Two-Month Operational Test of Well W385 in Laws Wellfield Data Analyses

Los Angeles Department of Water and Power

September 2020

The Los Angeles Department of Water and Power (LADWP) has analyzed data from the 2019-20 Operational Test of W385 to assess the effect on nearby groundwater-dependent resources and to improve the hydrogeologic understanding of the aquifer system in the west Laws Wellfield in the vicinity of well W385. The groundwater level data collected during the two-month pumping and subsequent recovery periods generally exhibited expected trends within the aquifer system. This report presents the results of the analysis related to the groundwater level response to pumping and the local aquifer system characteristics. Groundwater quality samples collected before and near the end of the operational test were analyzed to improve understanding of the provenance of groundwater in the aquifer system based on isotope, general chemistry, and field measurements. Impacts to surface water levels were analyzed to assess any long-term implications of pumping. All results from monitoring and sampling are presented in the *Production Well W385 in Laws Wellfield Two-Month Operational Test Report.*

As detailed in this report, the results of the operational test indicate that pumping W385 over a two-month period at an average rate of 3.7 cfs has no significant effect on either Fish Slough areas of critical environmental concern or the shallow aquifer zone which supports native vegetation in the Five Bridges area south well W385.

Utilizing the data from this operational test and subsequent operational test of W386, the updated groundwater model of Bishop/Laws Wellfield will be used to simulated the operational tests and to recalibrate the model. The recalibrated model will be a robust tool in groundwater management in the area.

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--------------------------------- Background --------------------------------

2020-19 Operational Test

The Los Angeles Department of Water and Power (LADWP) conducted a two-month operational test in well W385, located in the Laws Wellfield, commencing on December 16, 2019 for 64 days and terminating on February 18, 2020 ("pumping phase"). The average pumping rate for the entire period of pumping was approximately 3.7 cfs and the total volume pumped was approximately 463 acre-feet. Groundwater levels in 30 wells (including W385) in the surrounding area and the stage (surface water elevation) of nearby surface water features were monitored throughout the pumping phase Monitoring continued from termination of pumping until March 31, 2020 ("recovery phase").

The primary goal of the two-month operational test of well W385 was to determine the effectiveness of modifying wells W385 (and nearby well W386, which was modified similarly) to minimize or eliminate the effect of pumping these wells on shallow groundwater levels south of Owens River in the Five Bridges Area and potentially in the Fish Slough Area to the north.

A secondary goal of the operational test was to improve the understanding of the hydrogeologic conceptual model of the area in the vicinity of well W385 (and well W386), and to utilize the data collected during the operational test to improve the groundwater flow model of the Bishop/Laws Wellfield through simulation of the operational test and subsequent recalibration of the model. This should result in a more robust modeling tool to evaluate potential effects of operating the pumping well.

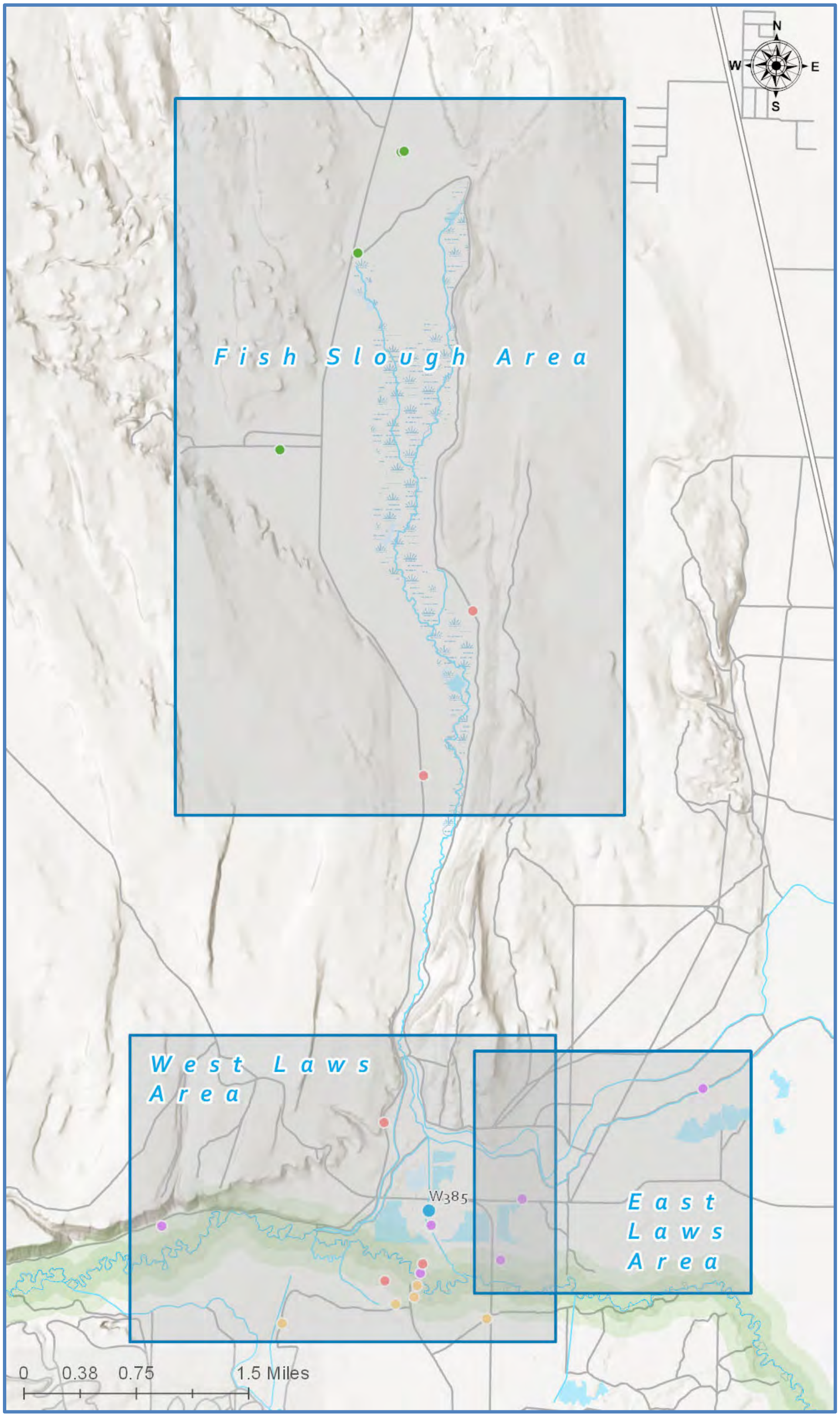

Figure 1 – W385 Operational Test Area of Study

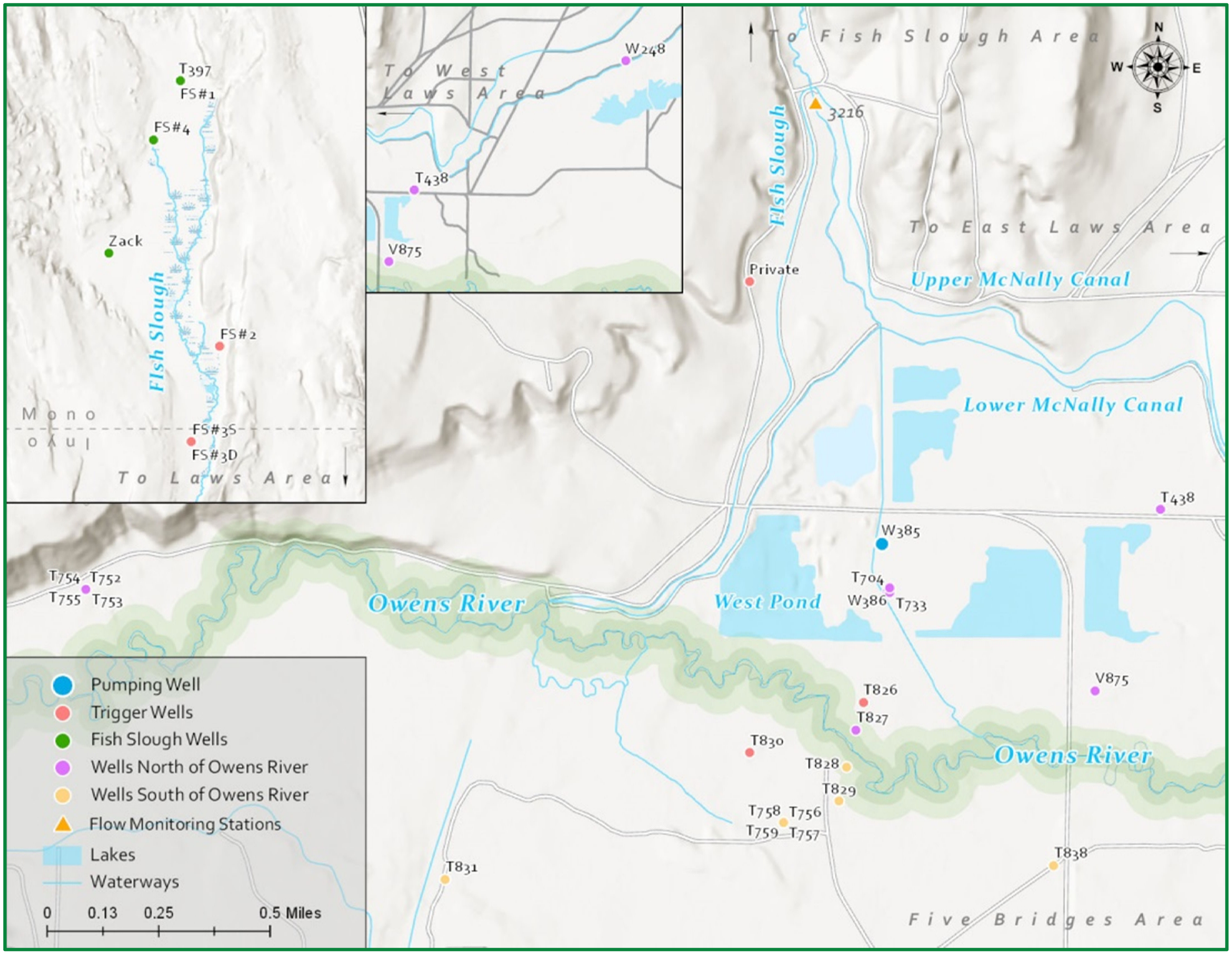

Figure 2 – W385 Operational Test Monitoring Wells and Surface Water Features
(Smaller Insets Not Scaled)

Well Modification

In 2014, LADWP modified W385 (and similarly W386) by sealing the portion of the wells screened in the shallow aquifer zone. Well W385 is now only screened from 323 to 550 feet below ground surface (bgs), resulting in a substantial reduction in its pumping capacity (from 10.1 to 3.7 cfs). This modification was designed to minimize or eliminate the effect of pumping on shallow groundwater levels, which sensitive vegetation in Fish Slough and the Five Bridges Area rely on.

Hydrogeological System

Based on W385 lithological and geophysical logs, the local aquifer system is generally stratified into two water-bearing zones: a shallow zone and deep zone, separated by the Bishop Tuff and a silt/clay semi-confining layer in between (**Error! Reference source not found.**).

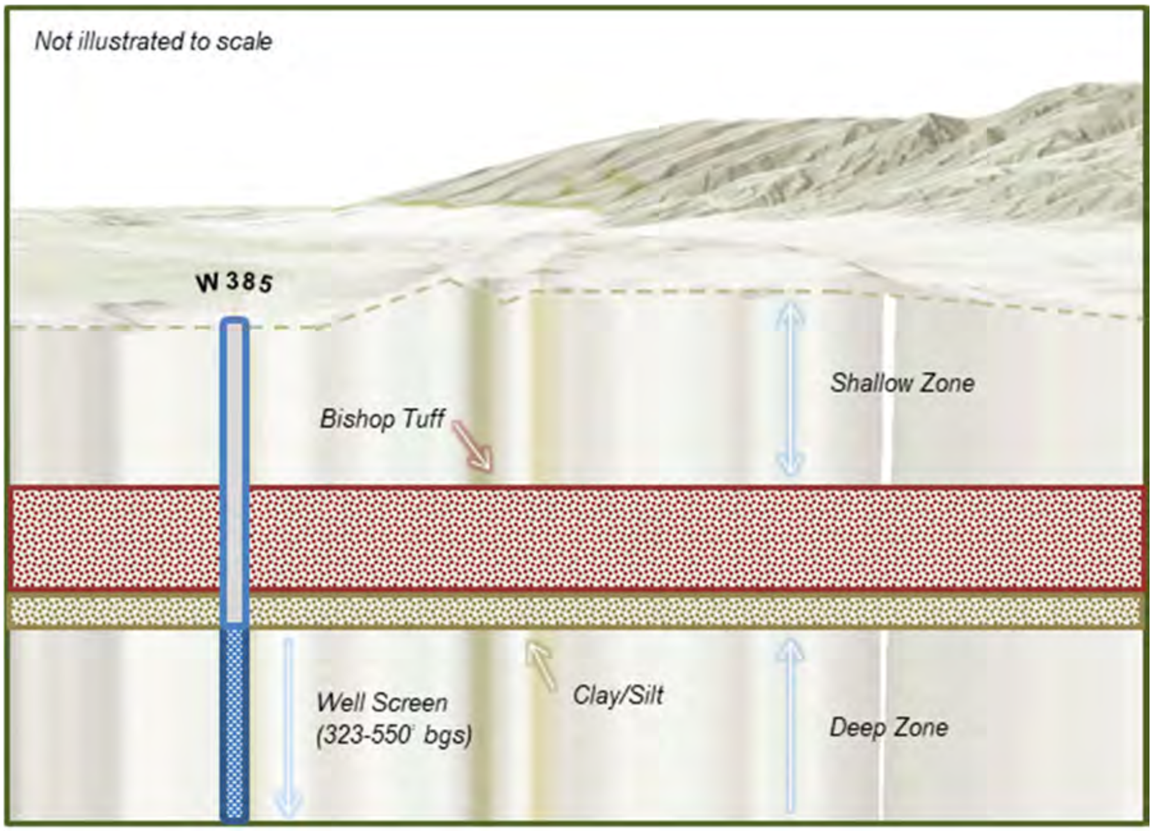

Figure 3 – Conceptualized Local Aquifer System Stratigraphy in the immediate vicinity of W385 (Looking North)

According to lithological and geophysical logs, the shallow zone consists of very coarse, permeable sediments (gravel and sand) from approximately 0 to 175 feet bgs. Volcanic sediments (pumice and tuff) are evident from approximately 175 to 290 feet bgs, which is likely the extent of the Bishop Tuff. The silt/clay layer is evident below the tuff from about 200 to 320 feet bgs, which is above the screen of W385. The deep zone consists of intermittent layers of medium to coarse sand/gravel mixtures and silt from approximately 320 to over 550 feet bgs. For reference, the W386 lithological log exhibits reddish pumice (likely tuff) layer between 200 to 320 feet flowed by clay lenses between 320 to 340 feet, supporting the presence of the semi-confining features evident in the W385 logs. The clay and tuff stratifications provide a net-confinement that restricts transmission from the shallow aquifer during W385's deep aquifer pumping.

A review of the lithological log of the nearby T752-T755 and T756-T759 well clusters show a similar clay/silt stratigraphy but at different depths, suggesting a complex geomorphological history of the area possibly influenced by intense faulting (see *Lithological* and *Geophysical Appendices*). However, there is no evidence of pumice/tuff in this area.

The logs of well cluster T756-T759 show a sandy formation from the surface to approximately 170 feet bgs (corresponding to the shallow zone), followed by sand interbedded with clay until roughly 500 feet bgs (corresponding to the deep zone). Thick clay formations in the deep zone around 250, 300, and 450 feet bgs are reflected in both the lithological and geophysical logs. Whether this formation maintains a consistent depth interval throughout the local region or is interrupted by faulting would require additional investigation and testing to determine.

At cluster T752-T755, the shallow zone extends to only approximately 77 feet bgs. A thin sandy/silty formation is encountered again around 150 feet bgs, but it is followed by a thick clay formation with thin interbeds of sand until approximately 500 feet bgs, according to lithological logs. The geophysical logs, however, only show the presence of silty/clayey sediments from 175 to 350 feet bgs. The similarity in lithology (as confirmed by both the lithologic and geophysical logs) between these two well clusters suggests there is consistency in the regional extent of the semi-permeable formation. While the exact thickness may vary, it is unlikely to be a discontinuous lens.
All these findings contribute to the conceptual aquifer stratigraphy model of the immediate vicinity of W385 presented in Figure 3 and used for initial analyses purposes.

Although the initial conceptual model is likely accurate in the immediate W385 area, it is likely variable throughout the entire area of study, especially farther away from W385. North of W385 in the Fish Slough area is the Volcanic Tableland, an eastward-dipping topographic feature comprised of thick ash and welded tuff of the Bishop Tuff with numerous discontinuous faults (Jayko and Fatooh, 2010). Tuff encountered below 100 feet in W385 was encountered below approximately 20 feet bgs in the Fish Slough area, indicating that tuff semi-confinement exists at shallower depths in this area (LADWP, 2019).

Further investigation and analyses presented in this document lead to a more representative conceptual stratigraphy model of the Laws area aquifer system farther away from W385 presented in further sections.

Local Fault System

Quaternary (Q) faults, strike-slip faults typically striking north-south, streak the landscape in Laws Wellfield. These active faults likely impede and facilitate groundwater flow and surface/groundwater interactions (USGS, 1964; Jayko and Fatooh, 2010). Based on geospatial data sourcing from the USGS Quaternary Fault and Fold Database (USGS, 2020), there are multiple strike-slip and normal faults within the immediate vicinity of W385 (Figure 4). The extensive normal fault system potentially traps and/or compartmentalizes parts of the aquifer (Ferrill, 1999). Based on the monitoring data, the nearest faults (one between W385 and T438; and one between the T752-T755 cluster and W385) likely have minimal impact on the operational test results. However, the Fish Slough Fault Zone east of T438 and west of W248 appears to impede groundwater flow across the east/west directions (USGS, 1964) as supported also by the minimal response at W248 during the operational test.

Figure 4 – Quaternary Faults in Area of Study (USGS, 2020)

--------------------- Groundwater Level Response ---------------------

Multiple factors affect the monitoring well groundwater level responses including W385 pumping. These include depth of monitoring well screens relative to the aquifer zone from which W385 pumps, locations of monitoring wells relative to W385, potential roles of faulting, and time elapsed since the start of pumping. This section is broken down into two perspectives for analyzing groundwater level responses from W385 pumping: well depth corresponding to the conceptualized aquifer stratigraphy model in the immediate vicinity of W385 and geospatial position of wells relative to W385.

Aquifer Stratigraphy

The groundwater responses in two generalized zones of the water-bearing aquifer system (shallow and deep) to the operational test were analyzed separately. Based on the conceptual aquifer stratigraphy model in the immediate vicinity of W385, monitoring wells were classified by zone according to their respective depths below ground surface, such that groundwater level measurements in each well indicate the water level of its respective aquifer zone. Stratigraphy throughout the area of study however is variable, and as will be discussed later, further review and analysis of the results improve the conceptual understanding of the aquifer stratigraphy throughout the area of study Test Hole (T) wells are typically screened within the 20 feet of the bottom of the well casing, which is approximately the total depth of the well.

The following classification of said wells is not exact due to the varying stratigraphy. This simplified stratigraphy classification is for initial analysis purposes.

Deep Zone

Wells measuring groundwater level primarily in the deep zone range from 310 to 680 feet in total depth and their distances from W385 vary from 0.1 to 2 miles (Table 1).

Table 1 – Wells Screened in the Deep Zone

Well	Total Depth (ft)	RP Offset from Ground (ft)	RP Elevation (ft-amsl)	Distance (Direct.) from W385 (mi)
T757	310	2.26	4154.86	0.7 (SW)
T755	490	2.99	4200.19	1.8 (W)
W385	550	2.50	4151.26	-
W386	550	3.64	4153.44	0.1 (S)
T758	575	2.24	4154.84	0.7 (SW)
W248*	602	0.28	4141.98	2.0 (NE)
T733	674	1.44	4151.24	0.1 (S)
T752	680	2.97	4200.17	1.8 (W)

**Additionally screened throughout the shallow zone.*

Drawdown Observations

The seven deep monitoring wells generally exhibited expected trends in groundwater levels (i.e. drawdown during pumping and recovery during post-pumping period; Figure 5). Drawdown in W248 and T757 will be described in subsequent sections, because they were likely affected by hydrogeologic features. Drawdown in Private well will also be described in a subsequent section, because it is so similar to those of the deeper wells as it is screened mostly in the Bishop Tuff.

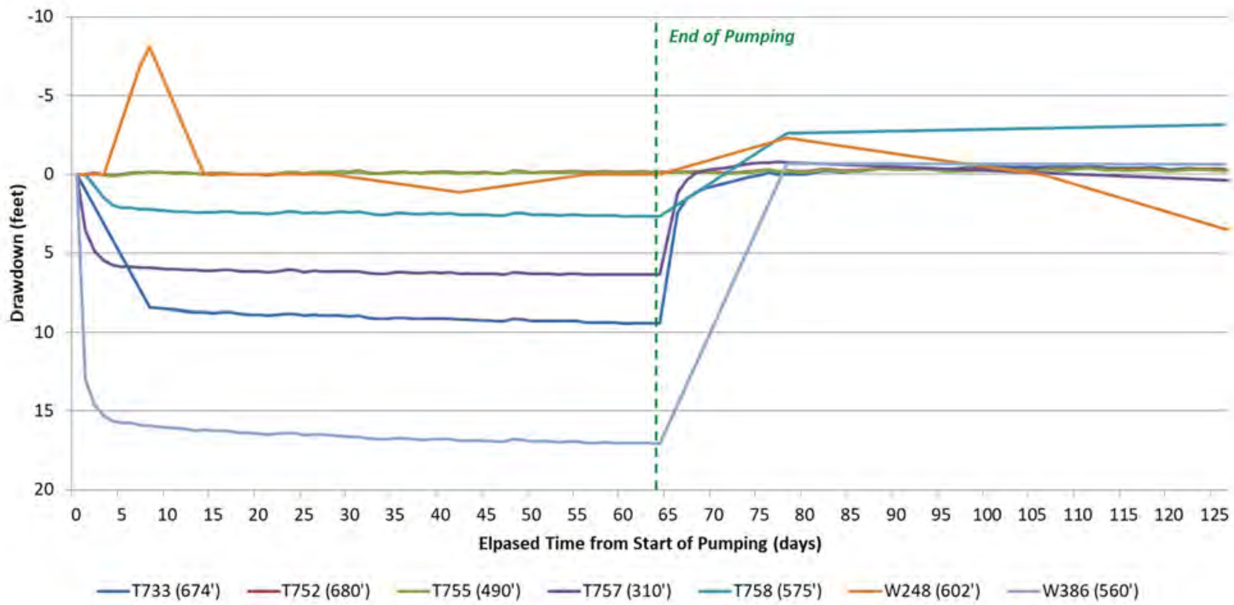

Figure 5 –Drawdown Hydrograph for Deep Wells during W385 operational Test

Water surface elevations (WSEs) at T752 and T755 throughout the operational test were higher than the other wells, likely due to semi-confinement and other differences in hydrogeology in this western part of the area of study. Conversely, the WSE at W248 was lower (Figure 6).

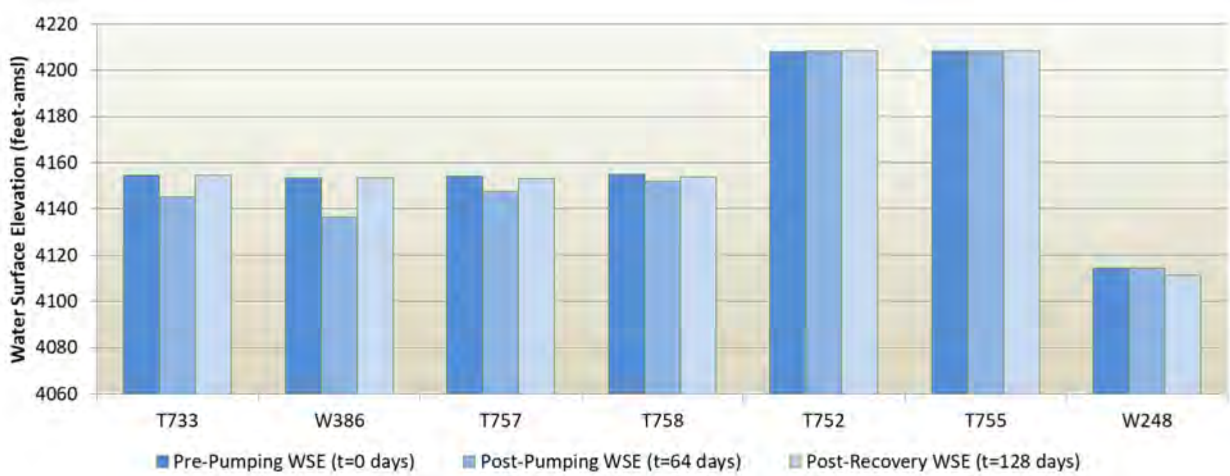

Figure 6 – WSE for Deeps Wells during W385 operational Test Milestones

W248 Drawdown

W248 is screened at intervals from 30 to 250 feet and 350 to 500 feet bgs. W248 is also two miles northeast of W385, so the borehole stratigraphy may differ from the conceptualized model presented. Groundwater levels at W248 exhibited an unexpected behavior of high recharge at *t = 3 days* of pumping and then diminishment of said recharge sometime after *t = 8 days* (groundwater levels in this well were recorded weekly, not daily). After *t = 28 days*, some drawdown occurred, but the water level rebounded to static levels after *t=42 days*. These phenomena may be due to the Fish Slough Fault Zone between W248 and W385, which may retard groundwater flow between these two parts of the aquifer system. Additional investigation is needed to deduce what may be the cause, but this is generally beyond the scope of this report.

T757-T759 Cluster Drawdown

Drawdown in T757 is initially intriguing because of the drawdown in T758 (both are within the same cluster). Although T758 is 265 feet deeper than T757 (575 vs. 310 feet), more drawdown occurred at T757 than T758 (about 4 feet). Drawdown over distance was analyzed for the deep wells at *t= 64 days*, the end of the operational test (Figure 7). Distance-drawdown data typically follow a logarithmic trend of which all the deep wells follow except for T757. This is more apparent on a logarithmic x-axis scale (Figure 8).

Furthermore, T759 (a shallow well within the same cluster) is 100 feet shallower than T757 (and 365 feet shallower than T758), yet it exhibits roughly the same drawdown in T758. These results suggest firstly that T759 and T758 are screened in the same aquifer zone, which supports the geophysical log for this cluster that exhibits the shallow zone ending at about 170 feet bgs, followed by the semi-confined deep zone. Secondly, these results suggest that T759 and T758 are still closely linked to the deep zone from which W385 pumps, although separated by 100 feet.

Thirdly, the results suggest that T757 is more susceptible to the effects of W385 pumping than T758 and T759. T757, which is screened from 280 to 310 feet bgs, is screened within the gravel pack which extends from 170 to 500 feet bgs. Therefore, T757would have a greater drawdown than the other two, which are less exposed to this gravel pack. This exposed zone is likely the sandy layer in between the thick clay layers observed at 250 and 300 feet bgs on the lithological log. T757 is also likely in the same stratigraphic zone as W385's screen, while T758 and T759 are slightly above and below, respectively, this zone.

There may also be fault activity influencing the groundwater level at T757, although no evidence of faults have been recorded.

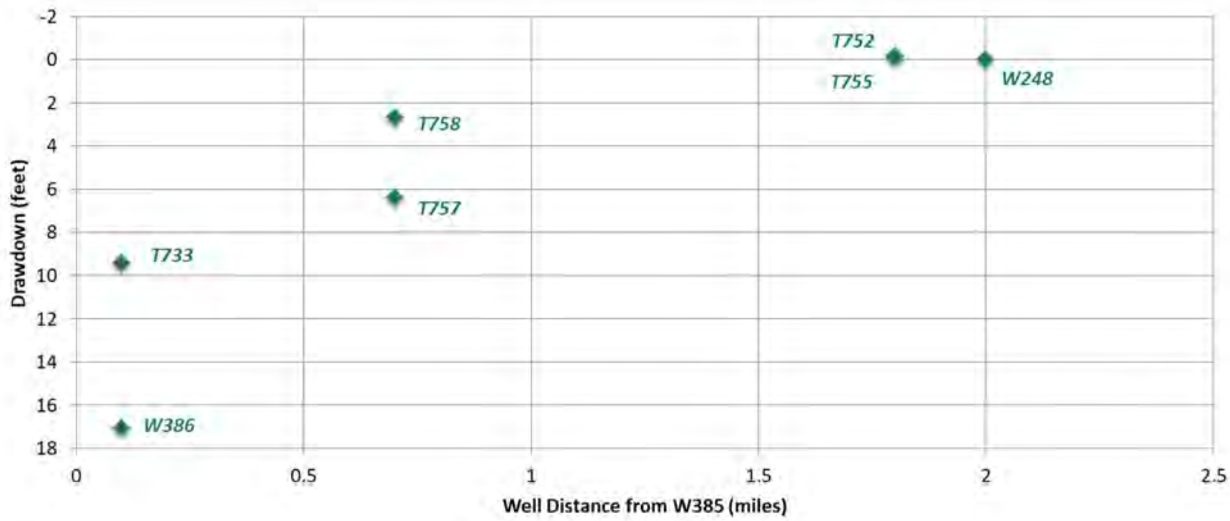

Figure 7 – Distance-Drawdown Plot for Deep Wells at End of W385 operational Test (t = 64 days) (Normal Axes)

Figure 8 – Distance-Drawdown Plot for Deep Wells End of W385 operational Test (t = 64 days) (Log x-axis)

Private Well Drawdown

Although Private Well, screened from 90 to 150 feet bgs, does not follow deeper well classification based on the conceptual aquifer stratigraphy model of the immediate vicinity of W385, it followed the same distance-drawdown trend as the deep wells (Figure 9; T759 is also presented). This is likely because the Bishop Tuff is lies at a shallower depth farther north from W385, so Private is likely deep enough to be influenced by W385 pumping. It is actually screened mostly in the Bishop Tuff, which is supported by lithological logs exhibiting intermittent tufa formations from 12 to 160 feet bgs. Although 2 feet of drawdown occurred at W385, the net confinement of the entire Bishop Tuff likely restricts transmission from the shallow zone due to W385 operation.

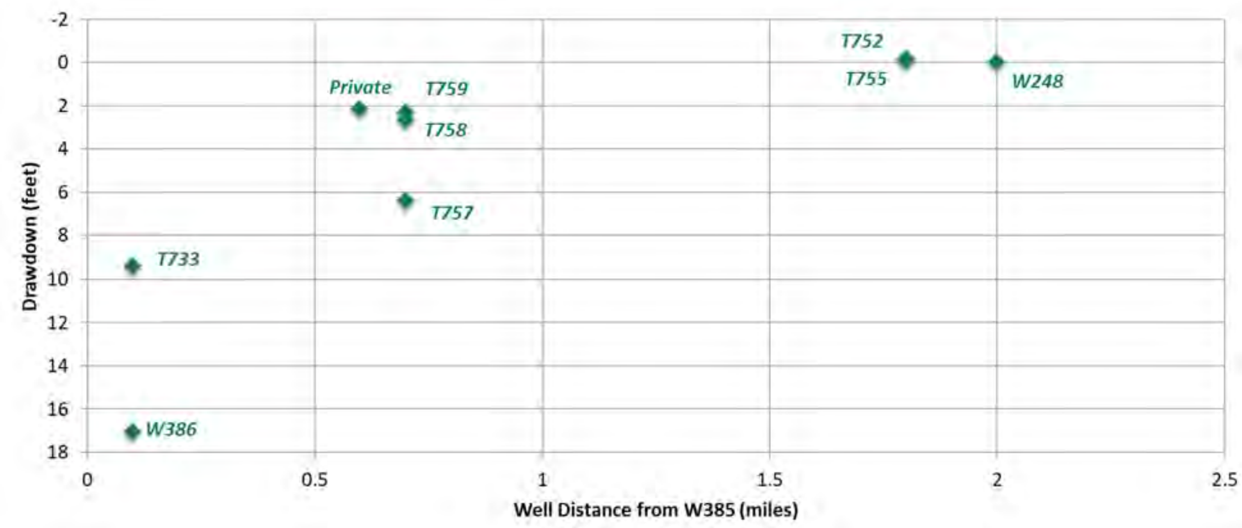

Figure 9 – Distance-Drawdown for Deep Wells End of W385 operational Test (t = 64 days) with T759 and Private Well Added

Shallow Zone

Wells penetrating the shallow zone span total depths from 8 to 257 feet bgs and vary in distances from W385 from 0.6 to 7.1 miles (Table 2). However, FS #3D, Private Well, T397, Zack, and T759 are all likely screened below the shallow zone than the initial conceptual model suggests due to the thinning out of Bishop Tuff and semi-transmissive clay lenses.

Table 2 – Wells Screened in the Shallow Zone

Well	Total Depth (ft)	RP Offset from Ground (ft)	RP Elevation (ft-amsl)	Distance (Direct.) from W385 (mi)
FS #4	8	1.98	4221.98*	6.4 (N)
T831	10	0.99	4176.49	1.2 (SW)
T830	14	1.05	4154.25	0.6 (SW)
T828	15	0.98	4147.68	0.5 (SW)
T827	16	0.25	4147.95	0.4 (S)
T826	17	0.94	4148.54	0.4 (S)
T829	17	1.98	4149.68	0.6 (SW)
V875	21	1.84	4132.85	0.6 (SE)
T704	32	2.33	4150.63	0.1 (S)
FS #3S	35	2.76	4194.22	2.8 (N)
T438	37	3.21	4142.11	0.6 (E)
T838	37	1.89	4137.29	0.8 (SE)
T756	45	2.00	4154.60	0.7 (SW)
FS #2	46	1.80	4185.25	4.0 (N)
FS #1	61	1.82	4201.82*	7.1 (N)
T753	100	1.97	4199.17	1.8 (W)
FS #3D	145	2.59	4194.84	2.8 (N)

Private Well	160	1.00	4186.00*	0.6 (N)
T397	180	1.87	4230.07	7.1 (N)
T754	210	3.82	4201.02	1.8 (W)
T759	210	1.78	4154.38	0.7 (SW)
Zack	257	1.18	4227.18*	5.2 (N)

*Ground elevation was estimated based on an elevation profile generated from Google Earth

Aquifer Drawdown

For visual ease, the six deepest shallow wells – T753, FS #3D, Private, T397, T754 and T759 – were plotted and analyzed separately. Five of these seven shallow wells exhibited little to no drawdown, while the aforementioned T759 and Private Well exhibited drawdown similar to deep wells (see the previous section; Figure 10). T759 and Private Well are also considerably closer to W385 than the rest of the wells, to which the response behavior may be attributable.

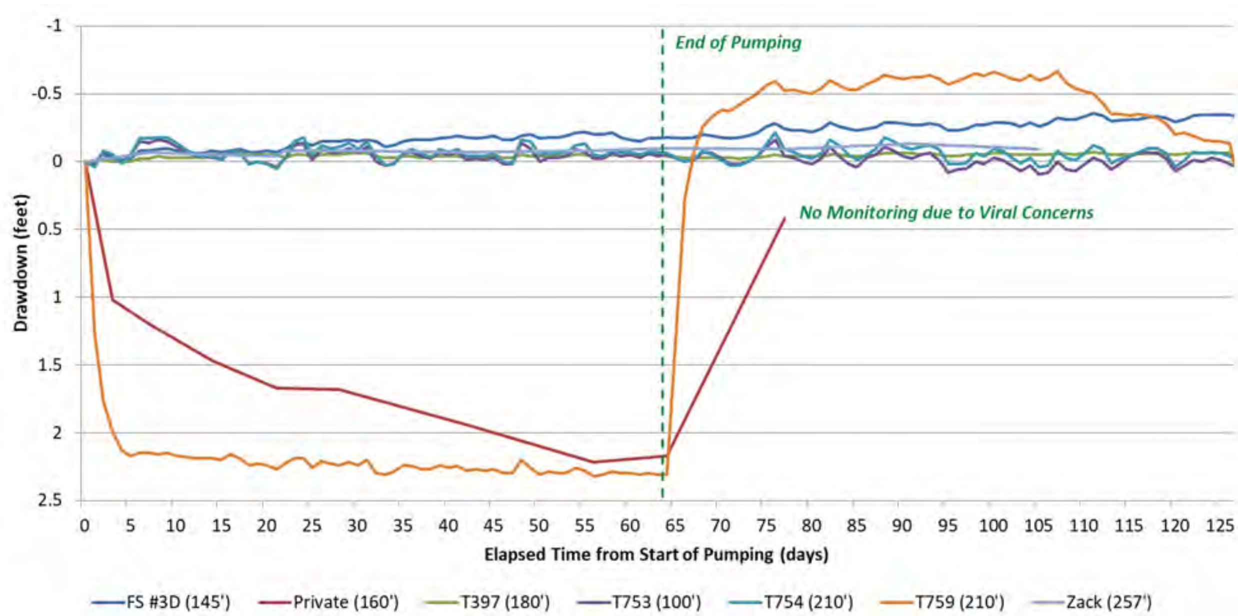

Figure 10 – Time-Drawdown for Shallow Wells (Deeper Set) during W385 operational Test

The 14 shallower wells (FS #2 was dry) span depths from 8 to 61 feet bgs and vary in distances from W385 from 0.1 to 7.1 miles (Table 3). FS #3S, FS #2, and FS #1 may be screened in the deep zone depending on how shallow and thin the Bishop Tuff is.

Most of these shallow wells exhibited minimal groundwater level response from pumping (Figure 11). Five even recharged throughout the operational test with some nearing and surpassing one foot of groundwater level increase. Three experienced essentially no change. The other wells experienced some drawdown but no more than one foot. Based on the results, W385 operation minimally impacted shallow groundwater levels throughout the area of study, supporting the effectiveness of the W385 modification.

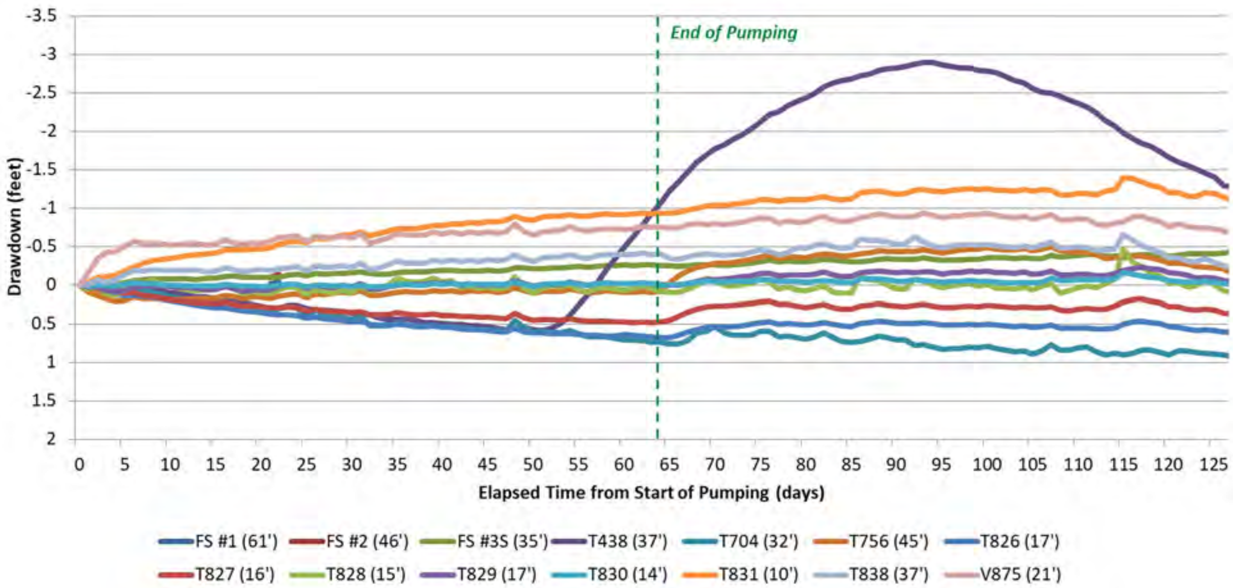

Figure 11 –Time-Drawdown for Shallow Wells during the W385 Operational Test

Drawdown over distance was analyzed for the shallow wells at *t= 64 days*, the end of the pumping phase (Figure 12). The majority of the wells did not show any drawdown or experience groundwater level rise. The maximum drawdown measurement at Day 64 was less than 0.8 feet. The data does not appear to follow any particular trend.

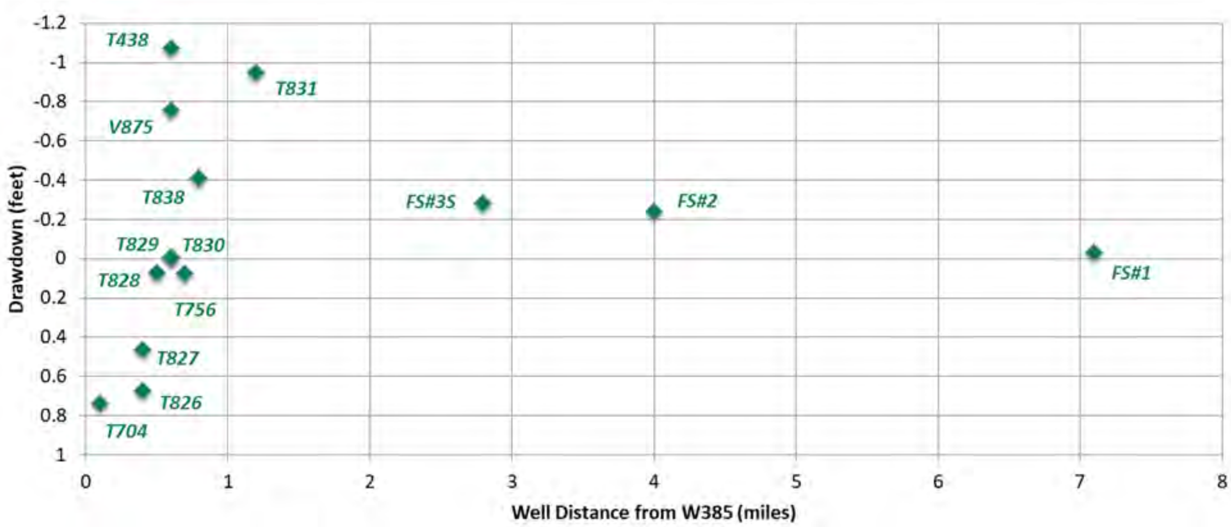

Figure 12 – Distance-Drawdown for Shallow Wells at *t = 64 days*

Geospatial Positioning

Wells were grouped spatially regardless of well depth to analyze aquifer system behavior throughout the area of study. Wells were categorized into five geographic groups of the aquifer system relative to distance from W385: *Western*, *Southern*, *Central*, *Eastern*, *and Northern (Fish Slough) Groups* (Figure 13). Some isolated wells are not included in the grouping.

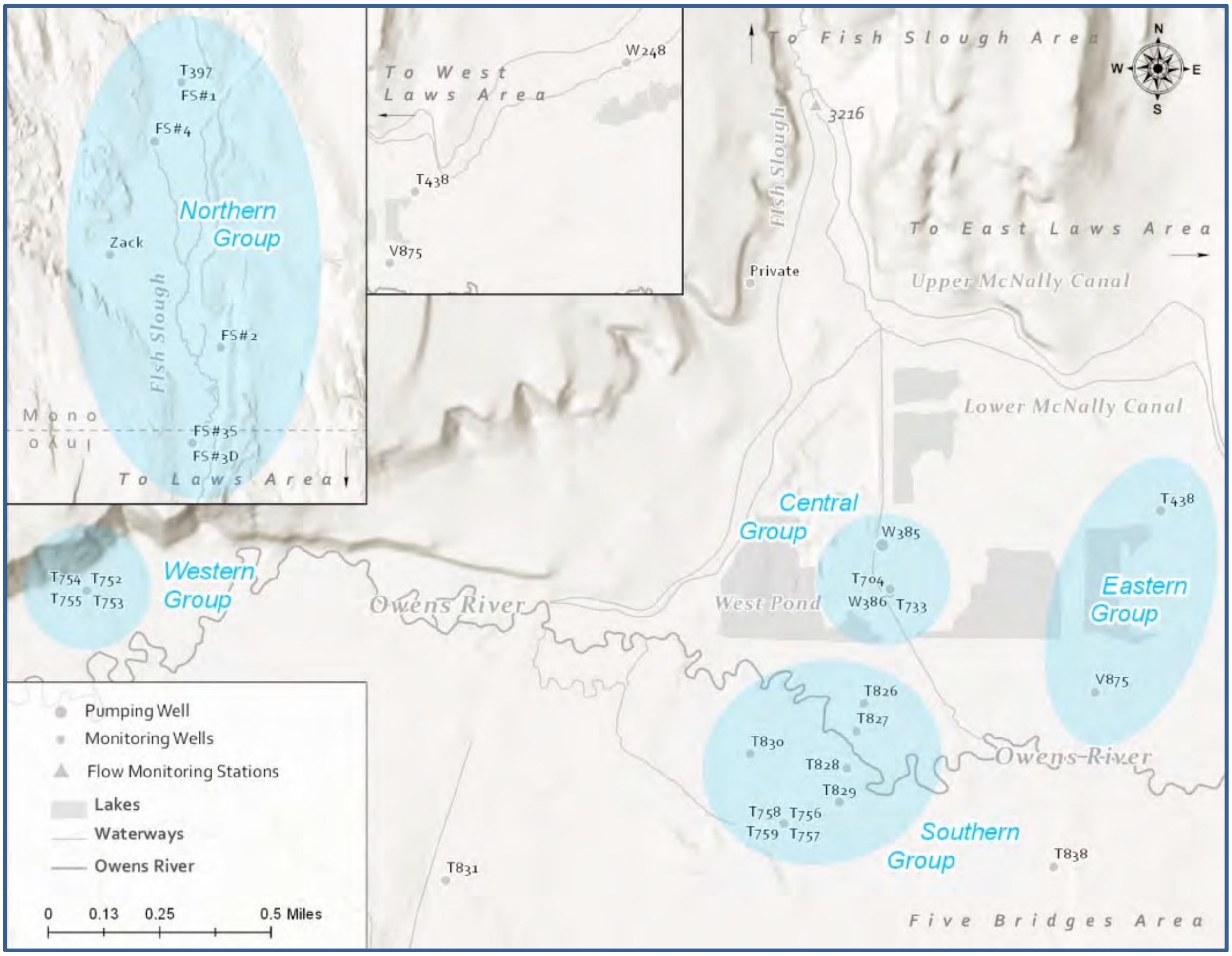

Figure 13 – Aquifer System Geospatial Groups in Area of Study

Western Group

The T752-T755 cluster comprises the wells in the Western Group (Table 3).

Table 3 – Western Group Well Characteristics

Well	Total Depth (ft)	Distance from W385 (mi)
T752	680	1.8
T753	100	1.8
T754	210	1.8
T755	490	1.8

The four wells follow a similar trend in drawdown over time with comparable amplitudes (Figure 14). These wells experienced minimal drawdown, likely because of their distance from the pumping well.

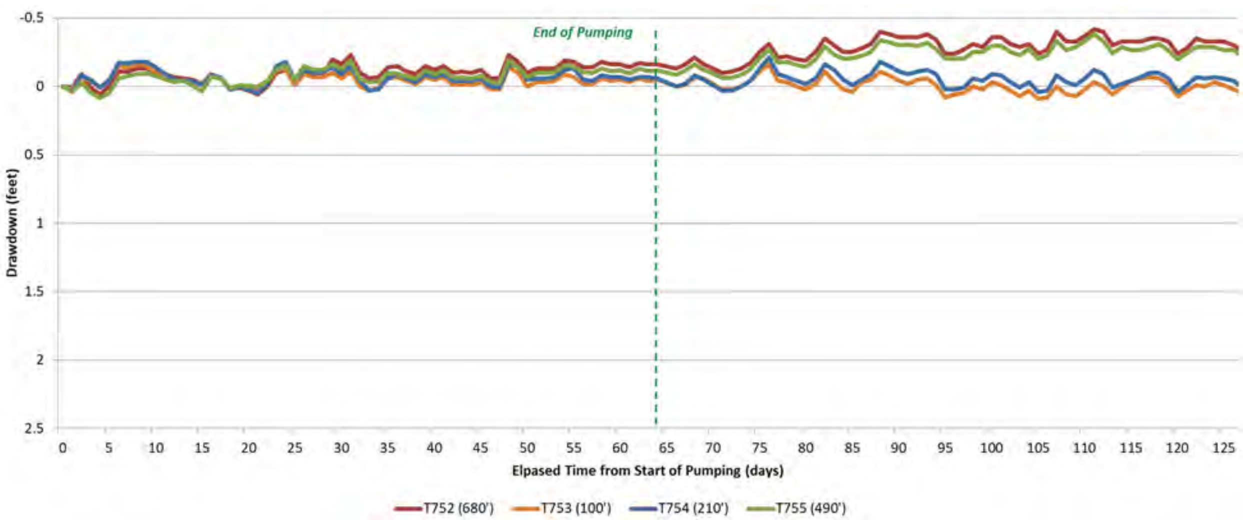

Figure 14 – Western Group Drawdown during W385 Operational Test

The WSEs at T752 and T755 are considerably higher than T753 and T754 (Figure 15). The former wells similarly flow artesian, likely due to confining zones above 460 feet bgs (above the well screen of T755). Similarly, T754's screen is likely below some confinement, since its WSE is higher than T753.

Figure 15 – Western Group WSEs during W385 Operational Test Milestones

Well depth vs. drawdown data for the cluster monitoring wells at *t = 64 days* exhibit a linear trend (Figure 16). T753, the shallowest well, exhibits more rise than the trend suggests, likely indicating a formation between 100 and 210 feet bgs that differs in transmissivity from the rest of the aquifer system, which is supported by lithological logs. The confining layer near W385 likely extends to the Western Group. This trend, however, has no discernible relationship with pumping activity. The Western Group of wells was likely unaffected by the operational test.

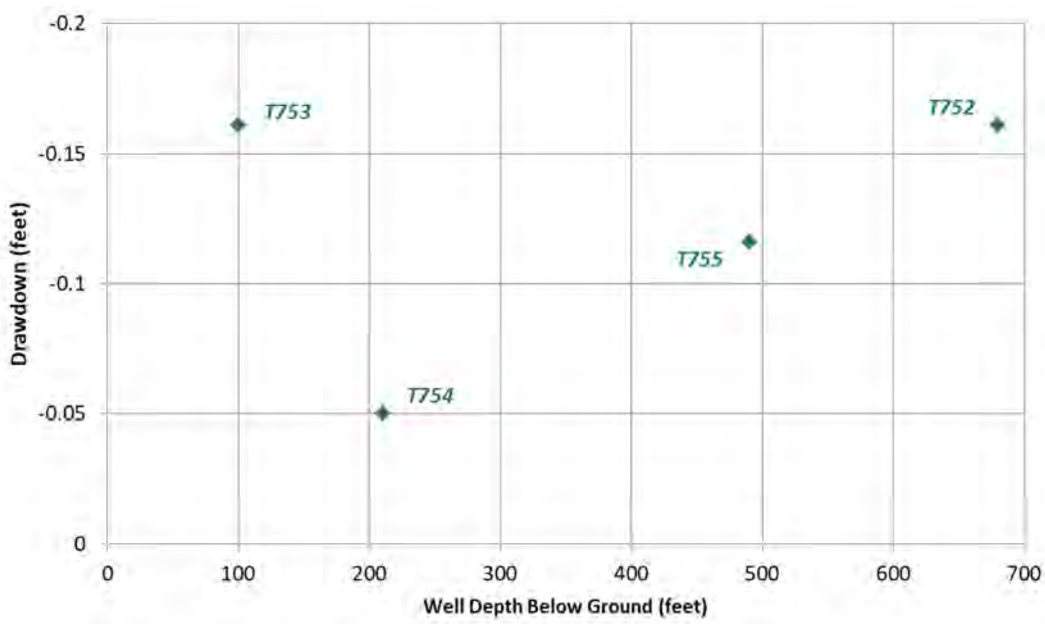

Figure 16 – Western Group Well Depth vs. Drawdown Plot End of W385 Operational Test (t = 64 days)

Southern Group

The T756-T759 cluster and nearby wells close to the Owens River comprise the wells in the Southern Group (Table 4).

Table 4 – Southern Group Well Characteristics

Well	Total Depth (ft)	Distance from W385 (mi)
T756	45	0.7
T757	310	0.7
T758	575	0.7
T759	210	0.7
T826	17	0.4
T827	16	0.4
T828	15	0.5
T829	17	0.6
T830	14	0.6

The drawdowns in monitoring wells T757, T758, and T759 are higher than the other wells in the Southern Group (Figure 17). These wells are farther from W385 than the other wells in the group, but they are much deeper. The shallow monitoring well T756, which is clustered with T757, T758, and T759, experienced little drawdown. This indicates the effectiveness of the net semi-confining layer separating T756 from the effects of W385 pumping.

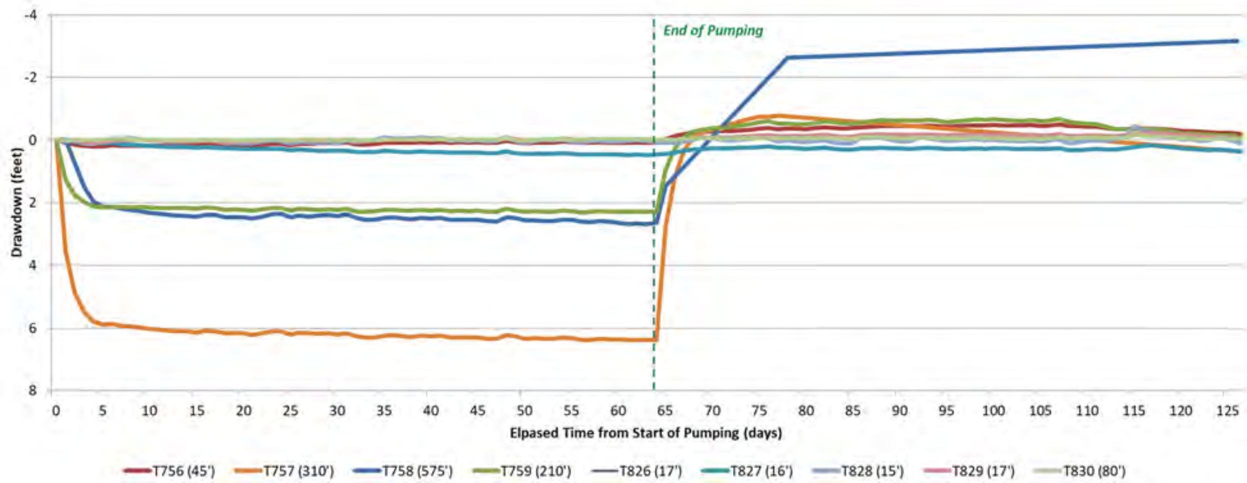

Figure 17 – Southern Group Drawdown during W385 Operational Test
**T758 remained artesian after t = 126 days*

The WSEs were considerably lower for the shallow wells near Owens River than the cluster wells, although T830 was not (Figure 18). This is likely due to the lowering of ground surface elevation towards Owens River, which is at approximately 4,143 ft amsl (above mean sea level). All wells exhibited significant recovery by *t = 128 days*. T756 has a lower WSE than the other cluster wells, likely because it reflects the groundwater level of the shallow aquifer.

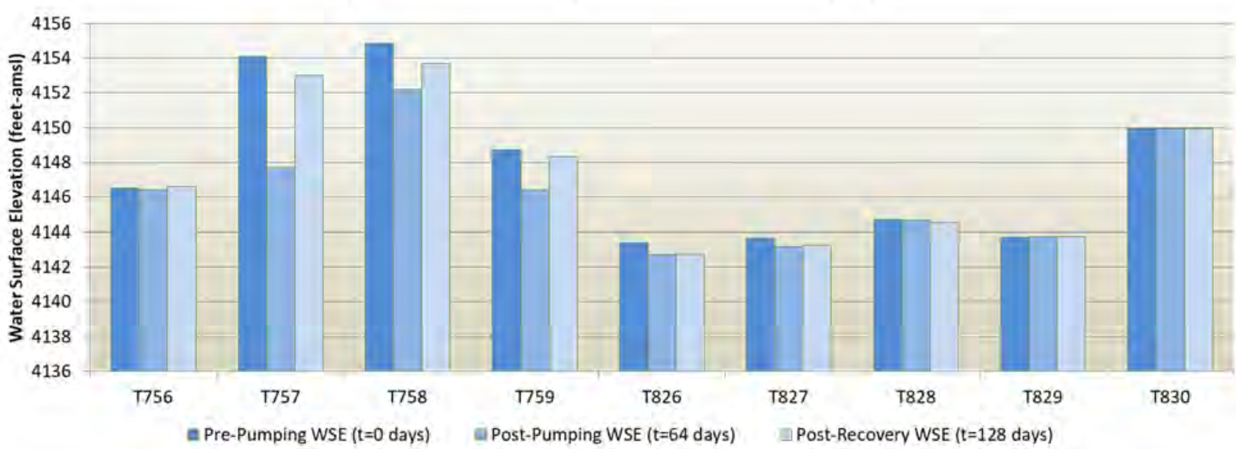

Figure 18 – Southern Group WSEs during Operational Test Milestones
**T758 was artesian prior to and after the pumping test (these two measurements presented are equal because exact water level is unknown)*

Well depth vs. drawdown data for wells in the Southen Group follow a general trend of experiencing less drawdown than deeper wells (Figure 19). However, T758, which is 575 feet deep, experienced drawdown comparable to T759. W385 pumping generally affected the Southern Group as expected (i.e. minimal effect on shallow wells). Seasonal pumping will likely have no singificant effect on the grounwater levels in the shallow aquifer in this area. Wells screened in the deep zone generally recovered quickly or have mostly recovered, exhibiting no long-term effects from pumping (recovery is slower in T758).

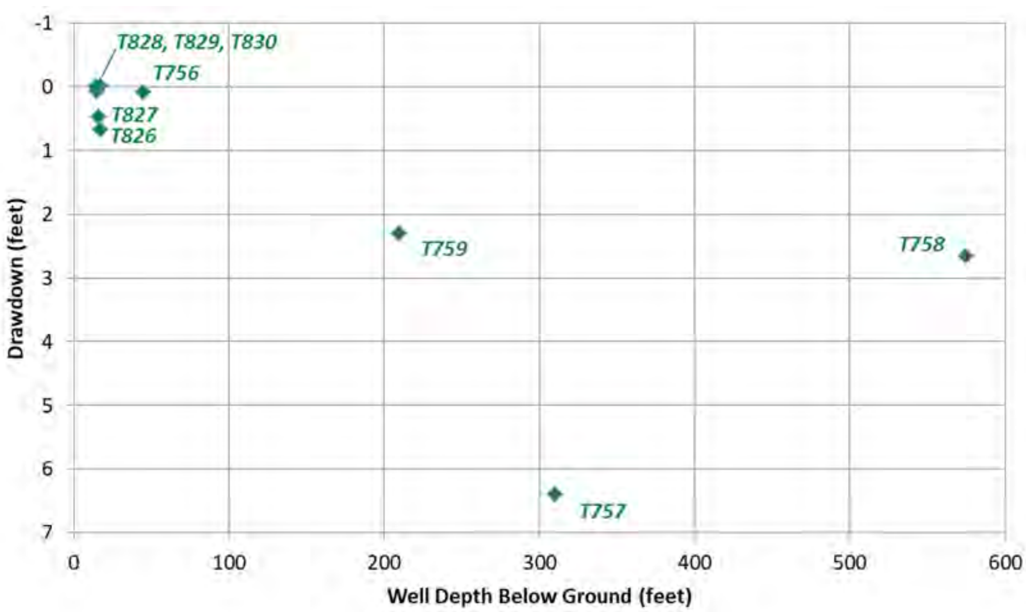

Figure 19 – Southern Group Well Depth vs. Drawdown at the End of W385 Operational Test (t = 64 days)

T756-T759 Cluster

Drawdown in T758 and T759 was similar, indicating that the two wells likely measure groundwater levels in distinct parts of the deep zone with comparable transmissivities (Figure 20). These parts are separated likely by intermittent semi-confining layers. A highly transmissive zone exists at T757's screen (310 feet bgs), which is connected to the deep zone from which W385 pumps. This is supported by lithological logs. T756 experiencing minimal drawdown supports the effectiveness of the net confinement between the deep zone and its screen (especially compared to the drawdown only 165 feet below it).

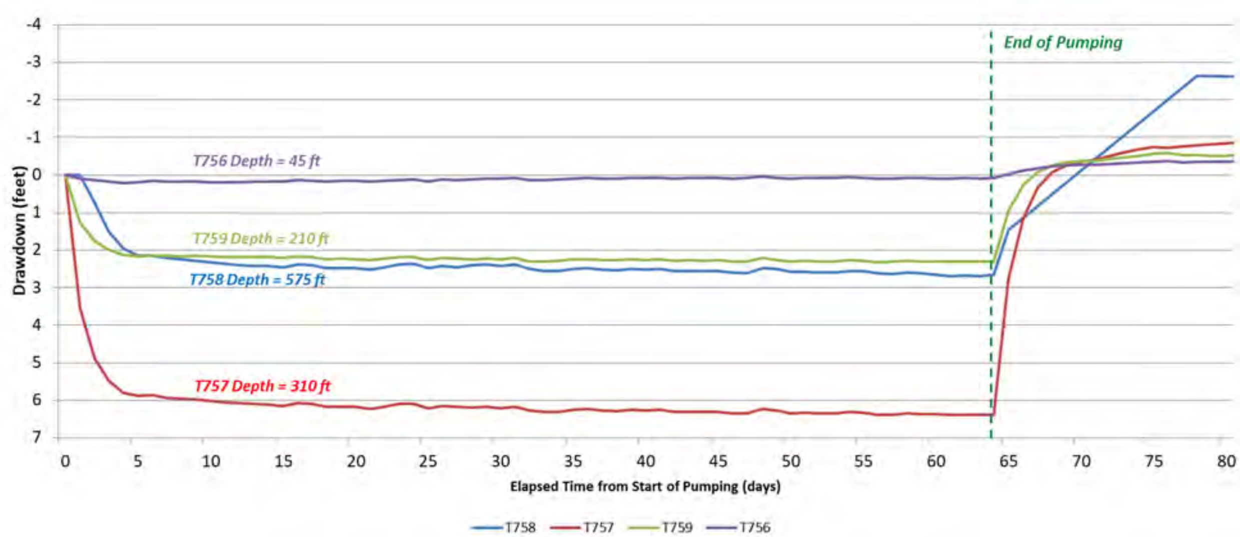

Figure 20 – T756-T759 Cluster Drawdown during W385 Operational Test

Central Group

Three wells just south of W385 comprise the wells in the Central Group (Table 5).

Table 5 – Central Group Well Characteristics

Well	Total Depth (ft)	Distance from W385 (mi)
T704	32	0.1
T733	674	0.1
W386	550	0.1

Both deep wells, T733 and W386, exhibited expected drawdown over the course of the operational test, while T704 exhibited a constant and very slow decline (even after pumping stopped) that may or may not be attributable to the operational test (Figure 21). The differences in groundwater level response in these wells to pumping W385 indicate an effective net confinement between the shallow and deep zones of the aquifer in the vicinity of W385.

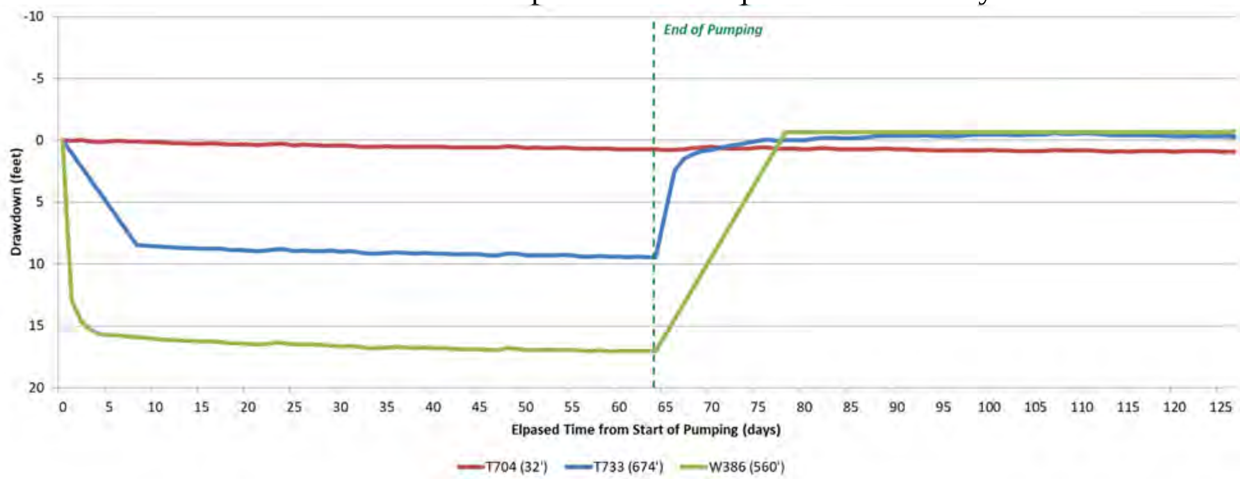

Figure 21 – Central Group Drawdown during W385 Operational Test

Post-recovery returned to intial pre-pumping levels (Figure 22). Long-term seasonal pumping of W385 will likely not have significant effects on the groundwater table for the Cenral Group based on these results.

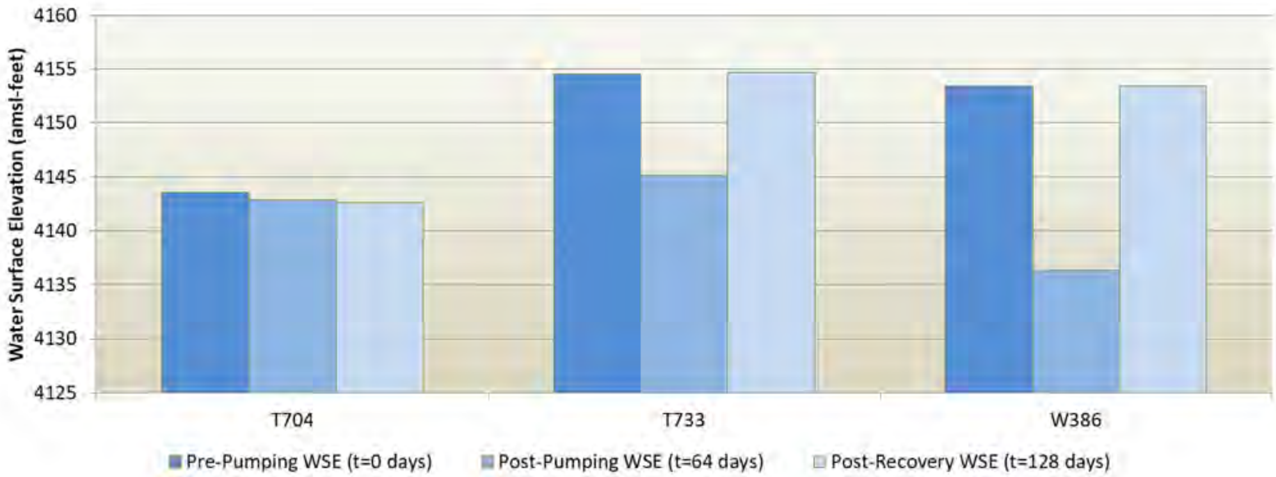

Figure 22 – Central Group WSEs during W385 Operational Test Milestones

Well depth vs. drawdown for the Central Group wells exhibited a linear trend, in which deeper wells experienced more drawdown that shallower ones (Figure 23), which again is an indication of an effective confinement beetweeen the shallow and deep aquifer zones.

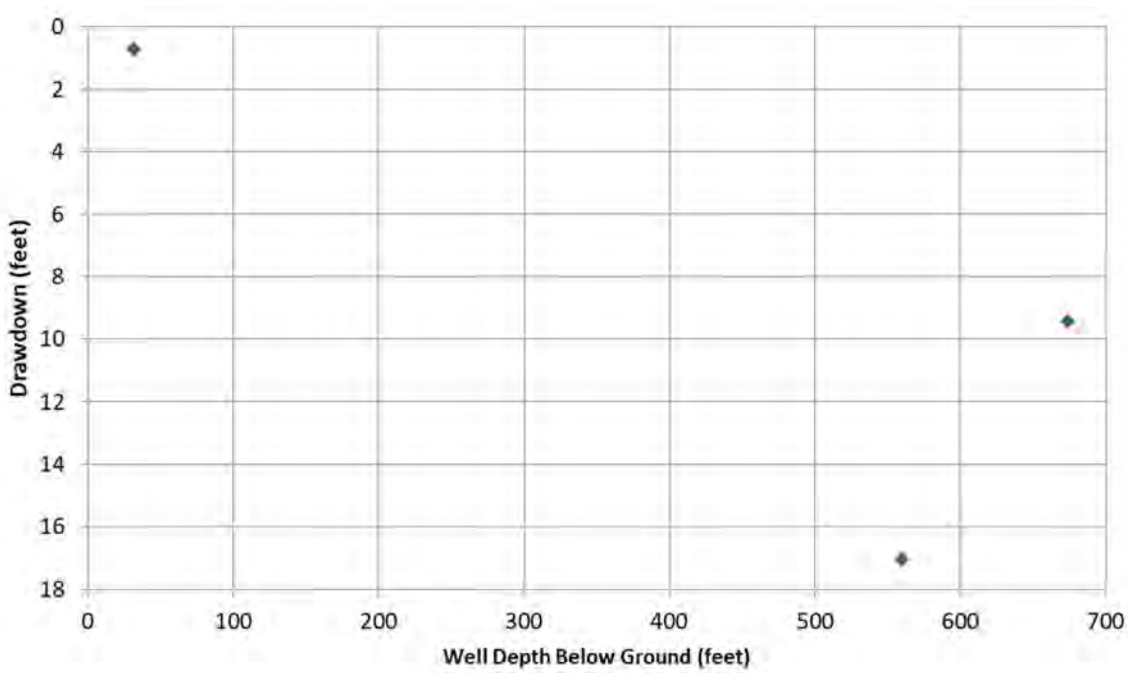

Figure 23 – Central Group Well Depth vs. Drawdown Plot at End of W385 Operational Test (t = 64 days)

Eastern Group

Only two wells, both of which are shallow monitoring wells, comprise the wells in the Eastern Group (Table 6). W248 is excluded in this analysis, because it is much farther from W385 than the other two and its groundwater level will not be representative of the operational test due to faults and geological differences.

Table 6 – Eastern Group Well Characteristics

Well	Total Depth (ft)	Distance from W385 (mi)
T438	37	0.6
V875	21	0.6

Groundater levels in T438 decreased during the operational test, while V875 experienced a gradual increase (Figure 24). T438 began rising after *t = 52 days*, before the completion of the pumping phase. The groundwater level rise after *t = 52 days* coincides with water disharge from gravel mining activity in the area near T438 of which it is likely attributed.

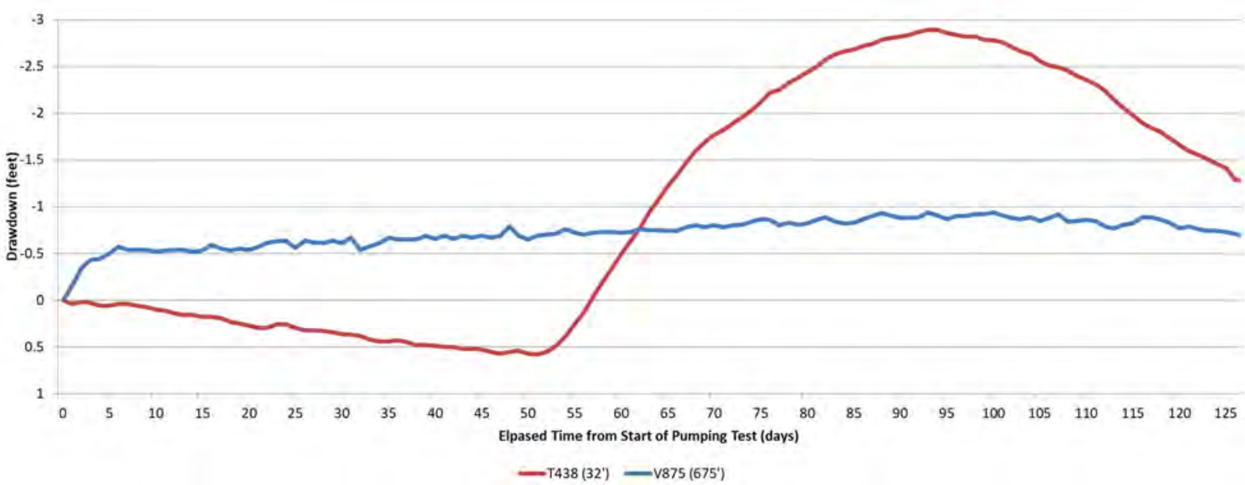

Figure 24 – Eastern Group Drawdown during W385 Operational Test

The WSEs for both wells increased by *t = 64 days*, although the decrease in groundwater levels in T438 would likely have continued if not for the impact from gravel mining (Figure 25). Although there is a decrease in water level during the operational test, it is not evident that this is due to W385 pumping. The intial trend before *t = 52 days* is linear, suggesting that groundwater levels had been gradually declining prior to the test, which is confirmed by groundwater level data (water level had been decreasing gradually since September 2019). Furthermore, there does not appear to be a clear effect on the groundwater level once pumping commenced, suggesting that there are influences other than W385 pumping. Groundwater levels in V875 did not appear to deviate from seasonal trends with increasing groundwater levels since September and decreasing of groundwater levels near April.

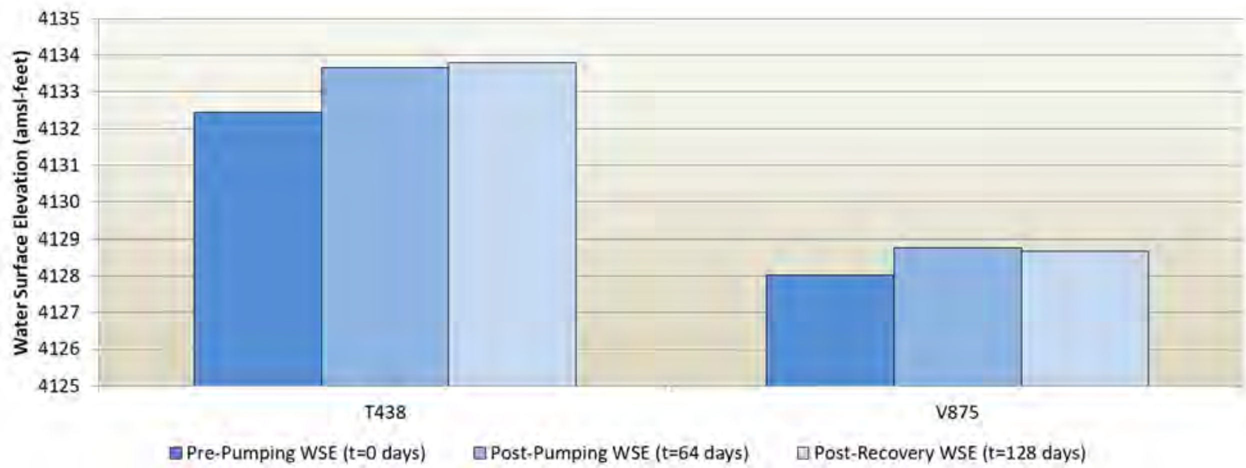

Figure 25 – Eastern Group WSEs during Operational Test Milestones

Northern (Fish Slough) Group

Six wells far north of W385, all considered shallow (although it is likely that some of these are screened in the deep aquifer), comprise the wells in the Northern (Fish Slough) Group (Table 7). FS #4 was not included, because it was dry throughout the operational test. Fish Slough, the Fish Slough Ecological Reserve, and several sensitive vegetation parcels lie within this area.

Table 7 – Northern (Fish Slough) Group Well Characteristics

Well	Total Depth (ft)	Distance from W385 (mi)
FS #1	61	7.1
FS #2	46	4.0
FS#3D	145	2.8
FS #3S	35	2.8
T397	180	7.1
Zack	257	5.2

Wells in the Northern (Fish Slough) Group experienced little to no drawdown. In fact, most of the wells experienced gradual increases in groundwater level (less so from FS #1 and T397; Figure 26).

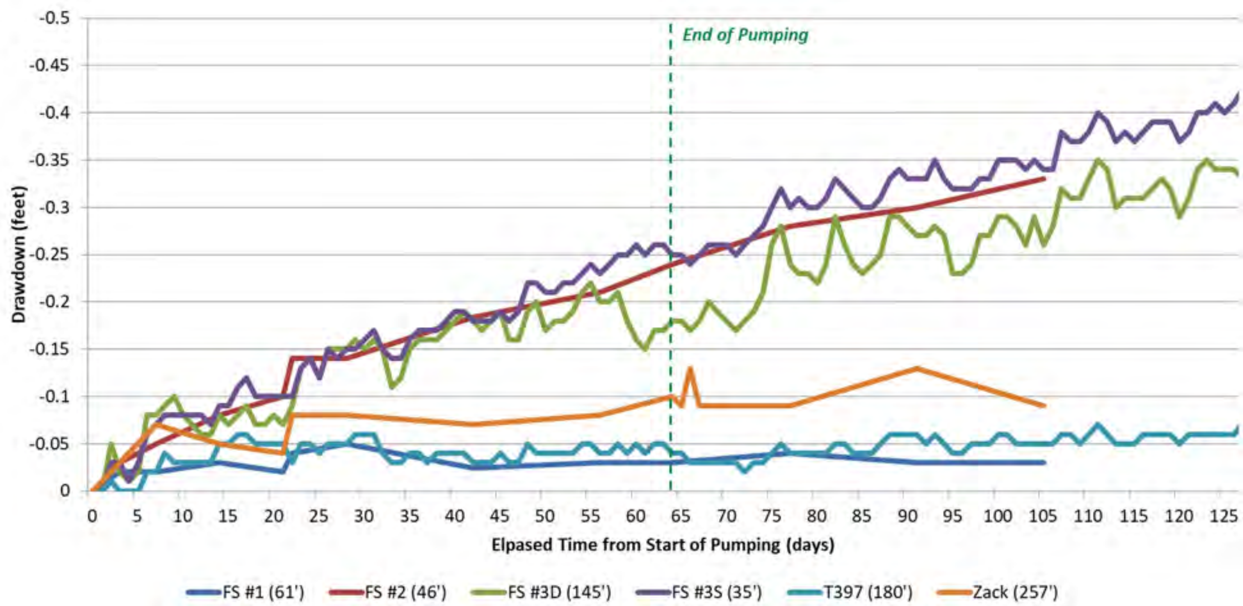

Figure 26 – Northern (Fish Slough) Group Drawdown during W385 Operational Test

Little to no change was observed in WSEs during the operational test in Northern Group (Figure 27). The deepest wells – T397, Zack, and FS #1 (all of which are close to one another in the northern portion of this area – have higher WSEs than the other wells. This is likely due to the presense of a confining layer above 61 feet bgs (depth of FS #1). In the southern portion of the Northern Group area, this formation likely does not exist at the same depth, because FS #3D has a similar WSE to FS #3S. Rather the formation is likely between the two well depths of 35 and 145 feet bgs in this area. This is supported by lithological logs, which idicate platy rock and welded tuff between 30 and 48 feet bgs. Cobbles of tuff exist at deeper zones. Generally, the aquifer system stratigraphy liekly varies between the northern and southern areas.

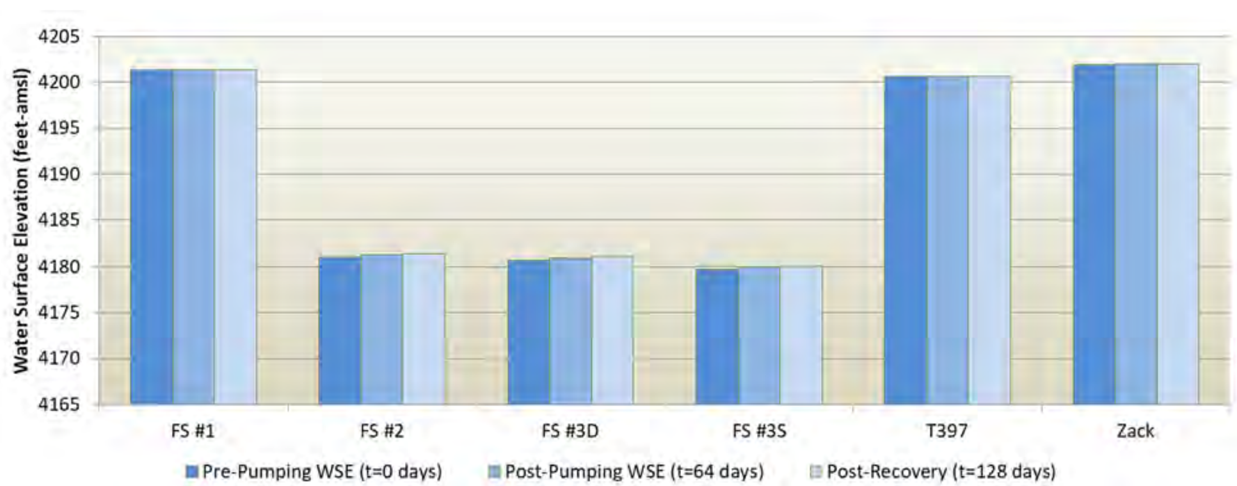

Figure 27 – Northern (Fish Slough) Group WSEs during W385 Operational Test Milestones (FS #1, FS #2, and Zack post recovery milestones are at t = 105 days)

Northern Group wells closer to W385 generally increased in water level more throughout the operational test, while groundwater levels in wells farther increased less (Figure 28). This indicates that pumping has no effect on water level in the Fish Slough area, since the opposite effect would be expected (Figure 29).Water levels had also been gradually increasing across Fish Slough even before the operational test. This trend, which is slightly logorithmic, is likely due to hydrogeological effects beyond the scope this report.

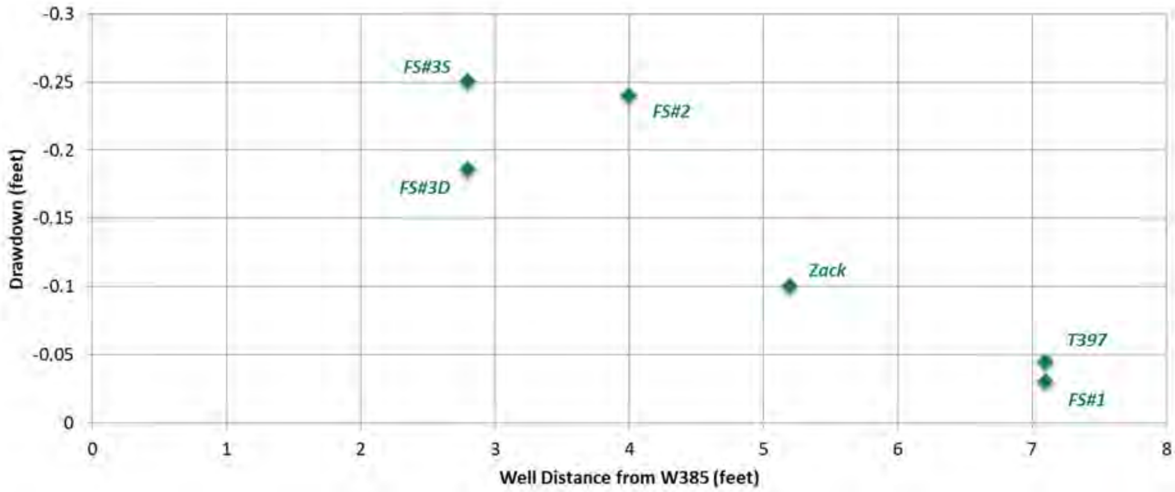

Figure 28 – Northern (Fish Slough) Group Well Distance vs. Drawdown at End of W385 Operational Test
(t = 64 days)

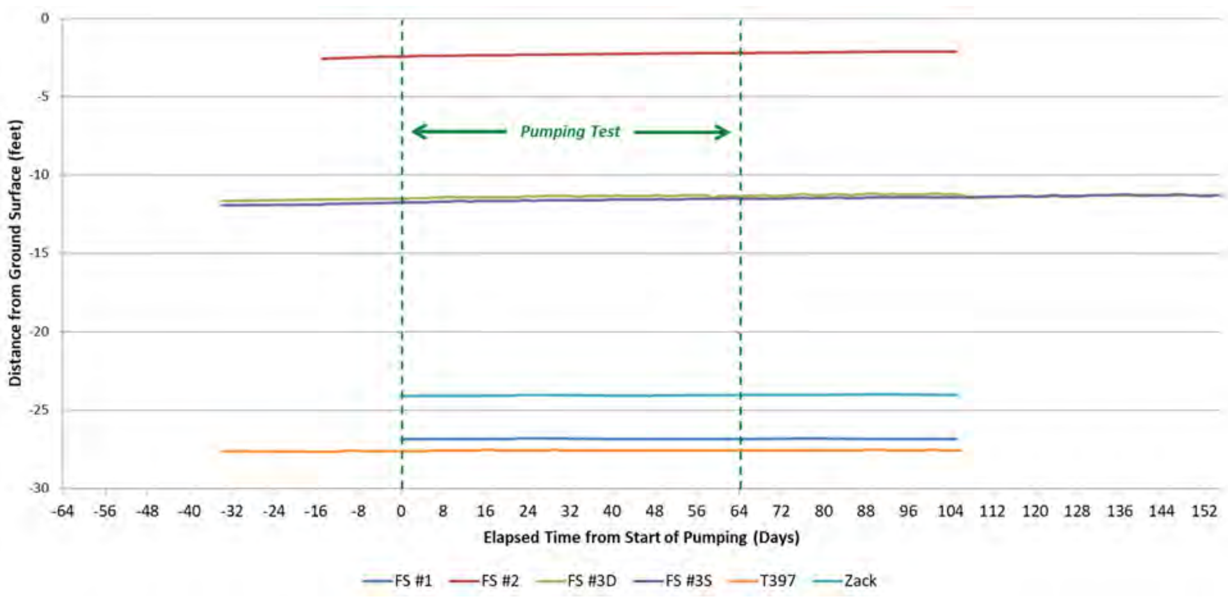

Figure 29 – Northern (Fish Slough) Group Well Groundwater Levels before, during, and after W385 Operational Test from t = [-64, 155]

Throughout the operational test, flow at Fish Slough monitoring station 3216 exhibited typical seasonal fluctuations. The average stage was 5.47 feet amsl with flow remaining above 4 cfs throughout the entire operational test. Additionally, groundwater levels in Fish Slough appeared to follow seasonal trends based on the historical groundwater levels in FS #1, FS #2, T397, and Zack wells (Figure 29). Groundwater levels have been steadily decreasing in the area since the

‘90s with no noticeable deviations during pumping. This lack of response in the area indicates minimal or no impact from pumping W385 on the aquifer in the Fish Slough area or its sensitive resources.

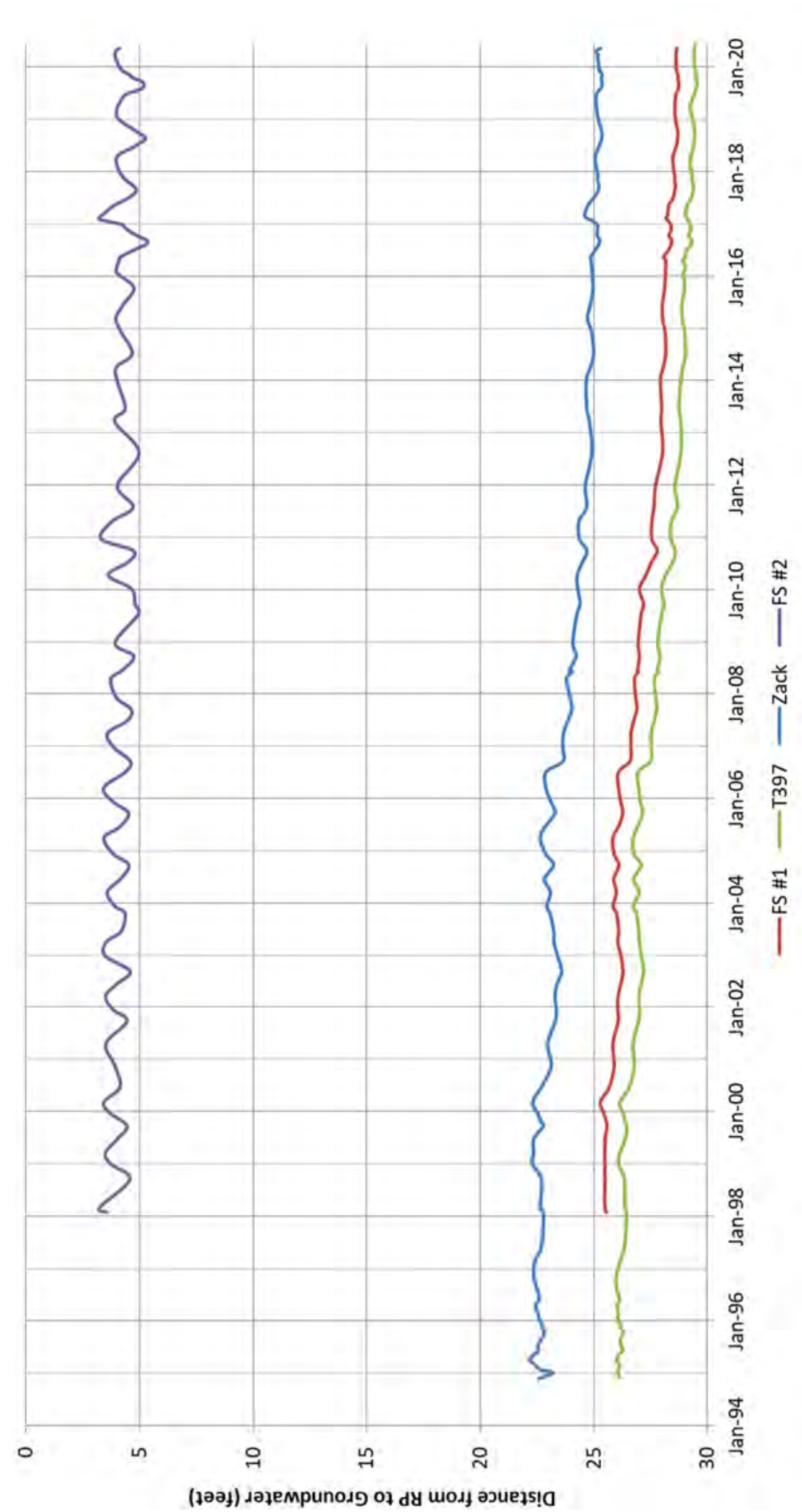

Figure 30 - Historical Groundwater Levels in Fish Slough Area Wells

-------------------- Deep Aquifer Zone Characteristics --------------------

The aquifer analysis program AQTESOLV was used to estimate the deep aquifer zone characteristics using select deep wells (Table 8). Although T759 and Private Well exhibited drawdown similar to other deep wells, they were excluded from aquifer zone characteristic calculations, because they are likely not completely screened within the deep zone from which W385 pumps (the production zone). T752 and T755 did not experience any drawdown, so they too were excluded. Additionally, W248 was excluded, because it is screened throughout both zones. T758 and T733 were excluded because they are screened above and below the production zone, respectively, based on available groundwater data. That left W385, W386, and T758 for aquifer characteristic calculations. Both drawdown and recovery data were utilized (*t = [0, 106] days;* data beyond *t = 106 days* becomes erratic, likely not due to the operational test, and may influence results). The thickness of the deep zone was assumed to be approximately 230 feet (*b*), the approximate well screen depth of W385.

Additionally, a cross section between the T757-T759 cluster and Private well was used to present an expanded aquifer stratigraphy conceptual model throughout the area of study (Figure 32 **– *Conceptual Model of Deep Aquifer Zone in Area of Study***). This conceptual model was developed using further information presented in geological logs (see *Lithological* and *Geophysical Appendices*) results from the W385 operational test. Note that this model includes additional wells not used in the aquifer zone characteristic calculations.

Figure 31 – Cross Section Used in Conceptual Model

Table 8 – Deep Well Aquifer Parameters

Well	TDZ Top of Deep Zone (ft bgs)	TWS Top of Well Screen (ft bgs)	BWS Bottom of Well Screen (ft bgs)	Offset of TDZ and TWS (ft)	Offset of TDZ and BWS (ft)	Distance from W385 (mi)
T758	170	535	575	365	405	0.7 (SW)
W386	320	367	550	47	230	0.1 (S)
W385	320	323	550	3	230	-

A Hantush-Jacob Solution was used to model drawdown over time. Because of the assumption both the shallow and deep aquifer have semi-confining characteristics (more the latter), a leaky aquifer solution of the model was used.

The model estimated the radial transmissivity (*T*) at 3,021 ft^2/day (0.03 ft^2/s) and the storativity (*S*) at 1.0E-10. Radial hydraulic conductivity (K_r) is estimated to be approximately 1.3E-4 ft/s ($T=K_r b$). This conductivity is characteristic of a coarse to fine sandy aquifer which is in agreement with existing boring logs (Domenico and Schwartz 1990). The hydraulic conductivity anisotropy ratio (K_z/K_r) was estimated at 0.30, which is within the range for stratified alluvial sediments. K_r is the radial hydraulic conductivity, perpendicular the direction of vertical hydraulic conductivity.

Water Table Interpolation

Deep aquifer groundwater levels throughout the entire area of study were interpolated at operational test milestones: the beginning of the pumping phase (t = 0 days), the end of the pumping phase (t = 64 days), and the end of the recovery phase (t = 106 days). Data was interpolated via autocorrelation (Krigging) for t = 0 and t = 106 days and inverse-distance (IDW) for t = 64 days. IDW was used for post-pumping, because the disparity between W385 and the other wells' groundwater levels was too large for an accurate autocorrelation interpolation. Interpolations estimated the distance of groundwater from the ground surface (distance from ground, DFG) across the area of study in the deep aquifer (positive values indicate the head is above the ground surface, Figure 33 (a-c)).

Groundwater levels throughout the deep aquifer within the 1.4 by 3.6 mile area generally recovered by the end of the operational test (observable via the interpolated data). This suggests that seasonal pumping may not be detrimental to groundwater levels in the deep aquifer.

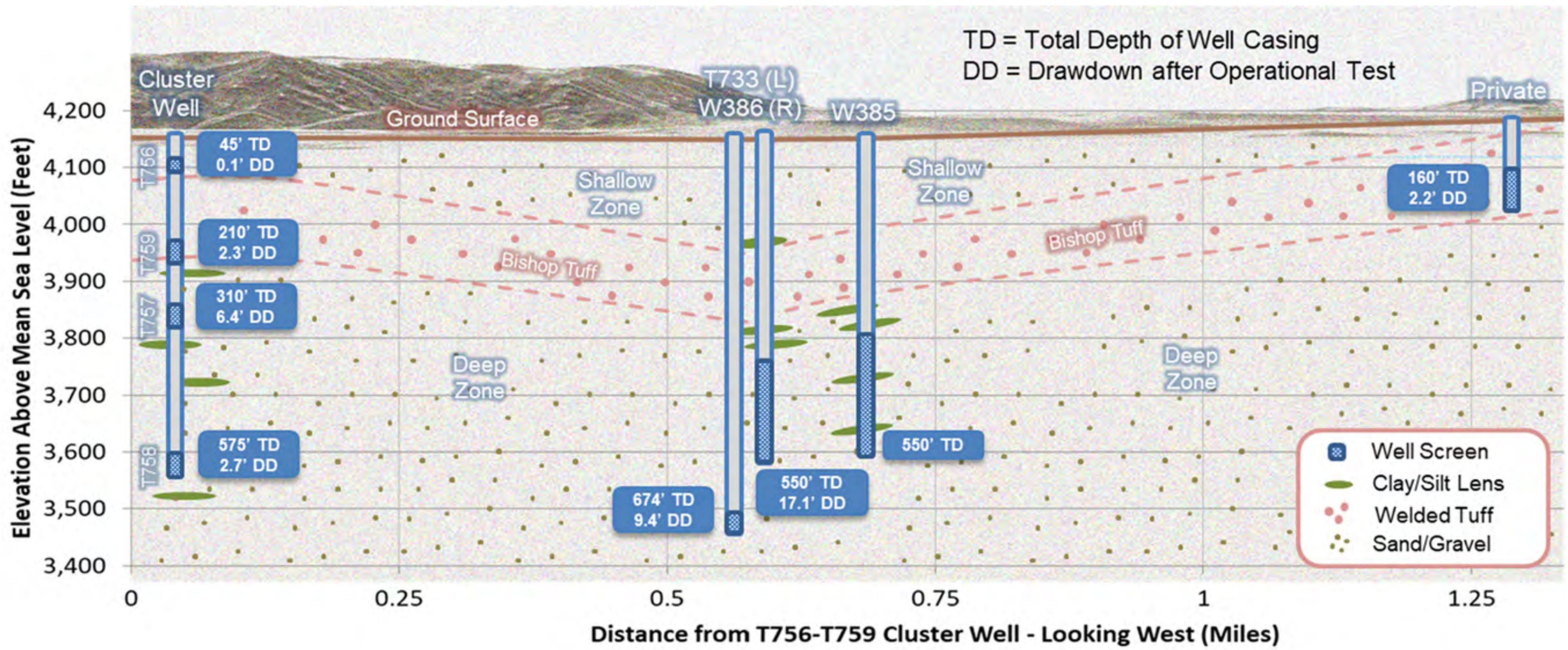

Figure 32 – Conceptual Model of Deep Aquifer Zone in Area of Study (cross section presented in Figure 30)

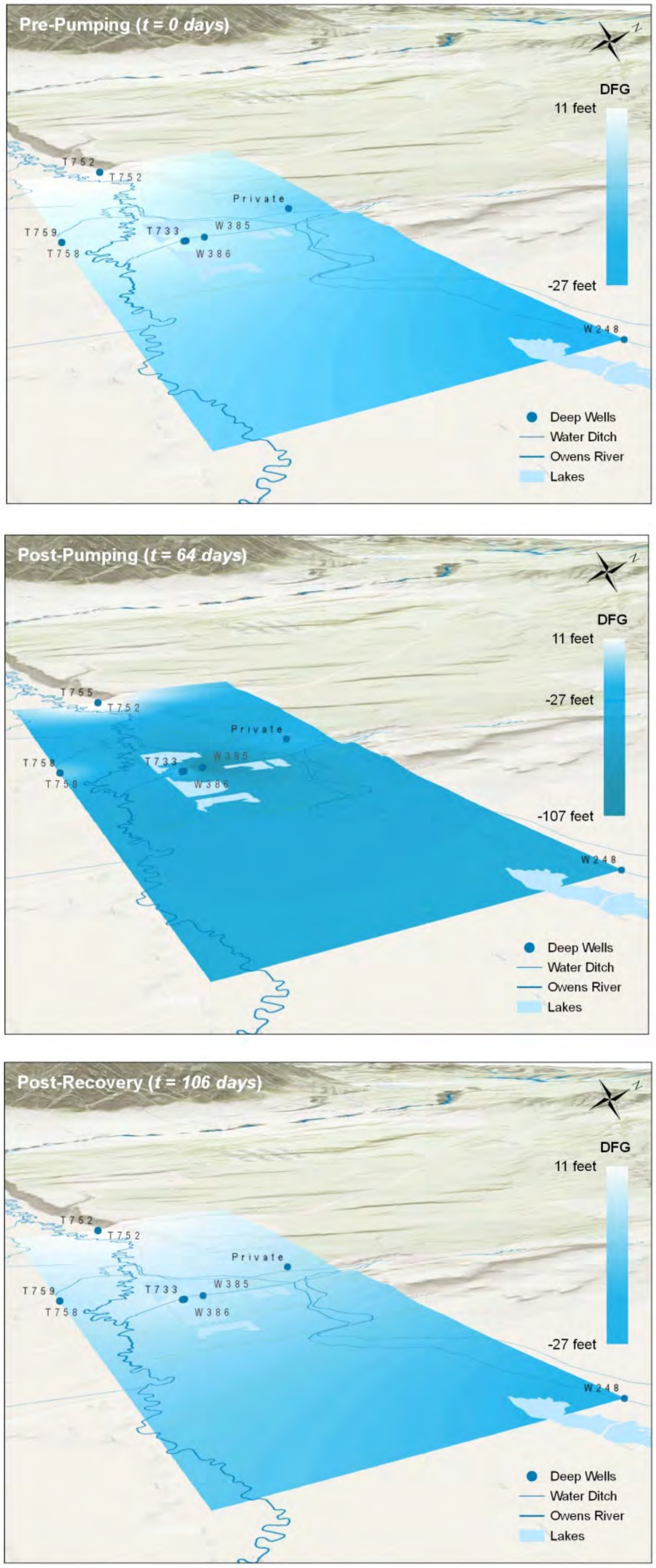

Figure 33 (a-c) – Interpolated Gradient Plots of DFG (Distance to Water from Ground) in the Deep Zone at (a) Pre-pumping, (b) Post-pumping, and (c) Post-recovery Milestones

------------------------------ Surface Water ------------------------------

LADWP monitored stage (water surface elevation) in Owens River and in West Pond as part of the monitoring program for the W385 operational test. LADWP does not have long-term surface water level data from these two features to allow for easy comparison. The WSE for Owens River remained relatively constant during the operational test, while the WSE for West Pond gradually lowered during the operational test, including the recovery period (Figure 34). Water level in West Pond is generally 5 feet higher than water level in the Owens River. So, some leakage from the pond to the River is plausible as just seven weeks prior to the start of the test, flow in the river dropped from about 700 to 150 cfs. The closest shallow monitoring wells to West Pond are T704 and T826. WSE at West Pond was comparable to T733, but was higher than T826. These monitoring wells experienced about 0.5 feet of drawdown during the operational test. Therefore, some the drawdown in West Pond can be attributed to the effect of pumping. The negative slope of West Pond WSE flattens over time once pumping stopped, likely indicating pumping had an effect on the water level. This also may or may not be attributable to gravel mining activity and W385 pumping.

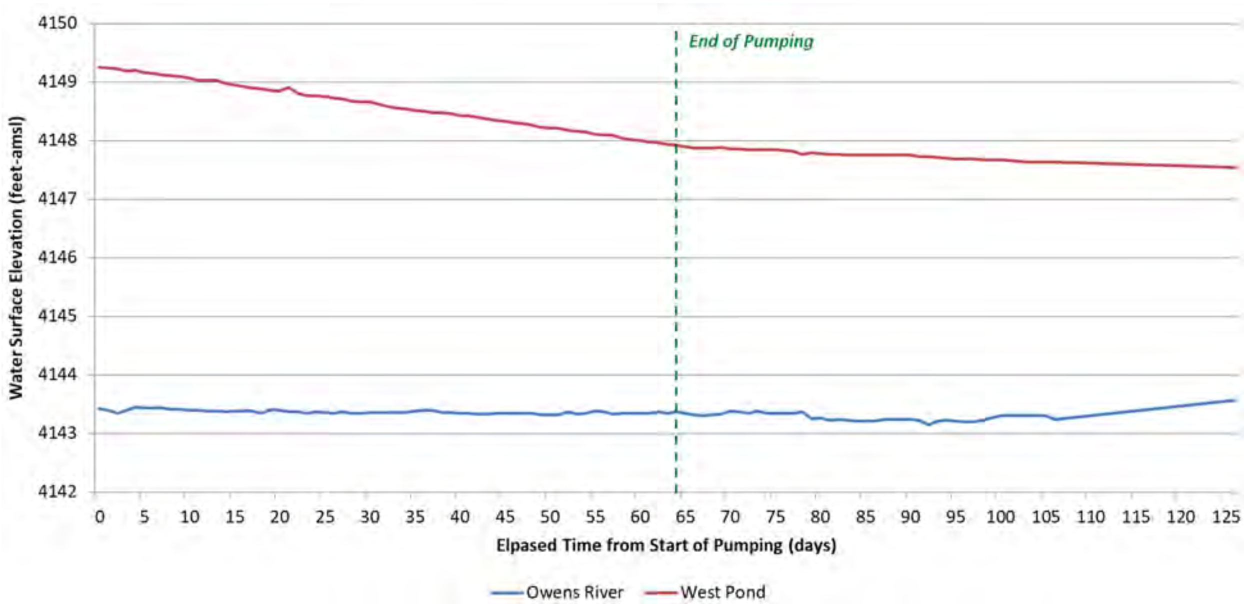

Figure 34 – Owens River and West Pond WSEs during W385 Operational Test

Long term flow records of flow in Fish Slough Ditch exhibit steady decreases in flow over last 50 years (Figure 35 – *Fish Slough Flow Rate before, during, and after W385 Operational Test at Station 3216*). The flow in the ditch measured at Station 3216 near Owens River and well W385 averaged 5.5 cfs during the operational test. Although flow rate was not constant during the operational test, there is no indication that W385 pumping affected it. Prior to the start of the operational test, flow rate had been steadily increasing according to seasonal trend (Figure 36 – *Historical Fish Slough Flow Rate at 3216*). Around the time pumping started, the flow rate exhibited some fluctuations and after the end of the operational test, flow rate steadily decreased again following the typical seasonal trend.

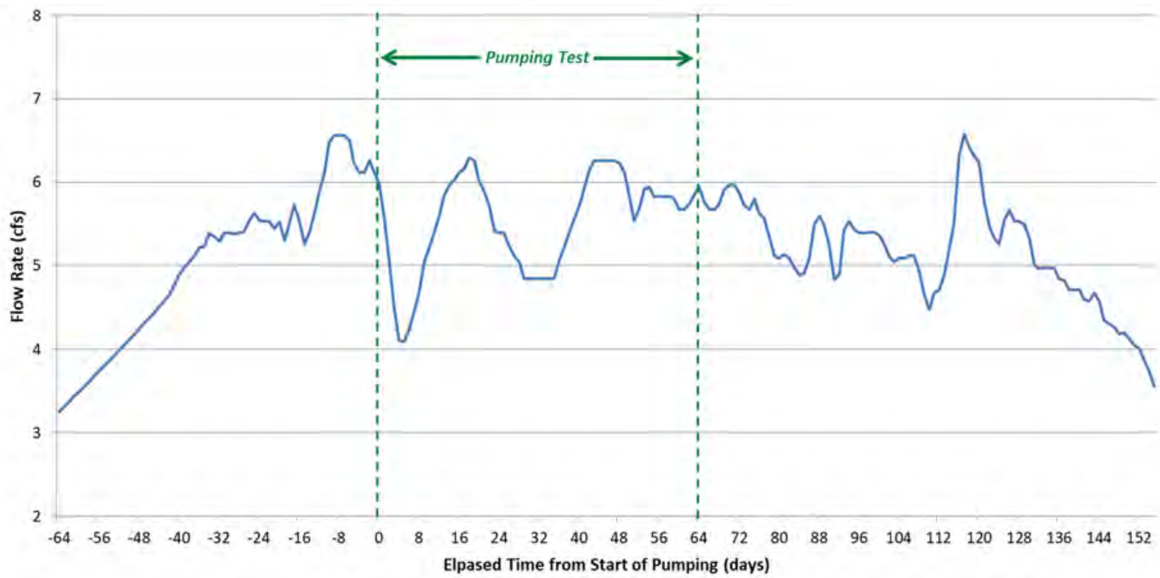

Figure 35 – Fish Slough Flow Rate before, during, and after W385 Operational Test at Station 3216

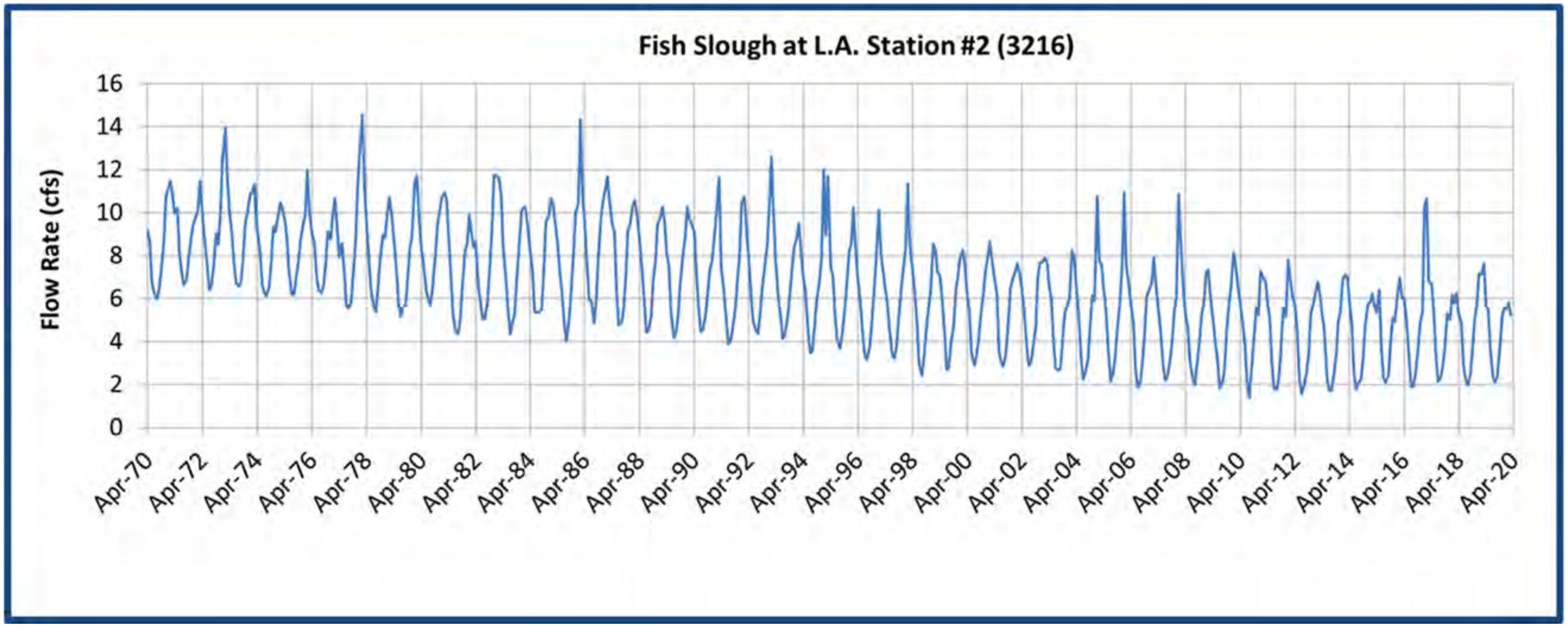

Figure 36 – Historical Fish Slough Flow Rate at 3216

------------------------------- Water Quality -------------------------------

LADWP sampled 7 monitoring wells before the operational test (12/5/2019) and near the end of the operational test (2/13/2020). W386 was additionally sampled near the end of the test (Table 9).

Table 9 – Wells Sampled for Water Quality Analyses

Well	Total Depth (ft)	Distance from W385 (mi)
FS#2	46	4.0
FS#3D	145	2.8
FS#3S	35	2.8
T755	490	1.8
T758	575	0.7
T826	17	0.4
W385	550	-
W385	550	0.1

Field measurements and laboratory analysis results were presented in an earlier report (*Production Well W385 in Laws Wellfield Two Month operational Test Report)*. Select constituent concentrations were tabulated, including *temperature, pH, specific conductivity, bicarbonate, oxygen-18, deuterium,* and *tritium* (Table10 to Table 16). Isotope concentrations were compared with historical data to determine the provenance of well water.

Constituent Levels

Temperature

Table 10 – Temperatures (°C) prior to and at the end of W385 Operational Test

	Well	12/3/19	2/15/20
Shallow	FS #2	13.3	11
	FS #3D	17.5	17.6
	FS #3S	18.2	17.4
	T826	No Analysis	19.6
Deep	T755	27.8	27.9
	T758	15.2	17.2
	W385	31.8	32.5*
	W386	No Sample	19.6

*measured by ICWD on 2/10/20

No significant changes in temperature were evident due to the operational test. Deeper wells generally were cooler than shallower ones.

pH

Table 11 – pHs prior to and at the end of W385 Operational Test

	Well	12/3/19	2/15/20
Shallow	FS #2	7.8	7.88
	FS #3D	8.43	7.84
	FS #3S	8.08	7.96
	T826	7.12	7.21
Deep	T755	7.88	8.21
	T758	8.6	7.16
	W385	7.84	7.77
	W386	No Sample	8.35

Although pH in FS # 3D, FS # 3S, and T758 was higher than the other wells (< 8.6), they decreased by the end of the operational test (< 7.8). W386 pH increased from < 7.6 to < 8.4 by the end of the operational test. pH in W385 remained unchanged, as well as the other wells.

Specific Conductivity

Table 12 – Specific Conductivities (µS/cm) prior to and at the end of W385 Operational Test

	Well	12/3/19	2/15/20
Shallow	FS #2	447	433
	FS #3D	511	527
	FS #3S	515	520
	T826	625	530
Deep	T755	455	465
	T758	227	535*
	W385	543	536
	W386	No Sample	354

*there was likely a measurement error since cation/anion concentration did not change

Specific conductivity did not noticeably change in any well by the end of the operational test. Values were highest in FS #3D, FS #3S, T758, and W385.

Bicarbonate

Table 13 – Bicarbonate Concentrations (mg/L) prior to and at the end of W385 Operational Test

	Well	12/3/19	2/15/20
Shallow	FS #2	No Analysis	158
	FS #3D	No Analysis	194
	FS #3S	No Analysis	173
	T826	No Analysis	251
Deep	T755	No Analysis	153
	T758	No Analysis	86.5
	W385	No Analysis	228
	W386	No Sample	164

Bicarbonate concentration was highest in T826 and W385. December 5, 2019 samples were not analyzed for bicarbonate concentration.

Oxygen-18

Table 14 – Oxygen-18 (% of Vienna Standard Mean Ocean Water) Measurements prior to and at the end of W385 Operational Test

	Well	12/3/19	2/15/20
Shallow	FS #2	-16.08	-16.02
	FS #3D	-17.48	-17.53
	FS #3S	-17.46	-17.36
	T826	-12.92	-13.64
Deep	T755	-18.58	-18.59
	T758	-17.7	-17.7
	W385	-16.67	-16.89
	W386	No Sample	-17.74

Oxygen-18 concentration increased in FS #2, but decreased in T826 and W386. W385 oxygen-18 remained unchanged, along with the rest of the wells. Oxygen-18 was significantly higher in T826 (< -15 % of VSMOW) than the other wells. This is likely due to the well's shallowness and resulting isotopic fractionation by evaporation since oxygen-16 evaporates first.

Deuterium

Table 15 – Deuterium Concentrations (% of Vienna Standard Mean Ocean Water) prior to and at the end of W385 Operational Test

	Well	12/3/19	2/15/20
Shallow	FS #2	-121.4	-120.9
	FS #3D	-136.9	-137.3
	FS #3S	-135.9	-135.5
	T826	-107.5	-110.2
Deep	T755	-141.6	-141.7
	T758	-134.9	-134.9
	W385	-129.2	-131.3
	W386	No Sample	-136.2

Deuterium concentration decreased in T826, W385, and W386, all of which are in close proximity. T826 and FS #2 deuterium concentrations were higher than other wells. This is likely due to the wells' shallowness and resulting isotopic fractionation by evaporation since deuterium is heavier than hydrogen.

Tritium

Table 16 – Tritium Concentrations (TU) prior to and at the end of W385 Operational Test

	Well	12/3/19	2/15/20
Shallow	FS #2	< 0.52	< 0.87
	FS #3D	< 0.65	0.97 ± 0.28
	FS #3S	< 0.54	<0.97
	T826	2.23 ± 0.21	3.42 ± 0.29
Deep	T755	< 0.45	< 0.92
	T758	< 0.41	< 1.01
	W385	< 0.51	0.83 ± 0.24
	W386	No Sample	< 0.79

Tritium concentration increased at T826 and remained low or near the detection limit at the other wells. Tritium is also generally high in T826, likely due to the well's shallowness and resulting isotopic fractionation by evaporation (tritium is heavier than hydrogen). The difference between the 12/3/19 and 2/15/20 tritium concentration at T826 is likely due to the variation in isotopic fractionation near T826.

Provenance

Oxygen-18 and deuterium values from the W385 test and historical sampling were plotted and marked according to their respective regions (Figure 37 and Figure 38). These regions lie north of the W385 and are considered to be possible sources for groundwater at W385. Generally, same-region samples cluster together. Samples with isotopic concentrations similar to regional samples may indicate the origin of its groundwater.

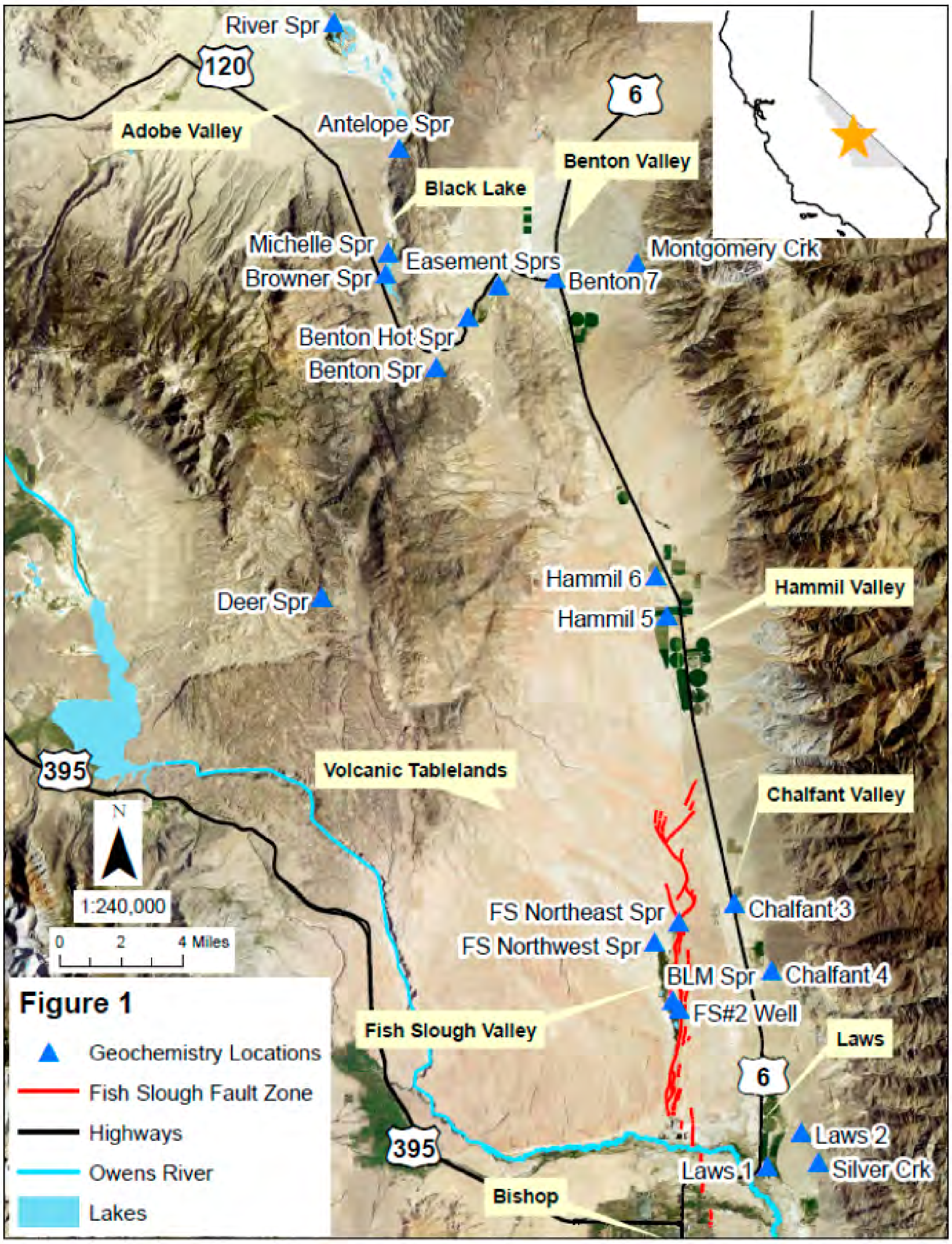

Figure 37 –Regional Valleys near the Area of Study (Zdon, Andy, et al., 2019)

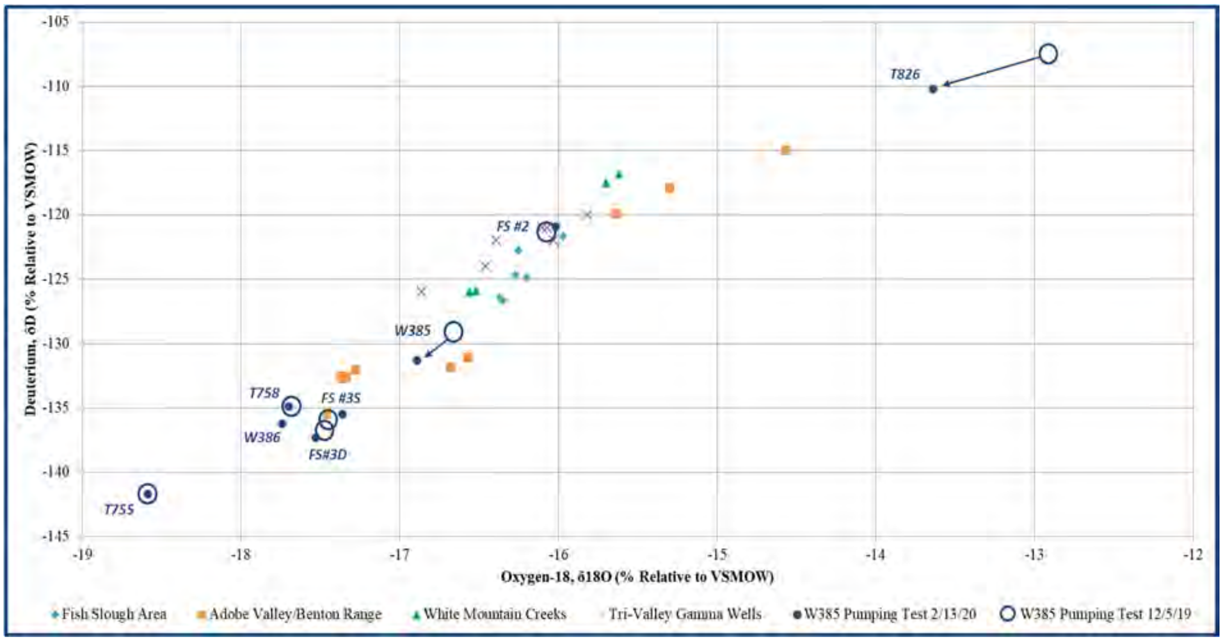

Figure 38 – Oxygen-18 vs. Deuterium Isotope Plots (Zdon, Andy, et al., 2019)

FS #2

FS #2 (46 feet bgs) lies far north of W385 in the Fish Slough area, past FS #3D and FS #3S. Isotope analysis reveals that W385 pumping had no significant effect on the isotope composition of groundwater. Oxygen-18 and deuterium concentrations were most similar to those in the Tri-Valley Gamma Wells (north of FS #2) and Fish Slough springs. It is likely that the source of groundwater in FS #2 is associated with both these areas. Isotopic concentrations are consistent with those of a historical FS #2 sample from March 2017.

FS #3S and FS #3D

FS #3D (145 feet bgs) and FS #3S (35 feet bgs) both lie north of W385 in the Fish Slough area. Isotope analyses reveal that W385 pumping had no significant effect on the isotopic composition of groundwater for these two wells, although oxygen-18 and deuterium slightly decreased for FS #3D and slightly increased for FS #3S. Oxygen-18 and deuterium concentrations are most similar to samples from Benton Hot Springs in the Adobe Valley/Benton Range, north of the two wells.

T755

T755 (490 feet bgs) lies far west in the area of study. Pumping had no effect on the isotopic composition of groundwater at T755. Oxygen-18 and deuterium concentrations sampled are lower than those of historical samples, but most similar to samples from springs in the Adobe Valley/Benton Range, north of T755.

T758

T758 (575 feet bgs) lies south of W385 and Owens River. Isotope analysis reveals that W385 pumping had no effect on the isotopic composition of groundwater in this area. Oxygen-18 and deuterium concentrations are most similar to samples from Benton Hot Springs and other nearby springs in the Adobe Valley/Benton Range area, north of T758. It is likely that T758's groundwater is sourced from this area.

T826

T826 (17 feet bgs) lies south of W385, but north of Owens River. Isotope analysis reveals that W385 pumping had no effect on the isotopic composition of groundwater. Oxygen-18 and deuterium concentrations are significantly higher here than the rest of the area of study. Concentrations are not similar to any historically recorded isotopic concentrations of nearby samples. Isotopic fractionation due to evaporation may have altered the isotopic composition of the water since it had been sourced.

W385

W385 (550 feet bgs), the pumping well, changed in isotopic concentration with both deuterium and oxygen-18 concentrations decreasing (tritium remained the same). The is expected since pumping pulls water in from other areas. These concentrations are most similar to samples from Easement South Spring and Easement North Spring, both within the Adobe Valley/Benton Range area, north of W385. Concentrations are also similar to White Mountain Creek samples and samples from springs in the Fish Slough area. The change in isotopic concentrations from less similar to the Mountain Creek and Fish Slough area sources (i.e. decreasing in concentration) and more similar to the Adobe Valley/Benton Range sources suggests that groundwater from W385 is primarily sourced from the Adobe Valley/Benton Range area, with contributing water from the other two regions.

W386

W386 (550 feet bgs) lies just south of W385. W386 was not sampled prior to the operational test. Oxygen-18 and deuterium concentrations at the end of the test are most similar to samples from Benton Hot Springs and other nearby springs in the Adobe Valley/Benton Range area, north of W386. It is likely that groundwater is sourced from this area.

---------------------------------- Discussion ----------------------------------

Monitoring Locations

This operational test included a large groundwater monitoring area. However, additional monitoring is needed to the north between W385 and McNally canals, ideally, multi-completion wells including one in the shallow aquifer and one in the deep, potentially into the Bishop Tuff formation. Groundwater level monitoring is limited particularly in the area just north of W385. Only Private Well is in this vicinity (the next wells north are all in the Fish Slough). LADWP proposes to install an additional cluster monitoring well in this area north of W385 as a monitoring point for future operational tests.

Pumping well W249, located in between W385 and W248, had been operating throughout the entire operational test, which may have influenced some of the data and analysis results, especially results at W248. Future testing of W385 and W386 should include suspending the operation of both W248 and W249, if possible. Unfortunately, one of these wells must operate during the winter season to supply water to the McNally Ponds. It may be useful to pump a well further away from W385 and W386.

All other wells utilized during the operational test provided good insight to W385 pumping's effect on the local aquifer system. No further modifications to current methods of groundwater monitoring and water quality sampling are needed.

Zone of Influence

The zone of influence from W385 pumping, pumping at a rate of 3.7 cfs for two months, appears to be limited to the West Laws Area (indicated in Figure 1) and to deeper zone of the aquifer system. This includes areas as far north as the Private Well, as far south as where the T756-T759 cluster, and as far east as T438 location. However, groundwater levels in the western T752-T755 cluster and the Fish Sough areas were not affected by W385 pumping. Since Private Well was the farthest well that experienced drawdown, the zone of influence likely extends beyond a radius of 0.6 miles. A full season of operational test of W385 can help in the understanding of the hydrogeology of the area. Additionally, computer simulations of this operational test can be very insightful.

The pumping rate during the 2019-20 operational test was approximately a fifth of the 1993-94 rate. Drawdown was experienced was generally less than one fifth. This suggests that vertical confinement was effective in restricting drawdown in the shallow zone.

Source Water

Based on the pre-pumping isotopic profiles of oxygen-18 and deuterium, the source water for W385 likely passes through (not necessarily originates from) the Adobe Valley/Benton Range area north of W385, with minimal contribution from the White Mountain Creeks, Fish Slough, and Tri-Valley areas. This is evident, because at the end of the operational test, the isotopic profile moved closer to those of Easement South Spring and Easement North Spring, both in the Adobe Valley/Benton Range area (see Figure 40). This evidence suggests that long-term pumping would draw water primarily from the Adobe Valley/Benton Range area.

It is also possible that groundwater flowed eastward (from the T755 area) toward W385 based on the temperature distribution profiles. T755 source water differs from historical isotope data, so it is possible that water in this area comes from a different source, likely somewhere east of the area of study. However, the relatively short period of pumping would generally draw water from the storage in the vicinity of the pumping wells. A longer operational test and possibly at high pumping rate could potentially more clearly describe and differentiate the source water to W385.

Long-Term Pumping Implications

Considering the results of the operational test analysis, monitoring well data, and groundwater modeling, there does not appear to be any significant implications for long-term seasonal pumping, particularly in the Five Bridges area as well as Fish Slough Area. Shallow wells generally were not significantly affected by W385 pumping. While the deeper wells experienced drawdown from pumping W385, they generally exhibited full (or nearly full) recovery by May 2020. Impact to the water level at West Pond, however, appears to be due to pumping. Owens River had no significant impact to water level attributable to pumping. The deep aquifer interpolation results suggest that long-term seasonal pumping may not be detrimental to groundwater levels in said aquifer because of the negligible drawdown observed in wells of similar depth. Additional operational tests, in addition to water quality sampling, will improve understanding of the hydrogeology of the area and effect from pumping on groundwater levels and water quality.

Further Testing

The operational test of W385 was conducted in the 2019 runoff year, which was a very wet year. In comparison, the 2020 runoff year is a dry year. Furthermore, McNally canals were operated most the year in 2019 but not in 2020. Conducting an operational test of W386 at about the same pumping rate and for the same length of time should show whether the runoff condition will have any effect on the pumping either W385 or W386 on nearby groundwater-dependent resources. LADWP will attempt to stabilize flow in Owens river earlier to ensure that change of water level in the river does not affect the nearby groundwater levels. To improve the monitoring plan during the operational test of W386, LADWP will install two new monitoring wells, one deep well east of W386 and one cluster well in the north at the mouth of Fish Slough. It is currently expected that the effect of pumping W386 on groundwater and surface water levels will be similar to that of W385 pumping.

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