

Project No. 1131-01-2011

Evaluation of Hydrologic Impacts of Additional Pumping from Two Wells in the Lower Big Lost River Valley

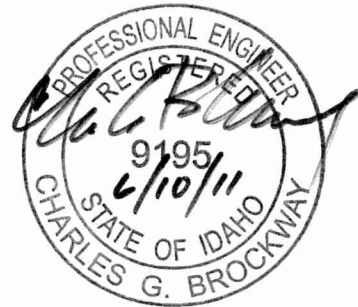
Prepared for:

James P. Speck, Speck & Aanestad
Paul L. Arrington, Barker Rosholt & Simpson

June 10, 2011

THIS REPORT SUPERSEDES A PREVIOUS PARTIAL REPORT ON THE
SAME TOPIC DATED MAY 25, 2011

For information concerning this report, contact
Charles G. Brockway, Ph.D., P.E.



CHARLES E. BROCKWAY, PH.D., P.E.
CHARLES G. BROCKWAY, PH.D., P.E.

2016 NORTH WASHINGTON, SUITE 4
TWIN FALLS, IDAHO 83301

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Brockway Engineering, PLLC
C. G. Brockway, Ph.D., P.E.

June 10, 2011

A. BACKGROUND AND METHODOLOGY

This report presents the methodology and results of a hydrologic analysis to evaluate the effect of additional groundwater pumping at two wells located approximately 1 mile south of Moore, Idaho (Figure 1). A claimant in the Snake River Basin Adjudication (SRBA) is asserting that an accomplished transfer was made to these wells, which would allow additional flow to be diverted.

Groundwater rights 34-2459, 34-2460, 34-2461, and 34-2462 are currently appurtenant to two (2) wells known as the “Airport Wells,” situated near the Arco airport. Groundwater right 34-7037 is appurtenant to two wells known as the “Island Wells,” situated approximately 7 miles north of the Airport Wells. The place of use for all rights is located south of the Airport Wells. The Island Wells pump into the Island Ditch, which flows into the East Canal and subsequently into the Big Lost River. Near the point of injection to the Big Lost River, water is rediverted into the Munsey Ditch and conveyed further southward where it is pumped from the ditch to the place of use.

A study was performed to evaluate the potential impact of the proposed accomplished transfer of the Airport Well rights, and to assess whether an accomplished transfer actually occurred prior to November 1987. The claimant asserts that the Island Wells began to be used as additional or substitute points of diversion for the above rights prior to November 1987. The Airport Well rights are limited to 12.5 cfs, but allow 24.5 cfs in combination with 34-7037. Therefore, if the accomplished transfer is valid, an additional 12.5 cfs could be withdrawn from the Island Wells above the 12.0 cfs licensed under right 34-7037 or a total of 24.5 cfs. Since 12.0 cfs is already licensed and therefore its impact presumably authorized, only the impact of pumping the additional 12.5 cfs was evaluated. Further, the evaluation was conducted without regard to the present capacity of the wells, which appears to be less than the 24.66 cfs which measured by the field examiner for 34-7037.

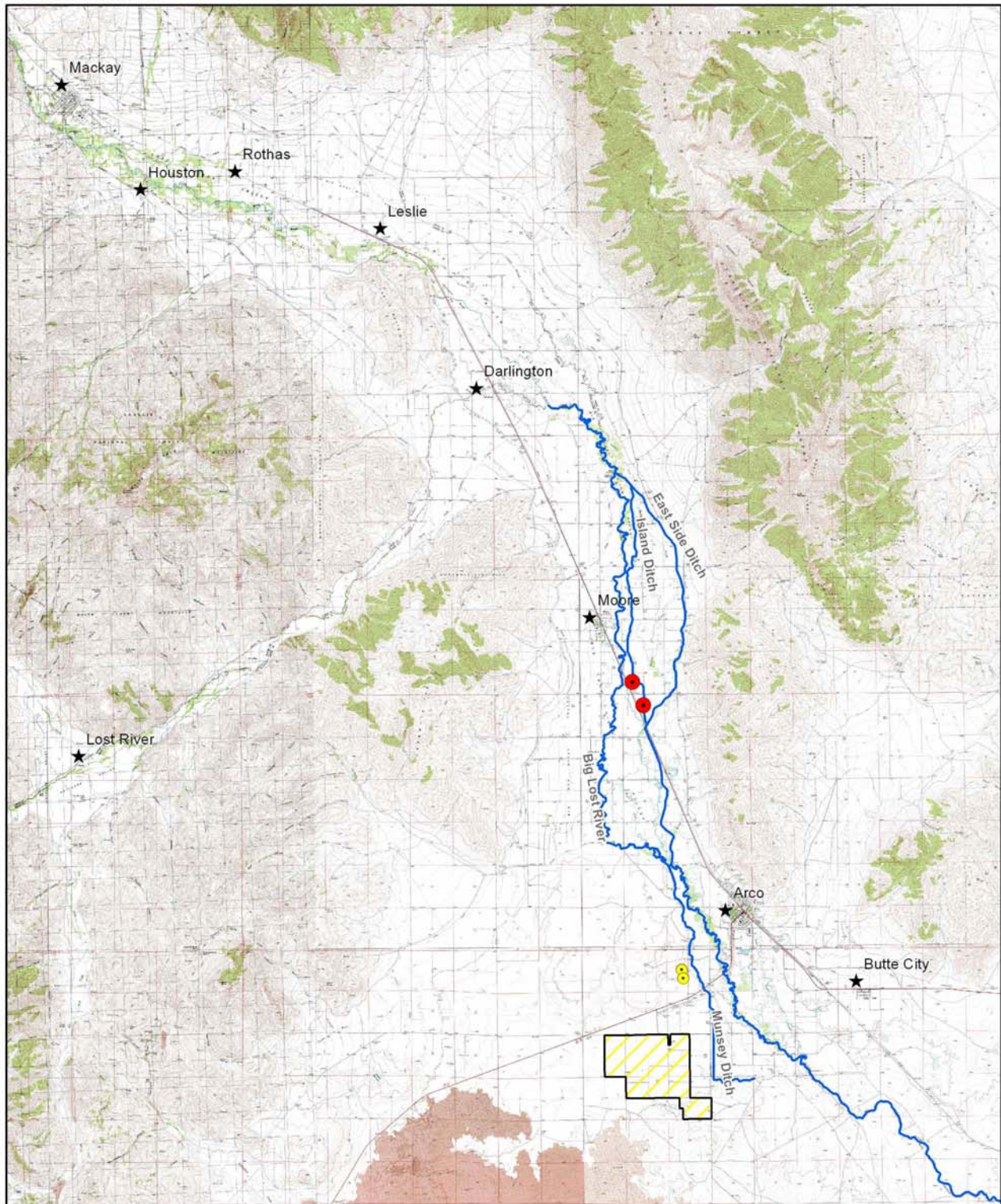


**FIGURE 1 VICINITY MAP
TOPOGRAPHICAL BASE 7.5'**

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ALR - JUNE 9, 2011

Legend

- Island Well
- Waterways
- ★ cities
- POU 34-2459,2560,2461,2462,10925
- WRPOD 34-2459,2560,2461,2462,10925

The potential impact of additional pumping was evaluated by examining the physical mechanisms by which the pumping may alter the water supply either in the aquifer or in the surface stream. These mechanisms include the following:

1. Localized drawdown induced in the aquifer by point withdrawal (often termed “local well interference”). This analysis is described in **Section D**.
2. Impacts on the water balance of the aquifer, groundwater development effect on water levels since 1950, and the expected seasonal and long-term effect of additional depletion of the aquifer. This analysis is described in **Sections E and F**.
3. Depletion of surface flows due to hydraulic connection between the aquifer and river systems. This analysis is described in **Section G**.

An evaluation of actual water diverted from the Island Wells prior to November 1987 was performed and is described in **Section H**.

B. HYDROGEOLOGIC SETTING

Crosthwaite (1970) is the most extensive review to date of the geology, hydrogeology, and occurrence and movement of surface water and groundwater within the Big Lost valley. Subsequent reports by Szczepanowski (1982), Johnson et al. (1991), and Bassick and Jones (1992) provide additional description and analysis. The Big Lost aquifer consists of deep valley-fill alluvium with discontinuous basalt intrusions from the south. Alluvial valley sediments may range from 1000 to 5000 feet in thickness. Near Moore, the thickness may be up to 2500 feet, based on seismic analysis.

The alluvium is heterogeneous and deposited in layers separated by basalt intrusions from the south and by fine-grained depositions. Basalt flows have been documented to extend up the valley at least to Moore. The valley fill sediments are heterogeneous and are separated by clay layers which likely act as barriers to flow between water-producing strata. A substantial clay layer exists at approximately 200 to 280 feet below ground, above which a highly productive water-producing zone of sand and gravel is present with water levels typically from 20 to 80 feet below land surface (Crosthwaite, 1970). A typical lithologic profile is shown in Figure 2, in which a deep test well is illustrated and the clay layer is evident.

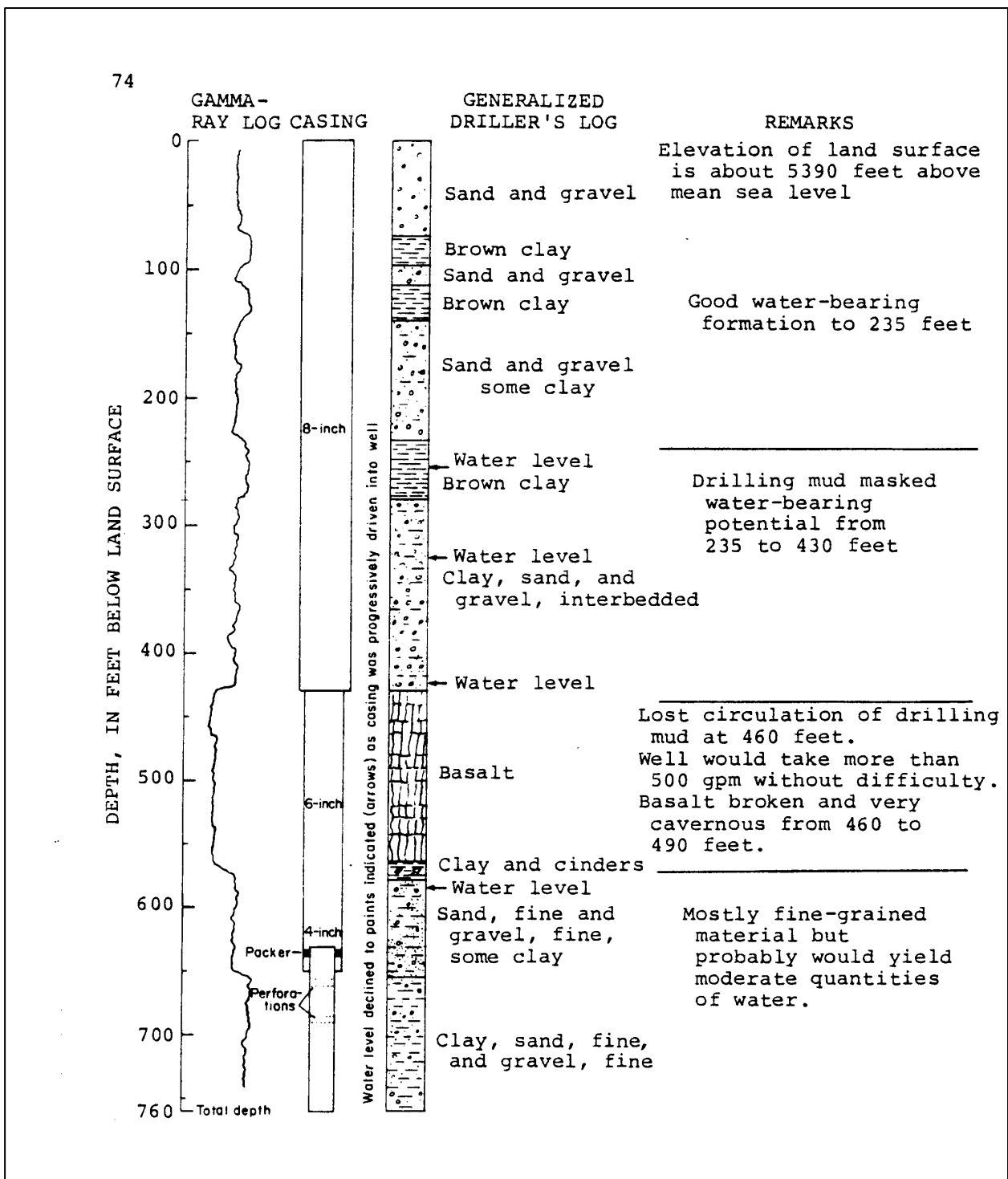


Figure 2. Generalized lithologic log for well 4N26E21ABB1 in the Big Lost aquifer system (after Crosthwaite, 1970)

Although additional water-producing alluvium is present beneath the clay layer, a study of well logs in the valley indicates that virtually all wells – both irrigation and domestic – are completed above the clay layer in the upper alluvium and are shallower than 250 feet in depth. Typically, irrigation wells in this area are fully cased to depth and perforations cut in the casing to allow entry of the water. Therefore, for the purposes of analysis, the aquifer was considered to be bounded on the bottom by a clay layer at an average of 250 feet below ground. The validity of this assumption was strengthened by the results of the transmissivity estimation and the water balance and groundwater pumping analyses described below. Flow in the basalt and sedimentary strata below the clay layer is considerable (Crosthwaite, 1970) but was not considered for this analysis. It appears that flow in this lower zone enters the ESPA directly as underflow without influencing surface water hydrology and without being pumped by groundwater wells.

The alluvial aquifer is bounded on the west and east by bedrock formations and by tributary valleys which contribute flow to the system, the magnitude of which is generally minor compared to the total groundwater flow in the main valley.

Groundwater flow direction is essentially parallel to the valley, with local distortions reflecting changes in aquifer properties and interaction with the Big Lost River. Both Crosthwaite (1970) and Bassick and Jones (1992) conducted mass measurements of well water levels and developed contour maps of the aquifer. The contour map created by Bassick and Jones (1992) is reproduced as Figure 3. This map was created from a mass measurement of 154 wells in March 1991. The gradient of flow in the region south of Moore is approximately 18 ft/mile or 0.0034 ft/ft.

At the mouth of the valley, the gradient drops sharply as the flow in the alluvial system discharges into the basalts of the Eastern Snake Plain aquifer. Depth to water in wells southwest of Arco can exceed 200 feet.

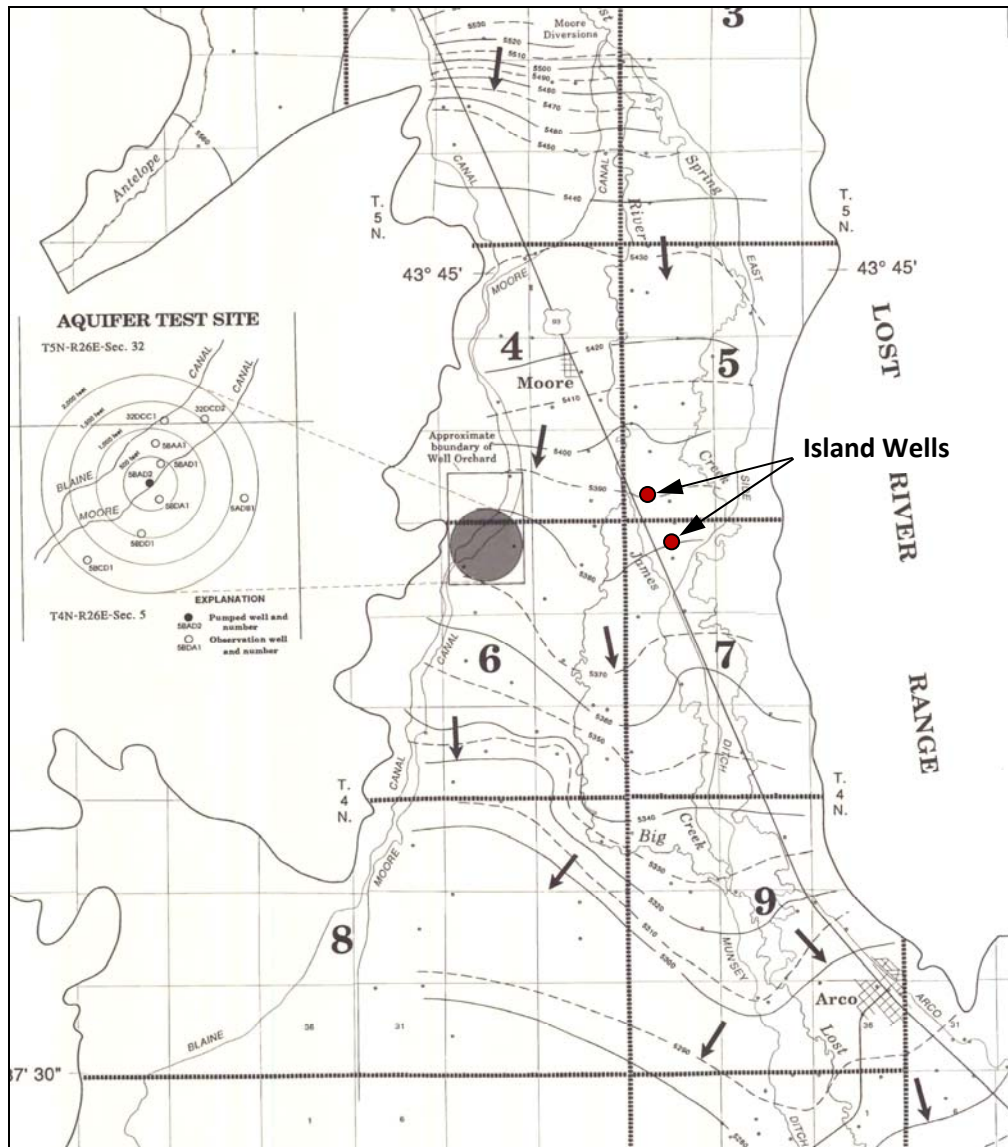


Figure 3. Water table contours and flow direction in the Big Lost River alluvial aquifer (after Bassick and Jones, 1992).

C. GROUNDWATER DEVELOPMENT HISTORY

Groundwater development in the Big Lost valley was minimal prior to the 1950s. Beginning in the late 1950s and continuing through the 1980s, many irrigation wells were developed, with most of the groundwater pumping concentrated in a region approximately 6 miles north to 6 miles south of Moore. Many of these wells pump directly into the pre-existing canal system for use downstream on lands which may also

be served by surface water rights or other groundwater rights. Several hundred such wells have been constructed. Groundwater rights have been decreed in the SRBA, and therefore an accurate assessment of actual appropriation can be made. The pattern of groundwater development since the 1950s is illustrated in Figure 4, in which the cumulative appropriation is shown as a function of priority date for wells located in T5N R26E and T4N R26E, which includes the Big Lost Valley below Antelope Creek and above Arco. Two periods of rapid development are evident: one in the early 1960s in response to the drought in those years, and a second in the mid-1970s. This graph illustrates the overall pattern of development but does not reflect actual amount of pumping due to effects of weather, surface water availability, and other factors; also, the decreed diversion rate on a water right often does not reflect total pumping authorization due to combined-use limits with other rights.

The Island Wells which are the subject of the present study were drilled in August 1976 (north well) and May 1982 (south well). The priority date of the existing license 34-7037 is May 4, 1973.

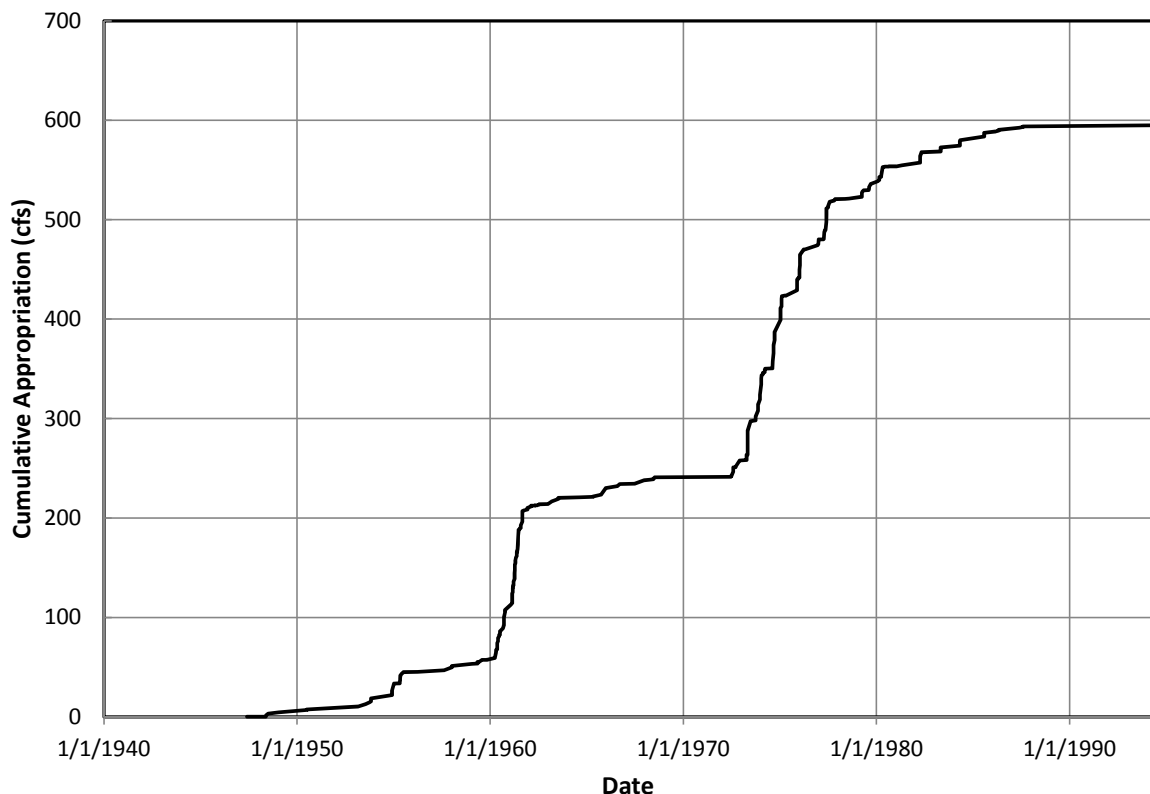


Figure 4. Cumulative appropriation of groundwater in the Lower Big Lost Valley.

D. LOCAL WELL INTERFERENCE ANALYSIS

Pumping additional flow from the Island Wells will cause a greater drawdown in the vicinity of the wells than would otherwise occur if the wells were limited to their licensed flow of 12.0 cfs. This effect, known as the “cone of depression,” will propagate outward from the wells and negatively impact water levels at surrounding wells. The effect generally occurs over a relatively localized area. The magnitude of the drawdown depends on the well pumping rate in combination with hydraulic properties of the aquifer, namely the transmissivity and storativity, and the location of aquifer boundaries.

All irrigation and domestic wells within about 3 miles of the Island Wells are completed in the alluvial system above the clay strata at approximately 250 feet below ground. Therefore, for the purposes of this analysis, the clay layer was assumed to be the bottom of the shallow aquifer and of sufficient extent that the deeper alluvium does not supply water to wells pumping from the upper zone. Static water levels recorded at the time of drilling for wells completed within the past decade average approximately 50 feet. Therefore, the saturated depth of the aquifer was taken to be 200 feet.

Irrigation wells in this area are typically cased to depth with perforations in the casing throughout a portion of the casing length. The length of casing with perforations is the “open interval” and varies from 14 feet to 129 feet in the analyzed wells.

a. Estimation of Transmissivity

Aquifer transmissivity was estimated from well test data using specific capacity and test duration data, applying the Theis approach with correction for partial penetration as outlined in Bradbury and Rothschild (1985). The correction for partial penetration is especially important in this case, where none of the analyzed wells fully penetrate the aquifer and many have open intervals less than 50% of the total aquifer depth. Not correcting for this effect can lead to underestimation of the hydraulic conductivity. Selected wells were limited to large irrigation wells with adequate reported data to conduct the analysis. A total of 17 wells were identified. In addition, a short pumping test was conducted on May 20, 2011 of the south Island Well which provided one additional specific capacity data point.

Calculated transmissivities ranged from 5,000 to 243,000 ft²/day (Appendix A). The average hydraulic conductivity was found by dividing the transmissivity by the saturated depth and was calculated to be 243 ft/day. This value is in good agreement with typical published values for sand and gravel aquifers. Storativity was assumed to be 0.15, a typical value for unconfined alluvial aquifers. Bassick and Jones (1992) conducted a

long-term pumping test of a well in the Big Lost alluvium while measuring eight observation wells, and calculated transmissivities ranging from 61,000 to 330,000 ft²/day. These transmissivities are slightly higher than those calculated in the present study, but the pumping well was located in the area known as the “well orchard,” a region of exceptionally high well productivity. Bassick and Jones (1992) also found a “most probable” storativity value of 0.001, indicating the presence of confined or semi-confined conditions, at least in the well orchard area. In the specific capacity analysis, the storativity is not of great import in determining transmissivity and does not affect equilibrium drawdown, but does effect the time to approach equilibrium drawdown as described below. To assess the effect of storativity on transmissivity estimation, the analysis was repeated with a storativity of 0.001, and the average hydraulic conductivity was found to be 297 ft/day.

The local drawdown due to well pumping was calculated using the analytical groundwater flow model WinFlow. This model essentially implements the Theis procedure for drawdown calculation but allows greater flexibility to evaluate multiple-well scenarios, aquifers that have a non-negligible gradient, and aquifers which are bounded and cannot be assumed to be infinite in extent.

The gradient of the aquifer was taken to be 18 ft/mile (Crosthwaite, 1970; Bassick and Jones, 1992) and the hydraulic conductivity was taken to be 243 ft/day. The model was used in steady-state mode to predict equilibrium drawdown.

b. Boundaries

The mountain bedrock on the west and east confines the alluvial system, acting essentially as a no-flow boundary condition. The effect of these boundaries is to cause a greater drawdown than would occur at the same pumping rate if the aquifer were infinite in extent. The average width of the aquifer between the estimated contact between bedrock and alluvium is 18,500 feet and was assumed to be uniform from the north to south limits of the study area. The effect of the boundaries was included in the model using the image well approach (Todd, 1980).

c. Results

The results of the drawdown modeling are shown on Figures 5, 6, and 7 for three scenarios: 1) both wells pumping a combined total of 12.5 cfs continuously (6.25 cfs each well); 2) the north well pumping 12.5 cfs and the south well pumping zero; and 3) the south well pumping 12.5 cfs and the north well pumping zero. The contour lines of

predicted drawdown represent increases over any drawdown which would already occur due to pumping 12 cfs under license 34-7037. Increased drawdown, or equivalently, decreased water levels, ranges from in excess of 10 feet in the immediate vicinity of the pumping well to less than 1 foot at a distance of about 2.5 miles from the pumping well. The maps also depict the irrigation and other wells that lie within the predicted zone of influence.

The contours represent steady-state conditions which develop over a period of time of continuous pumping. Within a narrow range of hydraulic conductivity, the primary factor in determining the transient behavior of drawdown is storativity. A transient analysis using the Theis equation was performed to assess the time to approach approximately 90% of the equilibrium level under different assumptions. With a storativity of 0.15, about 60 to 120 days would be required, depending on the location within the aquifer. Using a storativity of 0.001, similar to the value found by Bassick and Jones (1992), the time would be closer to 30 days or less.

d. Significance of Drawdown

There is no adopted definition of “significant” when defining drawdown from a pumped well. The adverse effects of increased drawdown on a well are increased pumping cost, reduced well yield, and perhaps a “dry hole” if the well is shallow. Pumping cost is directly proportional to pumping lift, i.e. if the pumping lift is 50 feet and the water level declines by 5 feet for any reason, the pumping cost will increase by 10%, but only if the well can pump at the same flow rate at a lift of 55 feet. In reality, a decrease in water level in an unconfined alluvial system with a finite depth will generally reduce the yield of a well because the open area available to convey water into the casing will be reduced. For this reason, a decrease in water level of 5 feet will generally result in more than a 5-foot increase in pumping lift. And, there is a limit to how much drawdown that can occur at a well in an attempt to pump the same flow since the aquifer depth is limited. The well can be deepened in an attempt to restore the yield, but this too is limited by the aquifer depth and may or may not be an adequate remedy. Both irrigation and domestic wells will be subject to these effects, although most domestic wells can deliver the very low yields required for domestic purposes even with declines in water levels unless the wells are excessively shallow. However, the power cost analysis is the same for both domestic and irrigation wells.

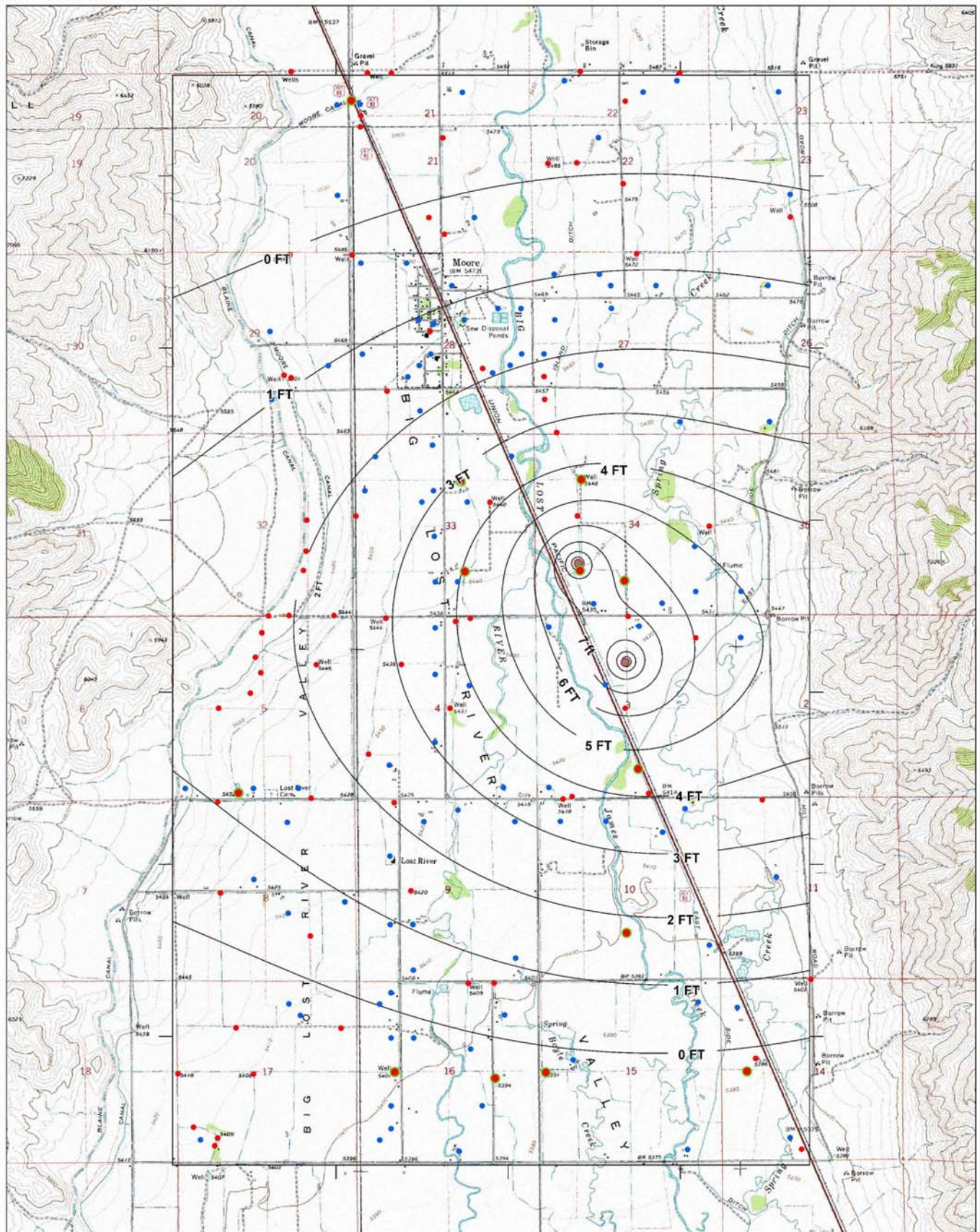


FIGURE 5. Equilibrium drawdown prediction, Scenario 1: 6.25 cfs each well.

Legend
Ground_Water_Wells
 • All Other Uses
 • Irrigation Wells
 • Irrigation Well Used for Transmissivity Est.
 • Island Well

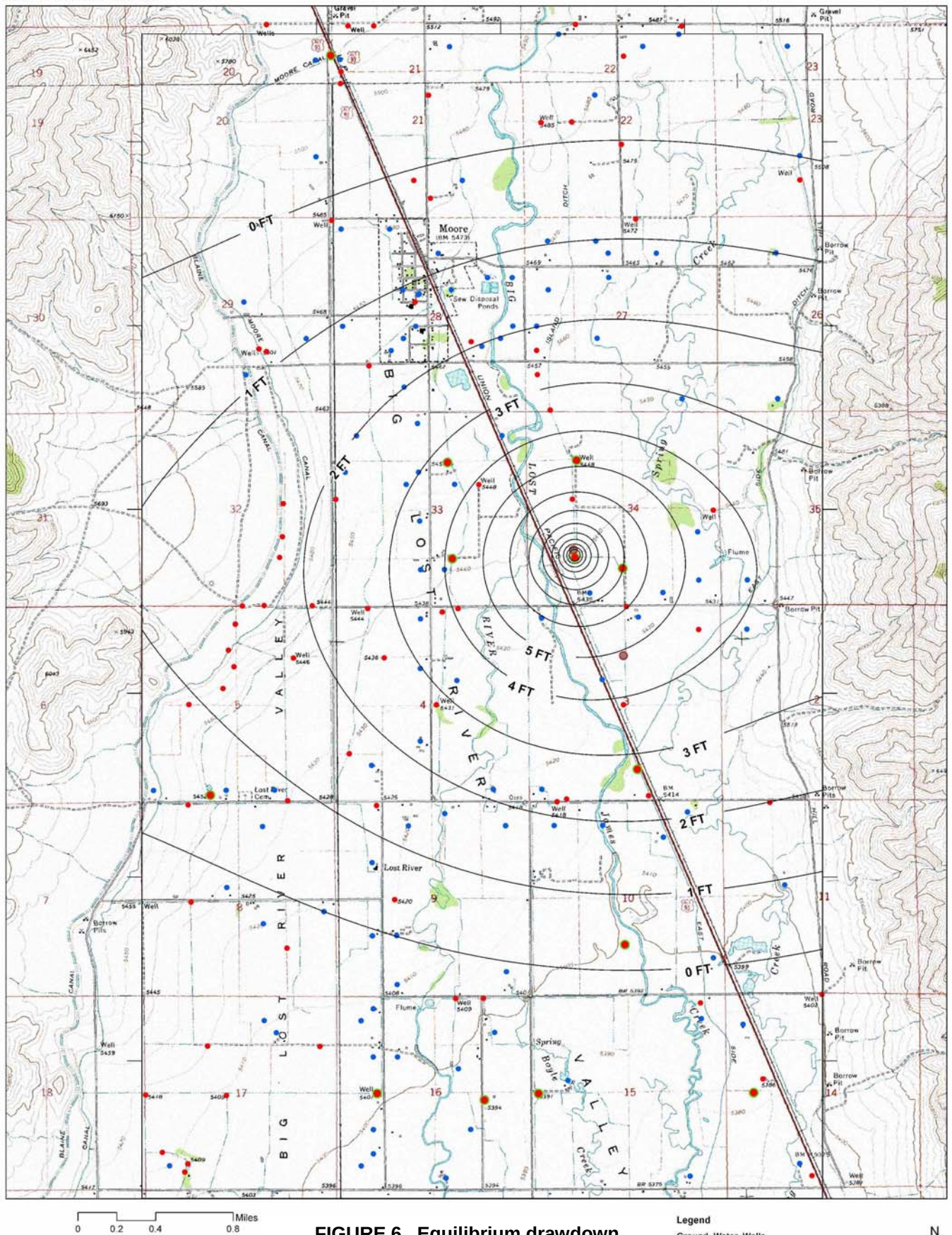


FIGURE 6. Equilibrium drawdown prediction, Scenario 2: 12.5 cfs north well.

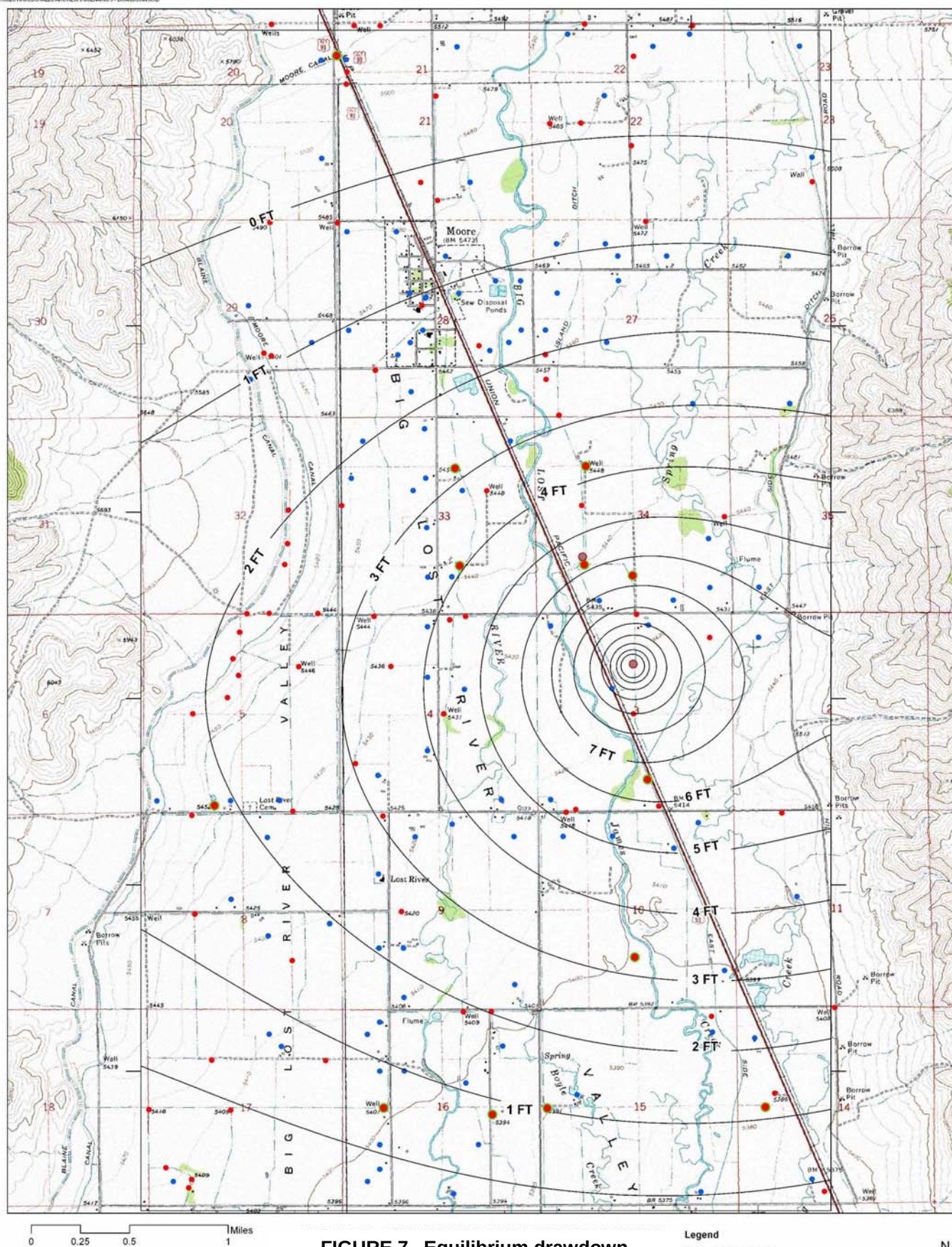


FIGURE 7. Equilibrium drawdown prediction, Scenario 2: 12.5 cfs south well.

E. AQUIFER CONDITIONS AND DEPLETION FROM PUMPING

The local well interference effect presented above would occur even if there were an infinite amount of groundwater available in the aquifer; it occurs simply because a gradient must be induced in order to convey water through the porous media comprising the aquifer to the point of withdrawal. A second effect that must be considered relates to the amount of withdrawal relative to the total available groundwater yield. The sustainability of groundwater pumping and the effect of additional pumping can be evaluated by examining total groundwater flow in relation to the amount of withdrawal, and by relating groundwater level trends to pumping or drought-related factors.

a. Groundwater Discharge

The amount of water flowing in the aquifer was estimated using Darcy's Law, a standard approach in which the total flow is related to the hydraulic conductivity, gradient, and cross-sectional area perpendicular to the flow. Using the above-defined parameters, Darcy's Law yields a groundwater flow of 35.5 cfs (70.4 ac-ft/day; 25,700 ac-ft/year) in the upper aquifer near Moore. Crosthwaite (1970) estimated the total discharge including flow through the entire profile of sediments and basalt units of 325 cfs or 235,300 ac-ft/year at Moore. However, as stated above, only the upper aquifer, bounded by a clay layer at approximately 250 feet below ground, has been developed for groundwater pumping. Therefore, the flow of 35.5 cfs or 25,700 ac-ft/year is of most interest for the present analysis.

b. Estimation of Groundwater Withdrawal

The amount of groundwater withdrawal is not constant, but varies significantly each year due to changes in demand for supplemental water which depends on available surface supply and climatic factors. Data on the amount of groundwater pumped prior to about 1994 is sporadic or nonexistent, with the exception of the 1984 through 1990 period for which the pumpage was estimated using power records (Johnson, 1991; Bassick and Jones, 1992). Crosthwaite (1970) also reports pumpage data for 1959 through 1968 for both primary and supplemental water supplies, but it is not clear what methodology was used to arrive at these values. After 1994, Water District 34 began reporting annual volume of groundwater pumpage, which appears to have been calculated using a combination of power record analysis and measured data (Appendix A).

To augment the sparse record, Johnson et al. (1991) outlined a method by which groundwater pumping volume can be estimated through a linear regression with annual

streamflow measured below Mackay Dam. The regression is a reasonably good fit, and has its physical basis in the fact that higher surface water supply leads to lower groundwater pumping demand, and vice-versa. The streamflow below Mackay Dam is a measure of the total water supply, i.e. natural flow plus storage releases. To develop this relationship, Johnson et al. (1991) used the data that was available from 1984 through 1990. As much more data is now available, the same analysis was repeated using a more complete record through 2009. The data and regression line are shown in Figure 8; more detail can be found in Appendix A. One difference between this analysis and Johnson et al. (1991) is the use of an exponential regression which provides the best fit to the data.

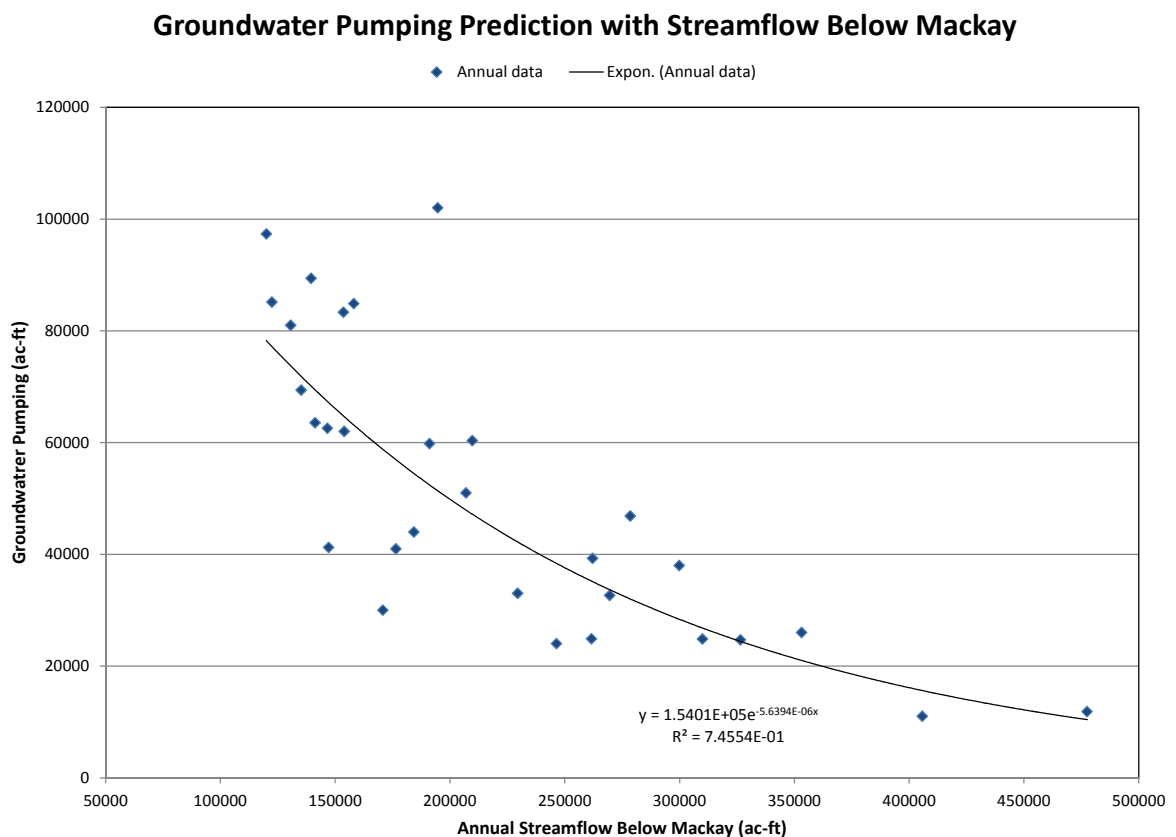


Figure 8. Regression of annual groundwater pumping with annual streamflow below Mackay Dam.

A record of annual groundwater pumpage from the aquifer was developed using all known measured or estimated data, plus estimated data using the above regression for years where data was unavailable. Calculations are included in Appendix A and the

resulting data set is summarized in Table 1.

Table 1. Summary of groundwater pumpage estimates (acre-feet).

Period	1959-1987	1988-2009
Maximum (Year)	102,000 (1966)	97,326 (2004)
Minimum (Year)	11,000 (1965)	24,845 (1995)
Average	38,290	60,730
Average (all years)	47,970	

The average or normal annual pumpage estimated by this procedure is 47,970 ac-ft, which is consistent with the estimate by Johnson et al. (1991) of 47,000 ac-ft.

The net depletion of the aquifer due to groundwater pumping is equal to the total diversion, less additional canal seepage caused by the conveyance of groundwater, less incidental recharge on the irrigated land from the application of the groundwater (assuming the land is situated over the aquifer). Canal seepage occurs more or less uniformly over the reach of the canal utilized to convey the pumped water, and the irrigated land is generally downstream of the groundwater withdrawal. Therefore, there will be an area of the aquifer which is subject to the full pump-out or something greater than the net depletion. Canal seepage is not known with certainty, but apparently the Big Lost River Irrigation District assesses a “shrink” of up to 50% on the water based on information from the owner and other water users. This assessment does not appear to be based on physical principles, since the addition of water to a canal which is already carrying water diverted from the Big Lost River would not generally result in much of the additional injected water being lost. Accounting for canal seepage and irrigation recharge, net depletion at any point in the aquifer would likely range from 50% to 100% of the gross pumpage. Each water right will be different depending on how it is conveyed and where it is used. In the case of the Island Wells, the depletion is equal to the full pumping rate at the wells, with some amount of return to the aquifer occurring over the length of the canals conveying water to the place of use southwest of Arco. The place of use is situated over the Eastern Snake Plain Aquifer and therefore incidental recharge of this water from irrigation application would not benefit the Big Lost aquifer.

A comparison of total pumpage and net depletion with annual average groundwater flow provides a measure of the sustainability of the groundwater development. The recent annual pumpage of 60,730 ac-ft significantly exceeds the calculated groundwater discharge in the aquifer at Moore of 25,700 ac-ft. This is also true for the net depletion. The lower annual pumpage in the 1959 to 1987 period of 38,290 ac-ft was still higher than the annual groundwater discharge, but the net depletion in these years was likely

close to or less than the groundwater discharge. Further evidence can be gleaned by examining the relationship of measured groundwater levels with groundwater pumping.

c. Groundwater level relationship with drought and pumpage

Water levels in USGS observation wells completed in the upper alluvium in T5N R26E and T4N R26E, and with sufficient data to be meaningful, are depicted on Figures 9 through 12. The best long-term records are those for wells 05N26E23CDA1 (located 2.5 miles north-northeast of the Island Wells), and 04N26E26DCD1 (located 4 miles south of the Island Wells). Relatively small seasonal fluctuations consistent with surface water irrigation recharge and later-season groundwater pumping have historically been evident. Water levels in the aquifer were reasonably steady from the 1950s through 1987, but began to decline in 1988 and decreased 25 to 45 feet within four years. Levels then recovered from 1995 through 1996 and remained near the historic levels through 1999, after which an even greater decline was observed.

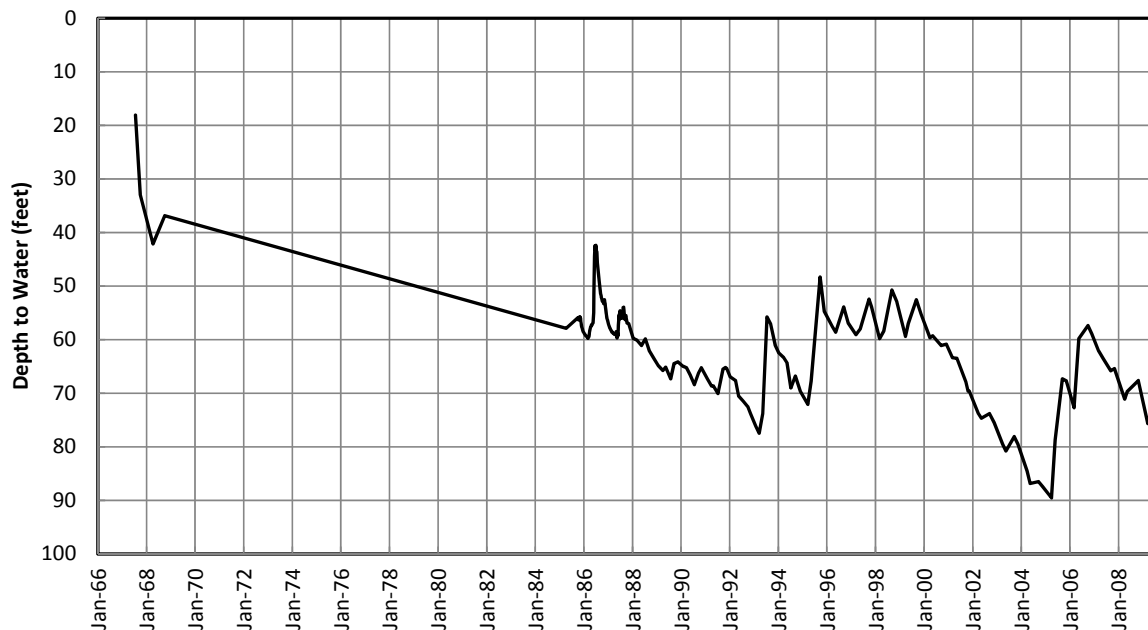


Figure 9. Depth to water record in well 05N26E05DCB1.

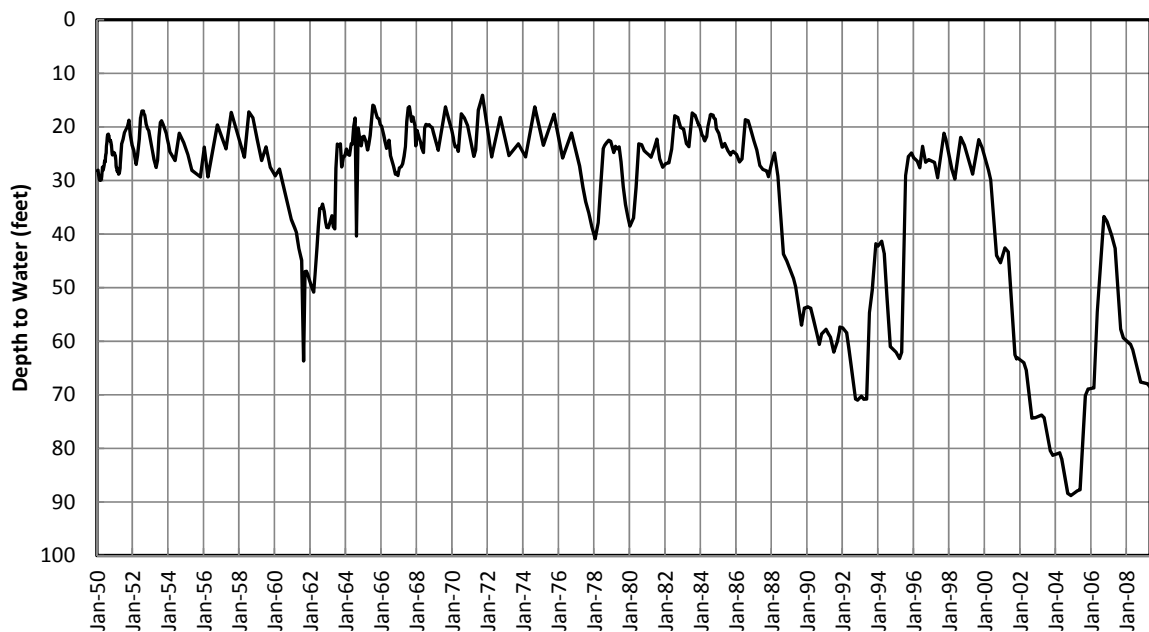


Figure 10. Depth to water record in well 05N26E23CDA1.

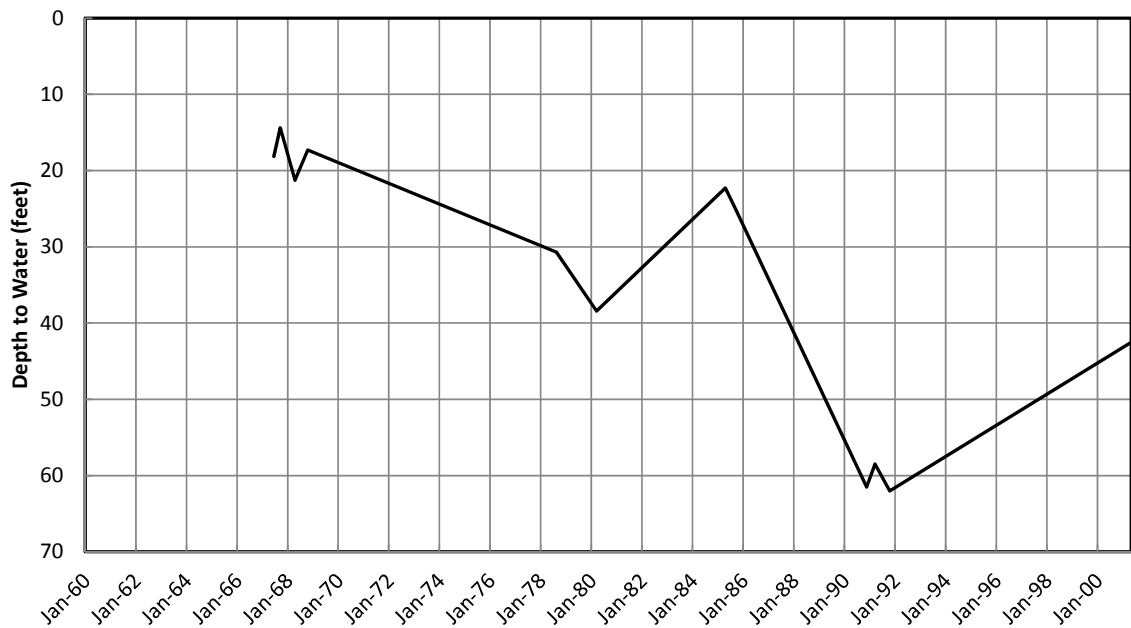


Figure 11. Depth to water record in well 04N26E04BBA1.

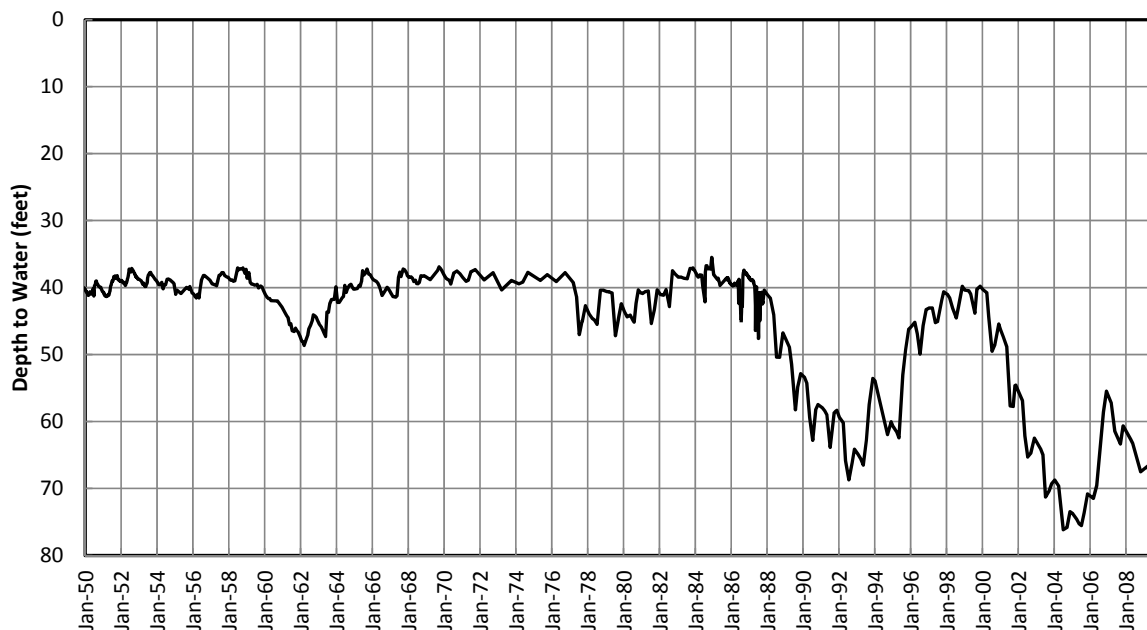


Figure 12. Depth to water record in well 04N26E26DCD1.

Since the late 1980s the aquifer appears to be sensitive to overall basin water supply, as suggested by the marked response to the 1987-1994 and 2000-2004 droughts and to the wet periods in between. The response in groundwater level observed since 1987 is likely due to 1) reduced natural recharge, 2) reduced recharge from river seepage and irrigation, and 3) greater pumpage from groundwater to meet irrigation demands. These potential influences were investigated.

Factor 1: Drought indicator. As an indicator of overall basin water supply, i.e. drought and wet periods, the precipitation record at the Mackay Ranger Station was examined. The annual total precipitation was expressed as a cumulative departure from average. This is a common procedure when analyzing precipitation data which results in a dataset in which sustained drought and wet periods are clearly evident. This data was then overlain on the water level in well 05N26E23CDA1 (Figure 13). Although some correlation is evident, particularly with the drought and wet periods since 1984, the analysis is not conclusive. For example, the wet period in the 1950s did not result in any increase in water levels. The relatively normal precipitation since 2004 has not corresponded with a sustained recovery of water levels (note that the cumulative precipitation for 2009 and 2010 is actually zero, not missing from the dataset).

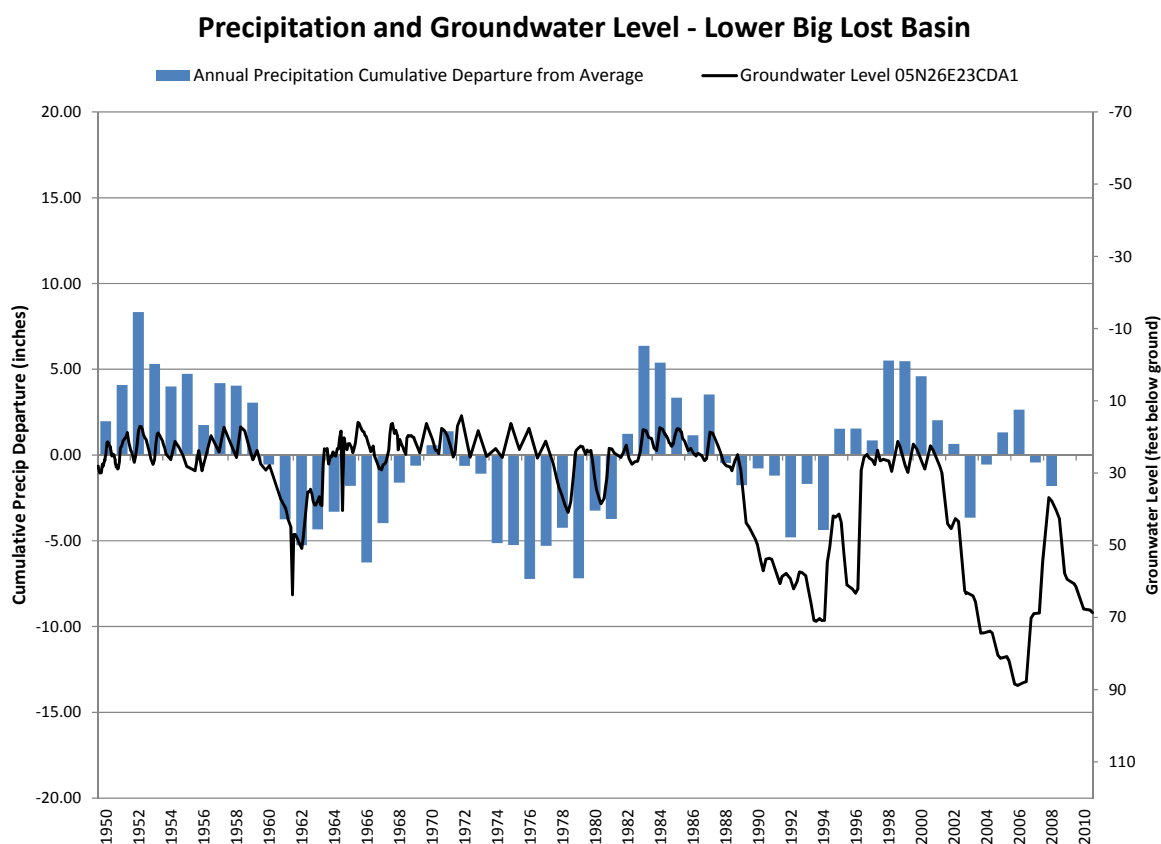


Figure 13. Groundwater level in well 05N26E23CDA1 and precipitation at Mackay (cumulative departure from normal) from 1950 through 2009.

Factor 2: Surface water supply. Annual streamflow at Mackay is a measure of the total surface water supply available for diversion. It may be hypothesized that years (or multiple years) with low surface water supply will lead to reduced river loss to the aquifer, and reduced diversions and hence reduced canal seepage and irrigation recharge, which may lead to lower groundwater levels. Annual water year streamflow at Mackay was expressed as a departure from average and overlain on the water level in well 05N26E23CDA1 (Figure 14). In this plot, the 3-year backward moving average of streamflow departure from average is shown. A 3-year backward average is justified on the physical basis that groundwater levels are normally influenced by reductions in net recharge and pumping withdrawals in the same year and in previous years due to the storage effects of the aquifer. This data indicates that periods of low water generally correspond to periods of reduced groundwater levels; however the correlation is not completely consistent. For example, periods of high flows do not always correspond to

high groundwater levels. During the extremely low groundwater levels seen in 2003 and 2004, the streamflow was not much lower than it was in the early 1960s and the early 1990s.

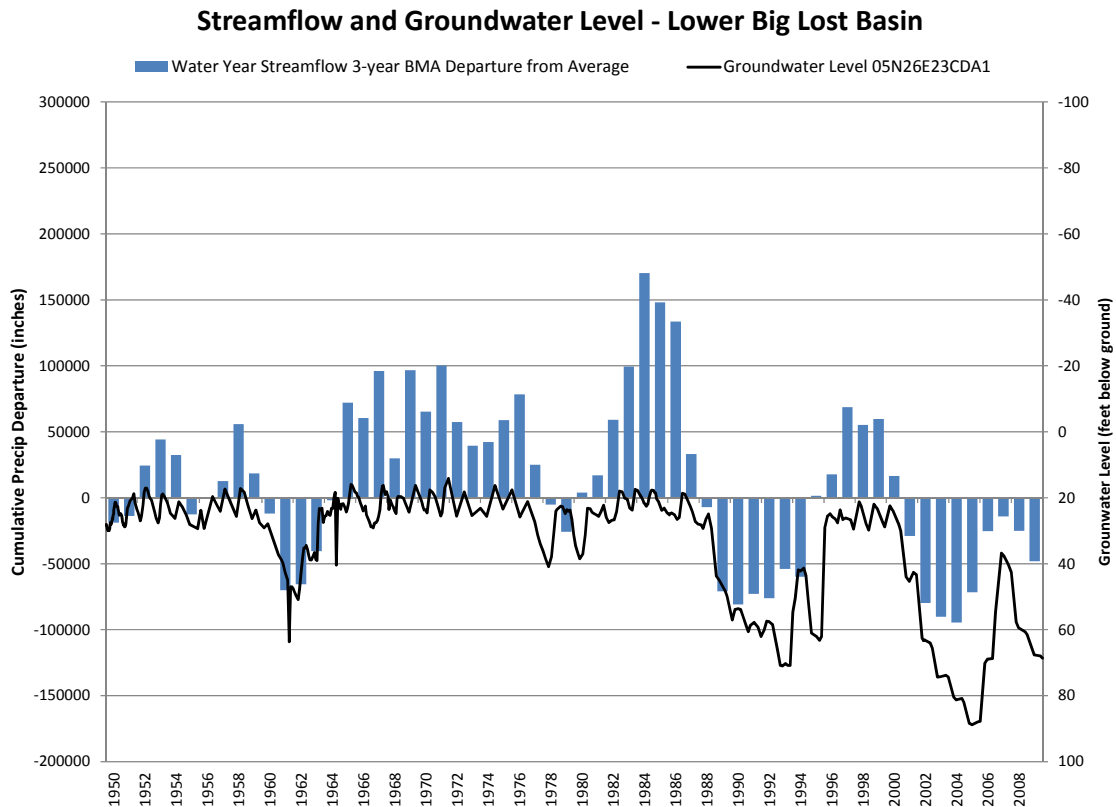


Figure 14. Groundwater level in well 05N26E23CDA1 and streamflow at Mackay (departure from normal) from 1950 through 2009.

Factor 3. Groundwater pumping. Withdrawals from groundwater reduce the amount of water in the aquifer and would be expected to negatively affect water levels. Again, a 3-year backward moving average was used for the physical reasons stated above. In Figure 15, the 3-year backward moving average of pumping volume is shown against the water level in well 05N26E23CDA1. From Figure 15 it is clear that groundwater pumping has a direct effect on aquifer levels, and this effect appears to have become more pronounced and direct in the years after 1987 as annual pumping volume has increase significantly.

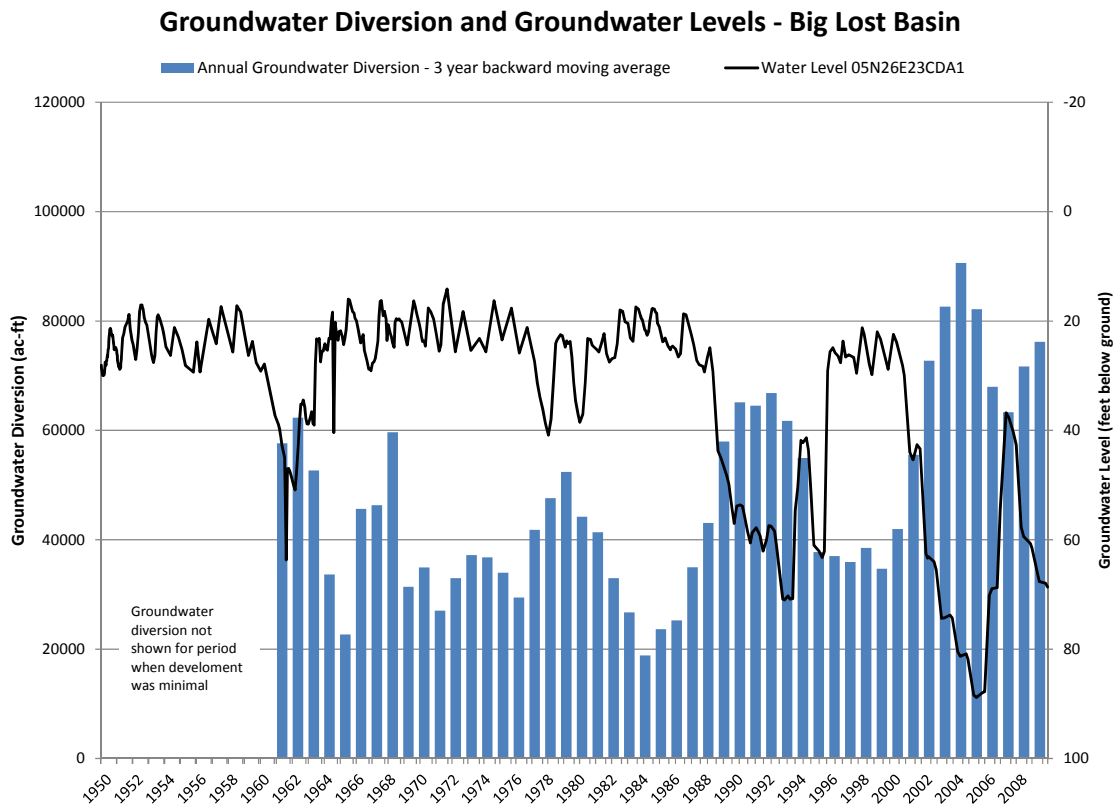


Figure 15. Groundwater level in well 05N26E23CDA1 and average annual groundwater pumping from 1959 through 2009.

As a further demonstration, scatterplots and linear regressions were created of water levels in well 05N26E23CDA1 and groundwater pumpage from 1959 through 1987 and from 1988 through 2009 (Figure 16). The slope of the regression line is much flatter using the early period data, and the relationship is less direct with an r-squared of 0.47. The slope is steeper using the later data and the relationship is much stronger with a very high r-squared of 0.92. The slope of the regression lines can be used to estimate the impact of groundwater pumping on water levels. For example, prior to 1988, an incremental increase in withdrawal of 10,000 acre-feet average for 3 years resulted in a decline of 3.8 feet in the aquifer. Since 1988, the same incremental increase in pumping resulted in a decline of 9.5 feet in the aquifer, in the relatively short term – not accounting for the potential additional negative effect of this pumping increment on long-term trend.

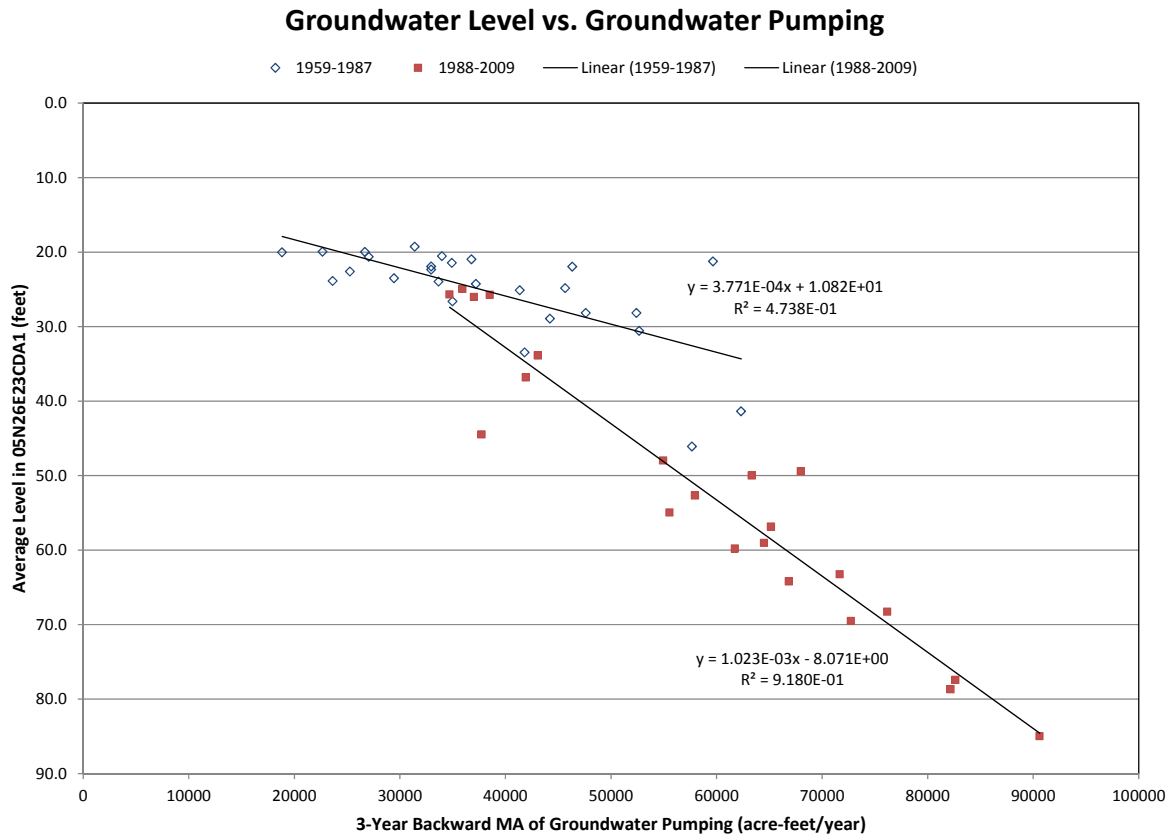


Figure 16. Scatterplots of groundwater level in well 05N26E23CDA1 and annual groundwater pumping from 1959 through 2009.

d. Separation of streamflow and pumping effects

As illustrated in Figures 14 and 15, both annual streamflow and groundwater pumping appear to be related to groundwater levels, and a valid physical justification can be formulated to explain how either effect, or both, would affect the aquifer water balance and therefore water levels. In order to separate these effects, a multiple regression was performed with annual water year streamflow and annual groundwater pumpage as predictor variables, and average annual groundwater level in 05N26E23CDA1 as the independent variable. The period 1988-2009 was used to develop the regression. The resulting equation is

$$GW\ Level = -0.0987 \times Streamflow + 0.777 \times Pumping$$

Where

Streamflow = Annual water year streamflow at Mackay, 3-year backward moving average of departure from normal, in 1000 acre-feet

Pumping = Annual groundwater pumping, 3-year backward moving average, in 1000 acre-feet.

GW Level = Average annual depth to groundwater in well 05N26E23CDA1, in feet.

Statistics of the regression are provided in Table 2.

Table 2. Statistics of the multiple regression to predict groundwater level.

Adjusted R-squared	0.94
Beta (streamflow)	-0.272
Beta (pumping)	0.728
F	170.5
p	<0.0001
SE estimate	4.56

The regression has an extremely high adjusted r-squared and F statistic, indicating that the regression model is an excellent fit. Both predictor variables have significant coefficients and both contribute to the explanation of groundwater level fluctuations, in a statistical sense: with higher streamflow, groundwater levels tend to be higher, and with higher pumping, groundwater levels tend to be lower. A residual analysis was performed to ensure that the assumptions of least-squares linear regression were reasonably satisfied.

The beta coefficients given in Table 4 are the standardized regression coefficients for the predictor variables. Because they are standardized, their magnitude may be directly compared to determine the relative effect of each predictor variable. In this case, the magnitude of the beta coefficient for pumping is 2.7 times greater than the magnitude of the beta coefficient for streamflow. This means that the effect of groundwater pumping on water level in the aquifer is 2.7 times greater than the effect of changes in surface water supply, i.e. streamflow.

This analysis indicates that the best explanation for the difference in aquifer response in recent decades is increased groundwater pumping. Physically, this may be explained by noting that the groundwater pumpage now exceeds annual groundwater flow on an average basis, as demonstrated in the previous section. Under this condition, the aquifer

would be expected to be sensitive to groundwater pumping and would not be expected to maintain its historic equilibrium level. The analyses described above were repeated using the data set for well 04N26E26DCD1, with similar results.

The data indicates (Figure 16) that if the groundwater pumpage is about 45,000 acre-feet per year or less, the aquifer can sustain the pumping and water levels should remain at or near historical levels. If withdrawal exceeds this amount, as it has in recent decades, the aquifer cannot sustain it and water levels will decline. This can be seen in Figure 15, and also in Figure 16 where a breakpoint in the slope occurs at about 45,000 acre-feet per year.

The expected result of over-pumping is a long-term downward trend, punctuated by drawdown and recovery periods in accordance with fluctuations in pumping. The hypothesis that a long-term declining trend is occurring is examined in the next section.

e. Groundwater level trend statistics

A visual inspection of the groundwater level time series for 04N26E26DCD1 and 05N26E23CDA1 appears to indicate little or no long-term trend from 1950-1987. Thereafter, the series appears to show a declining long-term trend, with shorter-term drawdown and recovery periods superimposed on the long-term trend. To test this hypothesis, a trend analysis was performed using the Mann-Kendall (M-K) method. This method is a non-parametric approach to trend analysis which is not dependent on assumptions regarding the underlying stationarity or probability distribution of the deviations from the trend line. As such, it is robust amidst a wide range of data conditions and is widely used in the analysis of hydrologic data sets. Helsel and Hirsch (2005) provides a good overview of the method. The results of the M-K statistical analysis are shown in Table 3.

Table 3. Mann-Kendall results on depth-to-water time series.

Parameter	04N26E26DCD1			05N26E23CDA1		
	1949-1987	1988-2009	All Data	1950-1987	1988-2009	All Data
S	-75	1642	67886	-9000	951	18810
Tau	-0.000405	0.234	0.257	-0.167	0.185	0.203
Zs	-0.0148	3.77	10.36	-4.51	2.75	6.30
p	0.4938	0.9997	0.9998	<0.0001	0.9967	0.9998

The M-K results indicate that for the 1950-1987 period, there is no statistically-significant trend in 04N26E26DCD1, and a slight statistically-significant decreasing trend (increasing water level) in 05N26E23CDA1. For the 1988-2009 period, there are statistically significant increasing trends (decreasing water levels) in both wells. Using the entire period of record, there are statistically significant increasing trends (decreasing water levels) in both wells. All trends were detected at very high confidence levels exceeding 99%.

F. ADDITIONAL DEPLETION FROM ISLAND WELLS

Annual depletion of the alluvial aquifer from the Island Wells depends on the extent to which they are utilized relative to utilization of the Airport Wells. A reasonable estimate of consumptive use on the 1980 acres near the airport to which all rights are appurtenant is 2.17 ac-ft/acre (Allen and Robison, 2008 – Alfalfa, less frequent cuttings). Assuming an on-farm efficiency of 75%, which is typical for sprinkler irrigation, the on-farm diversion requirement would be 2.89 ac-ft/acre or 5,722 ac-ft per year on the entire 1980 acres. Based on the water right diversion rates it appears that the Island Wells may supply about 50% of this or 2,861 ac-ft per year. Actual estimated or measured diversion volumes averaged 2,304 ac-ft for 1999-2010 and 1,896 for 1985-1987 (see Section G). If the accomplished transfer were to be valid the Island Wells could supply up to 100% of the irrigation supply and the diversion volume requirement at the wells would be limited by the water rights to 8,441.5 ac-ft/year. It should be noted that water right 34-7138 is a surface water right also appurtenant to the land; this right allows 16 cfs but has a late priority date (5/5/1976) and likely provides only a small amount of the irrigation supply.

Possible pumpage scenarios are illustrated in Table 4 relative to the total groundwater flow calculated at Moore. Net depletion of the alluvial aquifer, as discussed above, is equal to the gross pumpage less the additional canal seepage occurring within a reach that can actually benefit the alluvial aquifer. Assuming the additional seepage is 50% of the gross pumping (a very high assumption), then about half of this amount, or 25% of the gross, would return to the aquifer above Arco and could provide some offsetting benefit.

Table 4. Depletion from Island Well pumping.

Scenario	Annual Diversion from Island Wells		Net Aquifer Depletion (after canal seepage)*	
	Volume	Percent of Groundwater Flow at Moore	Volume	Percent of Groundwater Flow at Moore
Island Wells pump at pre-1987 volume	1,896 ac-ft	7.4%	1,422 ac-ft	5.5%
Island Well pump at 1999-2010 average	2,304 ac-ft	9.0%	1,728 ac-ft	6.7%
Island Wells pump maximum allowed under accomplished transfer	8,441.5 ac-ft	33%	6,331 ac-ft	25%

* Assumes 50% canal seepage total; 25% occurs within reach that can physically offset pumping from alluvial aquifer.

The potential additional depletion due to the accomplished transfer is a significant fraction of the discharge of the upper alluvium, and would exacerbate the declining aquifer levels, both in the long term and during drought periods when the groundwater level data indicates that the aquifer supply is not sufficient. In terms of impact on the alluvial aquifer, the accomplished transfer would be hydrologically equivalent to a new appropriation. Accurate quantification of the long-term future impact on water levels would best be quantified with a calibrated numerical groundwater model with sufficient cell resolution to capture local conditions in the Big Lost valley. The Eastern Snake Plain Aquifer Model domain does extend up the valley, but the cell size and resolution of aquifer depth and other parameters is not sufficient for the present purposes.

G. SURFACE WATER INFLUENCE

The relationship between groundwater and surface water in the Big Lost valley has been documented by Crosthwaite (1970), Szczepanowski (1982), and Johnson, et al. (1991). These authors document the “relatively free interchange” between surface and groundwater in the Big Lost valley and the fact that pumping of groundwater generally results in depletion of surface water to some extent. Johnson et al. (1991) evaluated the issue in greater detail and developed two procedures by which the impact of groundwater pumping could be estimated. Additional study of groundwater and river profiles has been completed by IDWR, the most recent of which was in 2004.

The direct exchange of water between the aquifer and the river can occur when the elevation of the water table is the same as that of the river, causing a hydraulic connection between the two sources. Under this condition, the aquifer may feed the river (reach gain) or the river may feed the aquifer (reach loss). A reduction in groundwater level causes a decrease in reach gain, or an increase in reach loss. If the groundwater level drops below the river, the direct hydraulic connection is broken and the river can only lose water to the aquifer. This condition is termed a “perched stream.”

IDWR (1991) and IDWR (2004) have determined the relationship between the water table elevation and the river elevation along the length of the river from Mackay to Arco, and have documented the changes in this relationship over time (Figures 16 and 17).

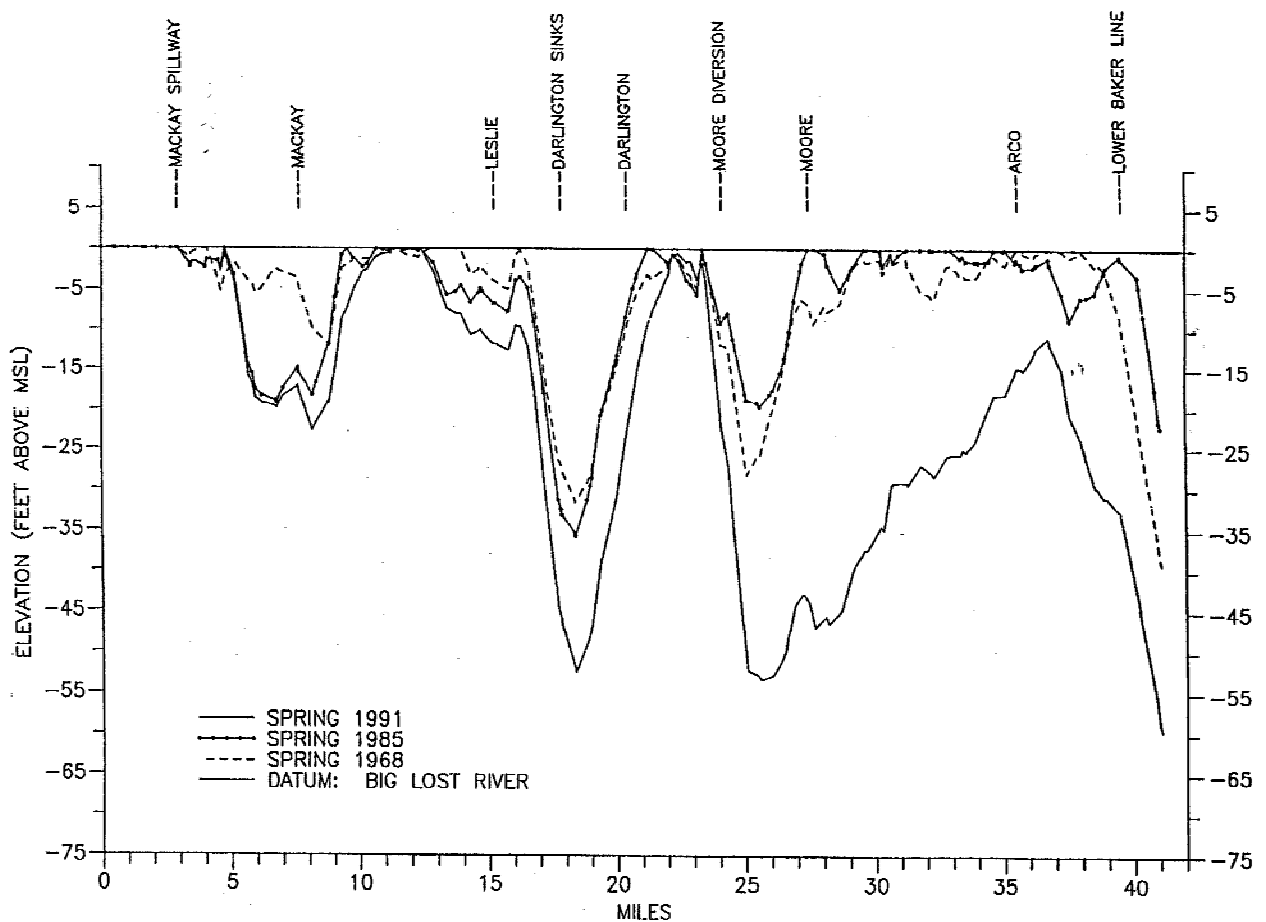


Figure 5. Profile of Water-Level Elevation Maps

Figure 16. Profile of groundwater elevation and adjacent elevation in the Big Lost River (from IDWR, 1991).

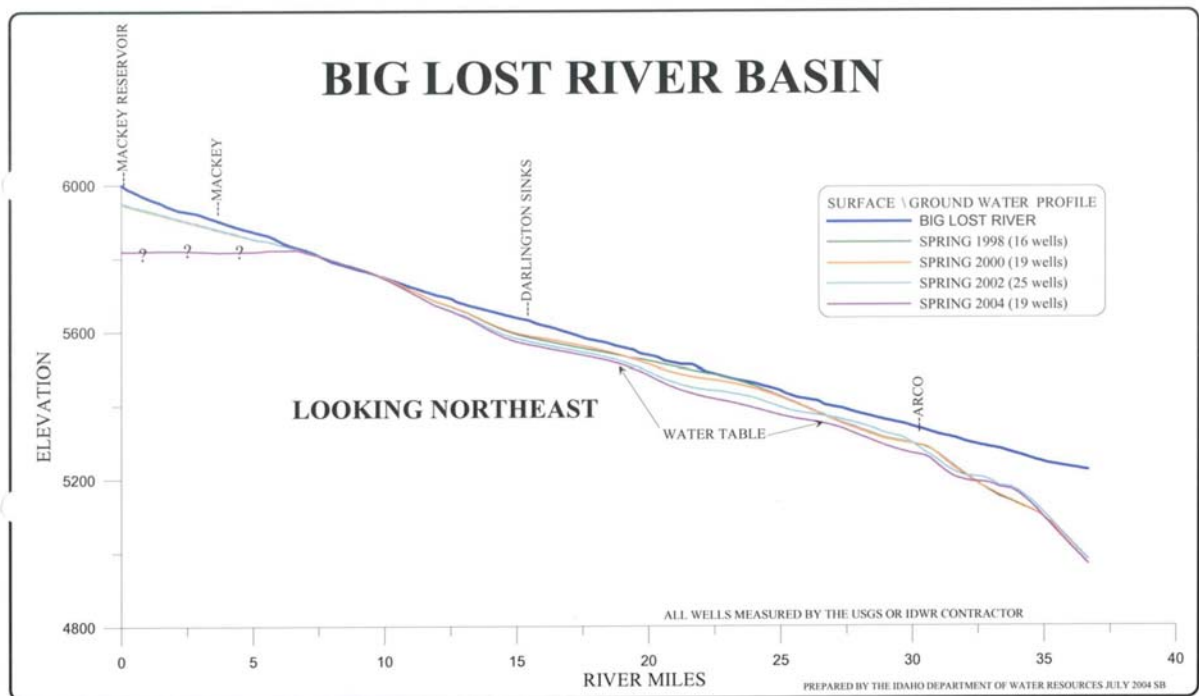


Figure 17. Profile of groundwater elevation and adjacent elevation in the Big Lost River (after IDWR, 2004).

Historically, many reaches of the river have gained water from the aquifer, both above and below the Moore Diversion. In the Darlington Sinks area and between the Moore Diversion and Moore, the river has always been perched. Based on the 1968 profile (Figure 16), the river and aquifer were connected and the river gained water from the aquifer in nearly the entire reach from Moore to below Arco. The 1985 profile shows a similar connection. As groundwater levels have declined since the late 1980s, the hydraulic connection from approximately Leslie (between Mackay and Darlington) downstream to Arco has generally been eliminated. The most recent measurements that indicate any gaining reach below Moore were in 1998 (Figure 17). A completely perched river is now generally the normal condition below Moore. Water levels have recovered somewhat since the last profile measurement in 2004, but not to the 1998 levels and it is likely that there is no gain occurring below Moore at this time.

The result of this pattern has been a reduction of surface water available for diversion. Reach gain is a source of surface supply to senior water rights that has historically been relied upon. Johnson et al. (1991) estimated the “diversion depletion” to be 20,000 to 30,000 acre-feet per year in low water years and 13,000 acre-feet per year in normal years. The authors attribute the diversion depletion to pumping of groundwater wells

which have caused decreased aquifer levels and increased reach loss or decreased reach gain in the Big Lost River. Additional groundwater depletion of the alluvial aquifer would exacerbate the diversion depletion. The Johnson, et al. study could be extended by incorporating recent data since 1991, but this analysis was not performed for the present study.

In most well logs shallow clay strata are present at 20 to 80 feet below ground. To the extent this layer exists and a well is cased through it, pumping the well may have less effect on the uppermost zone and therefore on the gain or loss from reaches of the Big Lost River which are interconnected with the groundwater. However, it appears such strata are discontinuous and may not provide complete segregation based on a review of well drilling records. The authors cited above do not address the effect of any shallow clay layers and generally assume free interchange of groundwater with the river. Although widespread, this shallow clay layer is not present uniformly in all wells; many well logs indicate very thin “gravel and clay” layers or fail to identify any clay at that depth. Therefore, it appears likely that the shallow clay is discontinuous rather than a valley-wide barrier to vertical mixing between the two alluvial zones. In areas where the clay is thin and/or contains significant gravel fraction, the layer may not be impermeable. An exhaustive analysis of drilling logs would be needed in order to map the location, nature, and extent of this layer. As noted above, a numerical groundwater model that incorporates surface water / groundwater interaction would be a useful tool in evaluating current and future impacts of pumping.

H. DISCHARGE AND VOLUME ANALYSIS OF ISLAND WELLS

a. Discharge Rate

Measured discharges pumped from the Island Wells are available from 1994 through 2004, made by either water district or IDWR staff (Appendix A). Discharge has been highly variable in both wells. Because there are no regulation valves on either well and the pumps discharge freely into the canal, the actual pumping rate at any given time is essentially equal to the well/pump capacity at that time. The well pumps were changed or modified in June 2003 and the horsepower was doubled on both wells. The modification resulted in an increase in total discharge of approximately 3000 gpm (6.7 cfs). Because of this change, data was divided into readings before and after the pump modification.

Groundwater levels in the Big Lost aquifer affect well discharge in two ways: 1) a pump can deliver less flow at a higher lift, and 2) reduced open area of the well will allow less

water into the casing at a given drawdown. No known measurements of water levels are available on either well with the exception of the 5/20/2011 reading on the south well. However, USGS observation well 05N26E23CDA1 can be used as a good proxy for aquifer levels at the Island Wells. Water levels in the aquifer in the vicinity of the wells were reasonably steady from the 1950s through 1987, but began to decline in 1988 and decreased 25 to 45 feet within four years. Levels then recovered from 1995 through 1996 and remained near the historic levels through 1999, after which an even greater decline was observed (Figure 10).

A strong correlation exists between groundwater level in well 05N26E23CDA1 and the pumping rates of the wells prior to June 2003 (Figure 18). The differences between the August 1985 and July 1990 measurements made by IDWR field examiners and the lower values measured by IDWR from 2000 through May 2003 can likely be explained by the groundwater level decreases observed after 1987. The two points representing the beneficial use examiner's measurements are noted on the graphs. A review of both field exams did not indicate any obvious errors in methodology. The high points in 1985 lie above the logarithmic fitted curves through the data, but do not appear to be outliers.

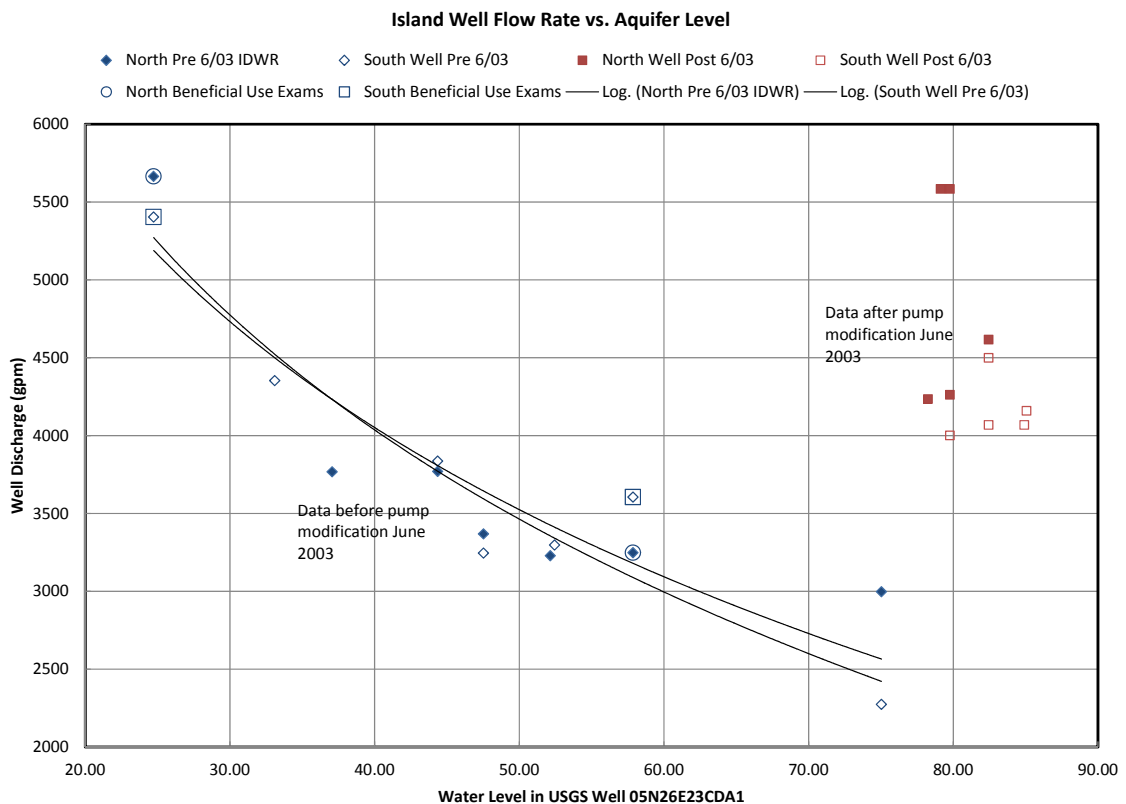


Figure 18. Measured flow rate from Island Wells as a function of groundwater level.

The pump curves of the original pumps were obtained and evaluated. The pump in the south well, according to the pump plate and the 1985 field exam, was a Berkeley 1604H, S/N 8200408. The pump plate on the discharge head of the north well indicates an Aurora/Verti-Line 16FH. The 1985 field exam does not indicate the exact model. The discharge head appears to have been unchanged since 1985, based a photo included in the field exam. Based on the water levels prevailing at the time of installation (which were near the historic levels), and an estimated drawdown of 30 to 40 feet (based on the 5/20/2011 well test), the pump curves indicate that the original pumps were likely capable of delivering greater than 20 cfs total.

b. Volume Pumped Prior to November 1987

Power records indicate that the north well was used in 1980 and 1981, and both wells were used in 1985, 1986, and 1987. 1985 was the first year that the south well was in service. The highest power usage data was recorded in 1987 (Appendix A).

Power consumption coefficients (PCC) were developed for each well by IDWR from several measurements made in 2000, 2001, 2003, and 2004. The 2000 measurements were made when water levels were near their historic levels and were nearly the same as those prevailing during the summer of 1987, and hence should be reasonably indicative of pre-1987 conditions. The 2001, 2003, and 2004 measurements were made when water levels were significantly lower and (after June 2003) the pumps had been modified; therefore the PCC developed at these times would not be representative of pre-1987 conditions. It was assumed that the most representative PCC for pre-1987 conditions is 121.1 kWh/ac-ft for the north well and 136.9 kWh/ac-ft for the south well. Estimated volumes are shown in Table 4. The total volume pumped in 1987 is estimated to be 2,961 acre-feet (Appendix A). It should be noted that Water District 34 utilized the PCC method in some years to estimate well volumes but the PCC used by the District may be different than those utilized in the present study.

The PCC method can be used to estimate volume pumped each month, but not instantaneous flow rate. However, an average flow rate can be calculated for each monthly power usage amount, and a seasonal average flow rate can be calculated from the total power used. For 1987, the highest estimated average flow is 12.5 cfs in July, and the estimated seasonal average flow is 10.8 cfs. Two conclusions can be drawn: 1) The total volume of 2,961 ac-ft in 1987 was covered by the pre-existing license 34-7037, and 2) the highest monthly volume (July) could have been delivered with a continuous flow only slightly greater than the 12 cfs allowed under 34-7037. Instantaneous pumping rate during the peak month cannot be determined from power records. These results

indicate that an accomplished transfer of the entire Airport Well water rights was not needed to supply the monthly or annual volumes.

c. Volume Pumped from 1999-2010

Power usage records were used to calculate volume pumped from 1999-2010, using the PCC calculated by IDWR during the 2003-2004 measurements. This period represents a lower water level condition and the modified pumps. Volumes in 2009 and 2010 were taken from the Water District 34 records which are presumed to be based on the discharge measurement using Cipoletti weirs, which were installed in 2009 and should be reasonably accurate.

From 1999-2010, the average volume pumped was 2,304 ac-ft. This compares to an average from 1985-1987 (the period when both wells were first in service) of 1,896 ac-ft.

I. CONCLUSIONS

1. The Big Lost River alluvial aquifer developed for irrigation since the late 1950s consists generally of highly productive sand and gravel with an estimated hydraulic conductivity near the Island Wells of 243 ft/day.
2. Pumping an additional 12.5 cfs from the Island Wells will result in a local drawdown in the alluvial aquifer from greater than 10 feet in the immediate vicinity of the wells, to nearly zero at a distance of about 2.5 miles from the wells. The predicted drawdowns are not negligible and will likely result in increased power costs, decreased well yields, and potentially the need to deepen or replace domestic and irrigation wells which are too shallow to provide the required yield.
3. The estimated average annual discharge in the upper alluvial aquifer developed for irrigation use is 25,700 acre-feet per year.
4. Average groundwater pumping from the aquifer for the period 1959 through 2009 is estimated to be 47,970 acre-feet per year.
5. Pumping has increased significantly since the late 1980s. The estimated average pumping for 1959 through 1987 is 38,290 acre-feet/year and the estimated average pumping for 1988 through 2009 is 60,730 acre-feet/year.
6. Prior to the late 1980s, the average net depletion was likely close to the average annual aquifer discharge, resulting in generally stable aquifer levels. This has not

been the case in the period since the late 1980s, over which time the average pumpage and net depletion have exceeded the average annual groundwater discharge.

7. Groundwater levels were reasonably steady from 1950 through 1987 with the exception of the early 1960s drought period. Major declines and recovery periods have been observed since 1987, but the levels have not recovered to historic levels.
8. The groundwater level fluctuations, including the major declines and recoveries observed since 1987, are best explained as a consequence of groundwater pumping. Excellent statistical correlation exists between 3-year average pumping volume and groundwater levels.
9. Statistically significant long-term downward trends exist since 1987 in the water levels in the alluvial system.
10. The groundwater and surface water systems are connected, but the reach gain which has historically provided a portion of the water supply in the Big Lost River below Moore has been eliminated by the declining groundwater levels. The reduction in surface water diversions due to this effect is approximately 13,000 acre-feet/year in normal years, and 20,000 to 30,000 acre-feet/year in low water years. Additional pumping from the aquifer will exacerbate this shortage and delay any incipient reconnection if groundwater levels recover, resulting in larger depletions of surface water supply for senior rightholders than would otherwise occur.
11. The maximum volume pumped from the Island Wells prior to November 1987 was 2,961 acre-feet in the 1987 season. Existing license 34-7037 was adequate to cover all of the pumped volume and all but 0.5 cfs of the monthly average flow rate. Therefore, an accomplished transfer of the entire Airport Well water rights did not occur.
12. Based on the data review and analyses contained herein, the proposed additional pumping that would occur if an accomplished transfer of water rights 34-2459, 34-2460, 34-2461, and 34-2462 were deemed valid will result in significant impacts to both groundwater users and surface water users.

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Appendix A

Data and Calculations

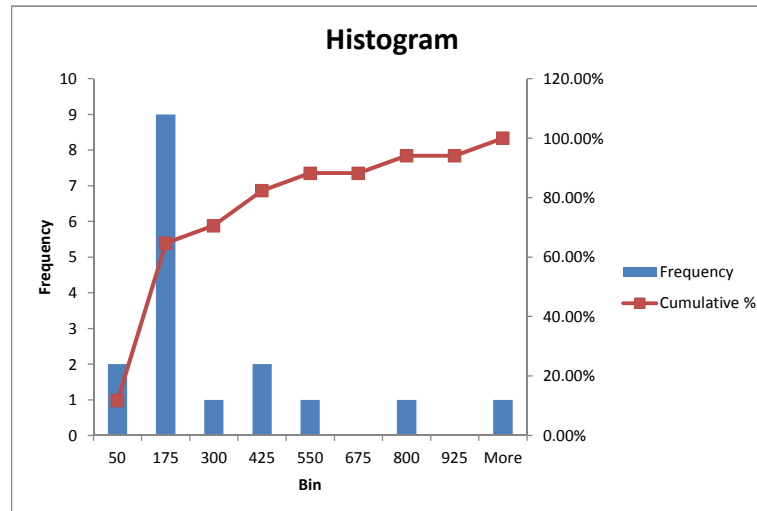
Big Lost Alluvial Aquifer Transmissivity Estimation

I.D.	Location	Pumping Rate [gpm]	Drawdown [ft]	Time [min]	Well radius [in]	Storativity	SWL [ft]	Aquifer bottom [ft]	Avg open interval [ft]	Average aquifer thickness [ft]	Specific capacity	L/b	G	sp	Trial T [ft ² /d]	Calc T [ft ² /d]	Calc K [ft/d]
Quist	SENW3, T4N, R26E	3640	52	720	10	0.15	18	250	110.5	206	70.0	0.54	1.57	3.40	20501.0	20501.2	99.5
Johnson	SWSE Sec 3, T4N, R26E	2000	40	1440	8	0.15	26	250	100	204	50.0	0.49	1.54	4.35	16816.0	16816.3	82.4
Pearson	SESW Sec 5, T4N, R26E	3600	45	720	10	0.15	60	250	115.5	167.5	80.0	0.69	1.78	1.59	18870.0	18869.7	112.7
Olsen	SWSE Sec 10, T4N, R26E	1200	52	1440	8	0.15	18	250	92	206	23.1	0.45	1.53	5.21	8112.0	8112.2	39.4
Walker	NWSW Sec 14, T4N, R26E	2295	41	180	8	0.15	20	250	89.5	209.5	56.0	0.43	1.53	5.66	19413.0	19412.5	92.7
Techich	NWSW Sec 15, T4N, R26E	2700	7	960	8	0.15	45	250	96.5	201.5	385.7	0.48	1.53	4.55	142229.0	142229.0	705.9
Buxton	NWSW Sec 16, T4N, R26E	2700	85	2400	10	0.15	31	250	100	176.5	31.8	0.57	1.60	2.87	8969.0	8968.6	50.8
Spraker	NESE Sec 16, T4N, R26E	900	15	130	12.5	0.15	21	250	14	221.5	60.0	0.06	2.53	41.98	87843.0	87842.9	396.6
Island South	5N26E34NWSW	4115	19.74	120	10	0.15	30.46	250	125	209.67	208.5	0.60	1.64	2.64	53482.0	53481.9	255.1
Jones	5N26E21SWNW	2693	9	240	9	0.15	50	250	113	195.5	299.2	0.58	1.61	2.88	85321.0	85321.4	436.4
Smith	5N26E27SWSW	2943	92	300	10	0.15	23	250	81	181	32.0	0.45	1.53	4.76	9910.0	9910.3	54.8
Moore 1	5N26E28SENW	450	5	210	6	0.15	17	250	40	230.5	90.0	0.17	1.99	19.73	72835.0	72834.7	316.0
Moore 2	5N26E28SENW	445	21.8	360	6	0.15	14.7	250	46	224.4	20.4	0.20	1.88	16.39	14088.0	14087.8	62.8
Babcock	5N26E33SWNE	4200	6	630	8	0.15	46	250	105	201	700.0	0.52	1.56	3.79	243241.0	243240.6	1210.2
Bleak	5N26E33SWSE	2600	24	360	8	0.15	37	250	94.5	201	108.3	0.47	1.53	4.71	36608.0	36608.2	182.1
Sowards	5N26E34NWSW	2000	84	360	8	0.15	42	250	110	166	23.8	0.66	1.74	1.93	5311.0	5311.3	32.0
Parkinson	5N26E34SWSW	4200	50	540	10	0.15	20	250	100	205	84.0	0.49	1.54	4.17	26522.0	26522.2	129.4
Toone	5N26E34SESW	3750	38	480	10	0.15	22	250	129	209	98.7	0.62	1.67	2.39	25565.0	25565.1	122.3

38.1

Mean 49757.6 243.4
Max 243240.6 1210.2
Min 5311.3 32.0
Std dev 60680.5 299.4

Bin	Frequency	Cumulative %
50	50	2 11.76%
175	175	9 64.71%
300	300	1 70.59%
425	425	2 82.35%
550	550	1 88.24%
675	675	0 88.24%
800	800	1 94.12%
925	925	0 94.12%
More	More	1 100.00%



Big Lost River Annual Groundwater Pumping Data

All values in acre-feet

Sources:

1 Johnson, et al. (1991). Total = 1.428 x Below Antelope

2 WD34 Records

3 Crosthwaite (1970)

Year	Strmfl blw Mcky CY	Strmfl blw Mcky WY	GW Below Antelope	GW Total	Source
1959	164090	170794		30000	3
1960	153889	153991		62000	3
1961	129650	130606		81000	3
1962	186497	184274		44000	3
1963	236632	229501		33000	3
1964	242979	246435		24000	3
1965	415295	405789		11000	3
1966	179785	194649		102000	3
1967	365037	353243		26000	3
1968	222042	207037		51000	3
1984	445595	477537	8300	11852	1
1985	238406	262152	27500	39270	1
1986	317175	326514	17300	24704	1
1987	175854	176506	28700	40984	1
1988	136335	141272	44500	63546	1
1989	137266	135239	48600	69401	1
1990	149574	146605	43800	62546	1
1991	163981	165067			
1992	122542	125882			
1993	223781	213139			
1994	136832	147185		41233	2
1995	320505	310007		24845	2
1996	260620	261636		44980	2
1997	308921	299944		37976	2
1998	265193	269609		32621	2
1999	271854	274894			
2000	167261	170601			
2001	125031	133284			
2002	127203	122425		85136	2
2003	136253	139583		89394	2
2004	119058	120074		97326	2
2005	193012	191130		59818	2
2006	282568	278587		46860	2
2007	146605	153628		83342	2
2008	158477	158114		84856	2
2009	214080	209736		60326	2

Big Lost River Groundwater Pumping Estimates 1959-2009

Pumping is measured or estimated from power records where indicated (bold);
 estimated using regression equation with streamflow below Mackay (water year) for other years
 Volumes in acre-feet, depths in feet

Pumping:		Streamflow:	
Average 1959-2009	47973	Average 1959-2009	231921
Average 1959-1987	38294	Average 1959-1987	264150
Average 1988-2009	60730	Average 1988-2009	189438

Year	Strmflow blw Mackay	3-year BMA	GW Pumping Estimate	3-year BMA	Avg Level in 05N26E23CDA1	Avg Level in 04N26E26DCD1
1950	185172				25.78	40.28
1951	243474				25.77	39.73
1952	310348	246331			20.98	38.43
1953	244321	266048			23.10	38.78
1954	208216	254295			23.67	39.34
1955	175224	209254			27.56	40.39
1956	282900	222113			24.27	40.01
1957	245508	234544			21.29	38.62
1958	304976	277794			20.42	37.97
1959	170794	240426	30000		24.98	39.46
1960	153991	209920	62000		31.45	41.82
1961	130606	151797	81000	57667	46.10	45.72
1962	184274	156290	44000	62333	41.39	46.18
1963	229501	181460	33000	52667	30.58	43.90
1964	246435	220070	24000	33667	23.99	40.77
1965	405789	293908	11000	22667	19.96	38.69
1966	194649	282291	102000	45667	24.85	39.87
1967	353243	317894	26000	46333	21.95	39.28
1968	207037	251643	51000	59667	21.25	38.72
1969	395509	318596	17200	31400	19.29	37.63
1970	259112	287219	36587	34929	21.47	38.42
1971	311528	322049	27375	27054	20.64	38.28
1972	267299	279313	34966	32976	21.94	38.32
1973	205320	261382	49272	37204	24.28	39.64
1974	319853	264157	26143	36793	20.97	38.79
1975	317102	280758	26544	33986	20.54	38.52
1976	263596	300184	35690	29459	23.52	38.45
1977	160289	246996	63214	41816	33.48	43.82
1978	225881	216589	43973	47626	28.19	43.27
1979	202424	196198	50067	52418	28.20	42.62
1980	249440	225915	38598	44213	28.94	43.20
1981	264903	238923	35433	41366	25.13	41.83
1982	328686	281010	24896	32975	22.35	40.14
1983	370387	321325	19765	26698	20.00	37.75
1984	477537	392203	11852	18838	20.03	37.97

1985	262152	370025	39270	23629	23.88	38.93
1986	326514	355401	24704	25276	22.62	39.66
1987	176506	255057	40984	34986	26.62	41.28
1988	141272	214764	63546	43078	33.90	45.72
1989	135239	151006	69401	57977	52.70	52.35
1990	146605	141039	62546	65164	56.86	57.60
1991	165067	148970	61565	64504	59.04	59.24
1992	125882	145851	76472	66861	64.21	64.07
1993	213139	168029	47185	61741	59.81	61.77
1994	147185	162068	41233	54963	47.99	58.64
1995	310007	223444	24845	37754	44.50	55.55
1996	261636	239609	44980	37019	26.04	46.15
1997	299944	290529	37976	35934	24.95	43.15
1998	269609	277063	32621	38526	25.75	42.14
1999	274894	281482	33527	34708	25.69	40.97
2000	170601	238368	59708	41952	36.85	44.81
2001	133284	192926	73403	55546	54.98	52.45
2002	122425	142103	85136	72749	69.53	61.19
2003	139583	131764	89394	82644	77.46	67.17
2004	120074	127360	97326	90619	85.00	72.77
2005	191130	150262	59818	82179	78.70	73.93
2006	278587	196597	46860	68001	49.44	63.77
2007	153628	207782	83342	63340	50.01	60.65
2008	158114	196776	84856	71686	63.27	64.47
2009	209736	173826	60326	76175	68.29	67.36

Summary of Discharge Measurements - North Island Well

North Well

Pole #583 / Well #31

June 2003 - pump was either overhauled or replaced, HP was doubled

Groundwater levels interpolated to date of flow measurement

Date	Water level		Q (gpm)	Q (cfs)	Analyst
	05N26E23CDA1				
8/8/1985	24.73		5664	12.62	IDWR-Wilson
7/5/1990	57.87		3247	7.23	IDWR-King
6/8/1994	47.53		3368	7.50	WD34
7/13/2000	44.37		3770	8.40	IDWR
5/17/2001	37.07		3767	8.39	IDWR
7/10/2001	52.16		3228	7.19	IDWR
5/30/2003	75.03		2996	6.68	IDWR
8/4/2003	78.25		4234	9.43	WD34
8/22/2003	79.13		5584	12.44	IDWR
9/4/2003	79.77		4262	9.50	IDWR
9/4/2003	79.77		5584	12.44	WD34
5/21/2004	82.44		4616	10.29	IDWR

Summary of Discharge Measurements - South Island Well

South Well

Pole #402 / Well #186

June 2003 - pump was either overhauled or replaced, HP was doubled

Groundwater levels interpolated to date of flow measurement

Date	Water level		Q (gpm)	Q (cfs)	Analyst
	05N26E23CDA1				
8/8/1985	24.73		5404	12.04	IDWR-Wilson
7/5/1990	57.87		3604	8.03	IDWR-King
6/8/1994	47.53		3244	7.23	WD34
6/8/2000	33.10		4352	9.70	IDWR
5/17/2001	44.37		3836	8.55	IDWR
7/12/2001	52.45		3296	7.34	IDWR
5/30/2003	75.03		2273	5.06	IDWR
9/4/2003	79.77		4000	8.91	IDWR
5/21/2004	82.44		4500	10.03	IDWR
5/21/2004	82.44		4068	9.06	WD34
7/8/2004	84.91		4068	9.06	IDWR
7/11/2004	85.06		4159	9.27	IDWR

Island Wells - Annual Volume Estimation using Power Records

C. G. Brockway, P.E. 5/31/11

IDWR PCC (kWh/ac-ft):

North Well

7/13/2000	121.1
7/10/2001	131.63
9/4/2003	241.54
5/21/2004	281.79

North Well PCC pre-1987 121.1 kWh/ac-ft

South Well PCC pre-1987 136.9 kWh/ac-ft

> Volumes for 1980-1987 are based on PCC calculated by IDWR during June-July 2000.

Water levels at this time were near historic pre-1987 levels and original pumps were in place.

> Volumes for 1999-2007 used PCC are based on average PCC calculated by IDWR during

2003-2004 (lower water levels and modified pumps). During this period, the in-line impeller

meters are believed to be unreliable. PCC used may differ from that used by WD34.

> Volume for 2009-2010 measured with weir boxes, believed to be accurate, reported by watermaster.

South Well

6/8/2000	136.91
7/12/2001	155.04
9/4/2003	229.97
5/21/2004	233.06
7/11/2004	233.11

Year	North Well 402			South Well 583			Total ac-ft
	PCC	kWH	ac-ft	PCC	kWH	ac-ft	
1980	121.1	180080	1487	136.9			1487
1981	121.1	261840	2162	136.9			2162
1982	121.1	0	0	136.9	Not in service		0
1983	121.1	0	0	136.9			0
1984	121.1	0	0	136.9			0
1985	121.1	101600	839	136.9	171182	1250	2089
1986	121.1	26480	219	136.9	57331	419	637
1987	121.1	175280	1447	136.9	207258	1514	2961
1988	No data						
1989							
1990							
1991							
1992							
1993							
1994			1041			1004	WD34 report
1995							
1996							
1997			0			0	WD34 report
1998			0			0	WD34 report
1999	261.7	57880	221	232.0	467669	2016	2237
2000	261.7	374900	1433	232.0	298763	1288	2720
2001	261.7	296910	1135	232.0	291708	1257	2392
2002	261.7	348960	1333	232.0	290750	1253	2587
2003	261.7	498740	1906	232.0	211822	913	2819
2004	261.7	526660	2012	232.0	190380	821	2833
2005	261.7	366220	1399	232.0	116860	504	1903
2006	261.7	195020	745	232.0	102340	441	1186
2007	261.7	618940	2365	232.0	226140	975	3340
2008							
2009			691			719	1410
2010			580			1339	1919

Highest volume prior to November 1987 = 2961 ac-ft

Assumed period of usage in 1987 (5/1 - 9/15) = 138 days

Average flow rate in 1987 = 10.82 cfs

Average volume 1999-2010 = 2304 ac-ft

Average volume 1985-1987 (yrs w/ both in service) = 1896 ac-ft

Island Wells - 1987 Volume Breakdown

C. G. Brockway, P.E. 5/31/11

North Well PCC 121.1 kWH/ac-ft

South Well PCC 136.9 kWH/ac-ft

PCCs calculated by IDWR in June/July 2000. Water levels at this time were near the pre-1987 levels

Month	North Well 402		South Well 583		Total	Avg Q
	kWH	ac-ft	kWH	ac-ft	ac-ft	
May	46880	387.1	34298	250.5	637.7	10.36
June	30880	255.0	28908	211.2	466.2	7.83
July	58320	481.6	39375	287.6	769.2	12.50
August	39200	323.7	58240	425.4	749.1	12.17
September	0	0.0	46437	339.2	339.2	5.70
October	0	0.0	0	0.0	0.0	0.00
Total		1447		1514	2961	

Assumed period of usage in 1987 (May 1 - Sept 15) 138 days

Average Q over this period 10.82 cfs