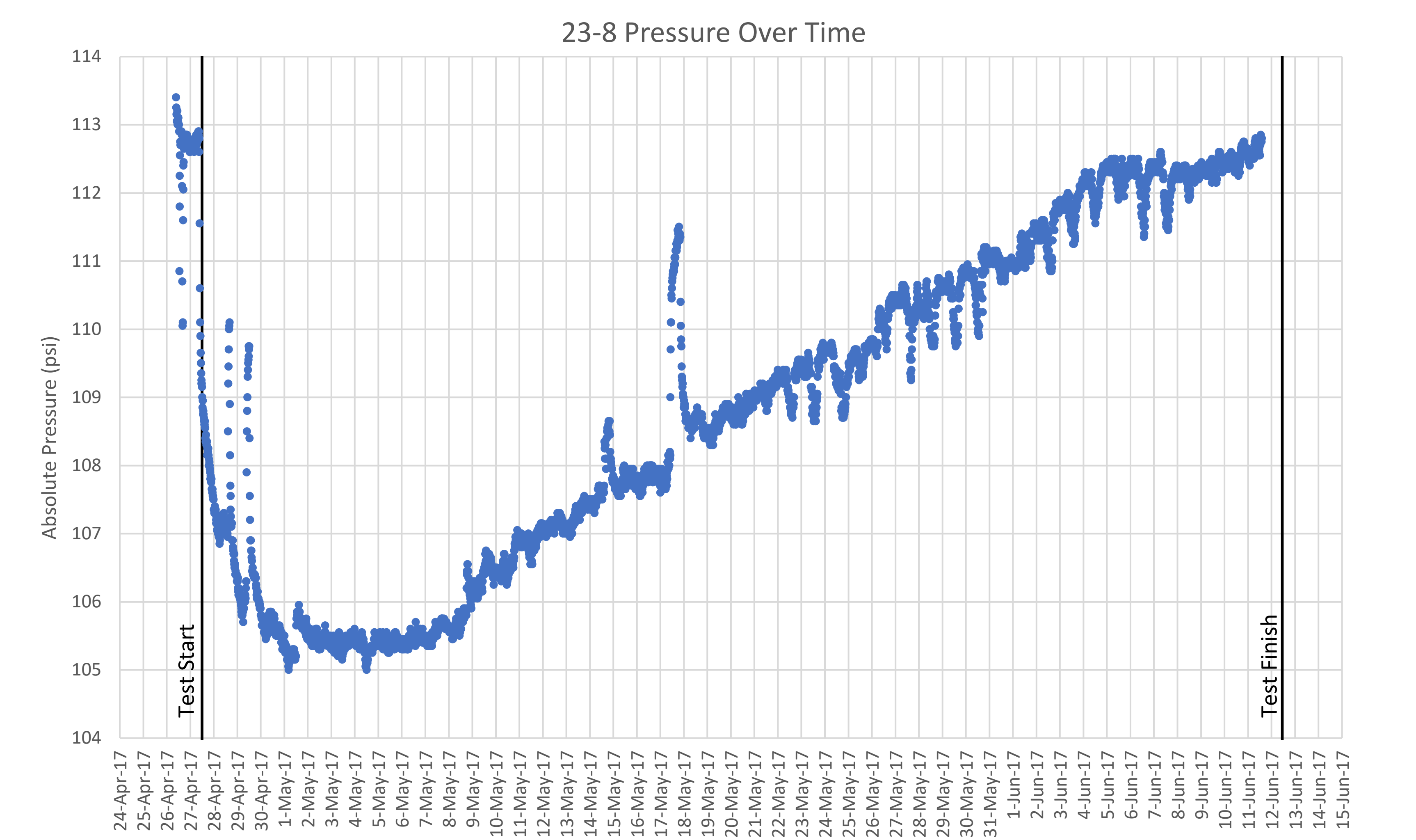
Environmental Engineering and Science

Title	Injection Rate Over Time at 75-4 During Flow Testing Operations			
Project Name	Dixie Meadows	Project Number	ORM007	Figure M3
Client Name	Ormat	Date	7/19/201	



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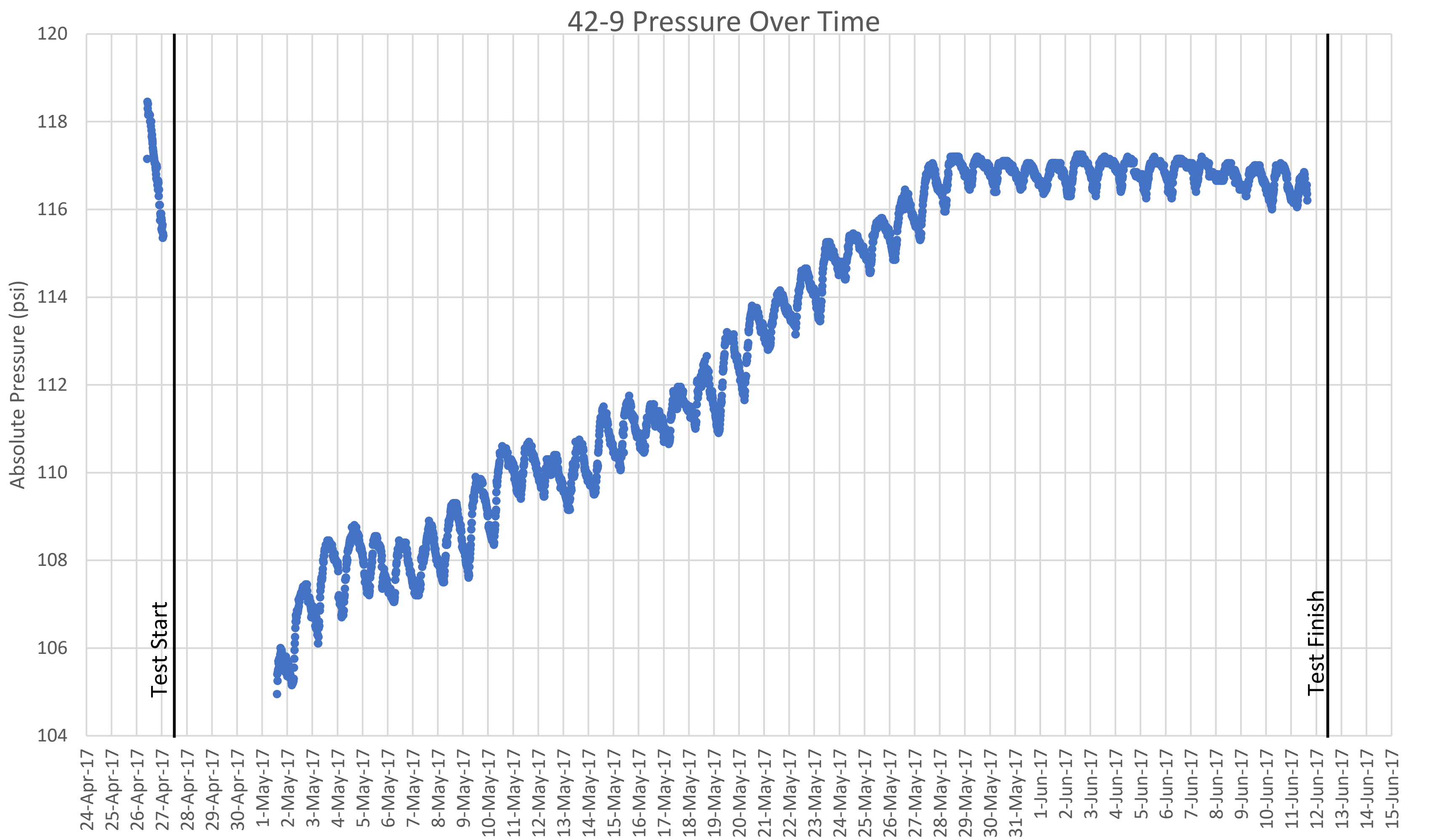
Title	**Pressure Over Time at 23-8 During Flow Testing Operations**		
Project Name	Dixie Meadows	Project Number	ORM007
Client Name	Ormat	Date	7/8/2019
Figure	M4		



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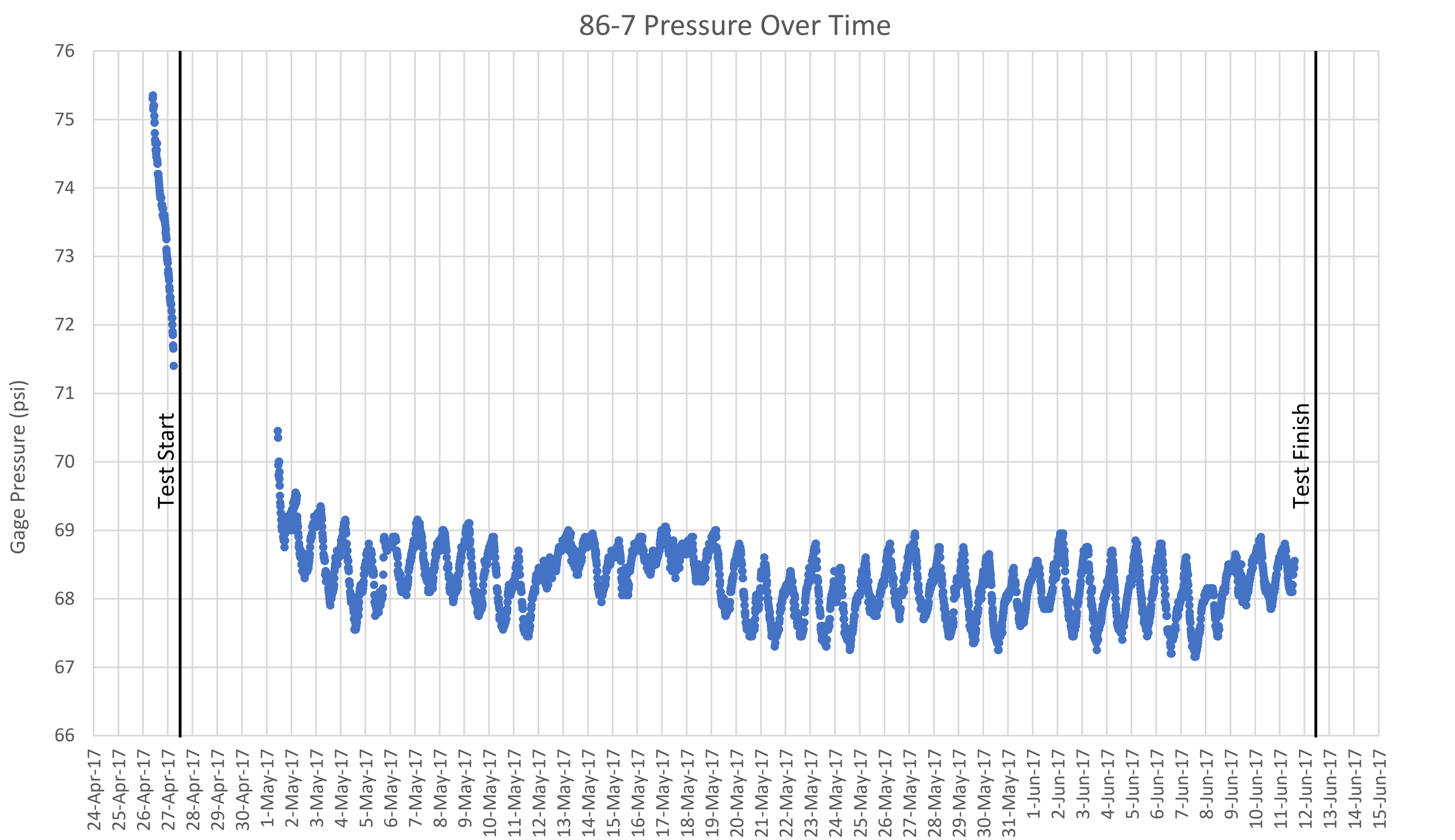
Title	**Pressure Over Time at 42-9 During Flow Testing Operations**		
Project Name	Dixie Meadows	Project Number	ORM007
Client Name	Ormat	Date	7/8/2019
Figure	M5		



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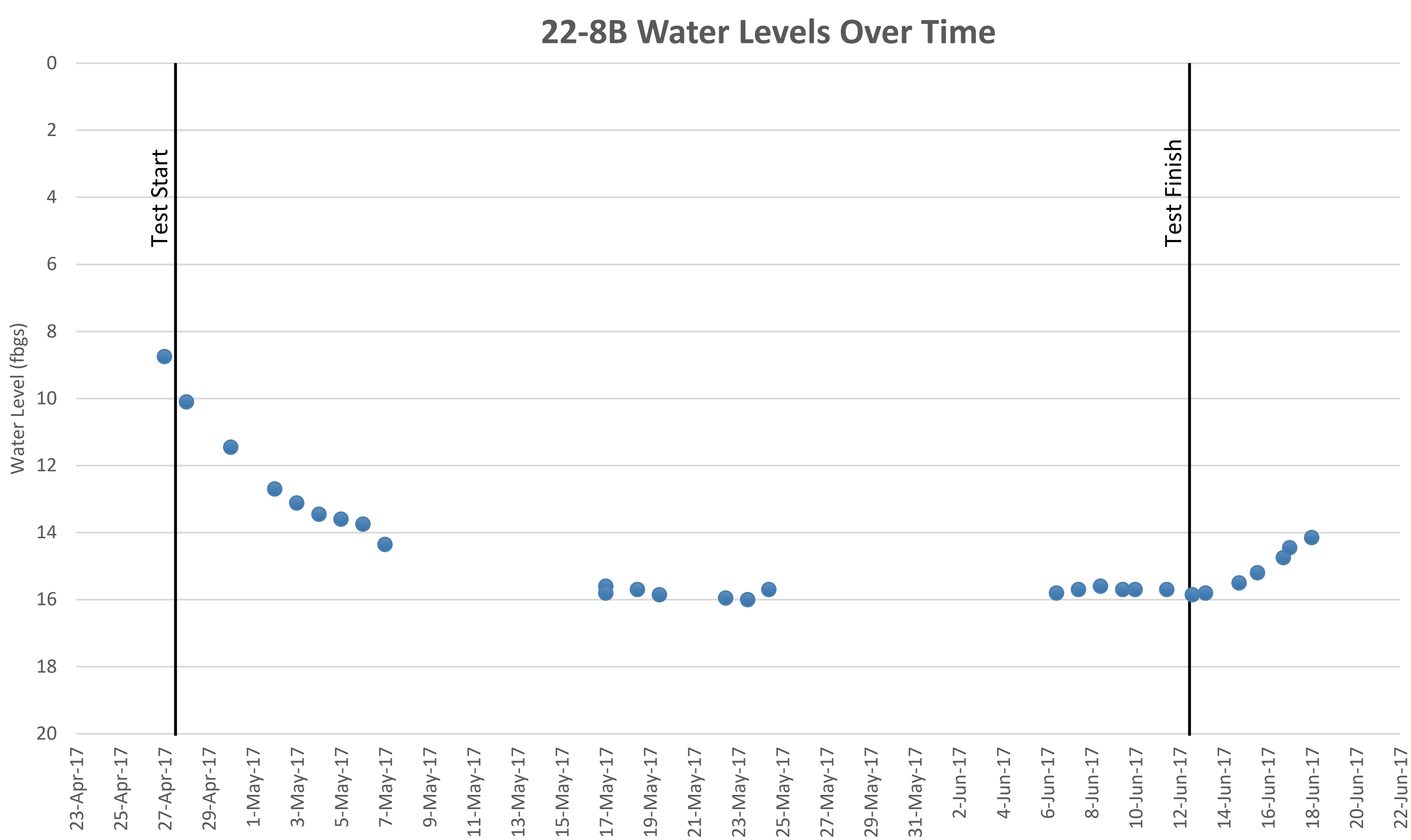
Title	**Pressure Over Time at 86-7 During Flow Testing Operations**			
Project Name	Dixie Meadows	Project Number	ORM007	Figure
Client Name	Ormat	Date	7/8/2019	M6



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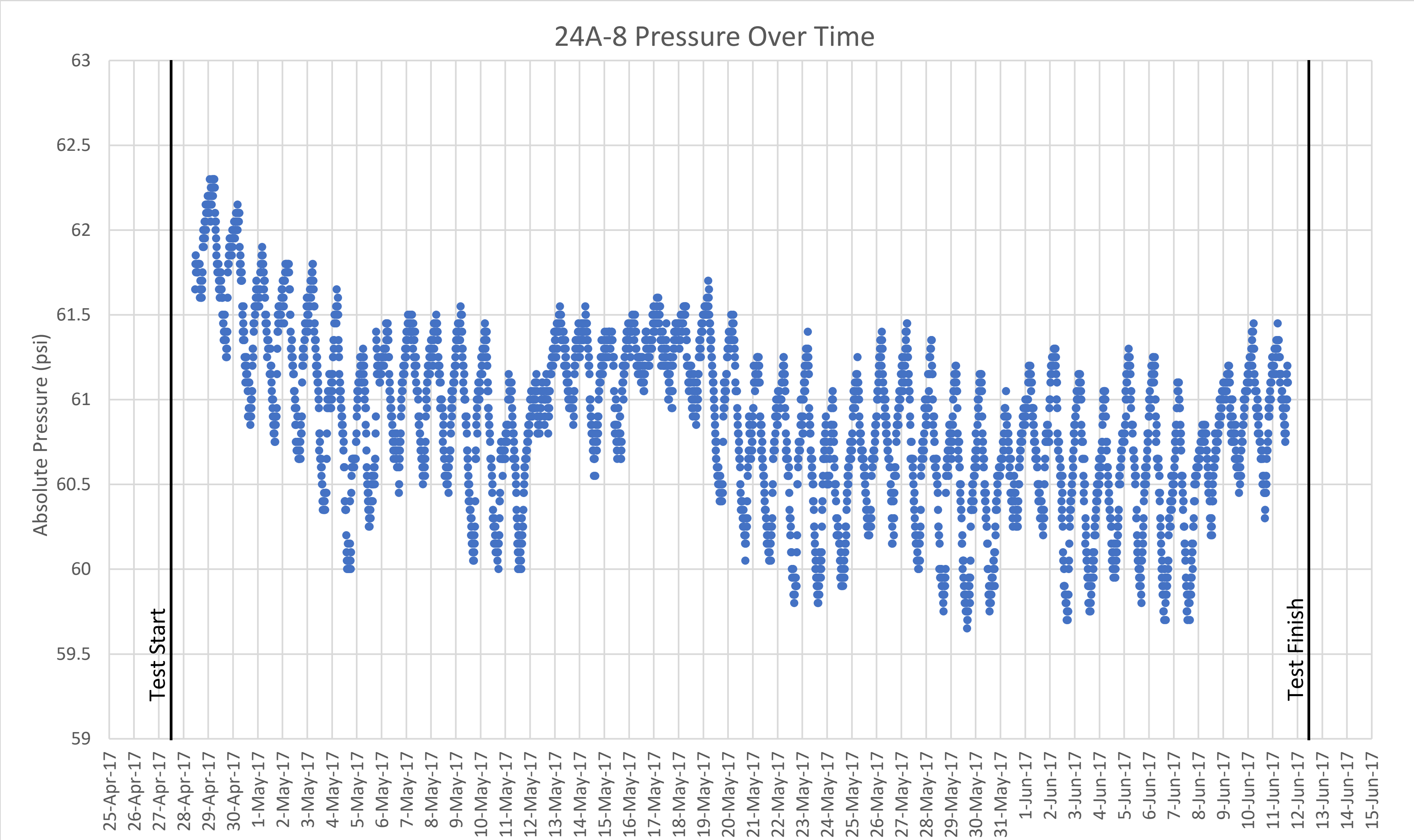
Title	Hydrograph for 22-8B During Flow Testing Operations			
Project Name	Dixie Meadows	Project Number	ORM007	Figure
Client Name	Ormat	Date	7/8/2019	M7



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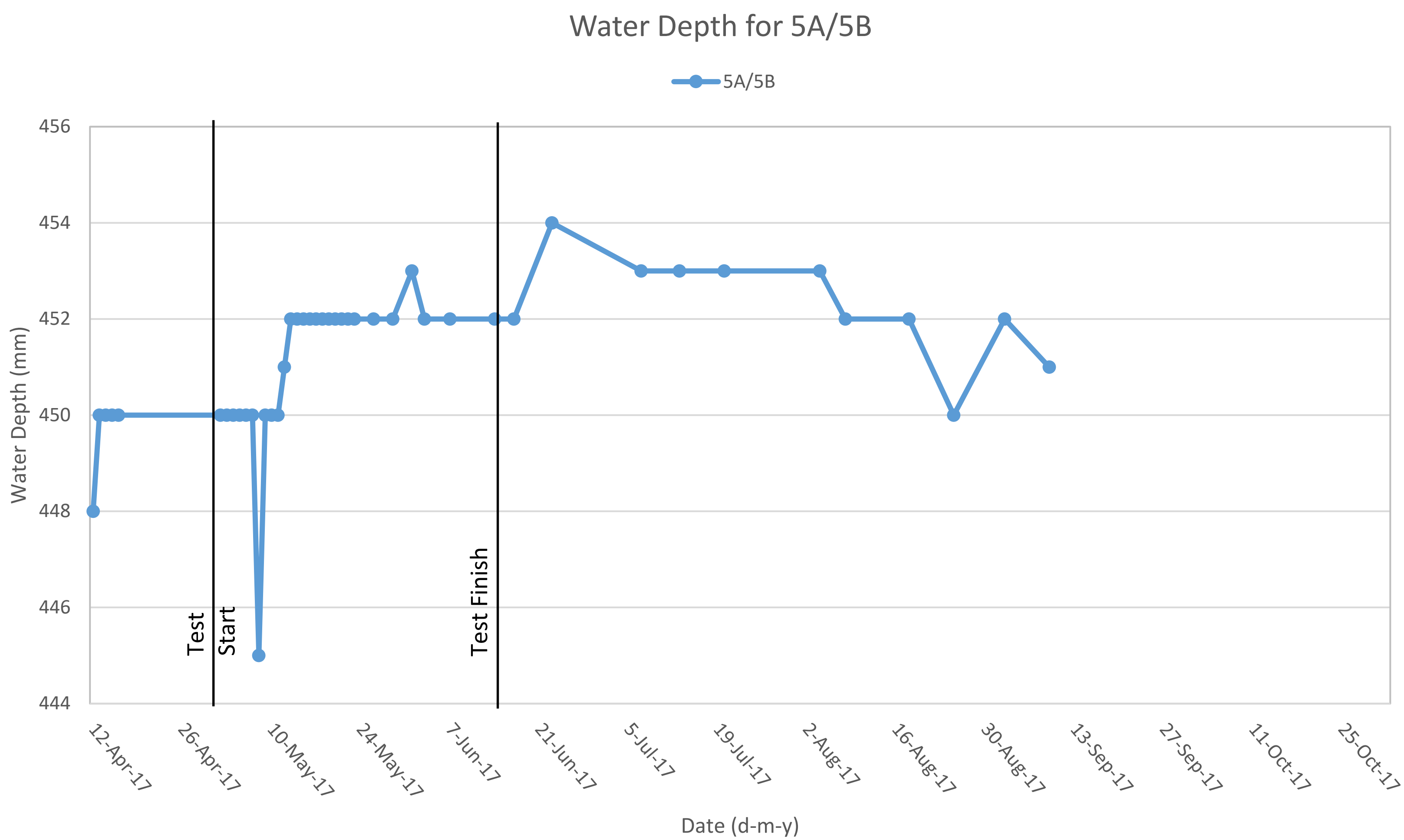
Title	**Pressure Over Time at 24A-8 During Flow Testing**
Project Name	Dixie Meadows
Project Number	ORM007
Client Name	Ormat
Date	7/8/2019
Figure	M8



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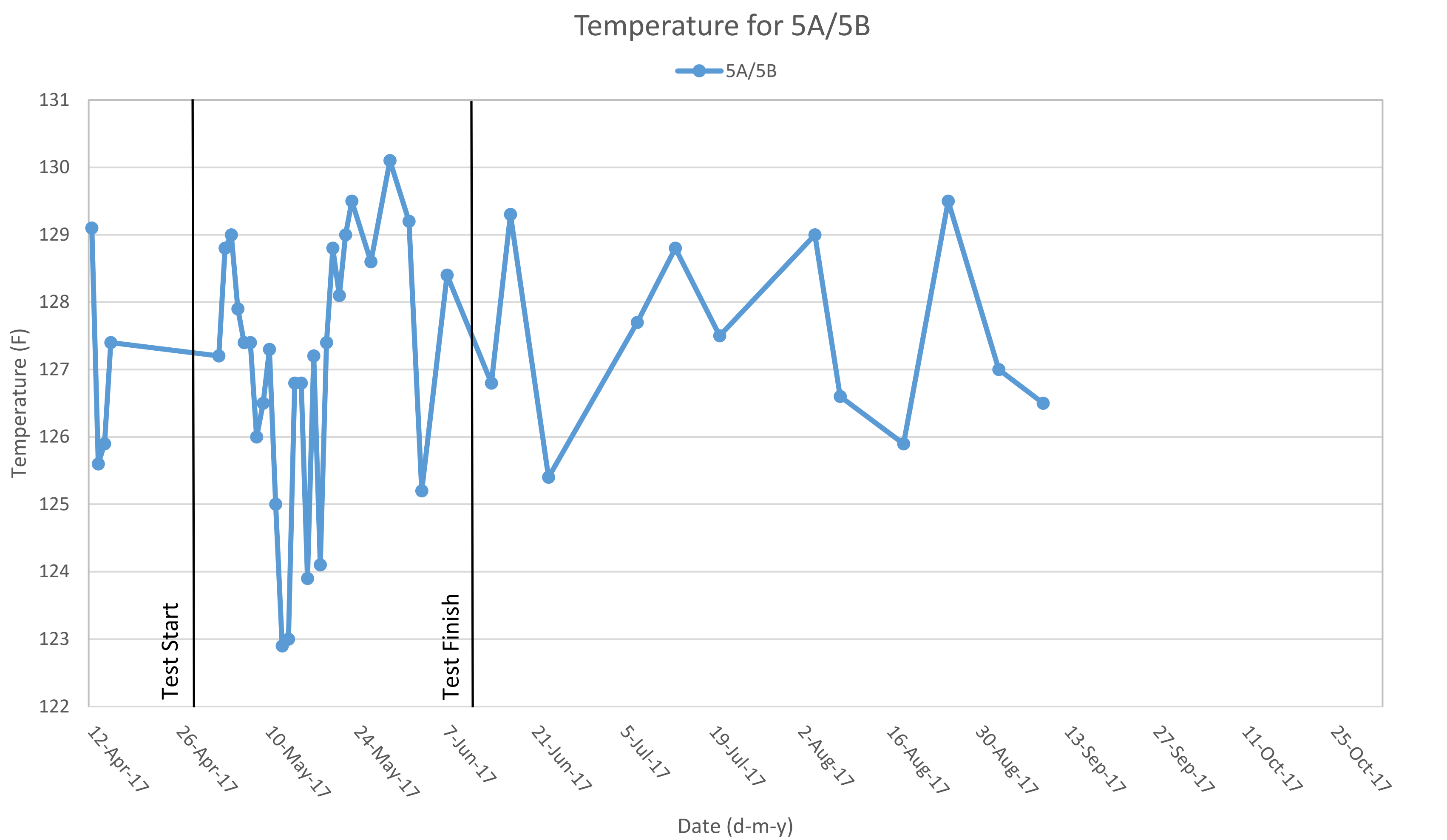
Title	**Water Depth at 5A/5B**		
Project Name: Dixie Meadows	Project Number: ORM007	Figure	M9
Client Name: Ormat	Date: 3/9/21		



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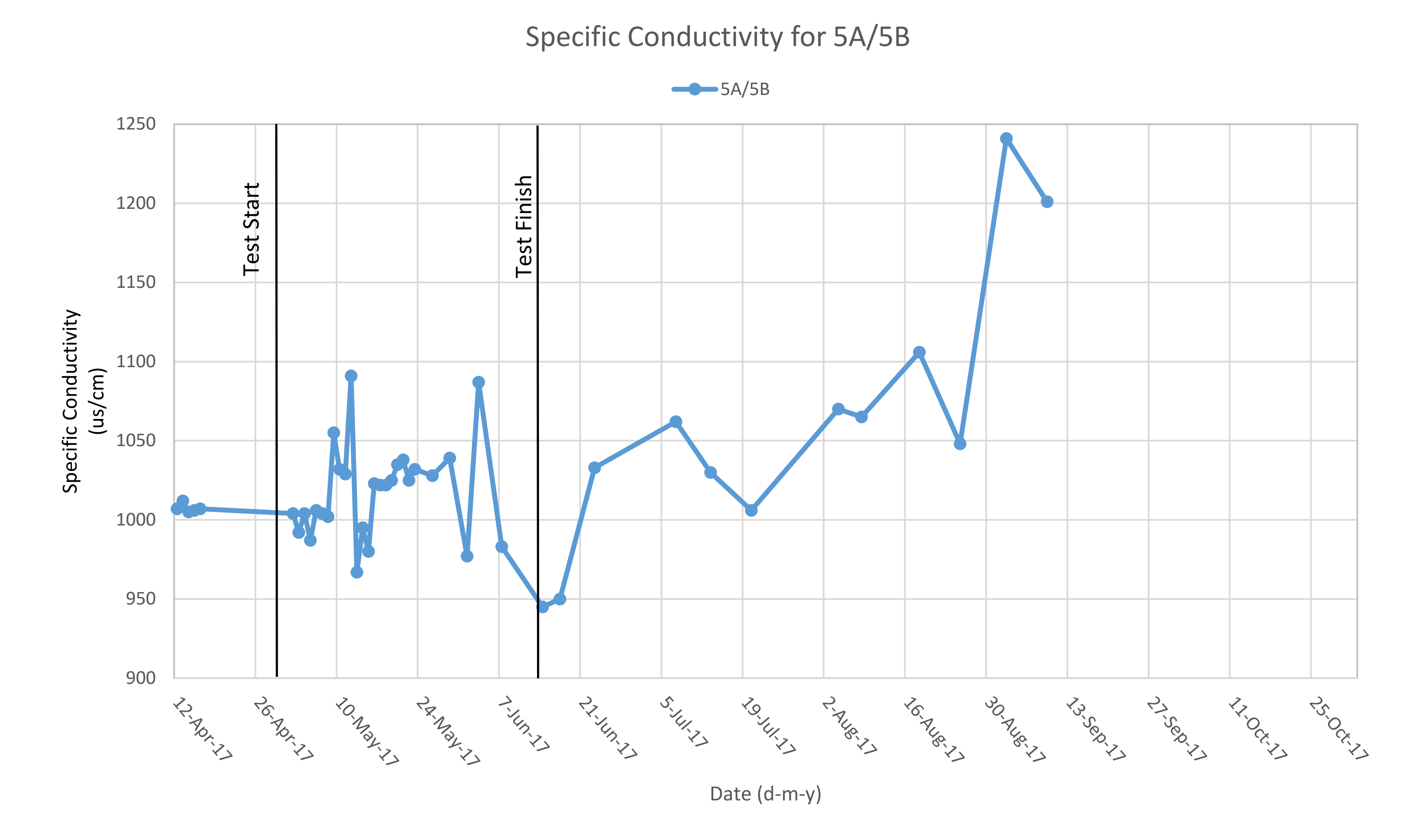
Title	**Temperature at 5A/5B**			
Project Name	Dixie Meadows	Project Number	ORM007	Figure M10
Client Name	Ormat	Date	3/9/21	



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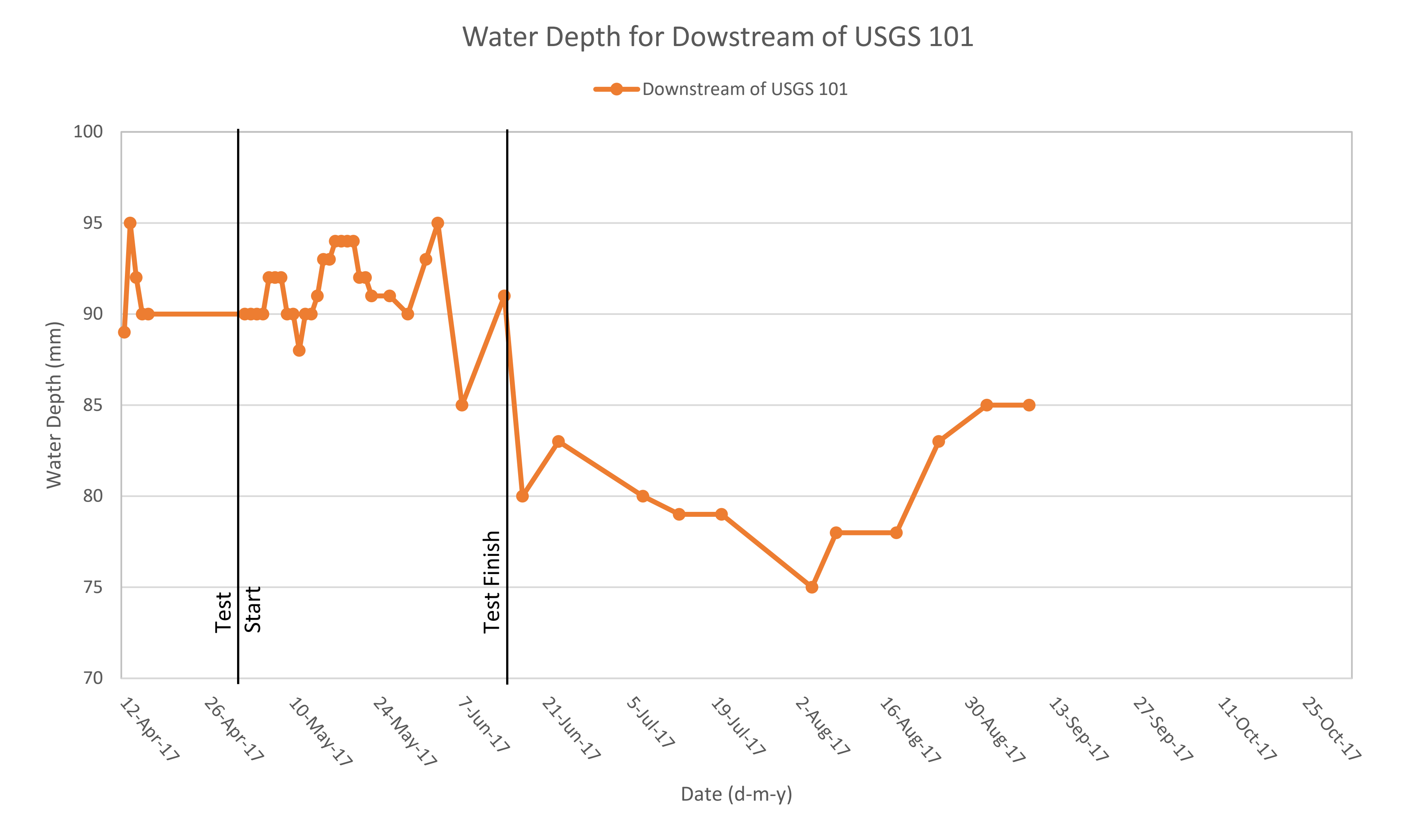
Title	**Specific Conductivity at 5A/5B**		
Project Name	Dixie Meadows	Project Number	ORM007
Client Name	Ormat	Date	3/9/21
Figure	M11		



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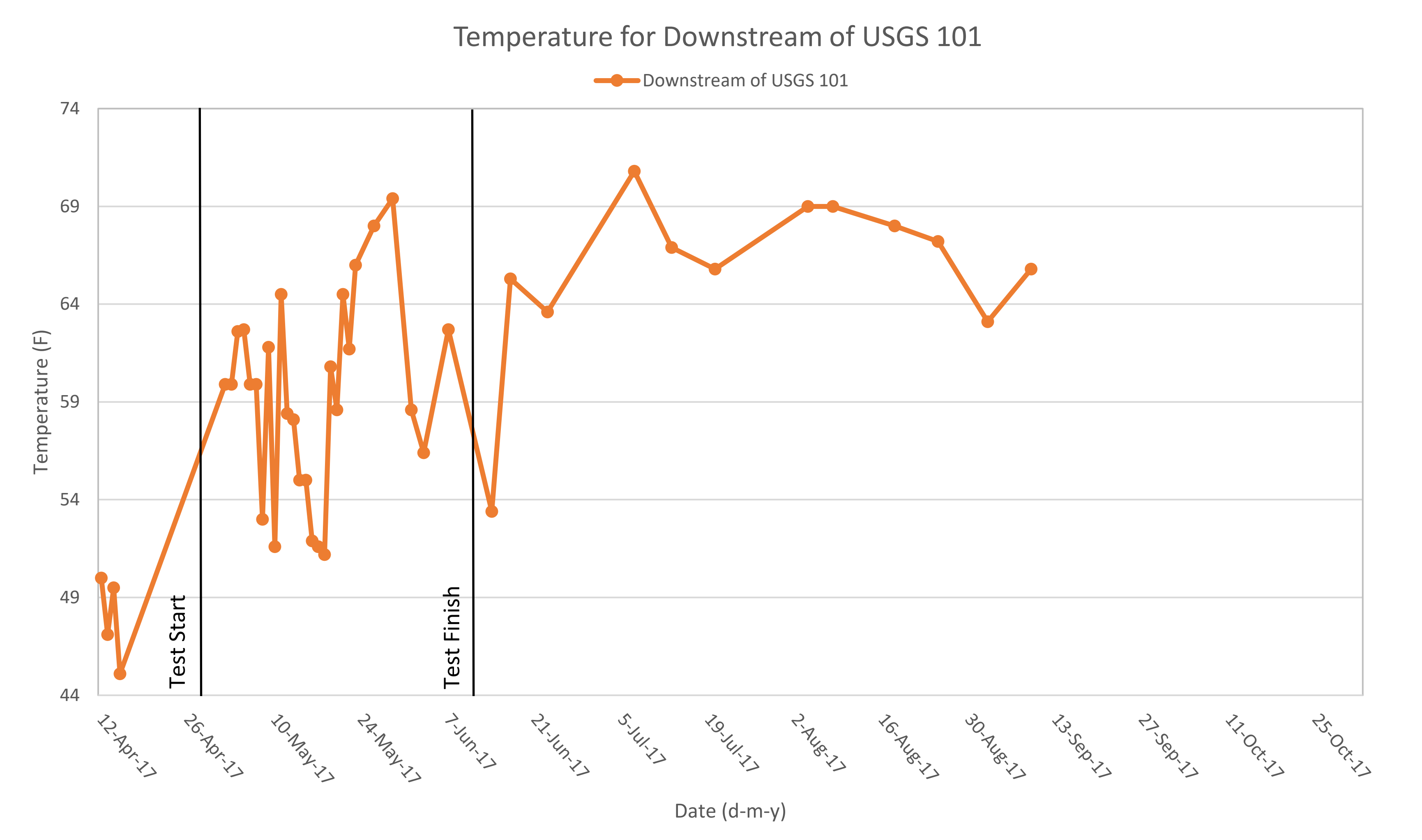
Title	**Water Depth at Downstream of USGS 101**			
Project Name	Dixie Meadows	Project Number	ORM007	Figure M12
Client Name	Ormat	Date	3/9/21	



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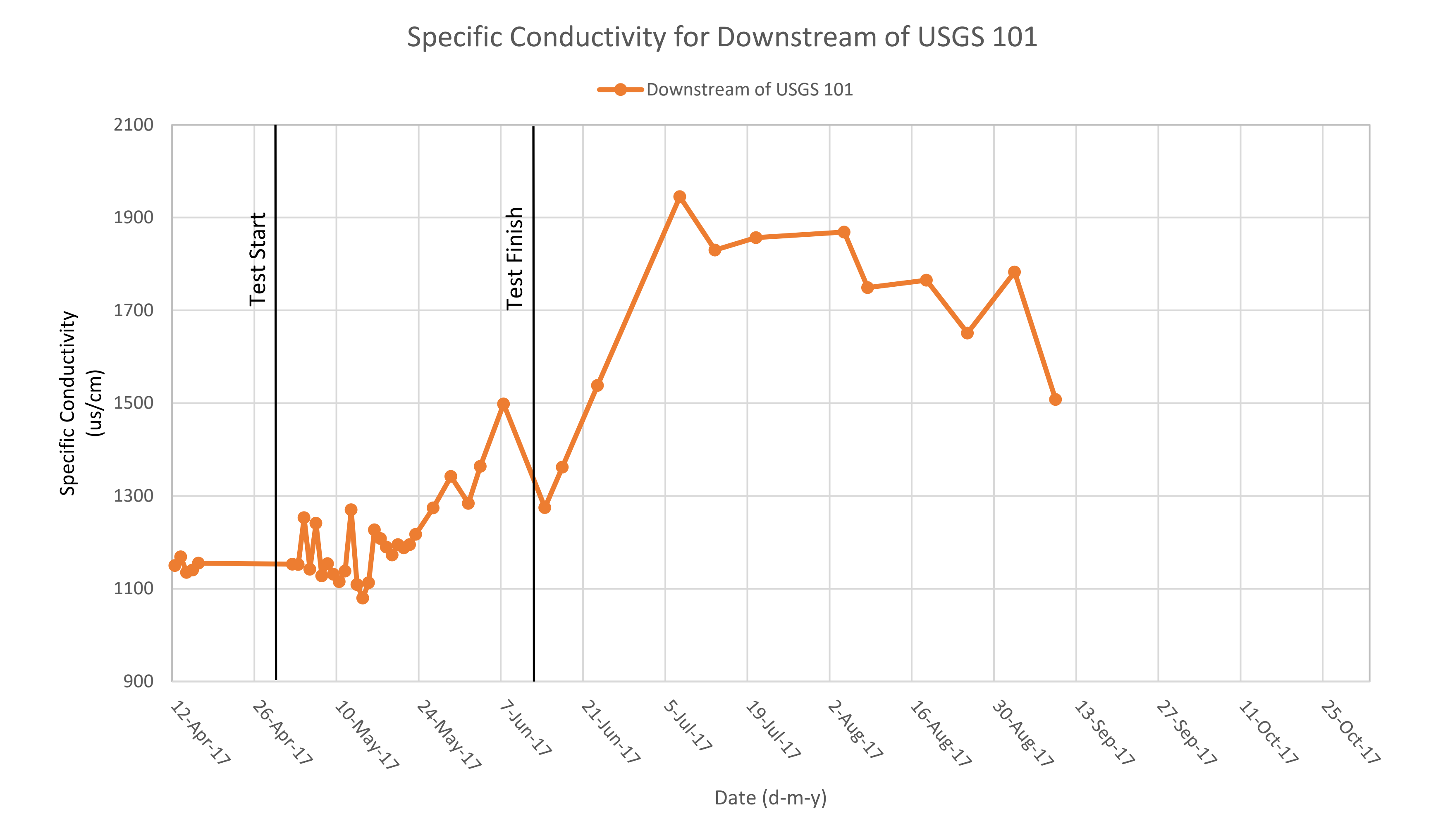
Title	Temperature at Downstream of USGS 101			
Project Name	Dixie Meadows	Project Number	ORM007	Figure M13
Client Name	Ormat	Date	3/9/21	



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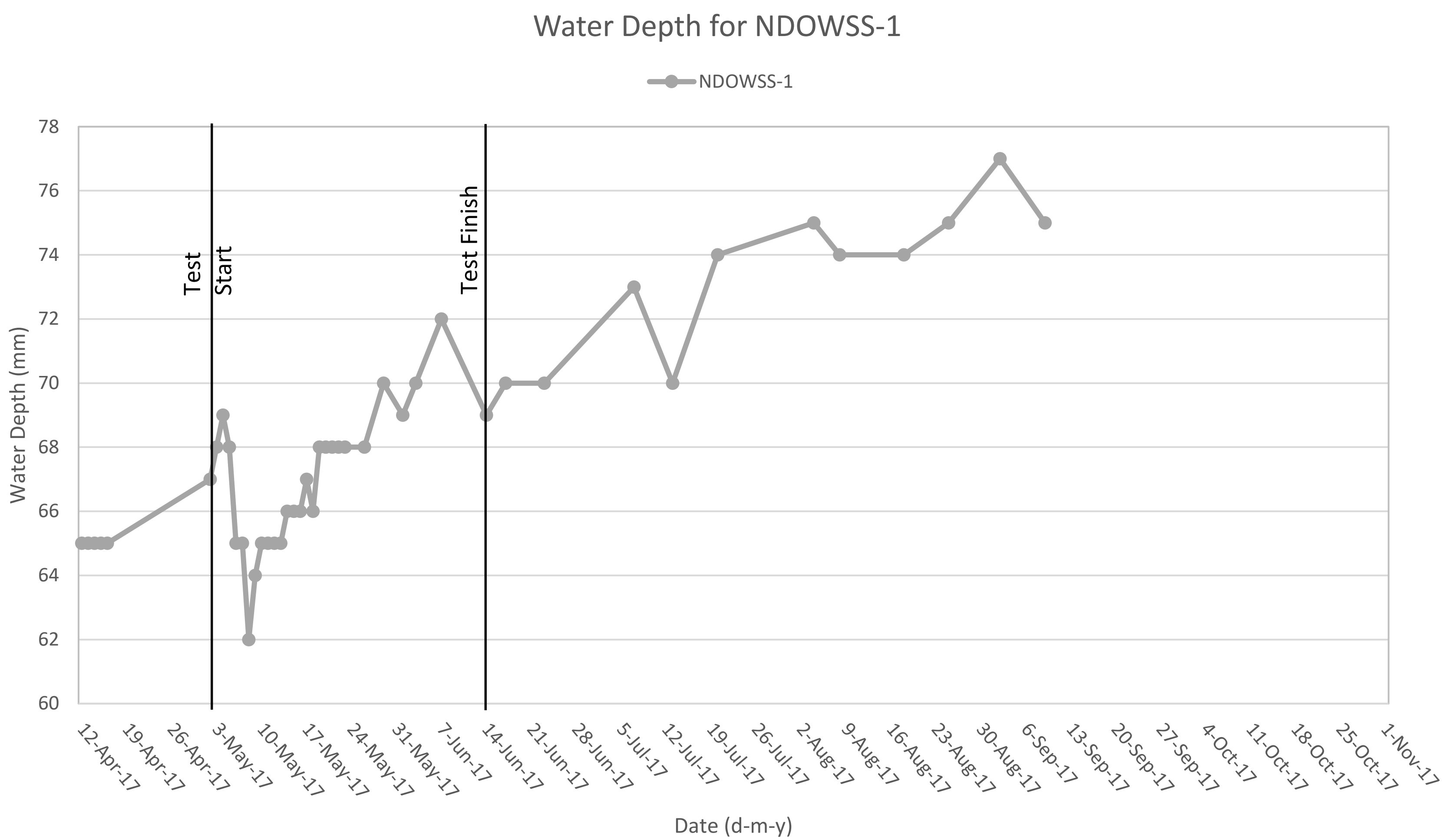
Title	Specific Conductivity at Downstream of USGS 101		
Project Name	Dixie Meadows	Project Number	ORM007
Client Name	Ormat	Date	3/9/21
Figure	M14		



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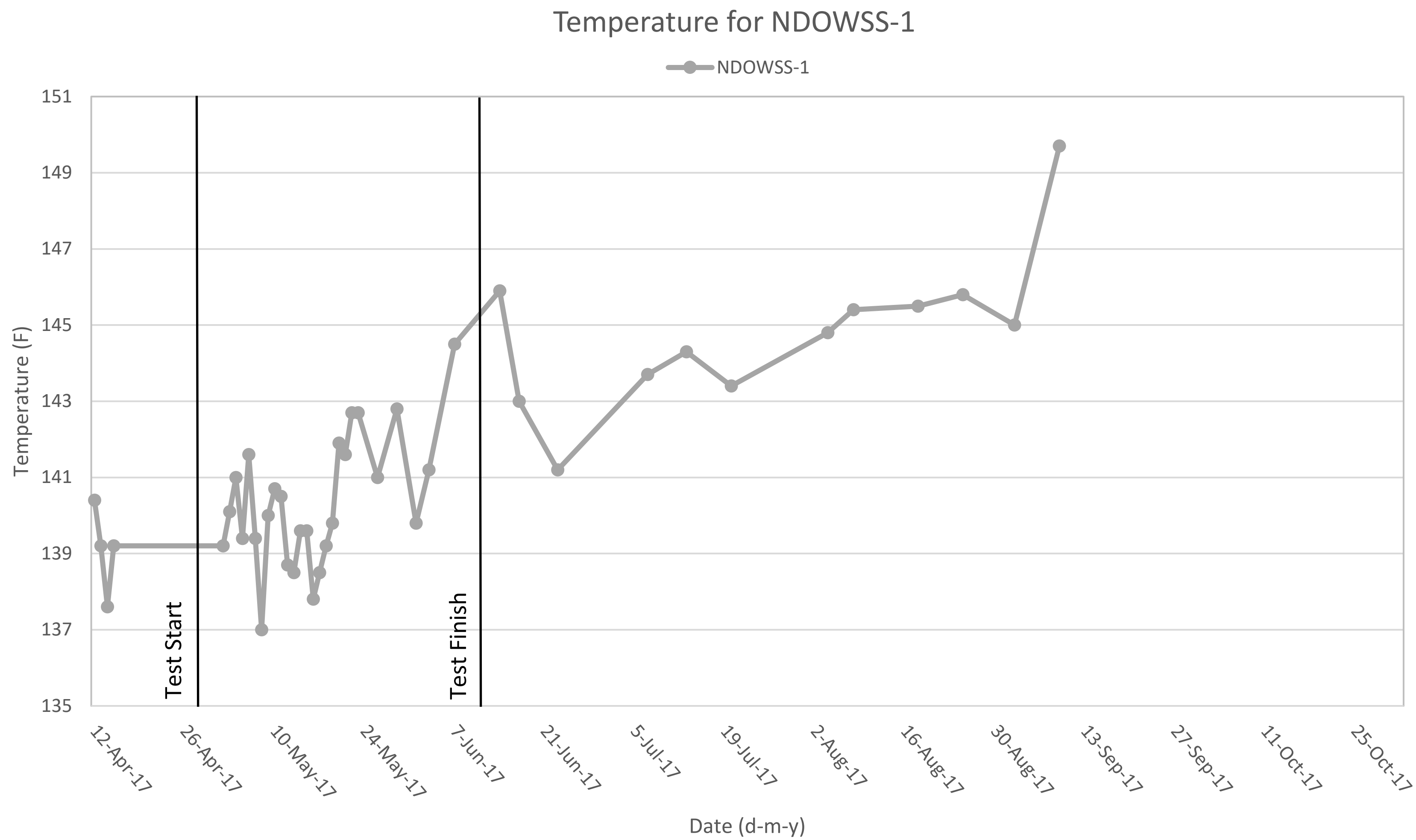
Title	**Water Depth at NDOWSS-1**			
Project Name	Dixie Meadows	Project Number	ORM007	Figure M15
Client Name	Ormat	Date	3/9/21	



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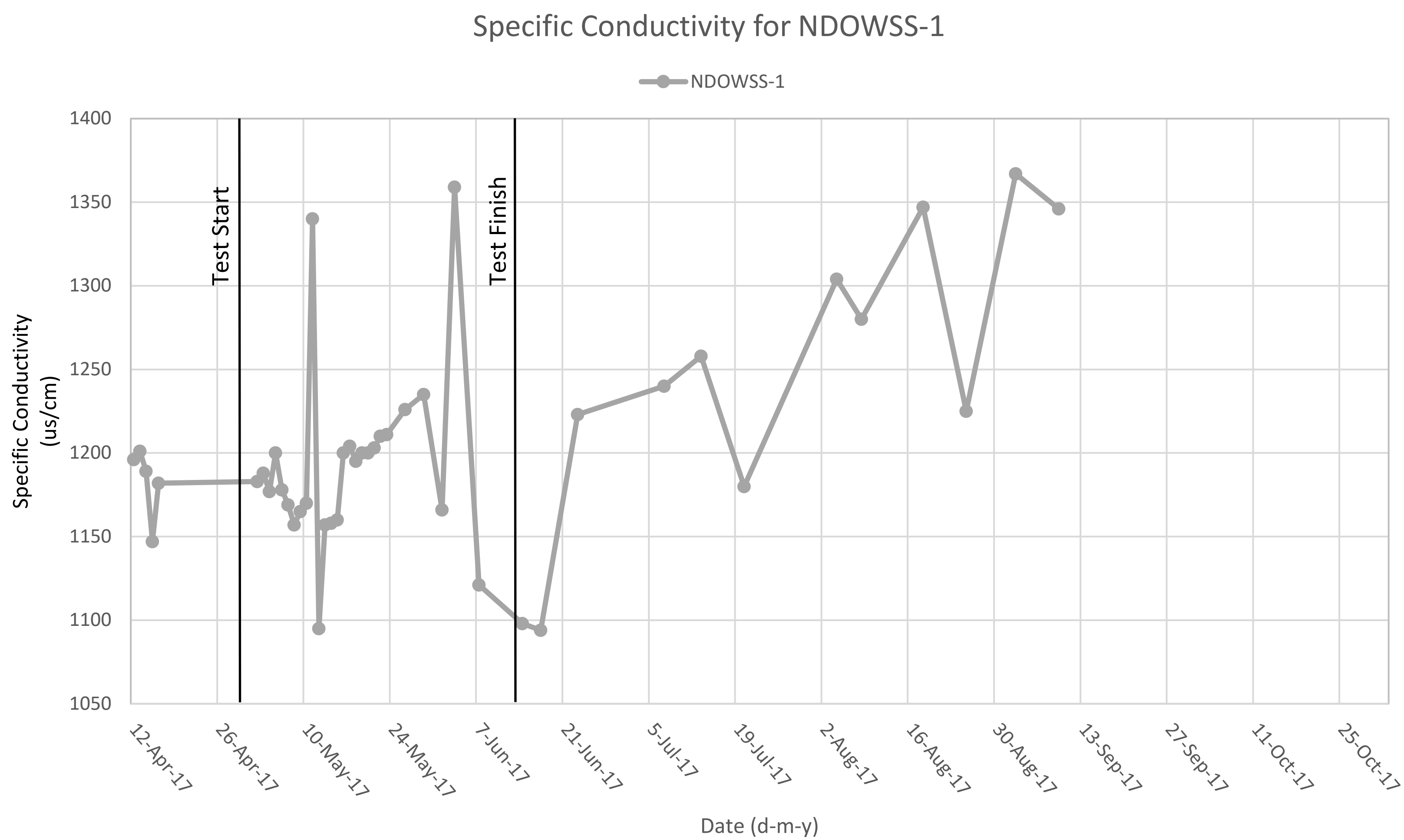
Title	**Temperature at NDOWSS-1**		
Project Name	Dixie Meadows	Project Number	ORM007
Client Name	Ormat	Date	3/9/21
Figure	M16		



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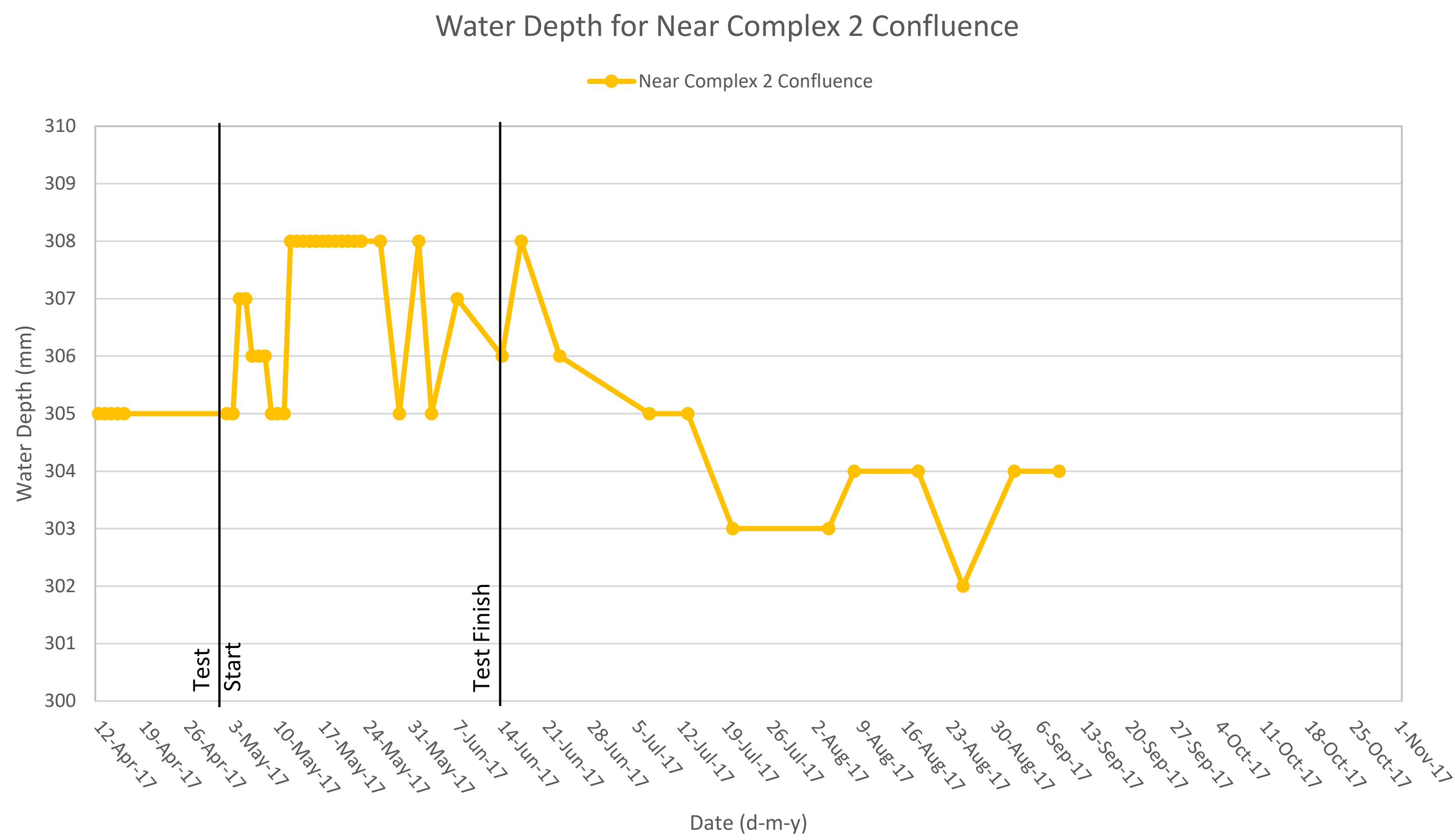
Title	**Specific Conductivity at NDOWSS-1**		
Project Name	Dixie Meadows	Project Number	ORM007
Client Name	Ormat	Date	3/9/21
Figure	M17		



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Title	**Water Depth at Near Complex 2 Confluence**		
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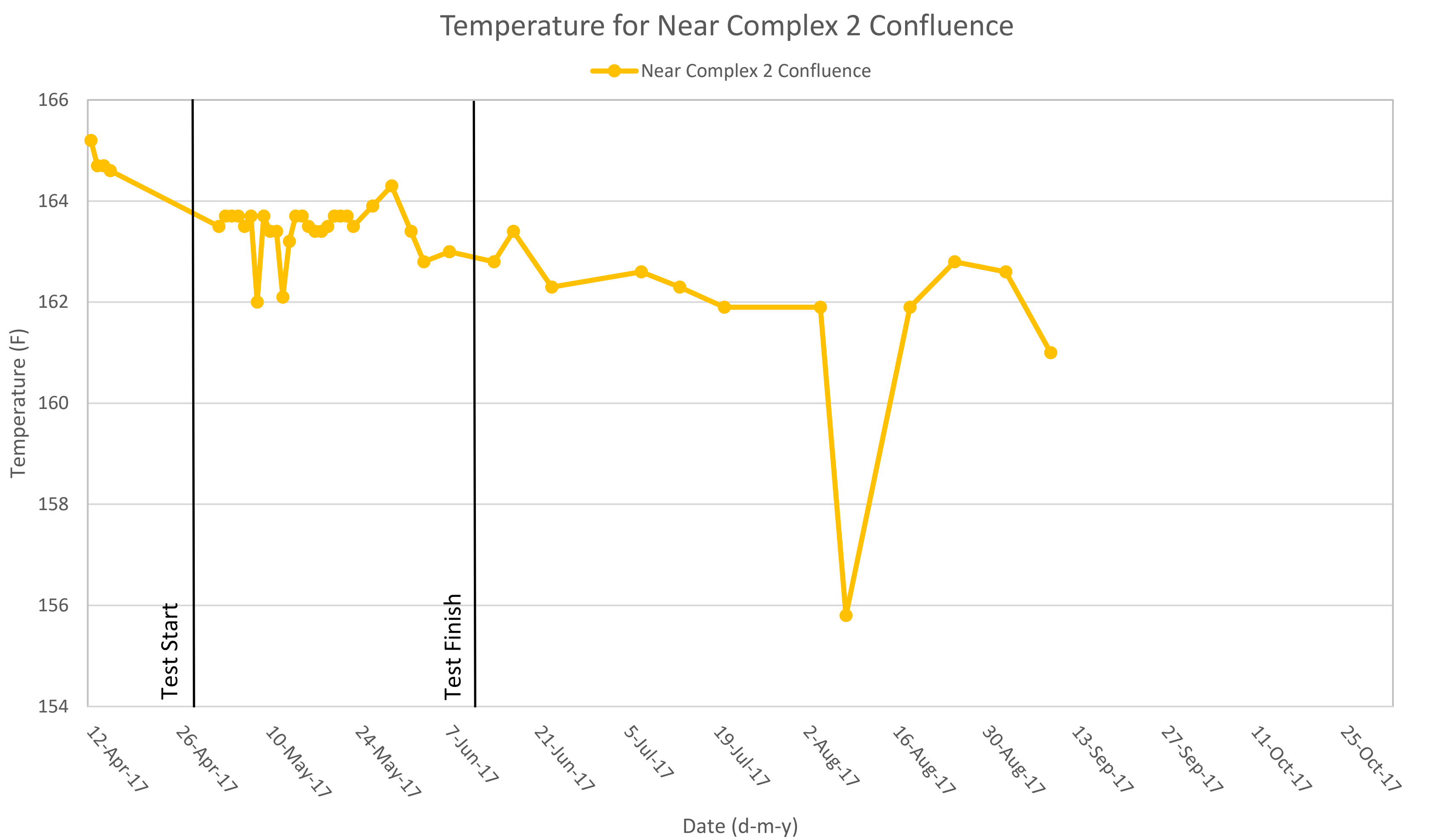
Client Name	Ormat	Date	3/9/21
Figure	M18		



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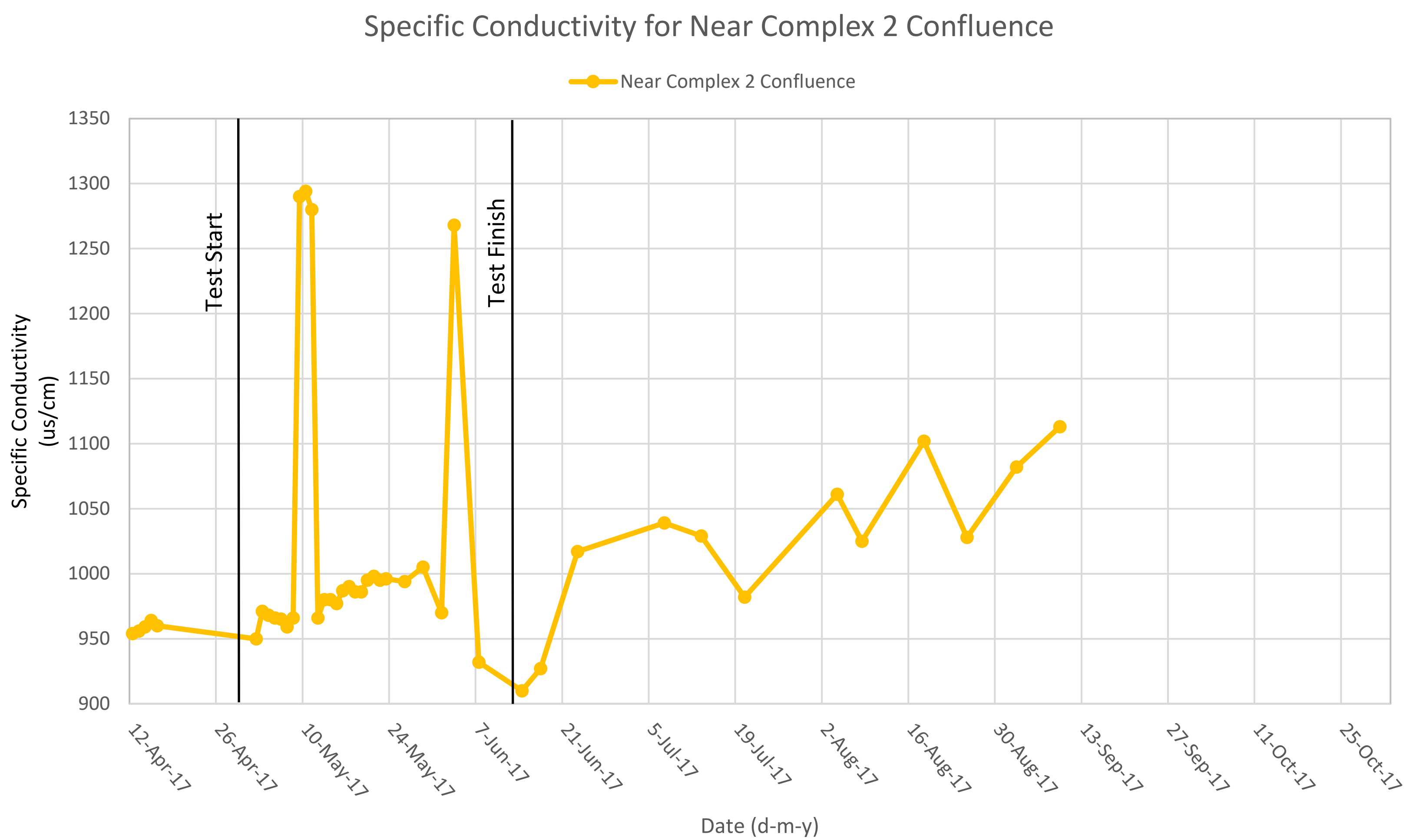
Title	**Temperature at Near Complex 2 Confluence**			
Project Name	Dixie Meadows	Project Number	ORM007	Figure M19
Client Name	Ormat	Date	3/9/21	



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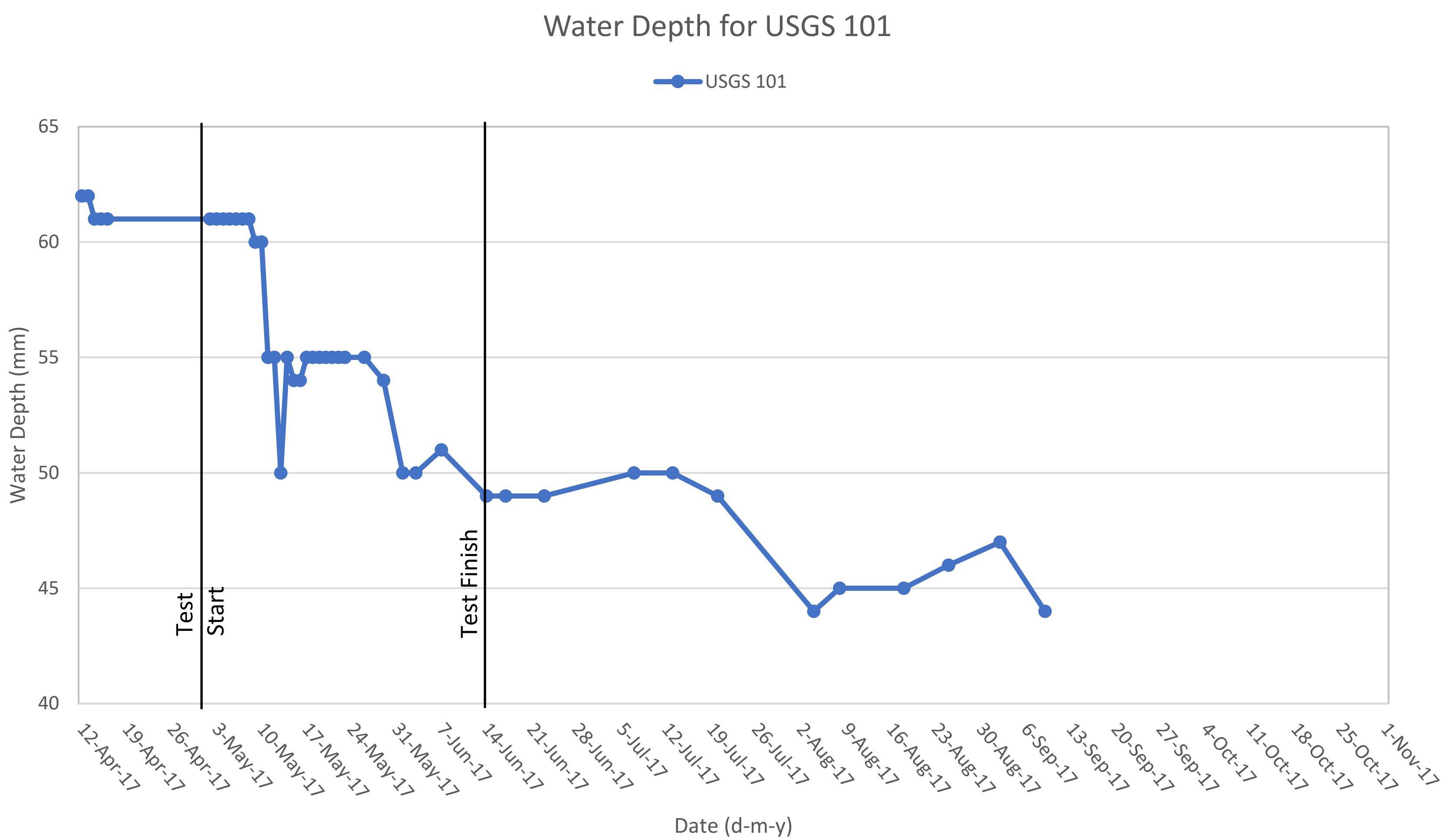
Title	**Specific Conductivity at Near Complex 2 Confluence**		
Project Name	Dixie Meadows	Project Number	ORM007
Client Name	Ormat	Date	3/9/21
Figure	M20		



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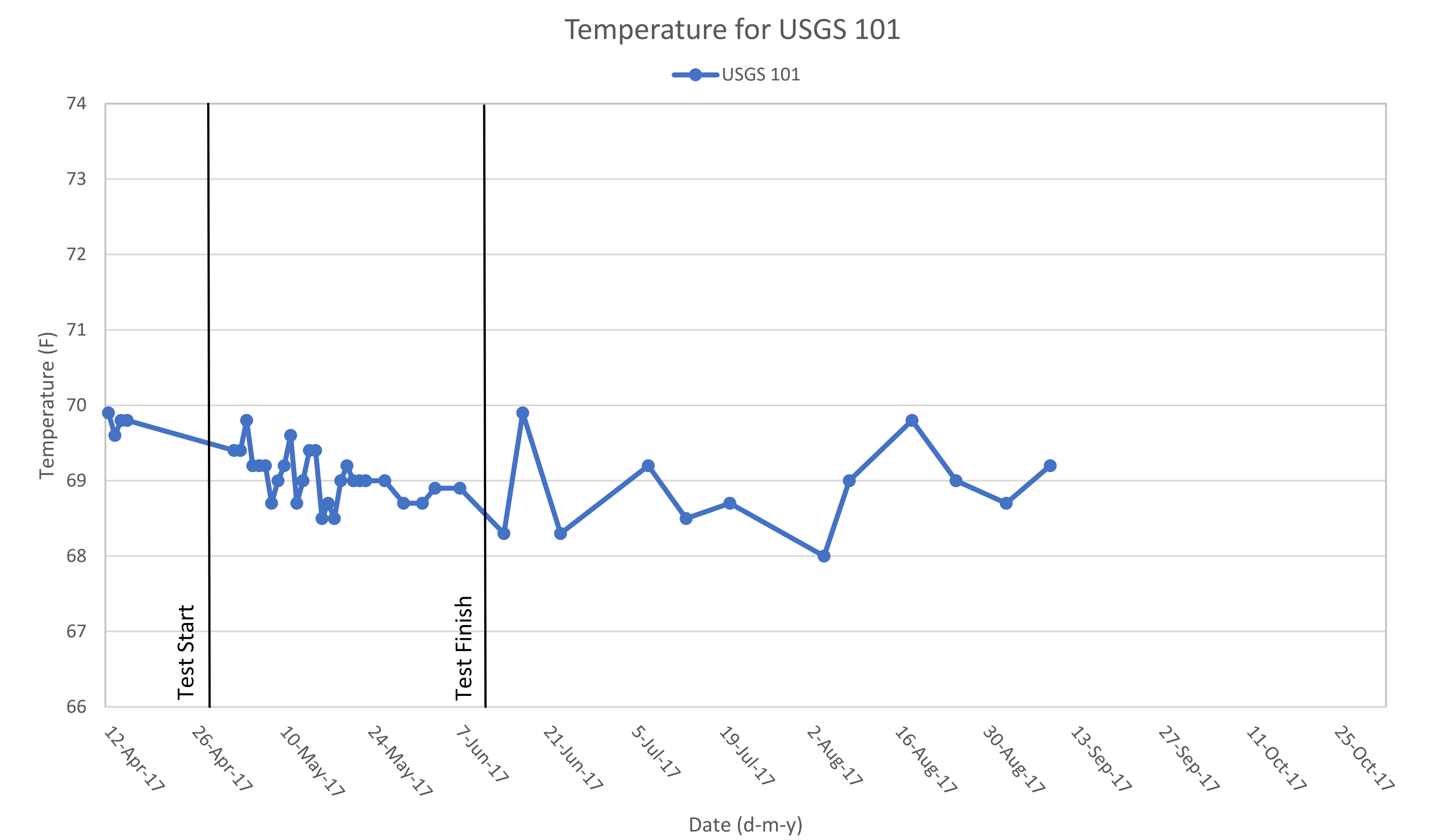
Title	Water Depth at USGS 101		
Project Name	Dixie Meadows	Project Number	ORM007
Client Name	Ormat	Date	3/9/21
Figure	M21		



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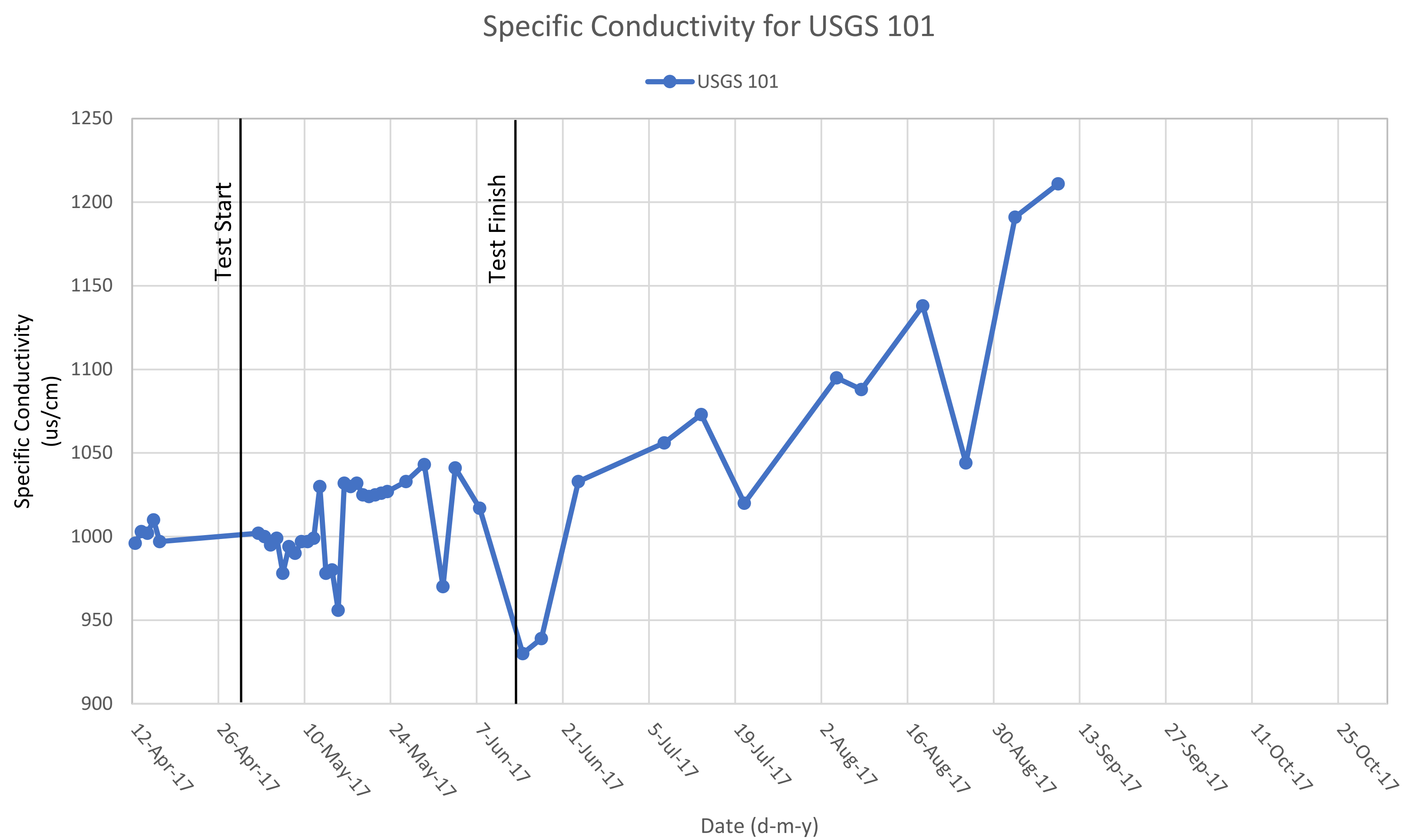
Title	**Temperature at USGS 101**		
Project Name	Dixie Meadows	Project Number	ORM007
Client Name	Ormat	Date	3/9/21
Figure	M22		



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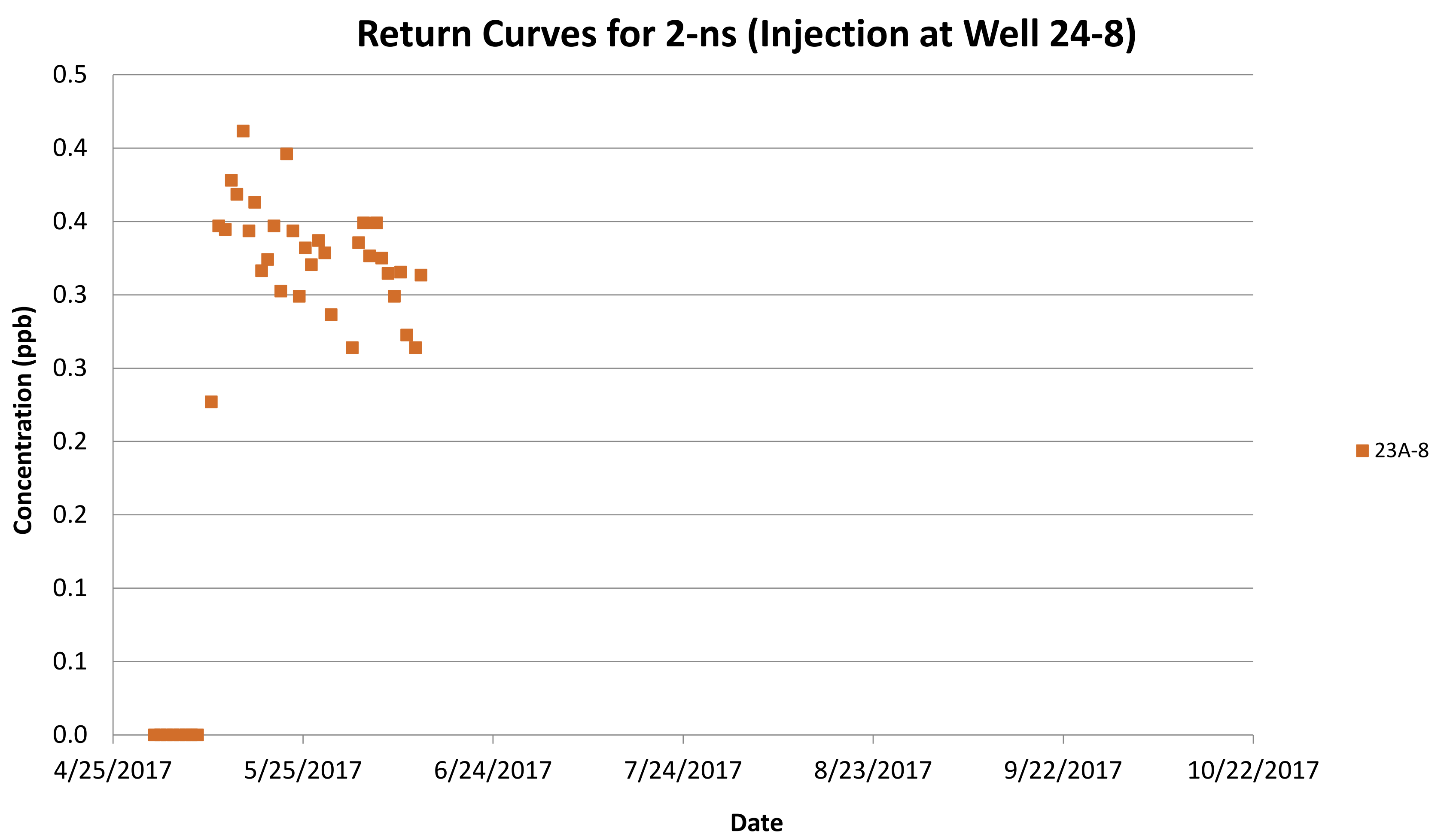
Title	**Specific Conductivity at USGS 101**			Figure
Project Name	Dixie Meadows	Project Number	ORM007	M23
Client Name	Ormat	Date	3/9/21	



Title	Return Curves for 2-ns		
Project Name	Dixie Meadows	Project Number	ORM007
Client Name	Ormat	Date	4/26/21

Figure M24

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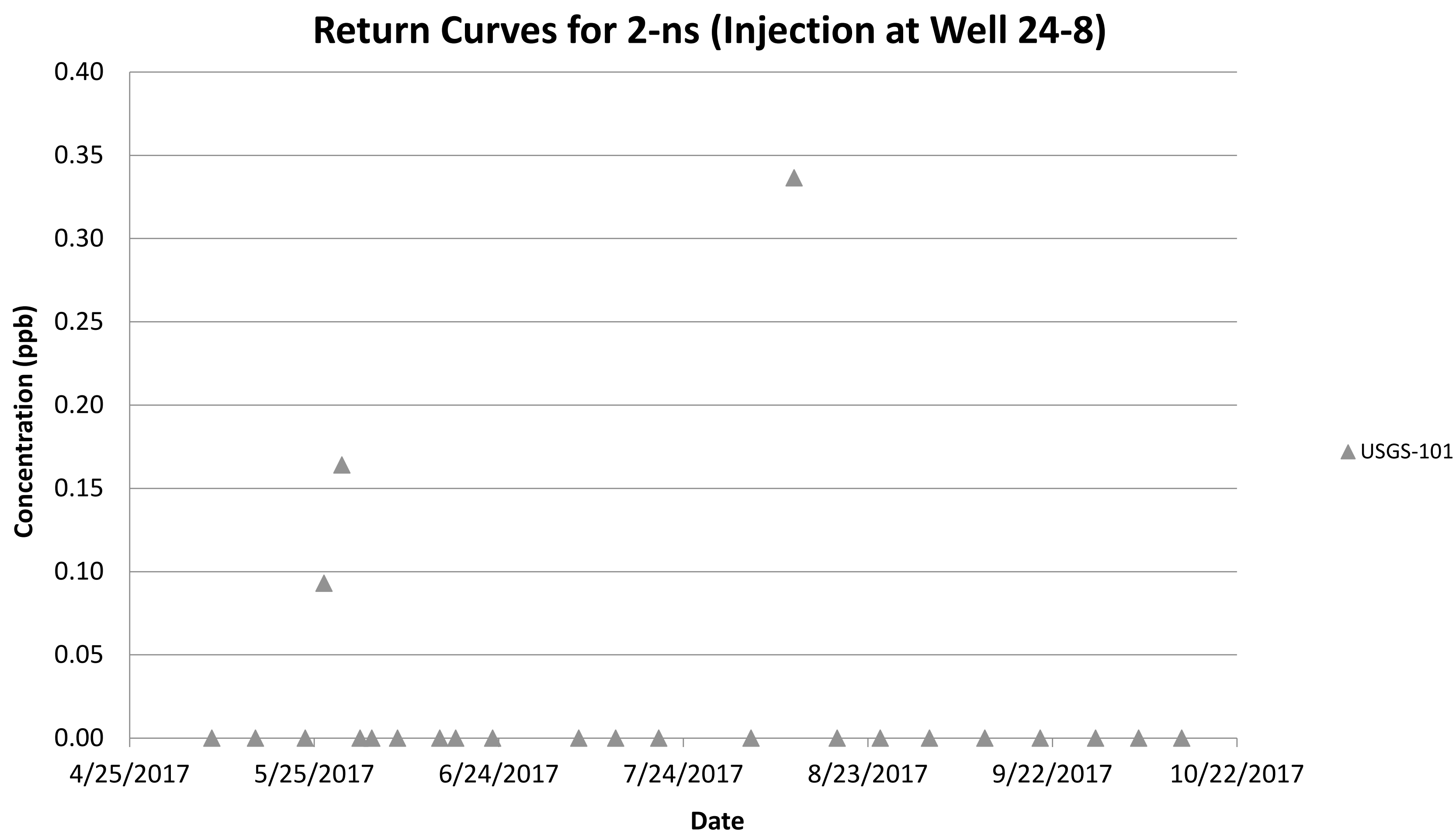

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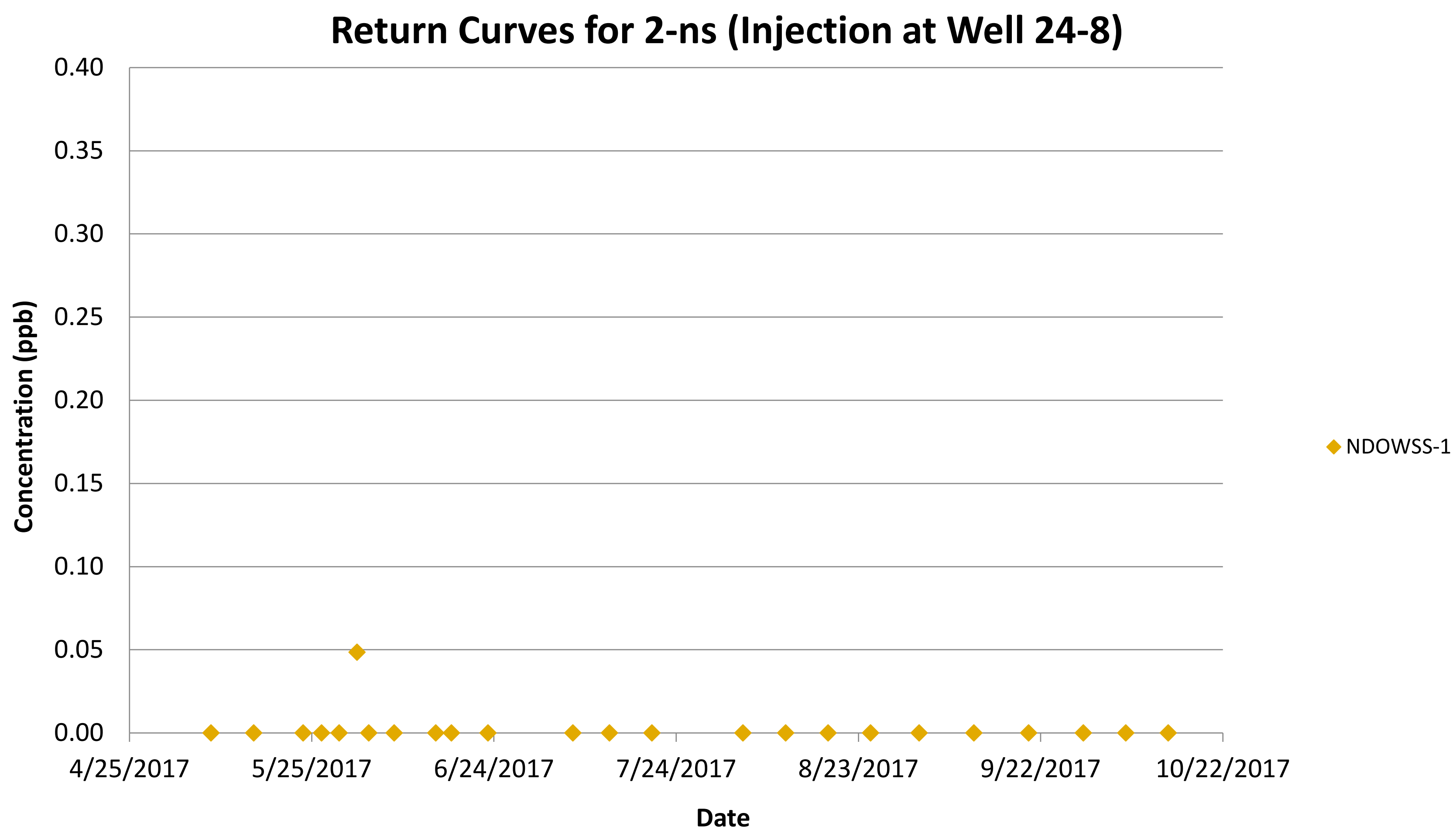
Title	Return Curves for 2-ns		
Project Name	Dixie Meadows	Project Number	ORM007
Client Name	Ormat	Date	4/26/21
Figure	M25		



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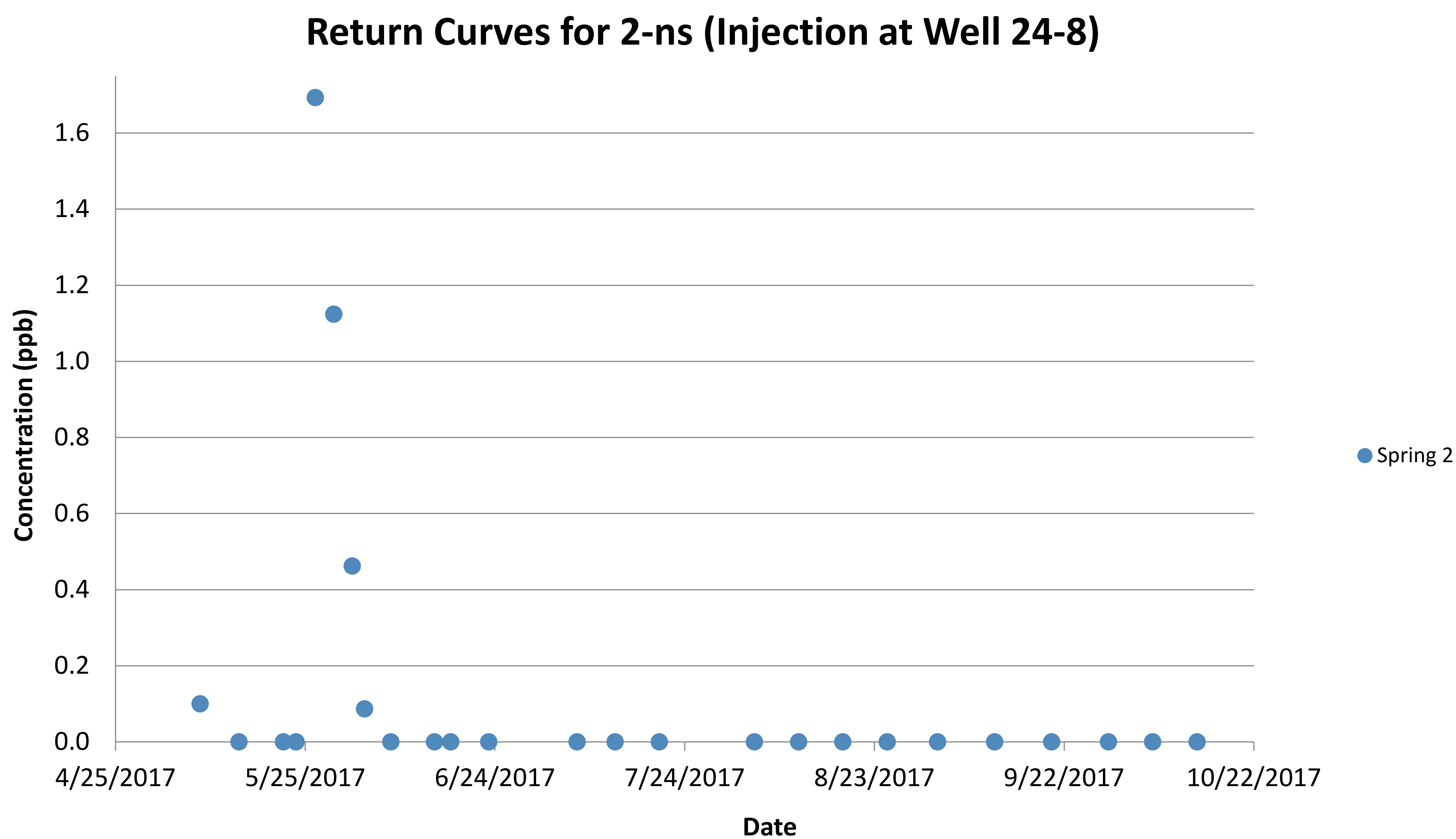
Title	Return Curves for 2-ns		
Project Name	Dixie Meadows	Project Number	ORM007
Client Name	Ormat	Date	4/26/21

Figure M26



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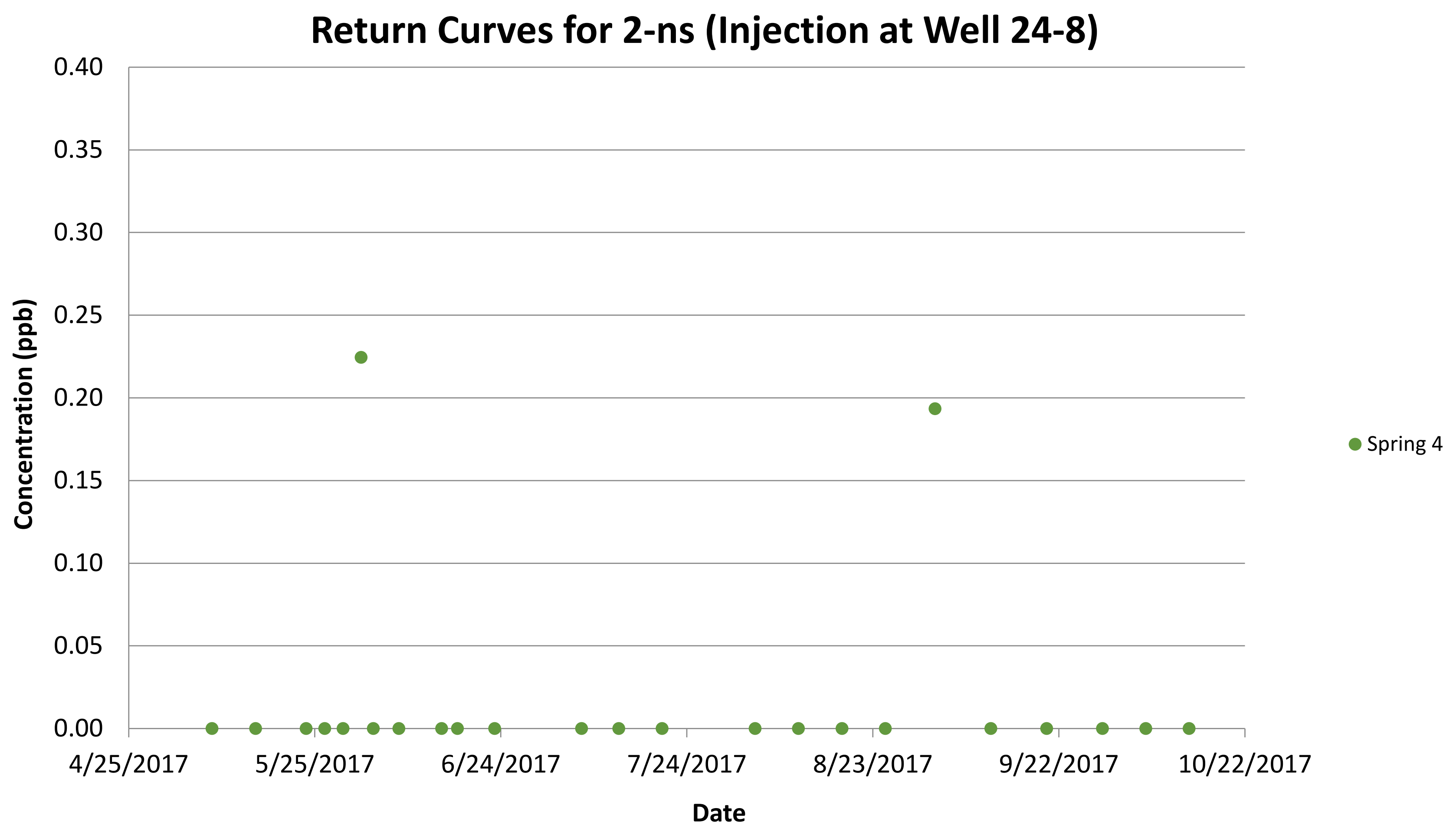
Title	**Return Curves for 2-ns**			Figure
Project Name	Dixie Meadows	Project Number	ORM007	M27
Client Name	Ormat	Date	4/26/21	



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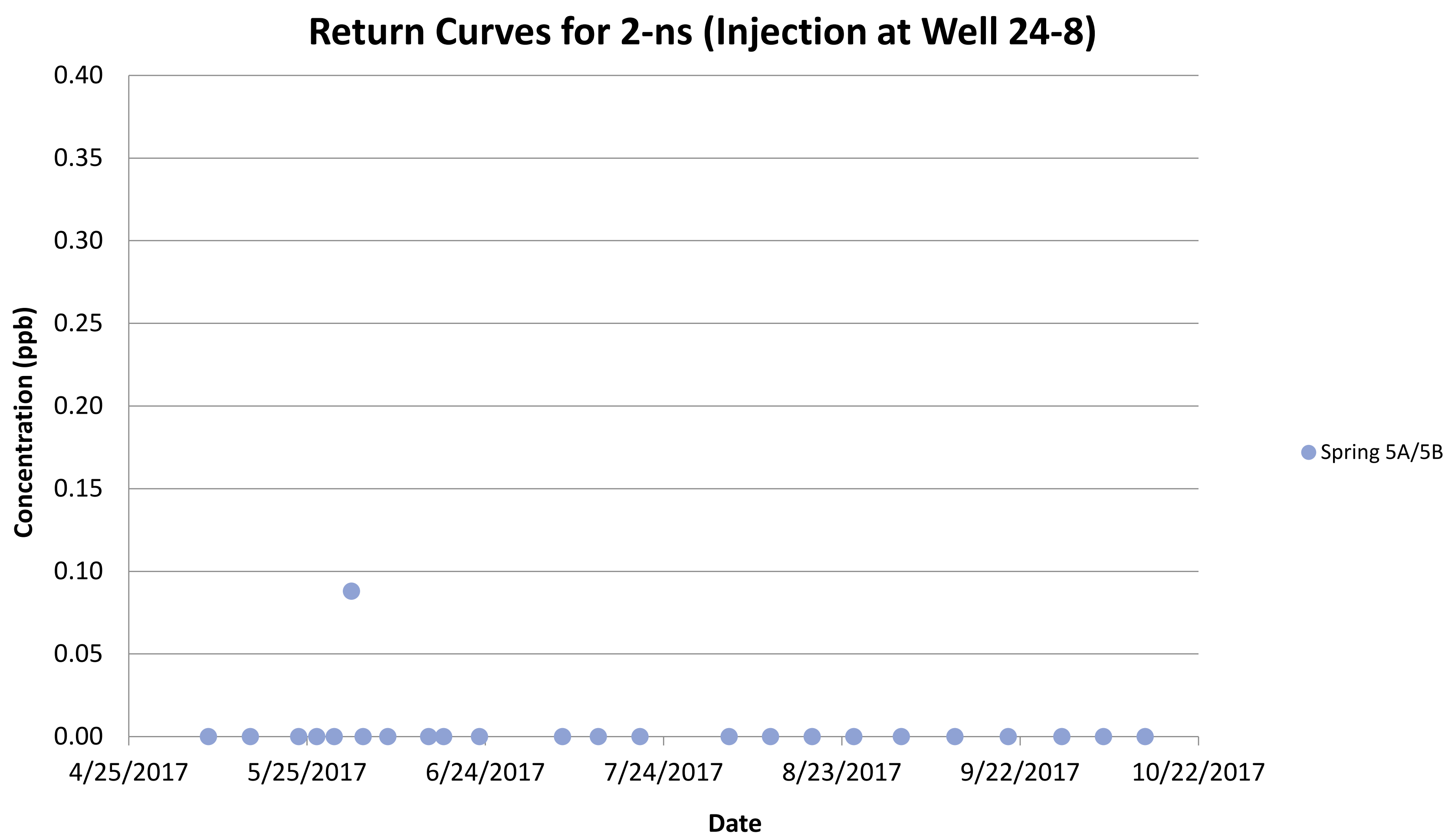
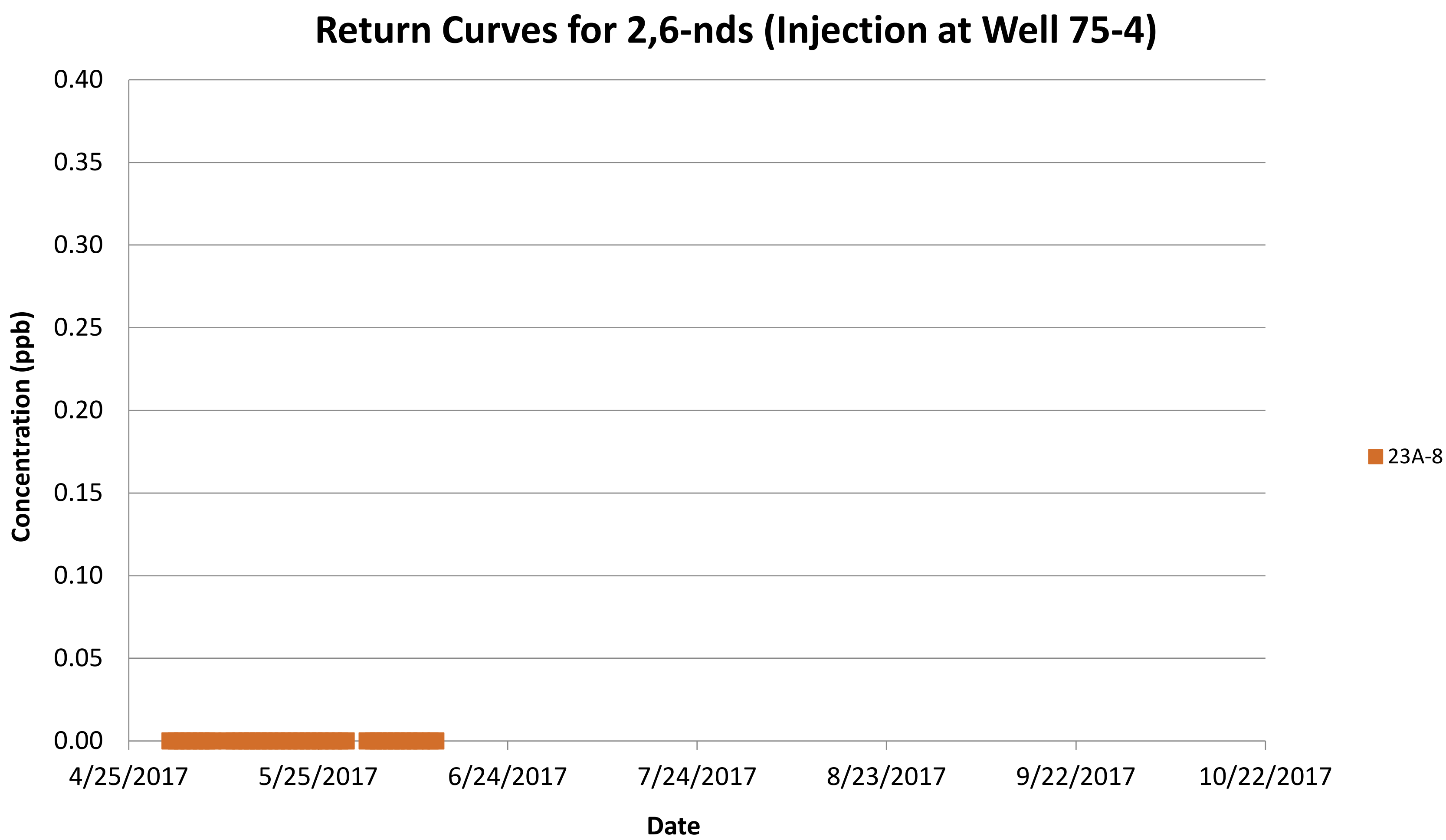
Environmental Engineering and Science

Title	Return Curves for 2-ns			Figure M28
Project Name	Dixie Meadows	Project Number	ORM007	
Client Name	Ormat	Date	4/26/21	

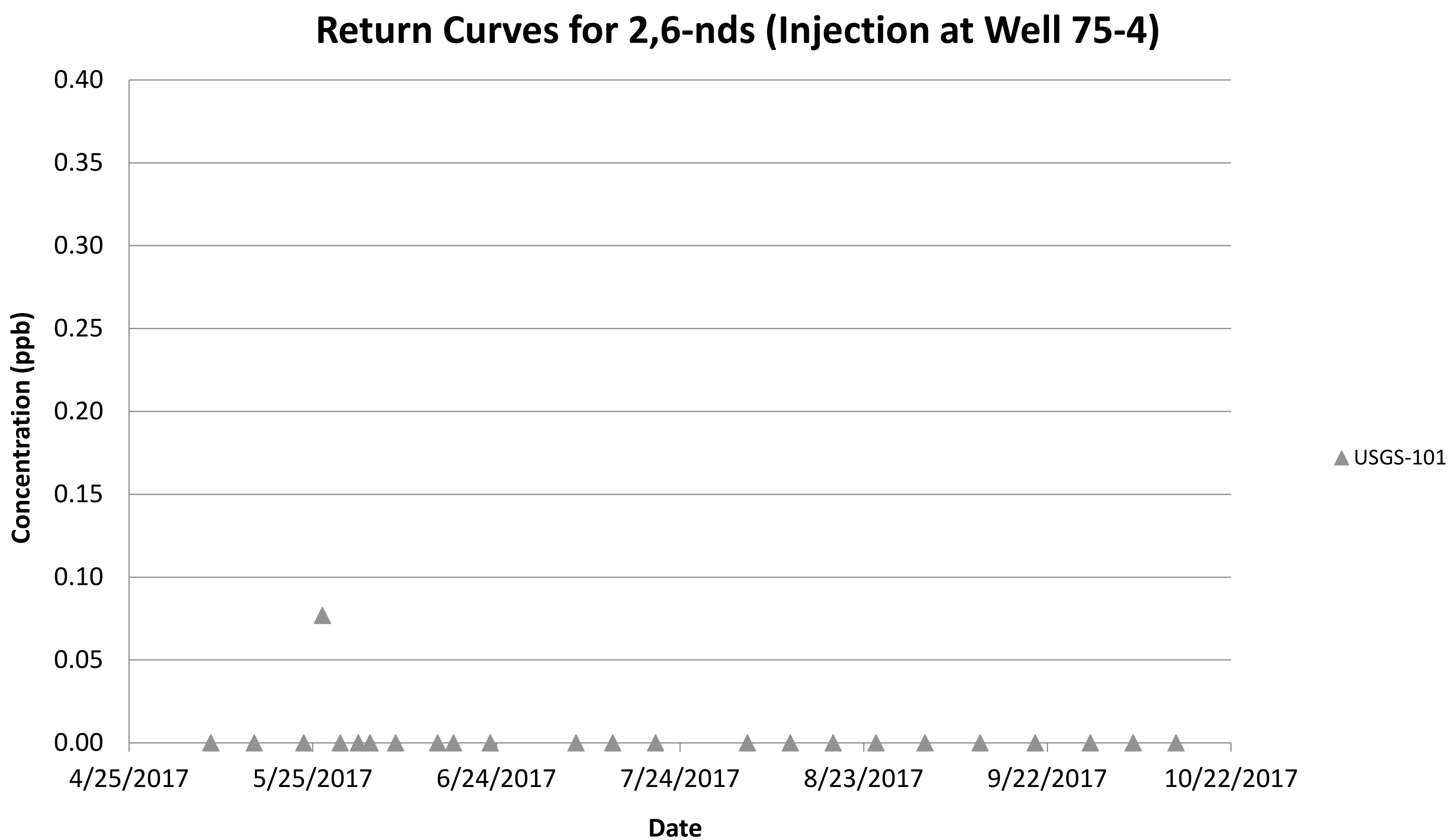


McGinley & Associates Environmental Engineering and Science	Title: **Return Curves for 2-ns**		
	Project Name: Dixie Meadows	Project Number: ORM007	Figure: M29
	Client Name: Ormat	Date: 4/26/21	



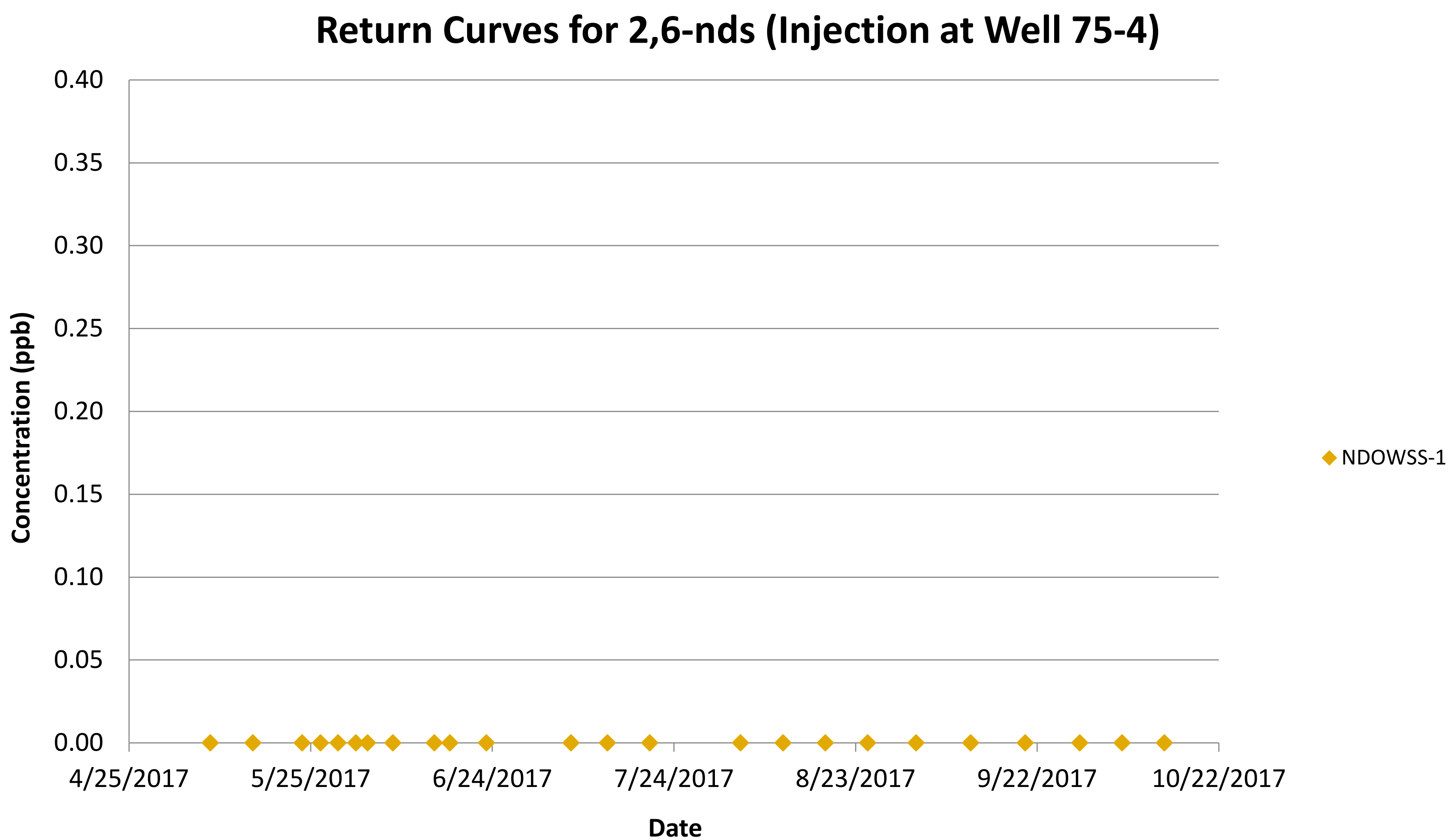
McGinley & Associates
Environmental Engineering and Science

Title	Return Curves for 2,6-nds		
Project Name	Dixie Meadows	Project Number	ORM007
Client Name	Ormat	Date	4/26/21
Figure	M30		



McGinley & Associates
Environmental Engineering and Science

Title	Return Curves for 2,6-nds		
Project Name	Dixie Meadows	Project Number	ORM007
Client Name	Ormat	Date	4/26/21
Figure	M31		



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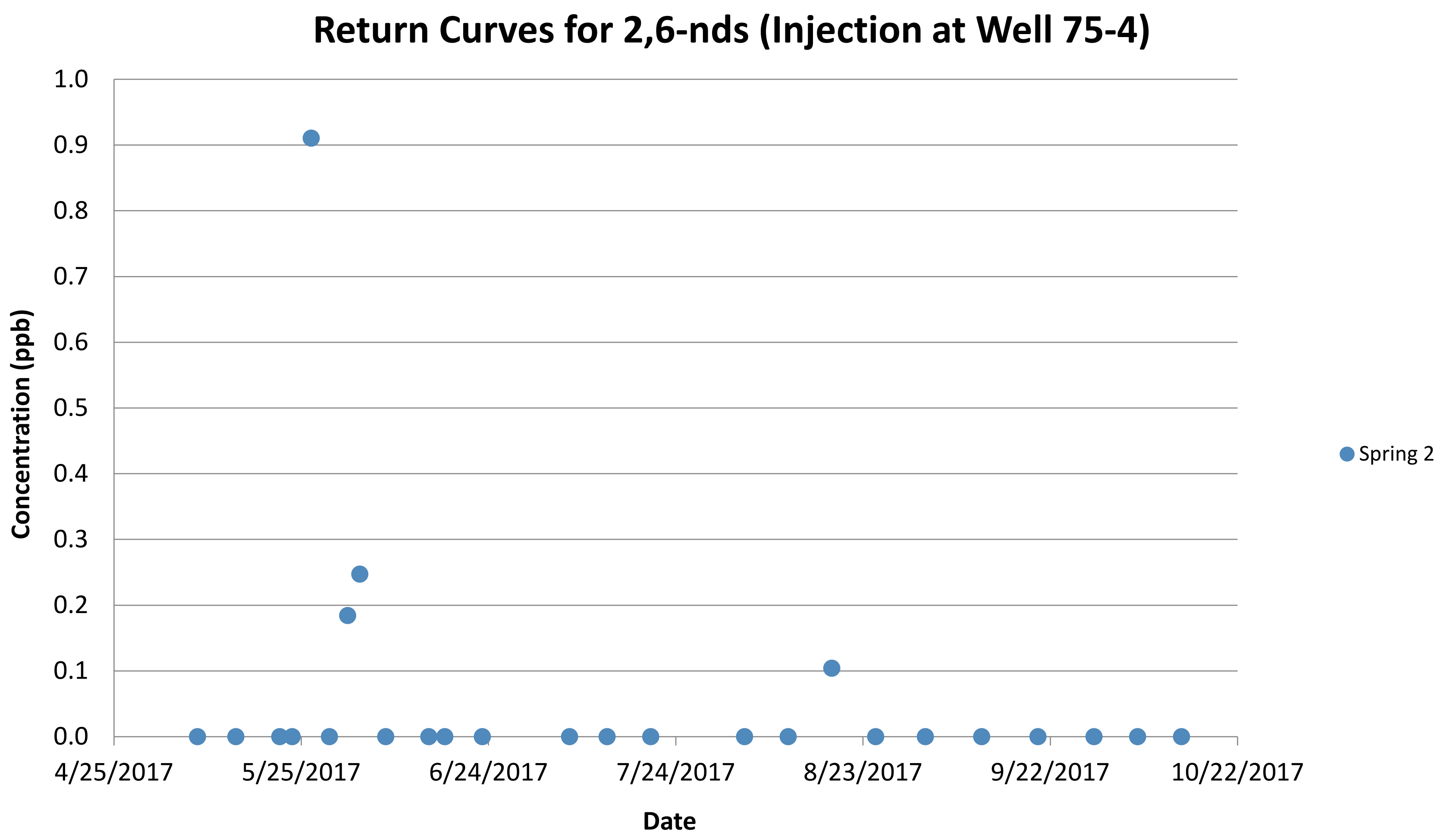
Environmental Engineering and Science

Title	Return Curves for 2,6-nds		
Project Name	Dixie Meadows	Project Number	ORM007
Client Name	Ormat	Date	4/26/21
Figure	M32		



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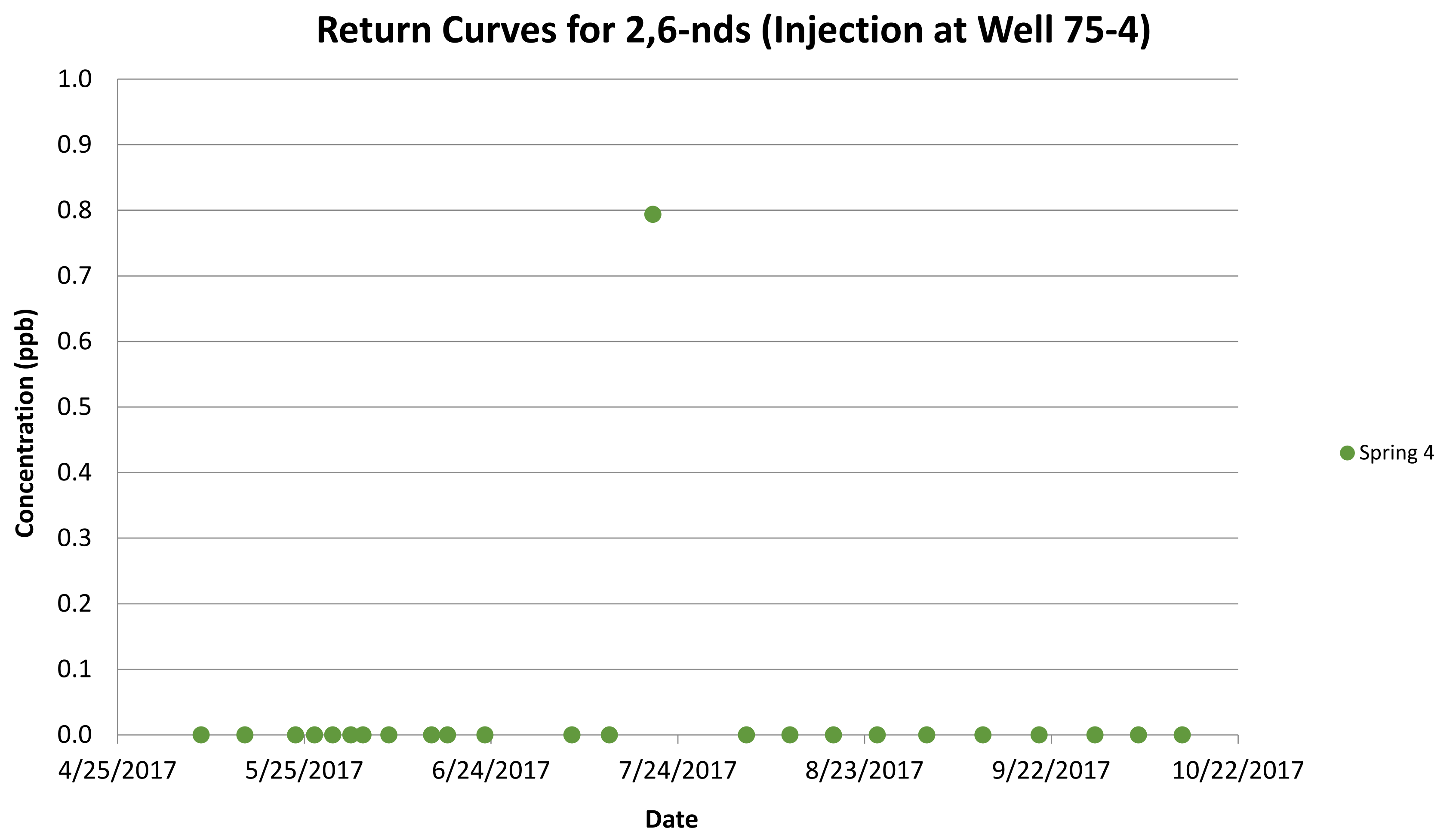
Title	Return Curves for 2,6-nds		
Project Name	Dixie Meadows	Project Number	ORM007
Client Name	Ormat	Date	4/26/21
Figure	M33		



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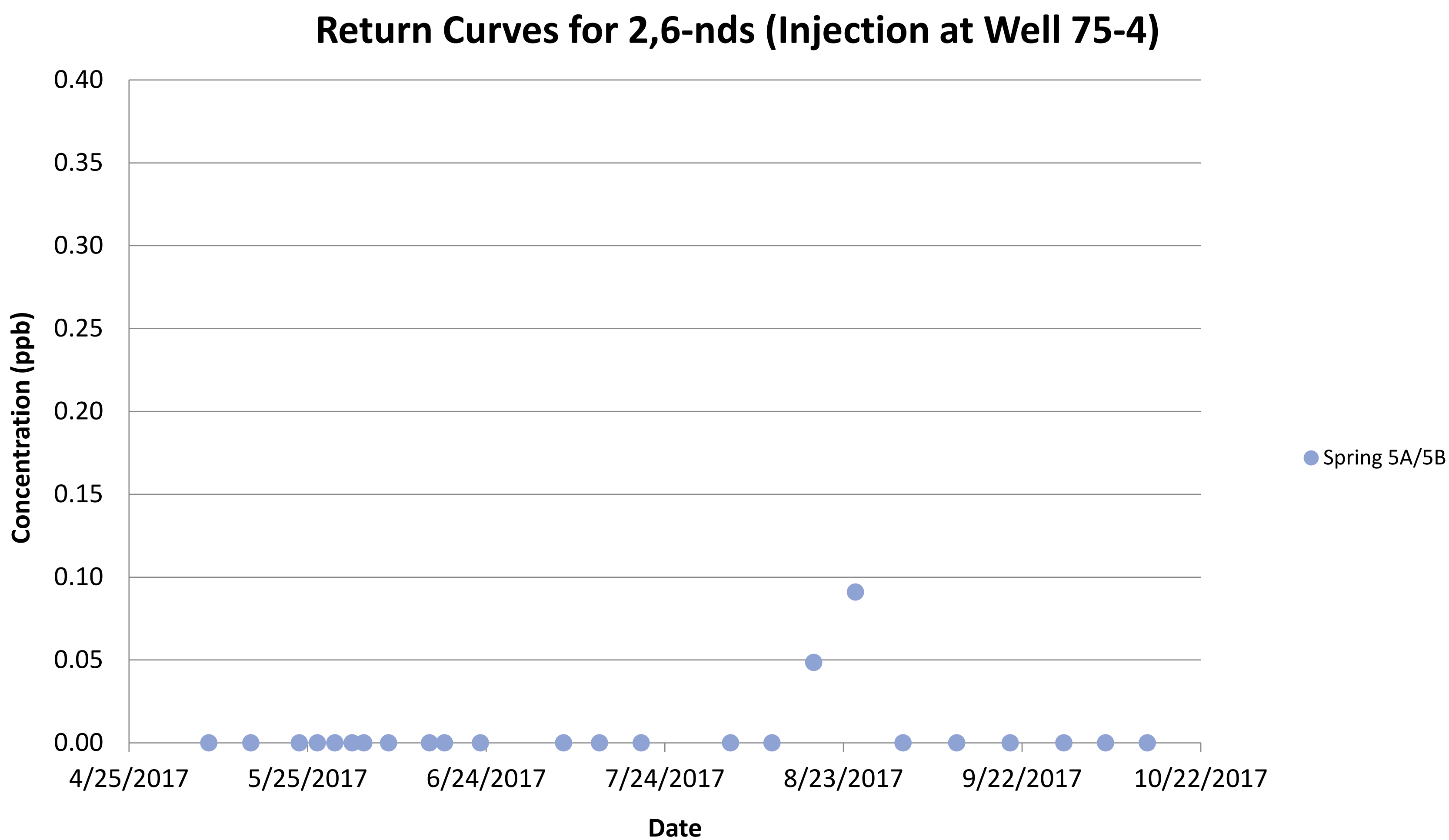
Environmental Engineering and Science

Title	Return Curves for 2,6-nds			
Project Name	Dixie Meadows	Project Number	ORM007	Figure M34
Client Name	Ormat	Date	4/26/21	



McGinley & Associates
Environmental Engineering and Science

Title	Return Curves for 2,6-nds		
Project Name	Dixie Meadows	Project Number	ORM007
Client Name	Ormat	Date	4/26/21
Figure	M35		

Table M1. Details for Existing Wells Near Dixie Meadows

Well ID**	Well Owner	Completion Date	Easting (m)	Northing (m)	TOC Elevation (ft amsl)	Borehole Depth (ft bgs)	Cased Depth (ft bgs)	Borehole Diameter (in.)	Well Diameter (in.)	Top of screen (ft bgs)	Bottom of Screen (ft bgs)	Well Completion Geology	SWL (ft bgs)	GW Elevation (ft amsl)
MW-1 (21-9)	-	7/27/2011	409,583.8	4,405,672.2	3,396.3	472	451	9.875	4	333	343	Quaternary alluvium and playa	24.9*	3,421.2
										385	395			
										410	430			
108770	USGS	9/15/2009	410,472.9	4,400,461.4	3,383.4	50	50	6.625	2	45	50	Quaternary playa	14.4	3,369.0
108771	USGS	9/16/2009	410,472.9	4,400,461.4	3,383.4	15	15	6.625	2	10	15	Quaternary playa	7.4	3,376.0
109435	USGS	3/19/2009	412,051.3	4,402,339.5	3,383.1	9.625	9.625	4	1	5.625	9.625	Quaternary playa	2.8	3,380.3
109491	USGS	3/17/2009	410,176.1	4,400,776.2	3,384.4	10	10	4	1	5	10	Quaternary playa	4	3,380.4
109574	USGS	3/10/2009	408,538.8	4,398,347.5	3,384.4	24.5	24.5	6.625	2	19.5	24.5	Quaternary alluvium and playa	0	3,384.4
21832	Phillips Petroleum Company	4/15/1978	-	-	-	200	200	4.75	1	N/A	N/A	Quaternary alluvium and playa	UNK	-
21833	Phillips Petroleum Company	4/1/1978	-	-	-	200	200	5.125	1	N/A	N/A	Quaternary alluvium and playa	UNK	-
23087	Nufuels Corps.	6/30/1981	-	-	-	1,460	151	UNK	UNK	N/A	N/A	Quaternary alluvium	105	-
23748	Nufuels Corps.	7/19/1981	-	-	-	500	160	8.75	6.625	N/A	N/A	Quaternary alluvium and playa	8	-
21834	BLM	n/a	-	-	-	300	300	5.625	1.25	N/A	N/A	Quaternary alluvium	UNK	-
22-8B	Ormat	7/27/2012	407,743.9	4,405,476.7	3,473.0	1,000	274	3.895	4.5	-	-	Quaternary alluvium	8.75	3,464.3
22D-8	Ormat	8/1/2019	407,755.0	4,405,482.0	3,481.6	4,010	1,342	8.5	7	N/A	N/A	Quaternary alluvium	40	3,441.6
23-8	Ormat	10/20/2015	407,916.9	4,405,313.3	3,462.8	4,700	829	3.895	4.5	-	-	Triassic siltstone	262.0*	3,724.8
23A-8	Ormat	3/2/2016	407,890.7	4,405,290.2	3,458.1	4,758	2,095	14.75	16	-	-	Triassic slate and siltstone	139	3,331.0
24(13)-8ST2	Ormat	9/21/2017	407,734.1	4,404,987.9	3,477.2	4,800	3,394	8.5-13	9.625-13.375	-	-	Triassic slate and Jurassic granodiorite	92	3,404.0
24A-8	Ormat	04/2016	407,729.0	4,404,984.4	3,483.1	750	151	3.895	4.5	-	-	Quaternary alluvium	142.9*	3,626.0
86-7	Ormat	8/9/2012	407,325.9	4,404,624.4	3,535.6	1,000	293	3.895	4.5	-	-	Quaternary alluvium	174.1*	3,709.7
42(12)-9	Ormat	10/26/2011	410,009.1	4,405,383.9	3,388.6	7,442	3,721	12.25	13.375	-	-	Tertiary tuff	273.5*	3,662.1
75-4	Ormat	1/21/2017	410,548.9	4,406,436.8	3433.0	5,476	2,493	12.25	13.375	-	-	Jurassic granodiorite and gabbro	142	3291

Data Source for well completion information: Nevada Division of Water Resources, Well Logs and Well Log Database, 2019; and Ormat (2019)

Coordinates in NAD 1983 UTM Zone 11N

*	Indicate water level in feet above ground surface. Calculated from gauge pressure.
**	NDWR Well Log ID Number, or Ormat ID Numaber
ft amsl	feet above mean sea level
ft bgs	feet below ground surface
in.	inches
m	meters
N/A	No screened interval or information not provided in Driller's Report
SWL	static water level
TOC	top of casing
UNK	Information not provided in Driller's Report

Table M2. Summary of Hydraulic Responses during Flow Testing								
Well ID	**Pressure (psi)**				**Depth to Water (fbgs)**			
	P_O	**Min P**	**ΔP**	**P_F**	**SWL**	**Max DTW**	**ΔDTW**	**DTW_F**
23-8	113.4	105	8.4	112.85	-	-	-	
24A-8	61.8	59.65	2.15	61.1	-	-	-	
42-9	118.49	104.95	13.54	116.2	-	-	-	
86-7	75.35	67.15	8.2	68.5	-	-	-	
22-8B	-		-	-	8.75	16	7.25	14.15

P_O	Original pressure = pressure recorded prior to flow testing
Min P	Minimum pressure recorded during flow testing
ΔP	Difference between Po and Min P
P_F	Final pressure = pressure recorded after completion of flow testing
SWL	Static water level = water level recorded prior to flow testing
Max DTW	Maximum depth to water measured during flow testing
ΔDTW	SWL - Max DTW
DTW_F	Final DTW = depth to water recorded after completion of flow testing

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