Summary of Aquifer Testing and Analysis, Dixie Valley

Prepared for: Churchill County, Nevada

Prepared by: Interflow Hydrology, Inc and Mahannah & Associates, LLC

November, 2012

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Prepared by:
Interflow Hydrology, Inc.
Truckee, CA
&
Mahannah & Associates, LLC
Reno, NV

Cover: Navy Well 07E discharging on the abandoned Knittle Ranch, central Dixie Valley, during a shut-in and recovery aquifer test conducted in May, 2012.

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Common Terms

Aquifer Test: A controlled discharge or recovery of a well or wells for determining the hydraulic characteristics of an aquifer.

Cooper-Jacob Method: A simplified and graphical method for estimating aquifer parameters based on the analytical method of Theis (1935). The method requires graphing drawdown data versus the logarithm of time and interpreting the slope of drawdown.

Recovery: The rise in water level or increase in water pressure in a well or borehole due to cessation of pumping.

Shut-in Test: For flowing, artesian wells, a type of aquifer test where the well is closed off and the rise in hydrostatic pressure is recorded and analyzed.

Specific Yield: The ratio of the volume of water that, after saturation, can be drained by gravity from a porous medium to the total volume (Todd, 1980).

Storage Coefficient: The volume of water that an aquifer releases from or takes into storage per unit surface area of aquifer per unit change in hydraulic head (Todd, 1980). The storage coefficient is expressed as a unitless ratio.

Theis Method: In 1935, Theis derived an equation, based on heat transport theory, which is a mathematical analog of the transient response of water levels in an ideal, homogenous, aerially extensive aquifer. The results of the theory are used as a benchmark for quantifying aquifer properties and pumping test data. Other mathematical models are generally variations of the Theis formula which take into consideration non-ideal effects, such as borehole storage, delayed yield, leakage from adjacent water bearing-units etc.

Transmissivity: A quantification of the productiveness of an aquifer. The units used in this report are ft^2/day, and thus represent the volume of water flowing through a cross-sectional area of an aquifer that is 1 foot wide multiplied by the aquifer thickness (in feet), under a hydraulic gradient of 1 ft. / 1 ft. per day. Generally, the larger the transmissivity value, the more productive the aquifer and the higher the potential yield.

Yield: A general term for the productiveness of a well or borehole, expressed in gallons per minute (gpm). Yield can change over the course of a pumping test due to boundary conditions, well efficiency, and pump efficiency.

Executive Summary

Aquifer testing was conducted in Dixie Valley, Churchill County, Nevada to provide information on the hydraulic properties of the basin-fill aquifer. Wells tested include the main reservoir pressure support well at the Terra-Gen geothermal power plant, a well used in a center-pivot irrigation operation, and a flowing artesian well located near the abandoned Settlement area of central Dixie Valley. Analysis of the aquifer response indicates that the transmissivity of the basin-fill aquifer in the vicinity of the power plant and at a ranch in northern Dixie Valley is on the order of 10,000 to 17,000 ft^2/day. The estimated transmissivity of a thin sand and gravel zone that provides artesian flow to wells on the abandoned Knittle Ranch is approximately 800 ft^2/day.

Storage coefficients for each area were also derived from the tests with the aid of data obtained from nearby observation wells, and indicate confined aquifer conditions at the Knittle Ranch and Terra-Gen (S values of 10^{-4}) and unconfined aquifer conditions at the Lincoln Ranch (Sy value of 0.05).

In addition to the aquifer tests mentioned above, the United States Geological Survey (USGS) conducted four shut-in tests in the Settlement area of Dixie valley with reported estimated transmissivity values ranging between 400 ft^2/day and 1,400 ft^2/day (Huntington and Allander, 2011). Two wells in south-central Dixie Valley were equipped with pumps and also tested (Huntington 2011a, 2011b). Estimated transmissivity for those sites ranges from 700 to 2,500 ft^2/day.

Introduction

Interflow Hydrology, Inc., in association with Mahannah & Associates, LLC conducted aquifer tests and analysis of data from selected wells to augment data collected by the USGS in the Dixie Valley Hydrologic Basin (Figure 1). These field activities and subsequent analyses are part of a broader hydrologic assessment of the basin being conducted by United States Bureau of Reclamation, Churchill County, contracted agencies and consultants, including the USGS.

The aquifer testing and analysis is useful in defining the hydraulic properties of the basin-fill aquifer and compliments existing data on weather, evapotranspiration, water levels in wells, surface and groundwater chemistry, and spring and stream flow that collectively improve the knowledge of the water resources of Dixie Valley. The aquifer testing results will also be incorporated into a numerical model of the groundwater flow system of the basin for use in managing the water resources. The following sections describe the testing procedures, data collection, and analysis of the data associated with three aquifer tests. Testing locations are shown in Figure 1.

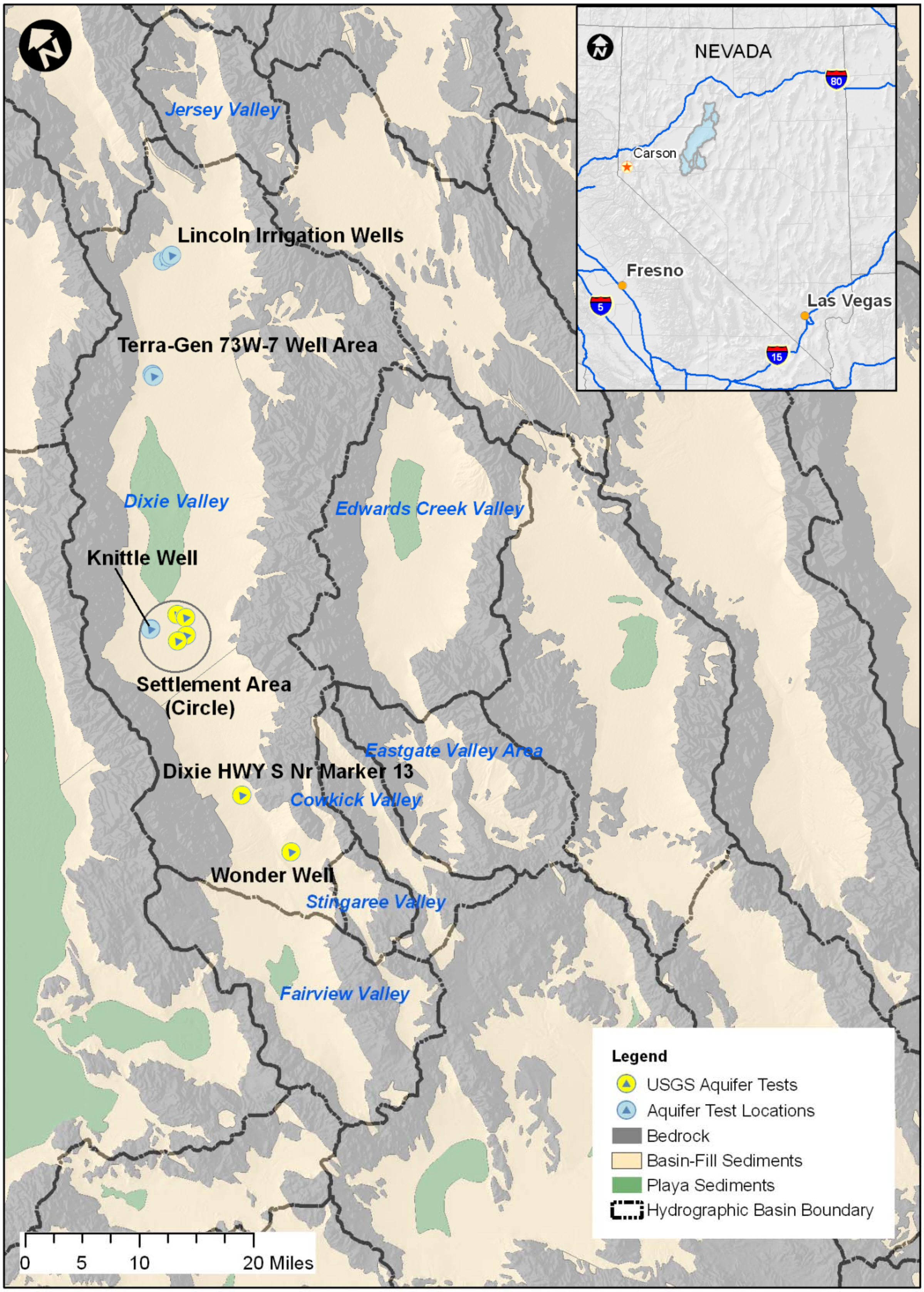

Figure 1: Location map for aquifer tests conducted in Dixie Valley Nevada.

Terra-Gen Well 73W-7

A short recovery test was performed in Dixie Valley on the 73W-7 well operated by Terra-Gen, owner and operator of the Dixie Valley Geothermal Plant (Figure 2, 3). It is understood that well 73W-7 is used almost continuously by the plant for pressure support of the geothermal reservoir, and that prolonged testing, particularly with a long pre-test recovery and monitoring period would be unlikely. With coordination with Terra-Gen staff, a 12 hour recovery test was performed starting at 1900 hours on 2/28/2012 and ending at 0700 hours on 2/29/2012. Well locations are shown in Figures 1 and 2.

Prior to the recovery period two Solinst Leveloggers were placed in nearby unused wells to allow for observations of aquifer water level response. The wells used for observation were the Goeringer Well and the Blackwater Well. These wells are 158 feet and 1105 feet from well 73W-7, as summarized in Table 1. An image of well 73W-7 is available as Figure 3.

Table 1: Information for wells involved in the well 73W-7 12-hour recovery test.

Well Name	Nevada Well Log No.	UTM North (m)	UTM East (m)	Distance from 73W-7 (feet)	Perforated Interval (ft)	Maximum recovery after 12 hours(ft)
Terra-Gen 73W-7	Unknown	4424315	427099	--	80-300	Unknown
Goeringer Well	11047?	4424363	427096	158	50-430	10.44
Blackwater	12750?	4423979	427075	1105	140-160	1.89

The water level recorders were deployed on 2/10/2012, and at that time 73W-7 was pumping. Evaluation of the data from 2/10/2012 to 2/28/2012 indicates that 73W-7 was being pumped continuously and the pumping water level was reasonably stable with no apparent upward or downward trend.

The pumping rate for well 73W-7 was determined using a totalizing flow meter currently installed on the pipeline leading from the well to the plant.

The aquifer at this location responded quickly to the cessation of flow, and within 12-hours, the Goeringer Well recovered approximately 10.4 feet. The Cooper-Jacob (1946) analysis was utilized and resulted in a transmissivity value of approximately 14,800 ft^2/day, and a storage coefficient of 1.8E-4, indicating confined conditions (Figure 4).
Analysis of the recovery data from the Blackwater Well provide similar values of 16,900 ft^2/day , and a storage coefficient of 7.5E-4 (Figure5).

The differences in the values, though small, may be caused in part by the selection of the slope of the line that dictates the value of Δs in the Cooper-Jacob analysis, but may also be attributable to spatial variation in aquifer properties. Some degree of heterogeneity and anisotropy is expected in all natural systems.

Conceptually, these values are consistent with a sand and gravel aquifer confined by silts and clays; these are most likely interbedded, so the values represent an average for the entire screened interval of the wells.

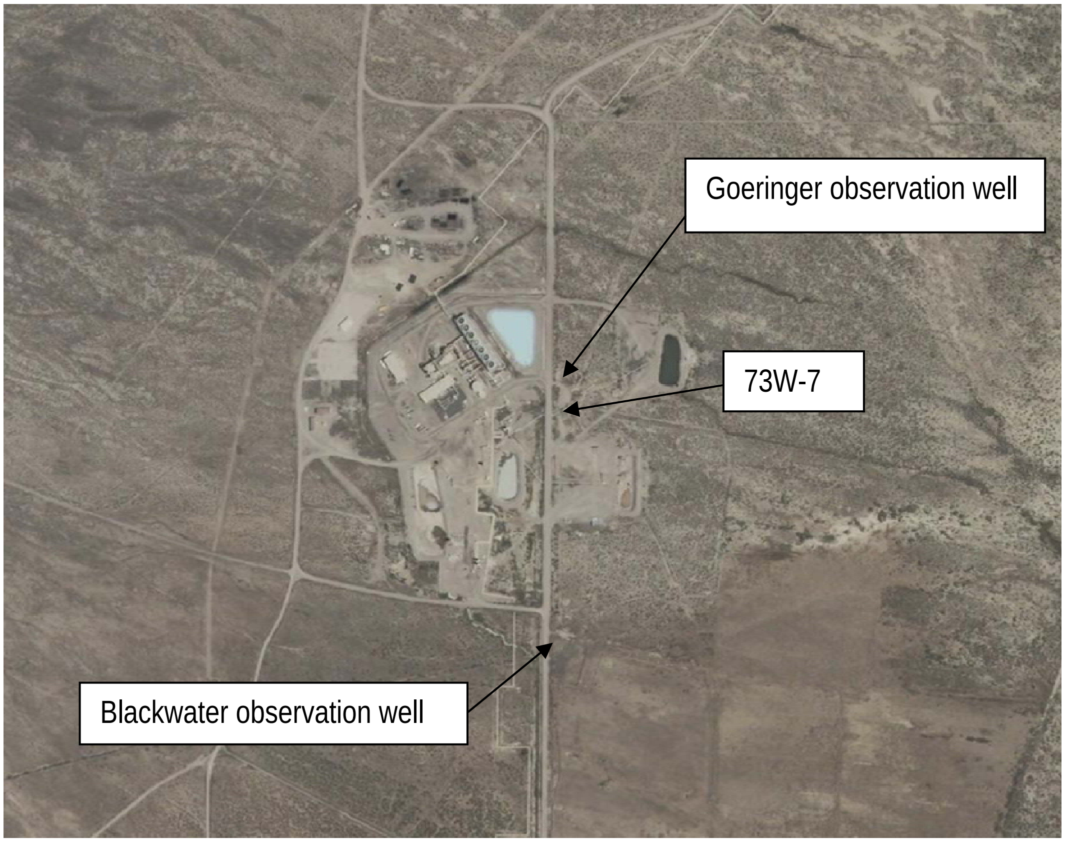

Figure 2: Aerial View of the Dixie Power Plant showing well locations.

Figure 3: Digital image of Well 73W-7 with the Dixie Valley Power Plant in the background.

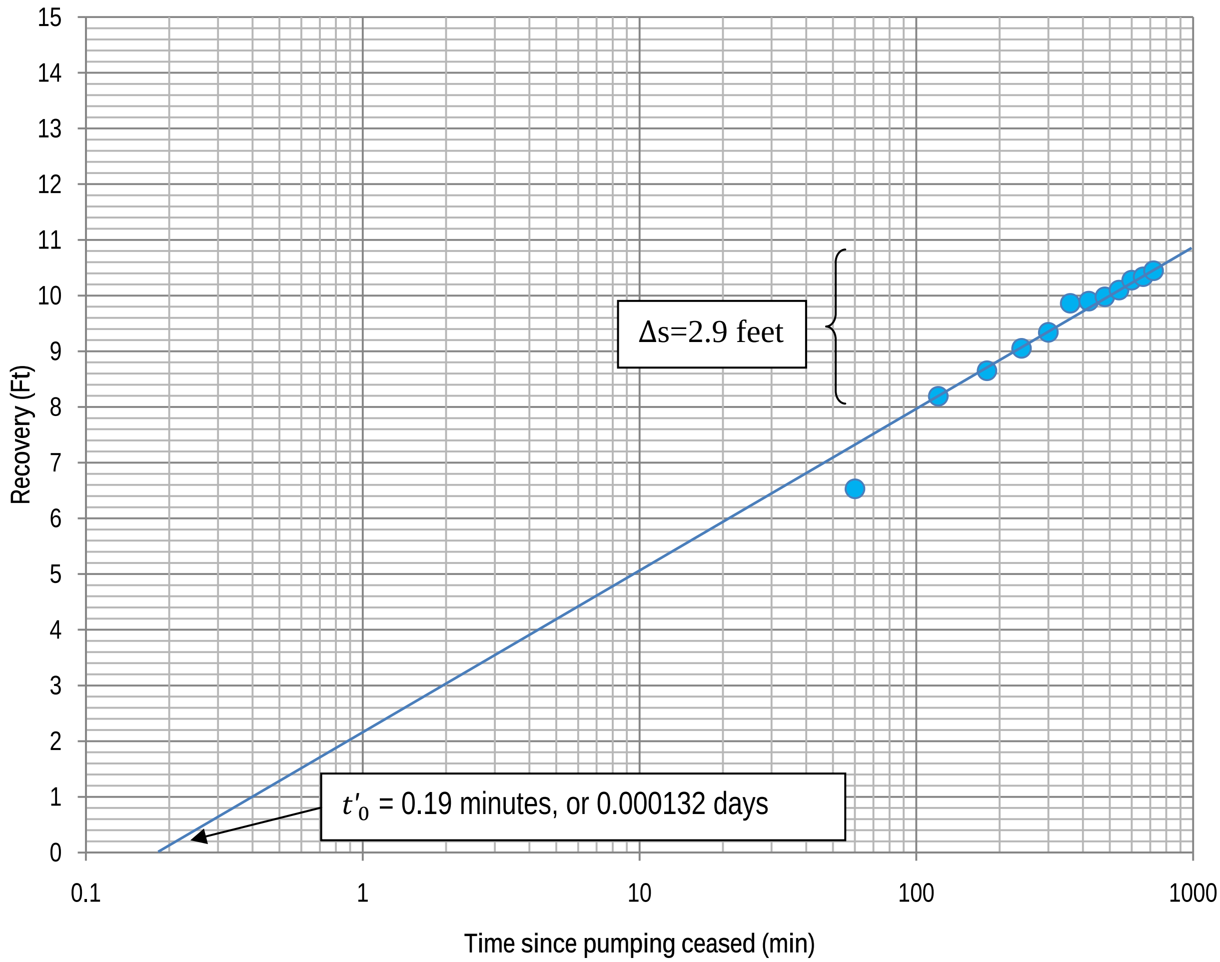

Figure 4: Goeringer Well recovery and analysis.

Computations:

$T = \frac{264Q}{\Delta s}$, $S = \frac{0.3Tt'_0}{r^2}$

Given: r = 158 feet, Q=1195 gpm

$T = \frac{264\ (1195\ \text{gpm})}{2.9}$=110,694 gpd/ft, or 14,798 ft²/day, a moderately high value

$S = \frac{0.3\left(110694\frac{\text{gpm}}{\text{day}}\right)0.000132\ \text{days}}{(158\ feet)^2} = \mathbf{1.76E-4}$, indicates confined conditions

In round numbers: T = 14,800 ft²/day , S = 1.8E-4

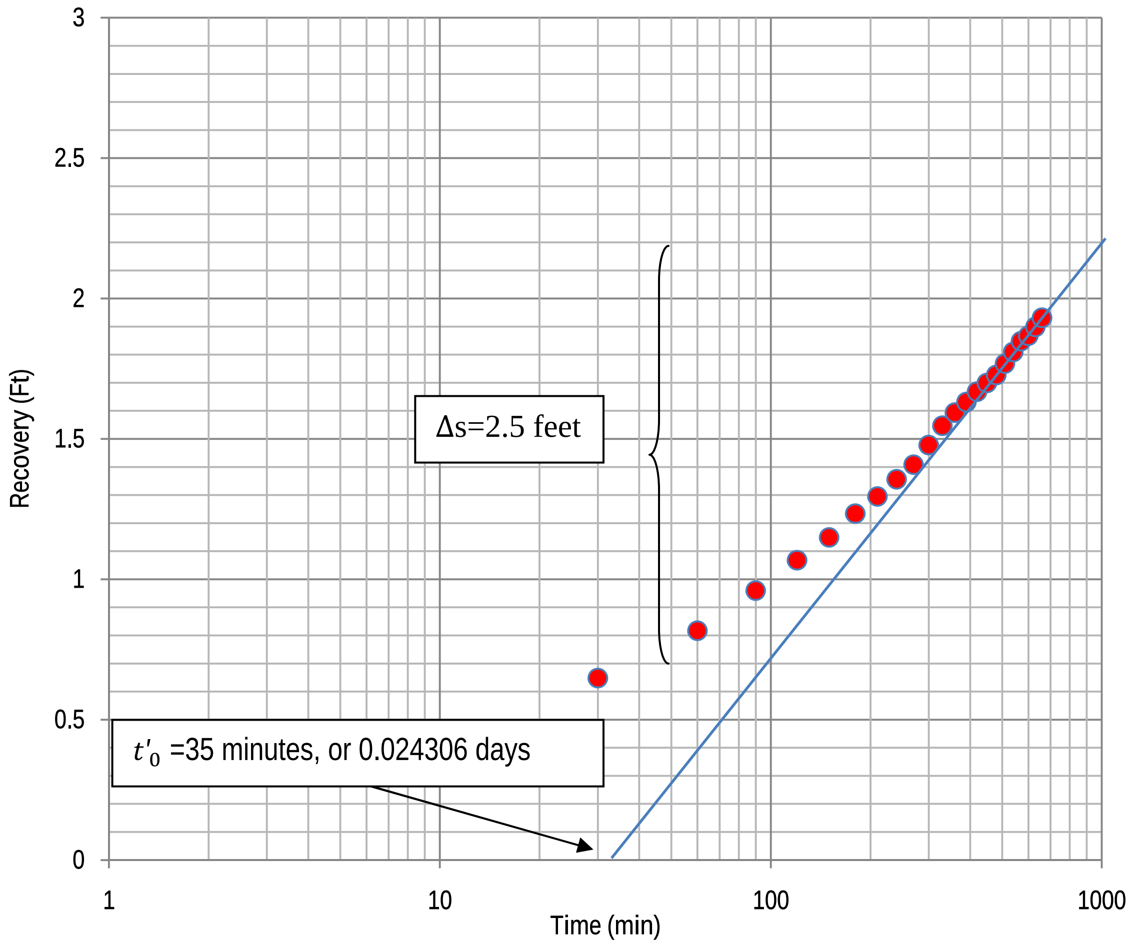

Figure 5: Blackwater Well recovery and analysis.

Computations:

$T = \frac{264Q}{\Delta s}$, $S = \frac{0.3Tt'_0}{r^2}$

Given: r = 1105 feet, Q=1195 gpm

$T = \frac{264\ (1195\ \text{gpm})}{2.5}$=126,192 gpd/ft, or 16,871 ft^2/day, a moderately high value

$S = \frac{0.3\left(126192\frac{\text{gpm}}{\text{day}}\right)0.024306\ \text{days}}{(1105\ feet)^2} = \mathbf{7.54E-4}$, indicates confined conditions

In round numbers: T = 16,900 ft^2/day , S = 7.5E-4

Lincoln Ranch Irrigation Wells

Groundwater level monitoring was conducted at the Lincoln Ranch in northwest Dixie Valley, prior to and during the startup of the 2012 annual irrigation season. Within the Dixie Valley Study Team, the wells mentioned in this report are known as the 7-Devils Ag. (agriculture) Wells, and are numbered #1 through #3. These wells are shown in Figure 6.

Ag Well #3 was utilized as an observation well while Wells #1 and #2 were pumped to serve a center-pivot irrigation system. The pumping wells were metered, each produces approximately 2,100 gpm, and it is understood that both wells operate simultaneously to serve the irrigation system. Wells #2 and #3 were not monitored for water level change during the test because of lack of physical access to deploy a water level recorder. Additional information on the observation and pumping wells is provided below in Table 2. A photograph of Ag. Well #2 is shown in Figure 7.

Table 2: Information for wells involved in the Lincoln Ranch monitoring.

Well Name	UTM North (m)	UTM East (m)	Role/Purpose	Distance from Ag. Well #3 (ft)	Nevada Well Log No.	Depth (ft)	Perforated Interval (ft)	Water Level Prior to Pumping (ft)
Ag. Well #3	4436004	438084	Observation Well	-0-	12565	270	90-270	94.8
Ag Well #1	4435914	439113	Pumping Well	3390	9621	350	100-235	102.1*
Ag Well #2	4435918	439572	Pumping Well	4890	9620	285	100-275	Unknown

*= Water level from 2009, Chris Mahannah, 2009, personal communication.

Background water level monitoring began in mid-February 2012, a month prior to any pumping. According to ranch records, pumping began on April 14th, 2012, and temporarily ceased on April 20th. Pumping resumed on April 24th. Pumping ceased again at the end of May, and started back up a week later on June 7th, after the first cutting of alfalfa, and continued until data were downloaded on June 28st 2012. A review of the transducer data retrieved from Ag. Well #3 indicates an upward trend in groundwater levels prior to irrigation (Figure 8), with marked drawdown occurring at times consistent with reported ranch pumping records. In order to evaluate drawdown from pumping, the upward trend in the water level data was removed by using a simple least squares linear regression to the raw data and subtracting the slope to result in a detrended data set.

Analysis of drawdown utilized detrended data from April 24th to May 21st. Even though some pumping had occurred prior to this time, water level recovery was deemed sufficient to analyze subsequent detrended data as originating from a relatively static condition. To simplify analysis and remove perceived changes in water levels due to probe sensitivity issues, detrended data were then smoothed (Figure 9) using the LOESS method (Cleveland, 1979), a common locally weighted regression method available in SigmaPlot™, a graphing software package.

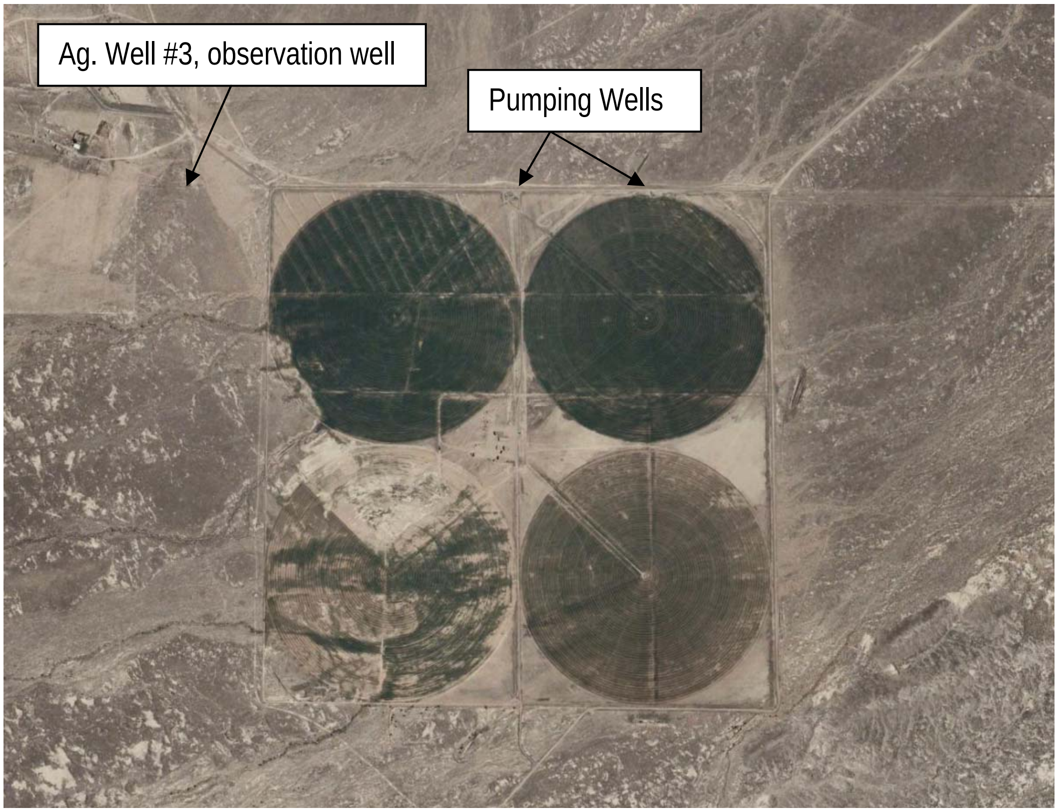

Figure 6: Aerial image of the Lincoln Ranch, northern Dixie Valley.

Figure 7: Image of Ag. Well #2, Lincoln Ranch.

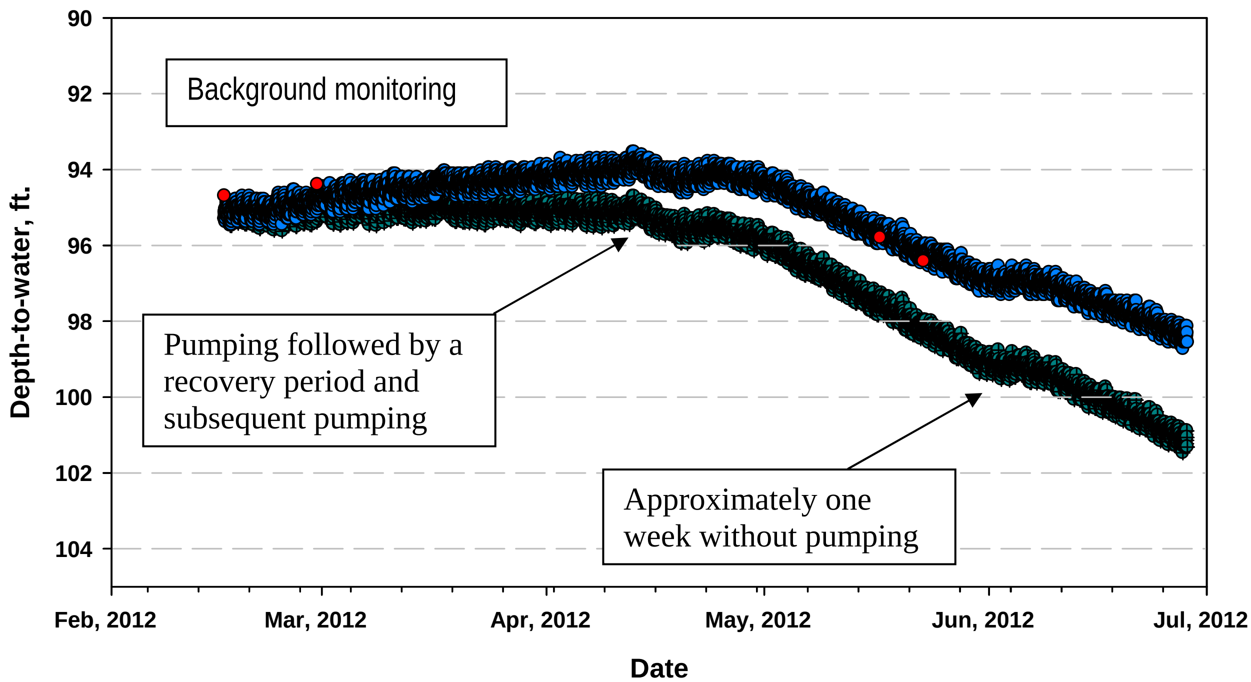

Figure 8: Raw transducer data (dark blue circles), manual measurements (red circles), and detrended transducer data (cyan circles), Lincoln Ag, Well #3, Dixie Valley, Nevada.

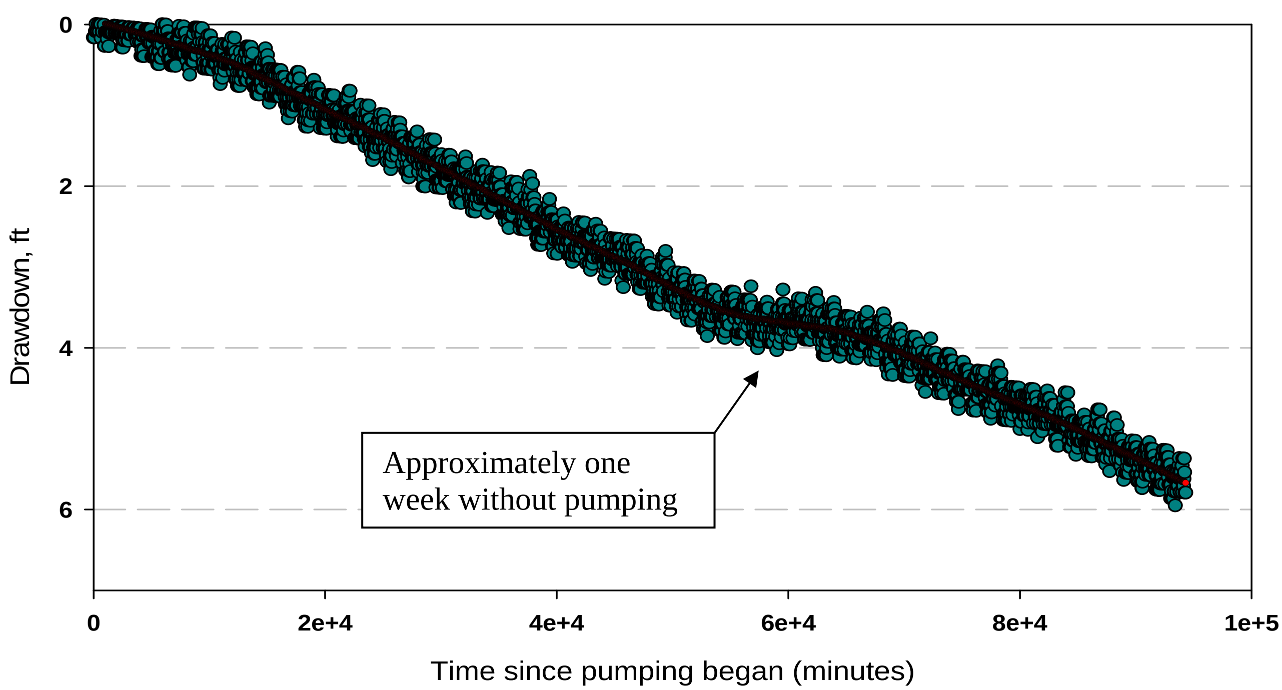

Figure 9: Detrended depth-to-water (cyan circles) and LOESS smoothed data (dark/red circles), Ag. Well #3, Dixie Valley, Nevada.

Smoothed, detrended depth-to-water values were then converted to drawdown by using a water level value prior to the time when pumping began on April 24th. These data were then imported into AQTESOLV (HydroSOLVE, 2007) for estimating the hydraulic properties of the aquifer.

Drawdown data, well locations, and pumping rates were input into AQTESOLV and analyzed using the Theis (1935) method (Figure 10). Estimated bulk hydraulic properties for basin-fill aquifer at the Lincoln Ranch include a transmissivity value of approximately 10,500 ft²/day and a storage coefficient of 0.05, indicating a relatively productive aquifer that is in an unconfined condition.

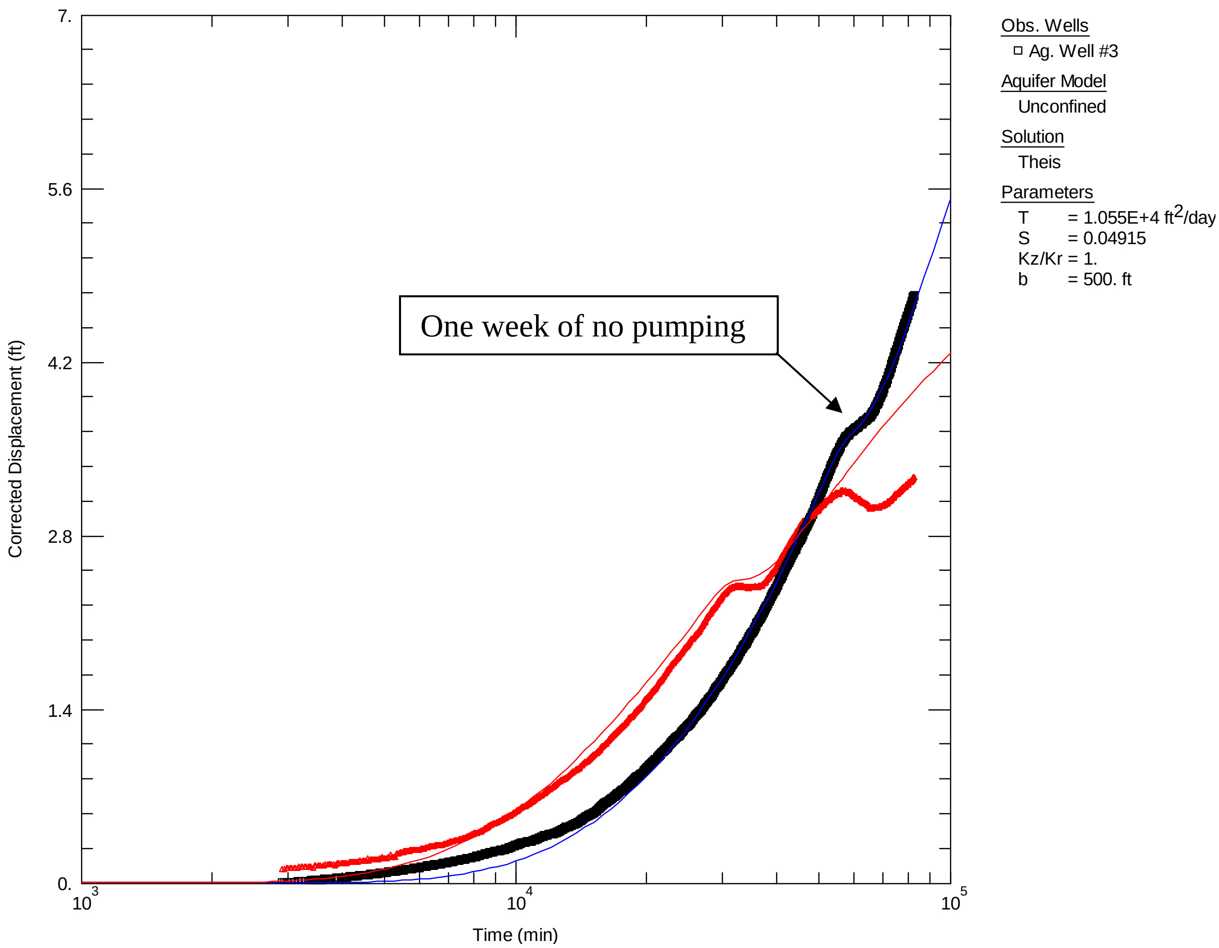

Figure 10: Drawdown data (black squares) and derivative of drawdown (red crosses) matched to a Theis type curve , Ag. Well #3, Dixie Valley, Nevada.

When utilizing these estimated hydraulic properties, the following caveats should be considered:

- Although not specifically detected, and unlikely due to the depth to water, return of irrigation water to the aquifer via secondary recharge could potentially affect the results of this test,
- Other unforeseen sources of recharge or discharge (other irrigators in the area) may affect the results of this test, and
- Even with these unknown factors, the results of the test are considered a reasonable order of magnitude estimate of aquifer properties.

In summary, monitoring of groundwater levels prior to and after the start of the irrigation season have shown a drop of approximately 2 feet in the water table in response to pumping for 10 days. Prior to pumping, an upward trend in groundwater levels was observed which is consistent with the expected seasonal recharge and post-irrigation season recovery effects. Analysis of the drawdown data indicate a transmissivity value of approximately 10,500 ft^2/day with a storage coefficient of 0.05, which is reasonably consistent with observations of well yield and lithologic descriptions provided on Driller's Logs associated with the pumping wells (see Appendix).

Figure 11: Image of flow meter on Ag. Well #2, Lincoln Ranch.

Knittle Ranch Flowing Wells

The abandoned Knittle Ranch is located northwest of the main Settlement area in Dixie Valley. Two flowing, artesian wells are located on the property, and are referred to as the Knittle Well and Navy Well 07E (07E). Well descriptions and locations are provided in Table 3 and wells are shown in Figures 1 and 12.

Prior to the aquifer test, both wells were flowing at a combined 16 gpm for months, and perhaps years. Both wells were outfitted with Wika™ 0-15 psi pressure gages and Well 07E was equipped with a 1-inch Sensus II™ flow meter. Back-up volumetric flow measurements were obtained through the portions of the test when 07E was flowing.

Table 3: Well information, Knittle Ranch, Dixie Valley, Nevada.

Well Name	UTM North (m)	UTM East (m)	Distance from 07E (feet)	Diameter (in)	Well Log No.	Perforated Interval (ft)	Total Depth (ft)
Well 07E	4396194	404806	--	6	5427	None*	175
Knittle Well	4396253	404776	217	16	10240	183-213	213

*Well 07E does not contain well screen; the bottom of the casing is open to the tested formation. Knittle Well is also known as USGS Site No. 394239118063901, and Site Name 128 N21 E34 01CCAD1 Knittle Well

Aquifer testing at this location consisted of three phases:

- An initial shut-in phase to observe the hydrostatic pressure build-up; this phase lasted approximately 2,200 minutes,
- A second phase lasting 750 minutes where 07E was allowed to flow at rates between 38 and 32 gpm (test average of 35 gpm),
- And a final shut-in phase where pressure recovery was observed for approximately 180 minutes.

Data were collected during the initial pressure build-up phase, and are plotted below in Figure 13. These data were analyzed as a “first cut” at a transmissivity value by considering the wells to be a single well that was pumping at 16 gpm and using the change in drawdown over log time (Δs) to calculate a transmissivity value (Figure 13). As a first approximation, the process produced a transmissivity value of approximately 600 ft^2/day using the Cooper-Jacob (1946) approach. Although seemingly low, the value is similar to other wells tested in the settlement area by the USGS (Huntington, 2011a).

The second phase of testing involved opening the valve on 07E and allowing the well to flow at approximately 38 gpm. The overall test average was 35 gpm as the flow rate fluctuated down to 32 gpm and was later readjusted. These changes in flow rate were well documented and have been incorporated into the Theis (1935) analysis shown in Figure 14. AQTESOLVE (HydroSOLVE, 2007) is capable of incorporating changes in the flow rate that otherwise would make manual estimation of hydraulic properties cumbersome.

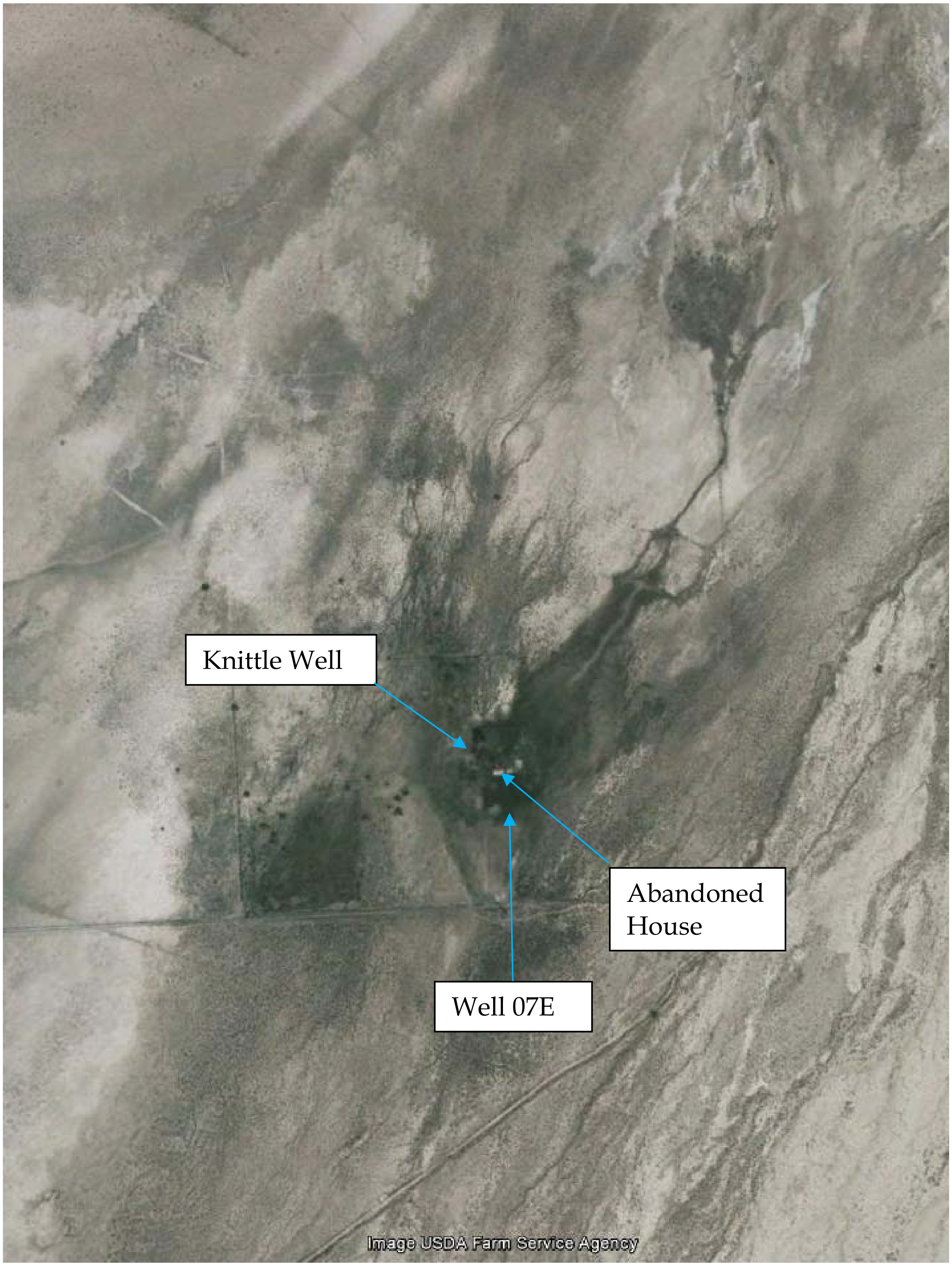

Figure 12: Areal image of the abandoned Knittle Ranch showing the locations of flowing wells, Dixie Valley, Nevada. One inch equals approximately 600 feet.

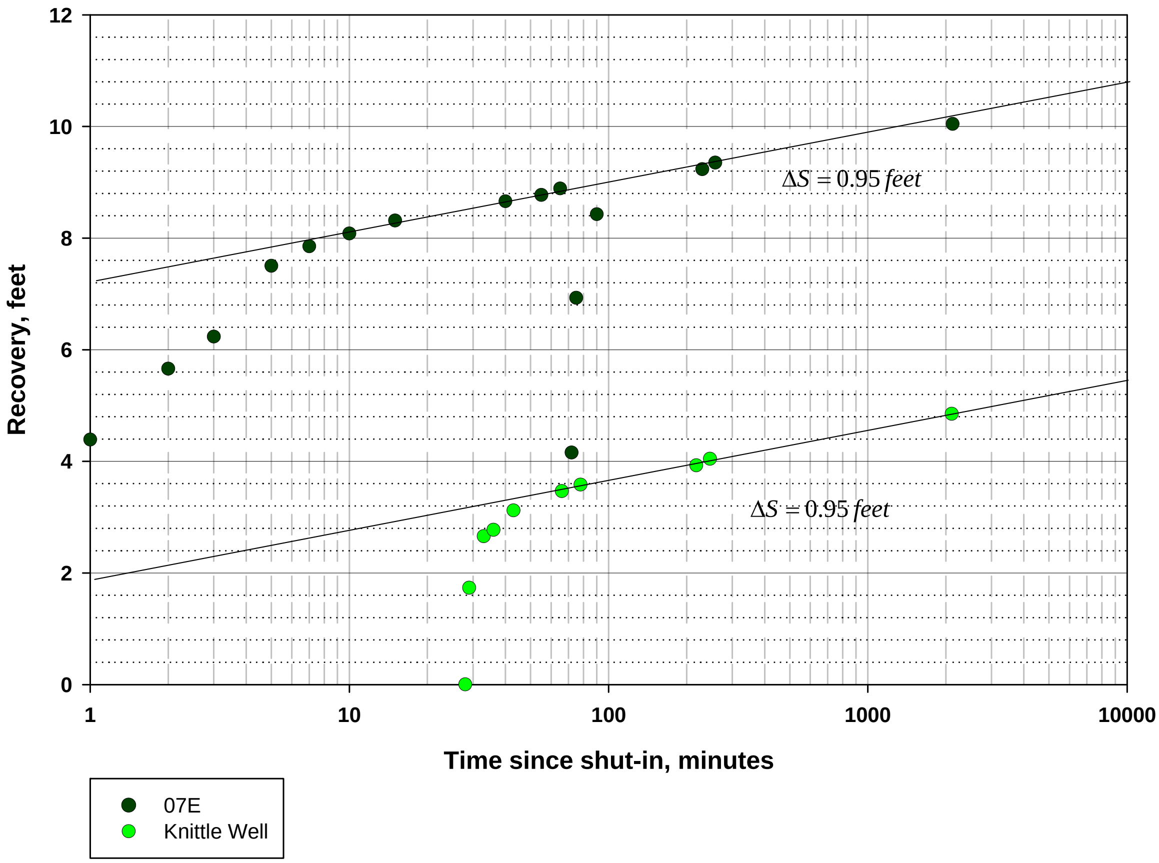

Figure 13: Initial shut-in of the flowing wells at the Knittle Ranch. Using the slope shown, a preliminary transmissivity value of 600 ft^2/day was calculated.

Of interest in Figure 14 is the calculated transmissivity of 812 ft^2/day with a storage coefficient of approximately 8E-4. The estimate is considered of good quality based on the similarity of the drawdown data to the type curve that governs the aforementioned hydraulic property values.

As a final step, recovery data from both wells were reviewed and plotted against the recovery type curve for T= 812 ft^2/day and S=8E-4, as shown in Figure 15. The Knittle observation well is well matched to the type-cure, and 07E is converging on the type curve at late time (left side of graph). The well that was flowing (07E) does not initially match the type cure, most likely due to well skin/well inefficiency, and wellbore storage effects (i.e. the pressure build-up in the casing may lag behind formation pressure build-up). This phenomena is common (See Fig. 5, Marinelli and Rowe, 1985) and likely due to the fact well 07E has no screens or perforations and is simply open-bottomed casing placed into the producing sands and gravels.

Analysis of data from the flowing wells on the Knittle Ranch indicate a confined (S= 8E-4) sand and gravel aquifer unit with a modest transmissivity value of about 800 ft^2/day. The transmissivity value is similar to the mean value of roughly 900 ft^2/day from other wells tested in the settlement area by the USGS (see next section).

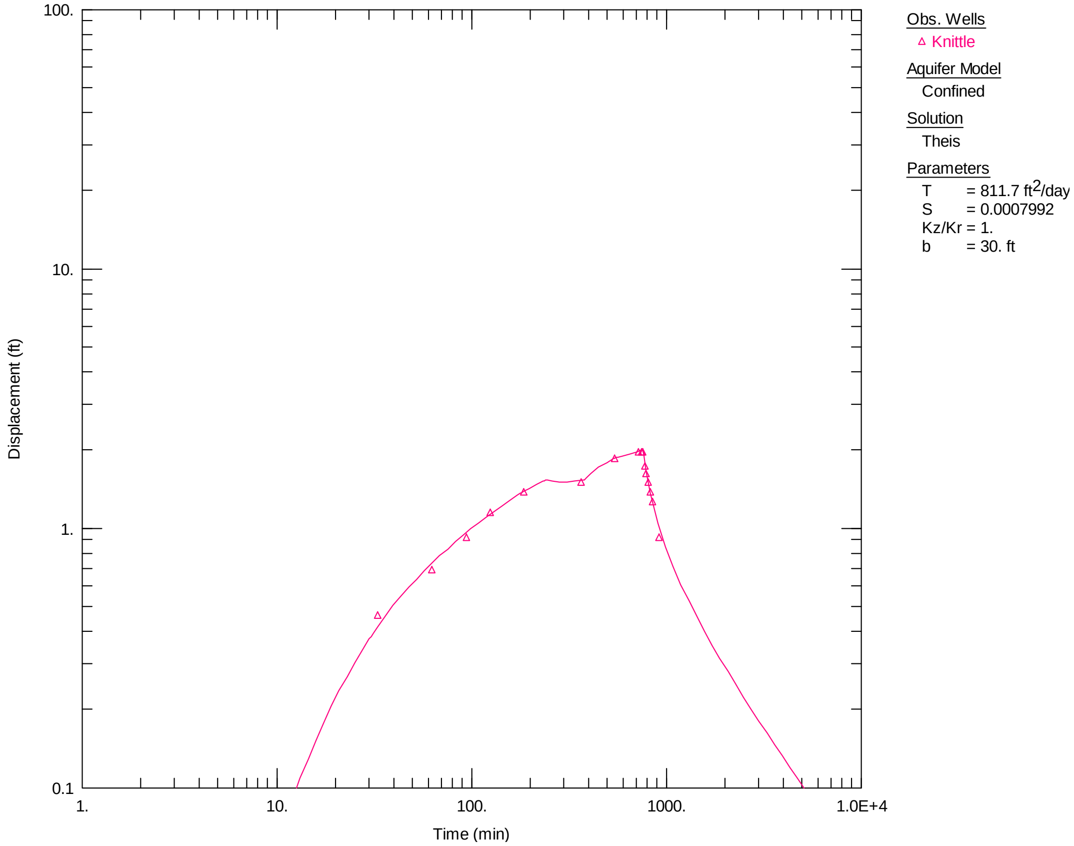

Figure 14: Match of Theis type-curve to Knittle observation well.

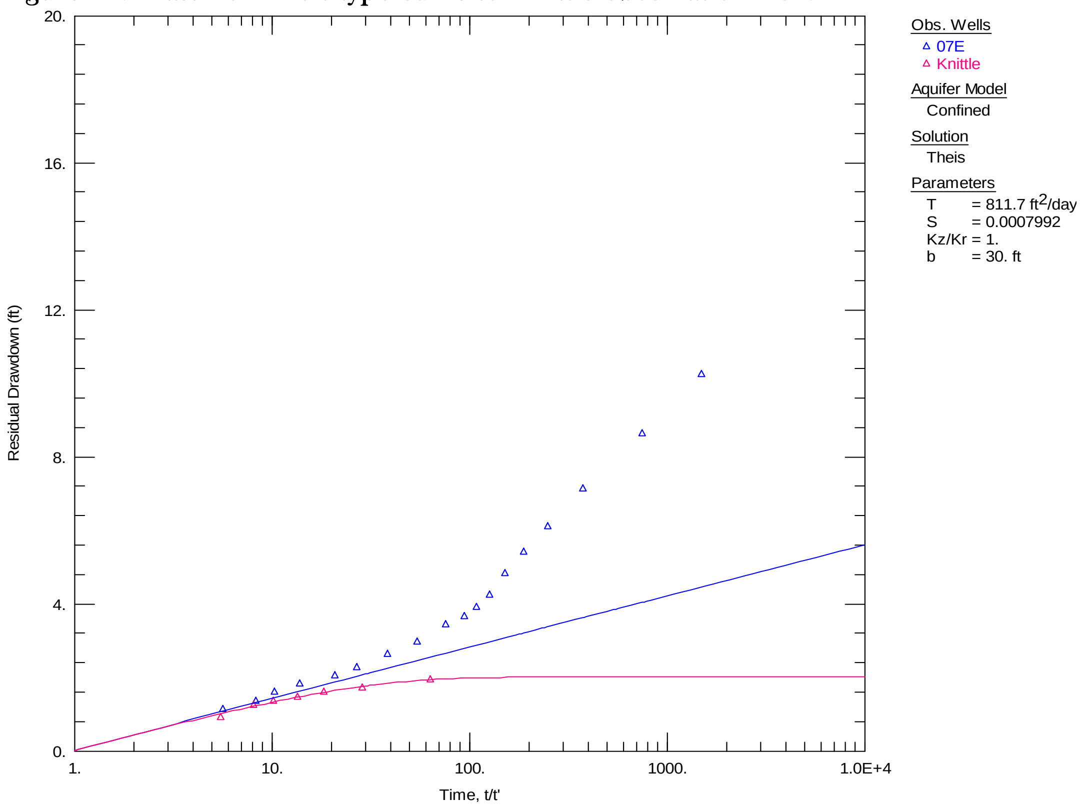

Figure 15: Recovery plot of the Knittle Well and U.S. Navy well 07E, Dixie Valley.

Summary and Discussion

The USGS has conducted four shut-in tests and two single-well 48-hour constant rate pumping tests in Dixie Valley (Huntington and Allander, 2011, Huntington 2011a, 2011b). The shut-in tests were located in the main Settlement area in central Dixie Valley south of the playa (Figure 16), and the pumping tests occurred in south-central Dixie Valley north of Highway 50.

Well information and results of the analysis of the tests are summarized in Table 4. Well locations for the shut-in tests are shown in Figure 16, and all aquifer test locations and results are presented in Figure 17.

In addition to the USGS testing, Mahannah and Associates and Interflow Hydrology conducted aquifer testing at three locations in the Dixie Valley basin-fill aquifer, discussed previously in this report and summarized in Table 5.

Aquifer testing indicates relatively modest transmissivity values for the Settlement area and southern Dixie Valley. The shut-in test and recovery at the 07E and Knittle wells compliments the USGS shut-in tests by quantifying a storage coefficient of 8E-4, a value consistent with the confined aquifer assumption producing flowing artesian wells in the area. The transmissivity in the northern portion of Dixie Valley, as tested at the Terra-Gen well 73W-7 and Lincoln irrigation wells was an order of magnitude higher than values calculated for southern wells.

Table 4: Results of USGS aquifer testing, Dixie Valley, Nevada

Site ID	Local Name	Location	Test Method	Open Interval (ft)	Estimated Transmissivity (ft^2/day)
392602118050101	84B	Settlement Area	Shut-in	25-145	1,000
394217118033801	31B	Settlement Area	Shut-in	134-194	400
394141118030901	34D	Settlement Area	Shut-in	80-130	900
394037118040901	86A	Settlement Area	Shut-in	?-184	1,400
392819118092501	Dixie HWY S Nr Marker 13	South Dixie	Pumping Test	399-519	700
391900118085801	Wonder Well	South Dixie	Pumping Test	400-500	2,500

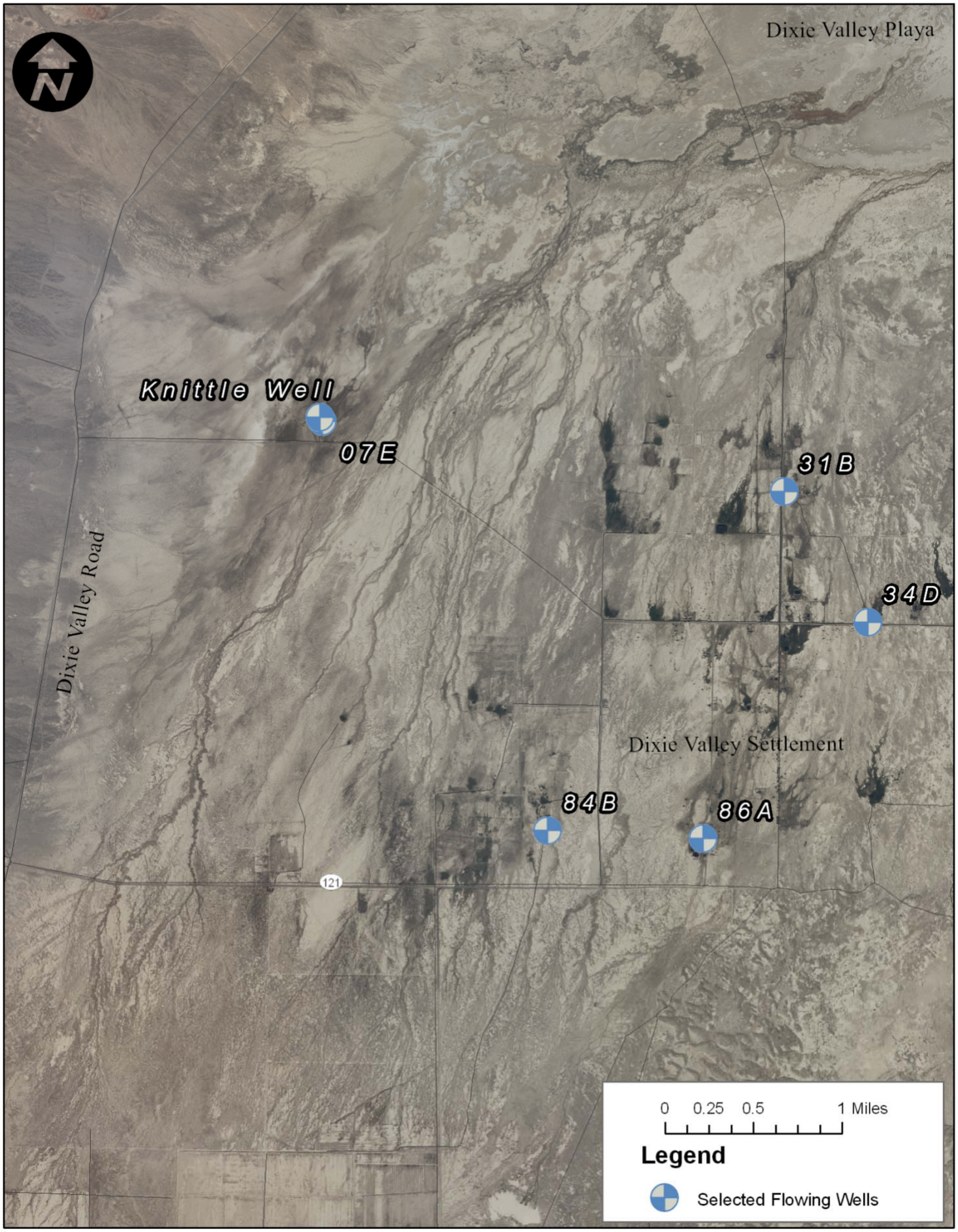

Figure 16: Dixie Valley Settlement area and selected flowing wells

Table 5: Summary of aquifer testing results, this study, Dixie Valley, Nevada.

Well Name	UTM North (m)	UTM East (m)	Role/ Purpose	Nevada Well Log No.	Depth (ft)	Perforated Interval (ft)	Estimated Transmissivity (ft^2/d)	Storage Coefficient (d'less)
Terra-Gen Well 73W-7 Test								
Terra-Gen 73W-7	4424315	427099	Pumping Well	Unknown	300	80-300	--	--
Goeringer Well	4424363	427096	Observation Well	11047	430	50-430	14,800	1.8E-04
Blackwater Well	4423979	427075	Observation Well	12750?	160	140-160	16,900	7.5E-04
Lincoln Ranch Monitoring								
Ag Well #1	4435914	439113	Pumping Well	9621	350	100-235	--	--
Ag Well #2	4435918	439572	Pumping Well	9620	285	100-275	--	--
Ag. Well #3	4436004	438084	Observation Well	12565	270	90-270	10,400	5.E-02
Knittle Ranch Test								
Well 07E	4396194	404806	Flowing Well	5427	175	Open Hole	800	8.E-04
Knittle Well	4396253	404776	Observation Well	10240	213	183-213	800	8.E-04

The storage coefficient calculated from data obtained from two wells near 73W-7 at the Dixie Valley Power Plant indicated confined conditions with values ranging from 1.8 - 7.5E-4. At the Lincoln Ranch, the pumping response is consistent with an aquifer having a storage coefficient of 5E-2. The storage coefficient indicates that the northern-most shallow basin fill aquifer is unconfined. Depths-to-water at the wells are consistently deeper than 90 feet, which would seem to make a confined system more plausible given the geologic history of Pleistocene lakes in the basin. However, the well logs for three irrigation wells does support an unconfined, relatively deep aquifer unit, or at the very least an aquifer than undergoes a confined-to-unconfined conversion during long-term pumping.

Lincoln Ranch Ag. Well #1 was drilled with a cable-tool drilling rig and indicated that water was first encountered at 96 feet below land surface (fbls) in a sand and gravel zone below a cemented gravel. According to Nevada Division of Water Resources (NDWR) well log #9621, clays above the cemented gravel were apparently unsaturated. Final depth-to-water at the time of completion was 92 fbls, placing the water level at the base of a clay unit and the top of the cemented gravel. Pumping of the well would likely draw the water level down below both the clay and the cemented gravel, causing an unconfined condition.

The well log for Lincoln Ranch Ag. Well #2 (NDWR well log #9620) indicates that the chief water-bearing unit was a “loose gravel sand” encountered between 95 and 100 fbls. The well log reported a static water level of 92 fbls. Again, it is likely that pumping would draw the water level below the top of the unit, thus possibly eliciting an unconfined response.

The well log for Lincoln Ranch Ag. Well #3 (NDWR well log #12565) indicated a static water level at 67 fbls, which is considered dubious, as its current static water level is around 90 - 95 ft below land surface, consistent with the other two wells on the Lincoln Ranch, all of which have similar land surface elevations. NDWR well log #12565 indicates sand and gravel from 67 to 170 feet below a seven foot interval of clay. If the lithology reported is accurate, then the current static water level is about 30 feet below any potential confining unit.

The calculated storage coefficient value of 0.05 at the Lincoln Ranch is a composite or average value derived from the specific storage and/or specific yield values of each individual permeable zone that contributes water to the wells. With that in mind, it would be plausible to consider an upper aquifer zone that may have a high value reflecting specific yield (and actual gravity drainage during pumping) overlying deeper, more confined permeable zones with much lower storage coefficient values. Such lithology is described in all three well logs.

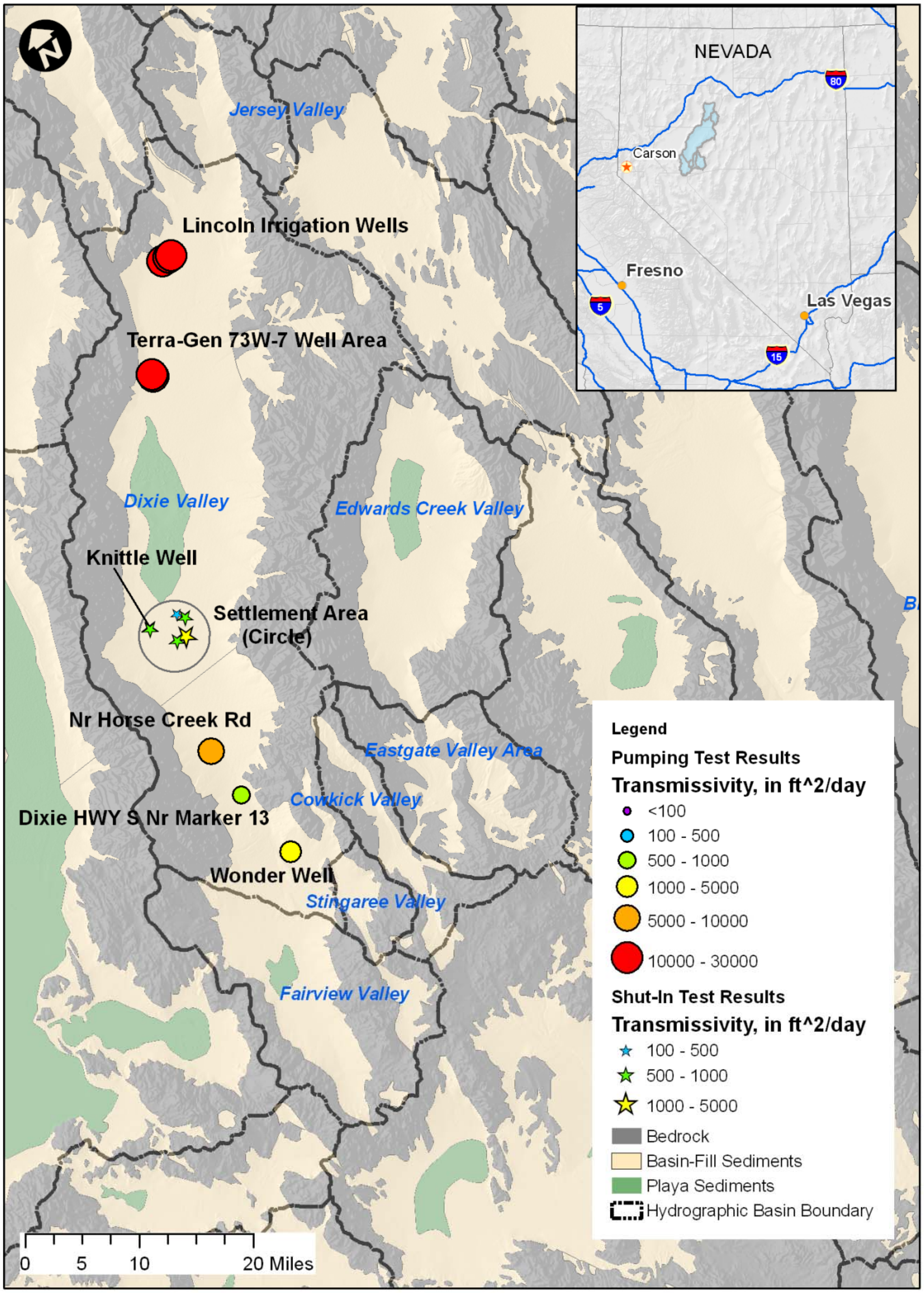

Figure 17: Estimated transmissivity distribution from aquifer tests in Dixie Valley, Nevada

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