Rudd Westside Winery Pump Test and Well Interference Analysis
4603 Westside Road, Healdsburg

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Introduction

In June of 2015, O'Connor Environmental, Inc. (OEI) completed a groundwater study for the proposed Rudd Westside Winery. In August of 2015, neighboring landowners hired EBA Engineering (EBA) to complete a peer review of the groundwater study. The EBA review proposed a list of supplemental studies that could be conducted prior to approval of the winery use permit to provide additional assurances to the neighboring landowners regarding potential impacts on groundwater resources. . This report addresses two of these supplemental studies: conducting a well pump test at the project site and evaluating the existing water system design. The results of the pump test analysis and water system design evaluation, in conjunction with the previous findings from the groundwater study, provided the basis for evaluating potential impacts of groundwater use for the proposed winery. Potential impacts are evaluated with respect to potential well interference and other potential impacts on groundwater supply on neighboring parcels.

The local area geology, local groundwater conditions, and groundwater recharge processes are described in the prior OEI groundwater study (June 2015). In this report it is assumed that the reader is familiar with the local area geology as described in the prior report.

Pump Test Design and Monitoring Plan

Seven wells were monitored before, during, and after the pump test: four existing wells (A through D) on the project parcel and three wells on the adjacent parcel located at 4395 Westside Road (Figure 1 & Table 1). Wells A through D are all completed within the fractured bedrock aquifer associated with Franciscan sandstone (geologic map unit TKfs) to depths between 200 and 252 feet. The well owned by Jack Salzgeber (S) is also completed within the TKfs geologic unit to a depth of 360 feet. The two wells owned by Terry Harrison (H1 & H2) are located across a concealed fault contact which separates the TKfs geologic unit from the KJfs geologic units comprised of greywacke and mélange. Well completion reports were obtained for all of the wells except H1 and H2. Mr. Harrison indicated that these two wells are relatively shallow; H1 is approximately 90-ft deep and H2 is approximately 60-ft deep (Table 1).

Well D was selected as the pumping well for the test since it is the closest project well to the wells on the neighboring parcels. Wells C and S were selected as the two primary observation wells. Well S is the closest neighboring well and is screened over similar depths as the project wells. Well B is the closest well to the pumping well (D) however anomalously deep static water levels were observed at this well suggesting that the next closest project well (C) would be more likely to respond to pumping at Well D and would better represent typical aquifer conditions than Well B. Three pressure transducers (Solonist Troll 700s) were deployed in Wells C, D, and S to automatically record water levels every one minute over the six day period between October 29th and November 4th, 2015. Manual water level measurements were taken periodically throughout this period using an electronic water level indicator to validate the data from pressure transducers and to provide monitoring data for the four wells that were not instrumented with pressure transducers.

Four days of pre-test data were collected to observe background trends in groundwater elevations. A constant rate 24-hr pump test with a pumping rate of 8 gallons per minute (gpm) was performed on Well D beginning at 9:45 AM on November 2nd. In addition, after the 24-hr pump test was completed, 24-hrs of well recovery data were collected. Well owners were advised a week prior to the test to fill storage tanks so that pumping during the monitoring period could be avoided, and with the exception of Well D, no pumping occurred at the other wells during the six day monitoring period.

Static Water Level Results

The water level data from Wells A, B, D, H1, and H2 all indicate a gradual trend of increasing water table elevation over the four day pre-test period (Figures 2 & 3). The rates of increase are very similar in each of these five wells (0.21 to 0.37 feet per day) suggesting that the response represents a regional aquifer response. The most likely explanation for the trend given the time of year and lack of significant rainfall is that it represents a response to decreases in groundwater discharge associated with the end of the growing season from reductions in evapotranspiration and/or from the cessation of pumping for irrigation. The drawdown at Well D in the beginning of the monitoring period represents a short-duration pump test that was performed on October 29, 2015 to determine an appropriate pumping rate to use during the 24-hr constant rate pump test conducted on November 2nd and 3rd, 2015. Wells C and S both exhibited significantly higher rates of water level increases over the pre-test period, 2.7 feet per day at C and 10.3 feet per day at S.

These trends most likely represent recovery from pumping that occurred prior to the beginning of the monitoring period in addition to the background trend of gradually increasing elevations. A small rainstorm occurred overnight and into the early morning of November 2nd bringing a total of 0.26 inches of rain as recorded at the Sonoma County Airport. This storm was almost certainly not large enough to generate groundwater recharge especially given the dry soil conditions, and the water level data do not show any discontinuity associated with the rainfall event.

An east-west oriented transect through Wells H1, H2, D, and A reveals a water surface that slopes uniformly from west to east with a slightly steeper gradient than the surface topography and with pre-test water depths increasing from west to east from 10.4 feet at well H2 to 37.3 feet at Well A (Figure 4). The pre-test depth to water was significantly higher at Well C (82.5 feet) and Sell S (131.9 feet) owing to the ongoing recovery associated with pre-test pumping as discussed above. The pre-test depth to water at Well B was 209.9-feet which is much deeper than any of the surrounding wells, and along with the anomalously low specific capacity for this well suggests that the well may not be well connected to the fracture system penetrated by the other wells.

With the exception of Well B and the two wells influenced by pre-test pumping, the uniform water surface across the transect and the consistency of the background trends in pre-test groundwater elevations between wells suggests that groundwater conditions are relatively

Table 1: Well completion details for the seven wells included in the monitoring plan.

Well	APN	Year Completed	Depth (ft)	10/29/15 Depth to Water (ft)	Top of Screen (ft)	Bottom of Screen (ft)	Distance to Well D (ft)	Map Unit
A	110-110-001	2007	200	37	59	186	1,021	TKfs
B	110-110-001	2007	252	210	40	240	286	TKfs
C	110-110-001	2007	250	82	40	240	533	TKfs
D	110-110-001	2007	250	23	40	240	0	TKfs
H1	110-180-003	na	90	23	na	na	1,126	KJfs
H2	110-180-003	na	60	10	na	na	1,098	KJfs
S	110-100-011	1995	340	132	85	340	935	TKfs

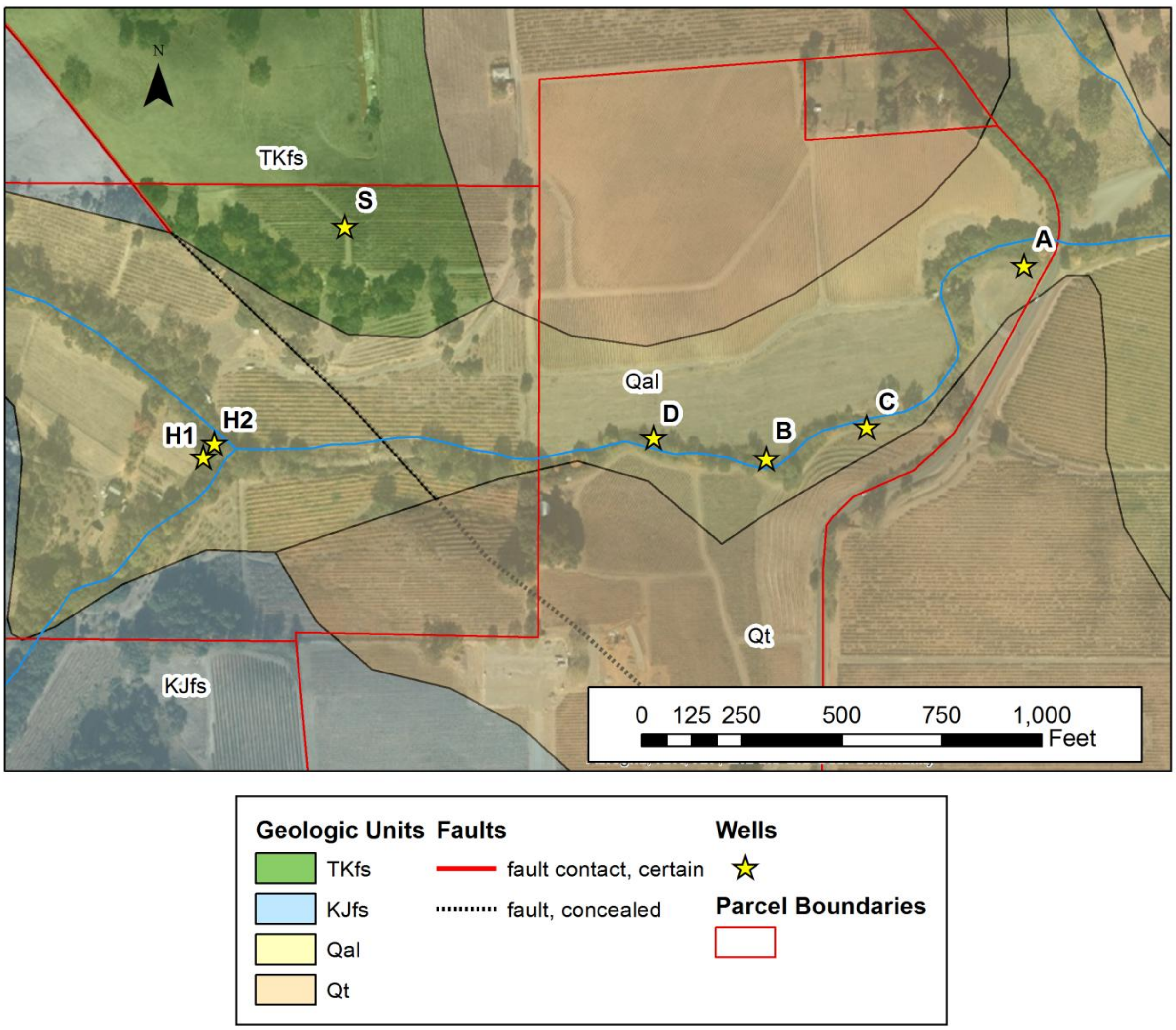

Figure 1: Well locations and surficial geology in the vicinity of the proposed Rudd Winery.

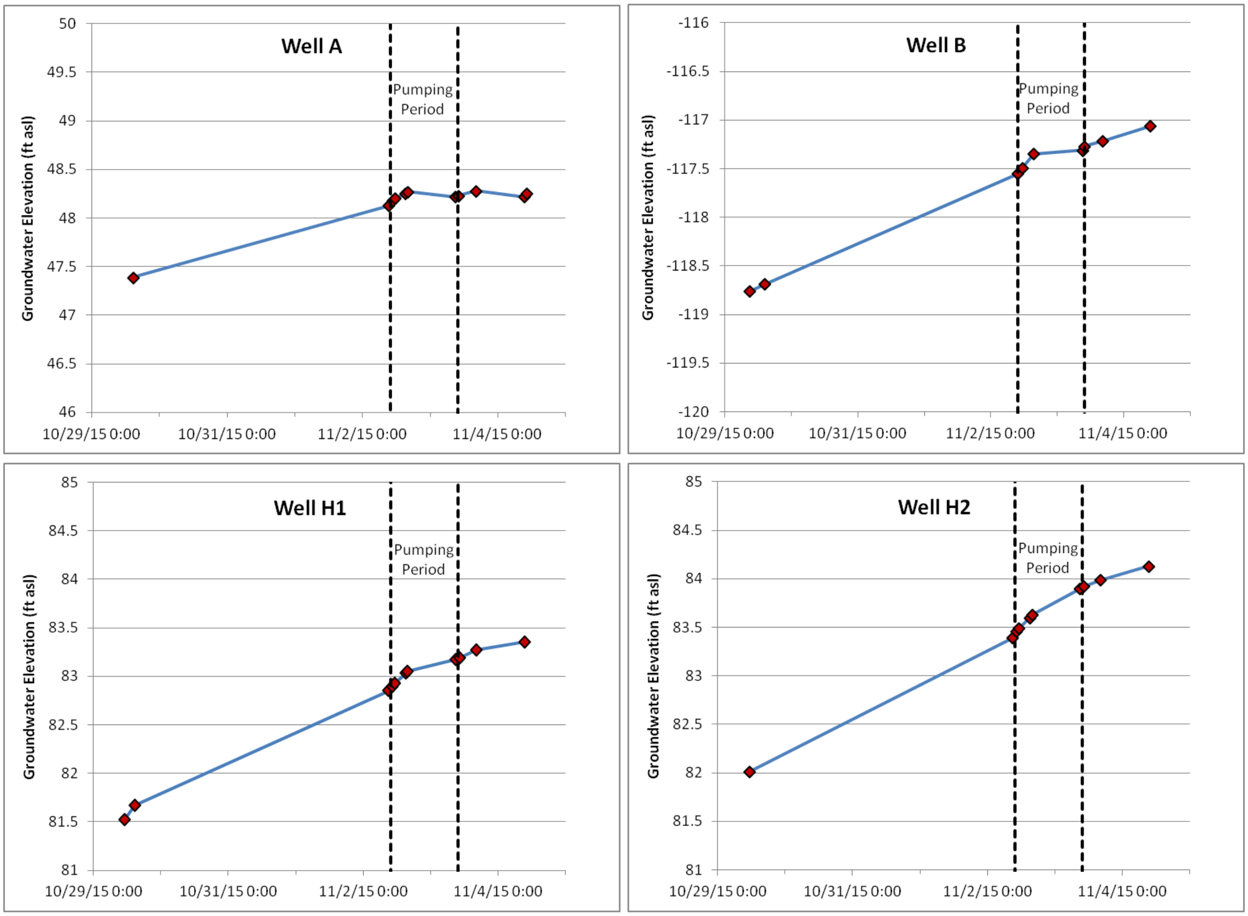

Figure 2: Groundwater elevation hydrographs at the four manually monitored wells (A, B, H1, & H2) during the 10/29/15 to 11/4/15 monitoring period.

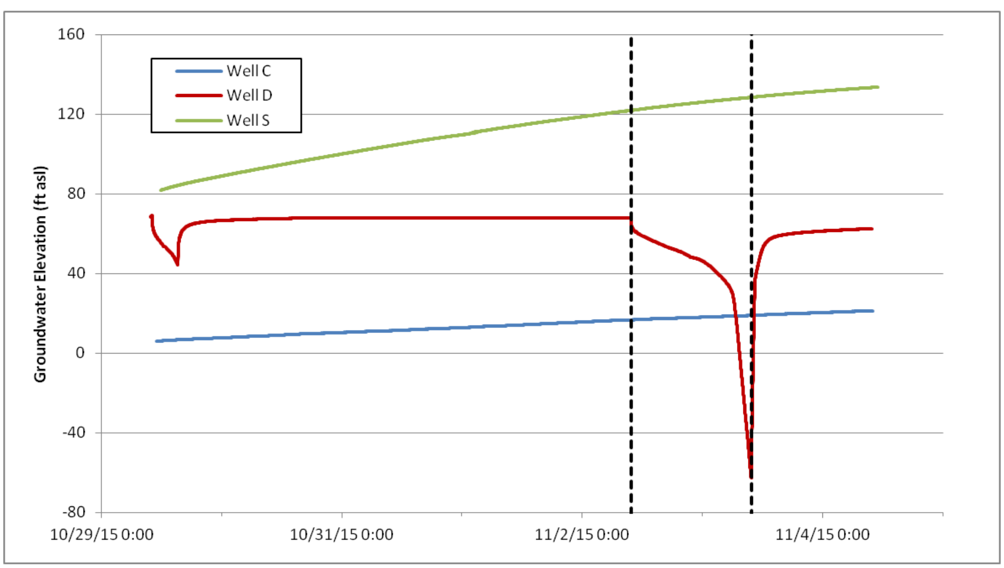

Figure 3: Groundwater elevation hydrographs at the three instrumented wells (C, D, & S) during the 10/29/15 to 11/4/15 monitoring period.

uniform across the study area and that the concealed fault contact separating the TKfs and the JKfs geologic units is not a significant barrier to groundwater flow. On the other hand, the anomalous conditions at Well B suggest that the fracture system is heterogeneous.

Static water level data is also available at the four project wells (A-D) from August and September of 2007 (RCS, 2007). Those measurements indicated that static water levels were 5 to 12 feet higher in 2007 as compared to October 2015. This difference highlights the fact that the pump test period represents very dry initial conditions after multiple years of drought and limited aquifer recharge. The 2007 data also show similar water levels in Wells A, C, and D and a much lower water level in Well B supporting the notion that Well C was in a recovery phase during the 2015 pump test monitoring period and that the water level in Well B is consistently lower than in surrounding wells. As described above, all well owners were advised to fill storage tanks one week prior to the beginning of the monitoring period so as to avoid pumping during the test period. The recovery at Well C is likely related to this pre-monitoring period pumping.

Pump Test Water Level Responses

The water level data at each of the seven wells was de-trended in order to remove the background trend of increasing water levels and establish a time-drawdown relationship solely representative of the drawdown due to pumping. The de-trending process involved calculating the rate of change in water level over the 24-hr period prior to the onset of pumping, projecting water levels forward in time by assuming that in the absence of a response to pumping this rate of change would continue forward in time, and then correcting the water levels by subtracting the projected water levels from the measured water levels.

The resulting time-drawdown data at the pumping well (D) indicates that 24 hours of pumping at a rate of 8 gpm resulted in a total drawdown of 129.5 feet (Figure 5). For the first 120 minutes of the test, the rate of drawdown rapidly decreases over time from 2.0 feet per minute to 0.02 feet per minute. Between 60 and 720 minutes into the test, the rate of drawdown is relatively stable. At about 750 minutes into the test, the rate of drawdown begins to increase again reaching 0.1 feet per minute 1,200 minutes into the test. During the last 240 minutes of the test, the rate of drawdown again increases sharply reaching 0.5 feet per minute at the conclusion of the test.

For the first 360 minutes of the recovery period, the rate of recovery rapidly decreases from 2.4 feet per minute to 0.01 feet per minute. Between 360 and 660 minutes into the recovery period, the rate of recovery continues to decline slowly and between 660 and 1,440 minutes into the recovery period, the rate of recovery is relatively constant and on the order of 0.002 feet per minute. The well recovers 50% of the maximum drawdown within the first 30 minutes of the recovery period and 90% within the first 150 minutes. At the end of the 24-hour recovery period, the residual drawdown is 4.7 feet which represents 96% recovery of the pre-test elevation (Figure 5).

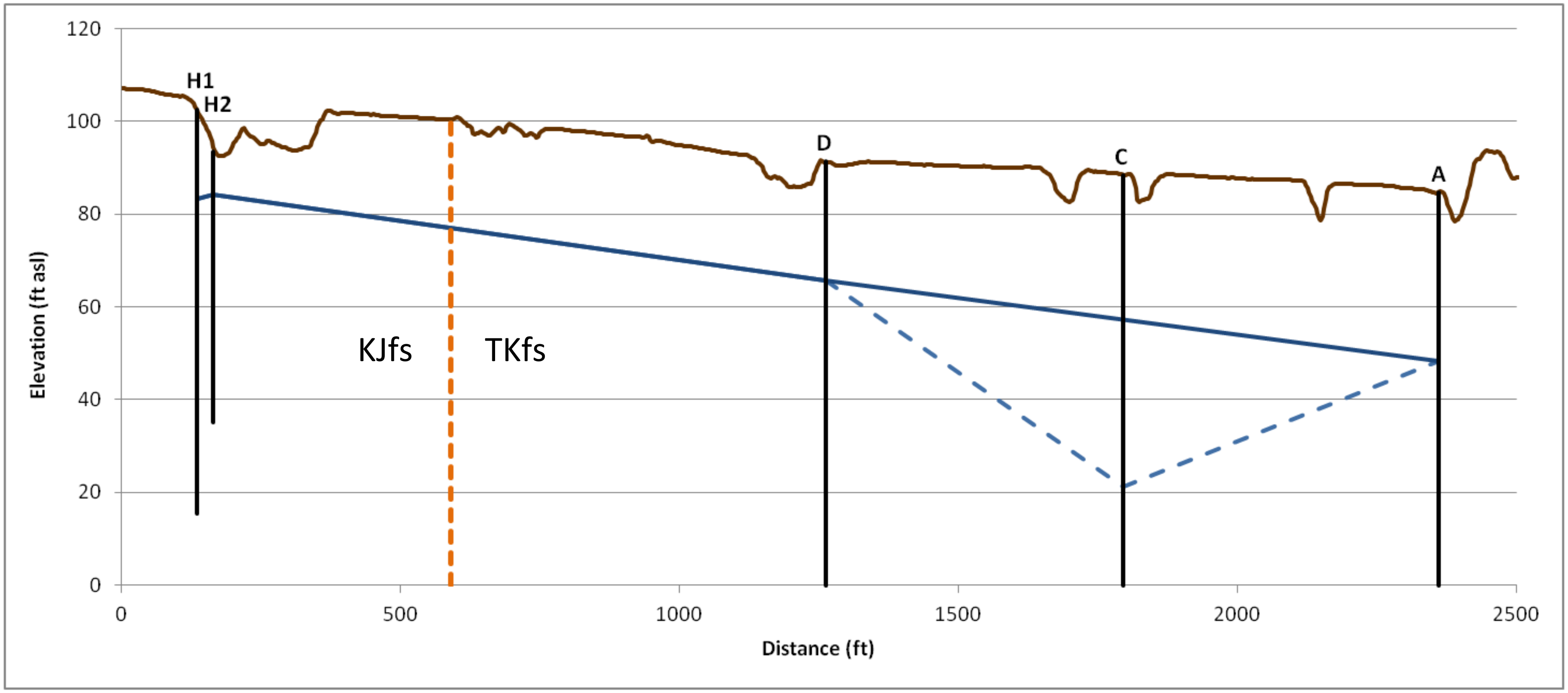

Figure 4: Transect of static groundwater elevations on 10/29/15 (blue dashed line includes the water level in Well C, orange dashed line represents the fault contact separating the KJfs and TKfs. The transect is oriented with west to the left and east to the right.

The time-drawdown data at the onsite instrumented monitoring well (C) indicates a response to pumping beginning about 240 minutes into the test (Figure 6). At the conclusion of the 24-hr pumping period, the total drawdown at Well C was 0.59 feet. The drawdown stabilizes for about 180 minutes at the end of the pumping period and then begins again at a similar rate for the remainder of the monitoring period reaching 1.04 feet 24-hrs after the end of the pumping period.

The time/drawdown data at the offsite instrumented monitoring well (S) does not show a response to pumping. The rate of recovery slowly decreases throughout the six day monitoring period however the change occurs gradually with no discontinuity associated with the onset or cessation of the pumping period (Figure 3), in contrast to observed changes in Well C (Figure 6). A response to pumping was not observed at any of the other four monitoring wells with the possible exception of Well A where a slight drawdown response (0.15 feet) was observed (Figure 2). The relatively limited number of observations at this un-instrumented well and the small magnitude of the response makes it difficult to detect the timing of this response or confirm that it is in fact a response to pumping at well D.

Pump Test Analysis

The time-drawdown data for the pumping well (D) and the instrumented monitoring well that showed a response to pumping (C) were analyzed using AQTESOLV and a type curve matching approach was used to estimate aquifer properties. Various diagnostic flow plots were first reviewed to identify the flow regime(s) indicated by the data. The pattern of declining rates of drawdown during early time, stable rates of drawdown during middle time, and increasing rates of drawdown during late time may be indicative of a dual-porosity flow regime at the pumping well. Dual-porosity flow regime solutions treat the aquifer as consisting of the composite of fractures and matrix blocks with the fractures supplying water to the well and the matrix acting as the source of water for the fractures. A near unit slope in the early time data on a bilinear flow (drawdown as a function of the fourth root of time on a log-log scale) plot at the pumping well suggests that the aquifer may be characterized by a finite-conductivity fracture flow regime. Finite-conductivity fracture flow solutions assume that the well intersects a single uniform-flux vertical or horizontal fracture and that drawdown is variable along the fracture in contrast to infinite-conductivity solutions which assume uniform drawdown.

The sharp increase in the rate of drawdown during the last four hours of the test may indicate that the cone of depression has extended far enough to intersect one or more aquifer boundaries. Another possible explanation for this late-time behavior is that the upper portions of the fracture network are higher yielding and become dewatered during late time. In contrast to the drawdown data from the pumping well, the recovery data from the pumping well and the drawdown data from the monitoring well (C) were both well-described by standard radial flow solutions. The radial flow behavior at the observation well is consistent with a single fracture model where radial flow through interconnected fractures is expected to dominate at observation wells during middle and late time.

Interpretation of drawdown data from an observation well is considered more reliable than drawdown data from a pumping well since the pumping well response is often biased by the effects of wellbore storage and flow turbulence associated with interfaces between the filter pack and well screen. In particular, observation wells can be used to estimate the aquifer Storage Coefficient (S) as well as the Transmissivity (T) whereas pumping wells can only be used to estimate T. Furthermore, the response in the observation well provides data characterizing aquifer hydraulics over the distance separating the pumping well and the observation well and is therefore more representative of aquifer conditions.

Two radial flow solutions for a confined aquifer (Theis, 1935 & Cooper-Jacob, 1946) were applied to the monitoring data from well (C) to provide estimates of S and T that describe flow in the aquifer. Applying a radial flow solution at the monitoring well is appropriate even in a fracture flow aquifer system such as this one given that a radial flow response is typical for wells in a fracture flow system that are located outside of the zone of linear flow (Jenkins and Prentice, 1982). The equivalent unconfined solutions were also applied and they resulted in similar aquifer property estimates with a poorer fit, thus only the confined solutions were retained. This exercise revealed a range of S values of $5.6e^{-4}$ to $8.2e^{-4}$ and a range of T values of 130 to 345 ft^2/day (Table 2).

The drawdown data from the pumping well (D) are not well described by any of the standard radial flow solutions. Several fractured aquifer solutions did describe the data well when the final four hours of data were omitted. These solutions were used in conjunction with the Storage Coefficient estimates derived from the analysis of the monitoring well data to provide additional estimates of the Transmisivity. These solutions include a double-porosity method (Moench, 1984) and two single fracture methods (Gringarten-Witherspoon, 1972 & Gringarten-Ramey, 1974). This exercise revealed a range of T values of 4.5 to 32.8 ft^2/day (Table 2).

The recovery data from the pumping well (D) were well described by the Theis (1935) solution for a confined aquifer. This solution was used in conjunction with the S estimates derived from the monitoring well analysis to estimate the Transmissivity. This exercise resulted in a T value of 17.6 ft^2/day regardless of the value of S that is used (Table 2).

Several of the applied solutions allow for the consideration of boundary effects. A hypothetical no-flow boundary condition was included at the inferred position of the concealed fault contact separating the TKfs and the KJfs. None of the solutions were able to provide an adequate fit when the final four hours of the test data were included regardless of the boundary condition assumptions that were made. This may imply that the response represents the effects of dewatering high-yielding portions of the facture system rather than the presence of a boundary, however it may also reflect limitations of the solutions to accurately representing aquifer boundary effects. Additional data characterizing the fracture system and/or a pump

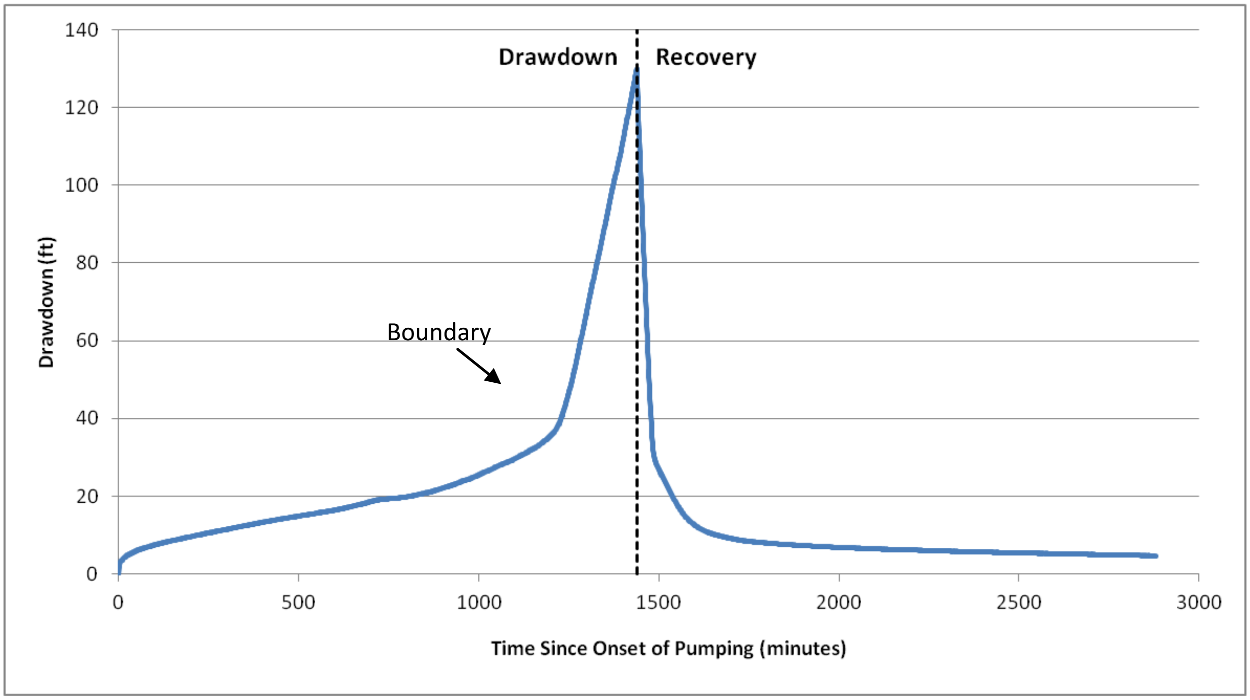

Figure 5: Time-drawdown data for the pumping well (Well D), a possible boundary effect is indicated by the abrupt increase in the rate of drawdown after about 1200 minutes of pumping.

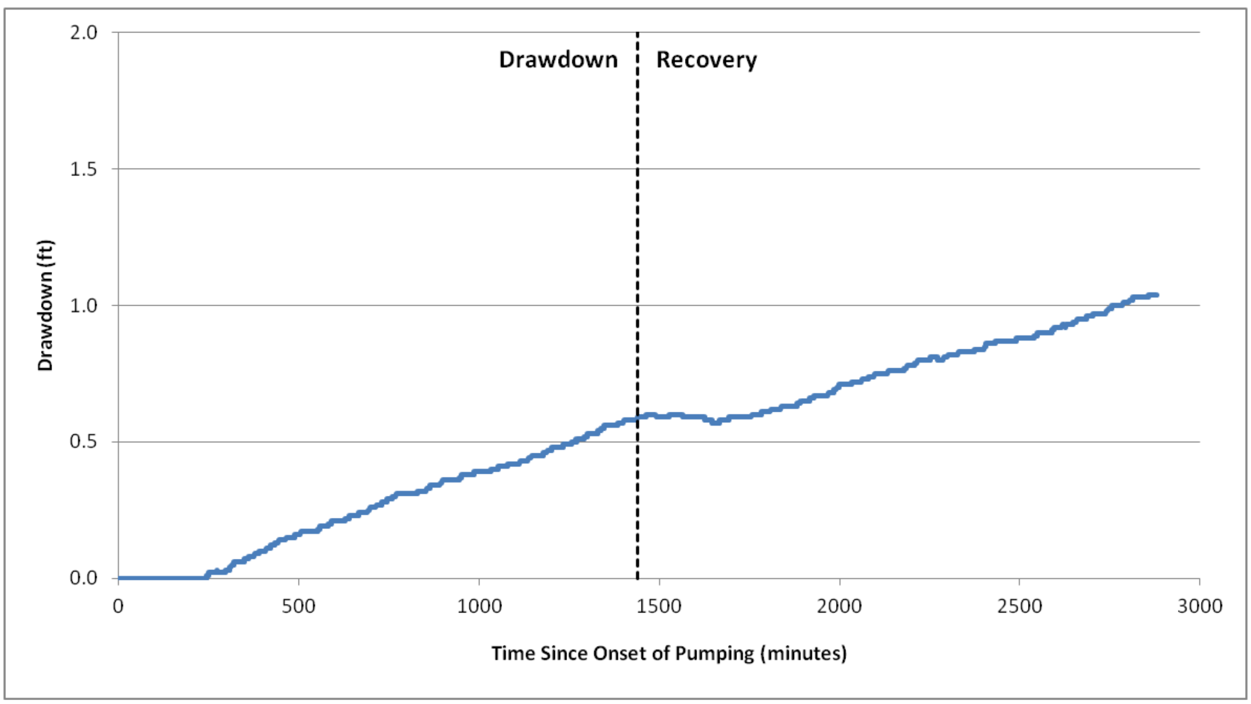

Figure 6: Time-drawdown data for the monitoring well (Well C).

test that captures a boundary response in one or more observation wells would be necessary in order to further evaluate the extent of the fracture system and confirm the presence of one or more no-flow boundaries.

In summary, the analysis indicates uncertainty regarding the causes of the late-time response which may be indicative of a boundary effect or of vertical variability in the fracture system. Regardless, the estimates of aquifer properties derived from the analysis of the first 20 hours of the test data and from the recovery data were well-described by several aquifer solutions and should be considered valid for pumping rates and durations small enough to avoid inducing the drawdown necessary for boundary effects to occur.

Table 2: Results of the pump test analysis for Wells C and D.

Solution	Transmisivity (ft^2/d)	Storage Coefficient	Notes
Theis	130	$8.2e^{-4}$	24 hrs drawdown
Cooper-Jacob	245	$5.6e^{-4}$	24 hrs drawdown
Well C AVERAGE	**237.5**	**$6.9e^{-4}$**	
Gringarten-Witherspoon w/ Vertical Fracture	32.8	$5.6e^{-4}$	20 hrs drawdown
Gringarten-Ramey w/Horizontal Fracture	10.6	$8.2e^{-4}$	20 hrs drawdown
Gringarten-Ramey w/Horizontal Fracture	4.5	$5.6e^{-4}$	20 hrs drawdown
Theis	17.6	$8.2e^{-4}$	24 hrs recovery
Theis	17.6	$5.6e^{-4}$	24 hrs recovery
Well D AVERAGE	**11.8**	**$6.9e^{-4}$**	

Sustainable Yield

Sustainable yield is defined as the discharge rate that will not cause the water level in the well to drop below a prescribed limit. As discussed above, a sharp increase in the rate of drawdown at Well D occurred 20 hours into the pump test. The total drawdown at 20 hours was 35.6-ft which increased to 129.5-ft by 24 hours. Based on the rate of drawdown during the end of the test, the pumping rate would likely have been sustained for approximately three additional hours before the pump would have lost suction. Thus the 11,520 gallons pumped during the test is a reasonable approximation of the maximum daily yield that could be obtained from the well.

This yield is greater than the sustainable yield; continuous pumping at this rate would not be possible due to excessive drawdown. The 9,600 gallons pumped during the first 20 hours of the test provides a reasonable estimate of the maximum sustainable daily yield. Restricting the duration of pumping to 20 hours limits drawdown to a reasonable level and allowing for 4 hours of recovery between pumping periods allows for the water level to recover to within 93% of the initial static water level.

Peak Use Estimates

In order to estimate the anticipated extent and magnitude of the cones of depression that may be expected to develop as a result of pumping from the project wells, it is useful to estimate the peak daily water demands on the project wells. A new well will be drilled to serve the proposed winery and the existing four wells will provide irrigation water for both the Rudd vineyards and the MacRostie vineyards (adjacent to the south). Peak demands for the proposed winery have already been estimated to facilitate design of the septic system (Always Engineering, 2015). The peak daily demand is estimated to include 800 gallons per day (gpd) peak harvest process use, 360 gpd peak employee use, and 750 gpd for a 150 person event for a total peak daily demand of 1,910 gpd.

Irrigation water use data is available for both the Rudd and MacRostie vineyards from the 2014 irrigation season. This data indicates that a total of 126,572 gallons was used to irrigate both vineyard properties over the 49 day period between 6/24/2014 and 8/12/2014. The frequency of irrigation applications and the degree to which irrigation is staggered between vineyard blocks is unknown, however if we conservatively assume all of the vineyard acreage is irrigated on the same days and irrigation occurs once per week, the peak daily irrigation demand would be 18,082 gallons. If we conservatively assume that the peak daily winery and irrigation demands occur on the same day, the total peak daily demand on the well field would be 19,992 gallons.

Water System Evaluation

The existing water system consists of four wells (A through D) which supply irrigation water to both the Rudd and MacRostie vineyards. These wells are plumbed to a 110,000 gallon storage tank and operation of the wells are triggered by a float. When the system is turned on, all four wells operate simultaneously until the tank is filled. The operational pumping rates of the wells ranges from 5 to 30 gpm for a total combined pumping rate of 65 gpm. Neglecting the buffering effects of the storage tank indicates that 4.6 hours of pumping at the operational pumping rates would be required to meet the peak daily irrigation demand of 18,082. A new well will be constructed with a 50 foot sanitary seal to supply domestic water for the proposed winery. Assuming this fifth (yet to be drilled) well has an operational pumping rate similar to well D (10 gpm) indicates that the peak daily winery demand of 1,910 gallons could be met with 3.2 hours of pumping.

Assuming the aquifer properties and sustainable yield estimates derived for well D are representative of conditions at the other wells, the four existing wells plus the new well will have a combined sustainable yield of 48,000 gallons per day. The peak daily demand on the well field of 19,992 gallons represents ~42% of the total sustainable yield of the well field.

Well Interference Analysis

Well interference is the term used to describe the effects of pumping a well on another well manifested by a depression of the water surface in an impacted well caused by the water table drawdown of a pumping well. Well interference effects are not necessarily significant if the extent of drawdown is small relative to the operational water levels in an impacted well. Generally, a few feet of drawdown caused by well interference would not be expected to significantly affect access to groundwater in an impacted well.

Fracture flow systems are often characterized by significant heterogeneity and as such it is difficult to extrapolate drawdown responses observed at one or two wells to a larger aquifer area. Despite these uncertainties such extrapolation is still useful, and in the absence of detailed characterization of the fracture network and/or pump tests at several different wells, is the best means of evaluating the potential for well interference associated with pumping the project wells. Equation 1 (Cooper and Jacob, 1946) can be used to simulate the drawdown and cones of depression associated with the operation of the four existing wells that would be required to meet the peak water demands:

$$s = 2.3Q/4\pi T \log (2.25Tt/r^2S)$$

where s = drawdown in feet, Q= pumping rate in ft^3/day, T = Transmissivity in ft^2/day, t = duration of pumping in days, r = distance from the pumping well in feet, and S is the Storage Coefficient.

The equation was solved using a range of estimates of T (11.8 to 237.5 ft^2/day) and S ($5.6e^{-4}$ to $8.2e^{-4}$) derived from the analysis of Wells C and D. The maximum predicted drawdown occurs when the high-end T estimate and the low-end S estimate are used. To be conservative these end-member values (T = 237.5 ft^2/day and S = $5.6e^{-4}$) were selected for the drawdown analysis.

The drawdown associated with each of the project wells decreases rapidly with distance away from the well (Figure 7 & Table 3). The largest drawdowns are associated with Well C which has the highest pumping rate. Drawdown at Well C decreases to less than 5 feet within 118-ft, less than 1-ft within 331-ft, and less than 0.1-ft within 418-ft. The closest well to the neighboring wells is Well D where drawdown decreases to less than 5 feet within 3-ft, less than 1-ft within 198-ft, and less than 0.1-ft within 397-ft (Table 3).

The closest neighboring well is Well S which is located 935-ft away from Well D. Based on this analysis the cones of depression from the various pumping wells will not extend far enough to intersect Well S and therefore pumping at these rates and durations will not result in well interference to the neighboring wells.

As discussed above under Sustainable Yield, pumping for durations longer than 20 hours is not recommended, nor is Well D likely to be able to maintain production for much longer than 24 hours. For illustrative purposes we calculate that continuous pumping at 10 gpm for 4.3 days would be required for 1-ft of drawdown to occur at well S and continuous pumping for 365 days would result in 3.9-ft of drawdown at well S. Thus even if pumping durations are significantly longer than is required to meet peak water demand or than is even possible given the production limitations of the well, significant well interference at neighboring wells is not expected to occur.

Table 3: Operational pumping rates and predicted drawdowns at various distances from wells A through D for the pumping durations required to meet peak daily water demands.

Well	Pumping Rate (gpm)	Drawdown at 10-ft (ft)	Drawdown at 100- ft (ft)	Drawdown at 400- ft (ft)
A	20	9.7	3.7	0.2
B	5	2.4	0.9	< 0.1
C	30	14.5	5.6	0.3
D	10	4.8	1.9	0.1

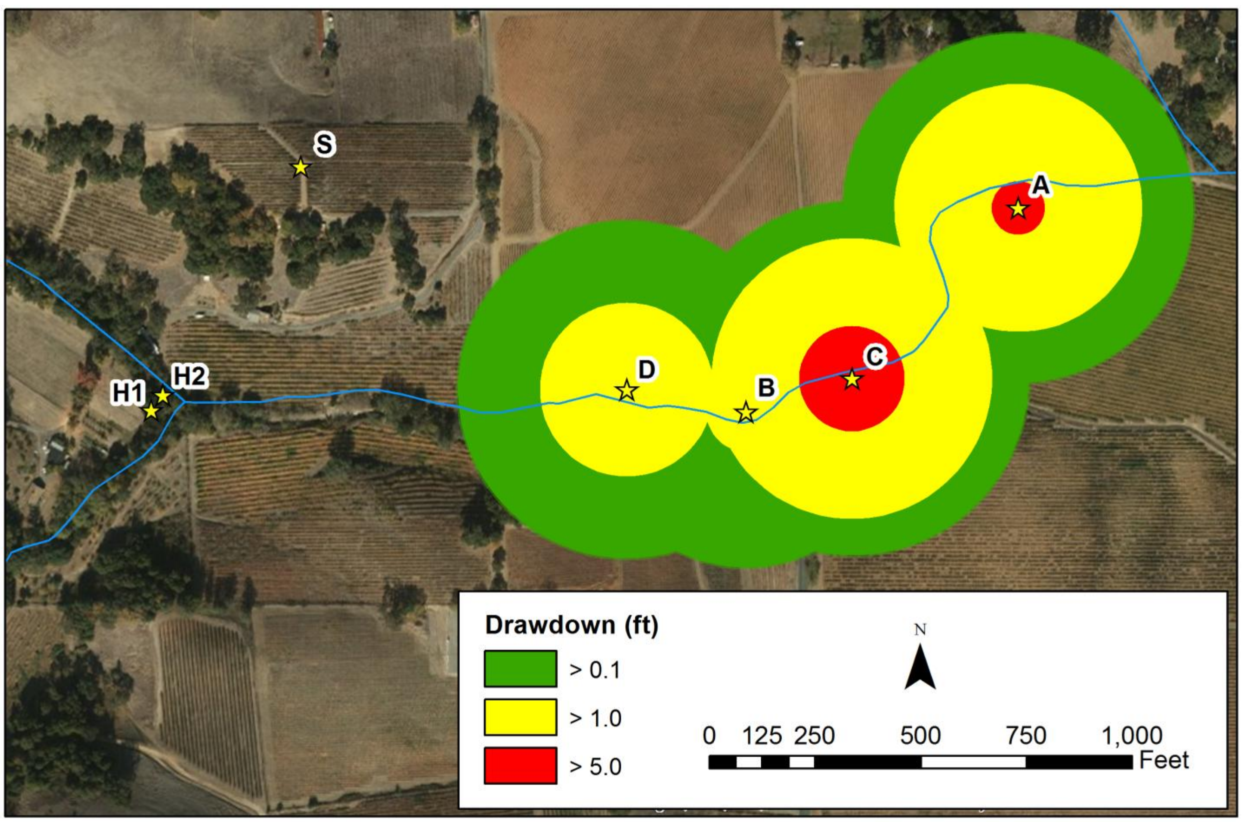

Figure 7: Estimated magnitudes and extents of the cones of depression resulting from pumping wells A through D at operational pumping rates and durations required to meet peak daily water demands.

Conclusions

A 24-hour duration constant rate pump test (8 gpm) was conducted at Well D on November 2nd and 3rd, 2015. The pumping resulted in 35.6-ft of drawdown at the pumping well after 20 hours which increased to 129.5-ft of drawdown after 24 hours. The well recovered rapidly with 90% recovery within the first 2.5 hours after the test. Well C, which is located 533-feet away from Well D, responded after about four hours of pumping with a total drawdown of 0.6-ft at the conclusion of the test. No response to pumping was observed at the three neighboring wells (H1, H2, and S) which are located between 935 and 1,126 feet away. The time/drawdown data from the pumping well were described using a variety of fracture flow solutions and the data from the monitoring well (C) were described using a variety of radial flow solutions resulting in estimates of Transmisivity ranging from 11.8 to 237.5 ft^2/day and estimates of the Storage Coefficient ranging from $5.6e^{-4}$ to $8.2e^{-4}$.

Based on the drawdown results for Well D, the total sustainable yield of the well field (including the four existing irrigation wells and the new yet to be drilled winery well) is estimated to be 48,000 gallons per day (9,600 gallons per day times five wells). Using a variety of conservative assumptions, the peak daily water demands for the proposed winery and existing vineyard irrigation on both the Rudd and MacRostie vineyards is 19,992 gallons or 42% of the total sustainable yield. The existing water system is capable of meeting the irrigation portion of this demand with 4.6 hours of pumping at current operational pumping rates and the winery portion of this demand could be met with 3.2 hours of pumping from the new well assuming a production rate similar to Well D.

The extents and magnitudes of the cones of depression associated with pumping at the rates and durations required to meet the peak water demands indicate that the area where drawdown would exceed 0.1-ft would not extend more than 400-ft in the direction of the wells on the neighboring property. The closest of these neighboring wells is located 935-ft away, thus no well interference is expected to occur as a result of pumping the project wells even during times of peak demand. Given that the existing water system is capable of producing the peak daily demands with only 3 to 5 hours of pumping and that the resulting cones of depression do not extend far enough away from the wells to intersect neighboring wells, no changes to the existing water system are deemed necessary.

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