MEMO

State of Idaho
Department of Water Resources
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Date: February 6, 2017

To: Sean Vincent, P.G., Hydrology Section Manager

From: Jennifer Sukow, P.E., P.G.

Subject: Groundwater in the Big Lost River valley

This memorandum was prepared in response to a request for a hydrologic review of groundwater in the Big Lost River valley. The review was requested to assist with the evaluation of a petition requesting the designation of a Critical Ground Water Area in the Big Lost River basin[1]. In the petition, the water users mention concerns about declining groundwater levels, declining streamflow in the Big Lost River, and drought. This memorandum discusses aquifer recharge and discharge, water use and water level trends. Figure 1 shows the location of geographic features referenced in the memorandum.

Aquifer recharge and discharge

Groundwater in the Big Lost River valley is recharged by infiltration of precipitation, seepage from streams, seepage from irrigation canals, and infiltration of excess water applied for irrigation. Groundwater in the Big Lost River valley is discharged to wetlands and streams within the valley, withdrawn by wells, and discharged to the Eastern Snake Plain aquifer (ESPA). Crosthwaite et al. (1970) noted, "*A distinctive feature of the Big Lost River basin is the large interchange of water from surface streams into the ground and from the ground into surface streams", and concluded, "Surface and groundwater are so closely related that neither can be considered as a separate source of supply.*"

[1] A petition for designation of a Critical Ground Water Area in the Big Lost River basin was received on September 19, 2016. http://www.idwr.idaho.gov/files/ground_water_mgmt/20160919-Petition-to-designate-the-Big-Lost-River-Basin-as-a-CGWA.pdf

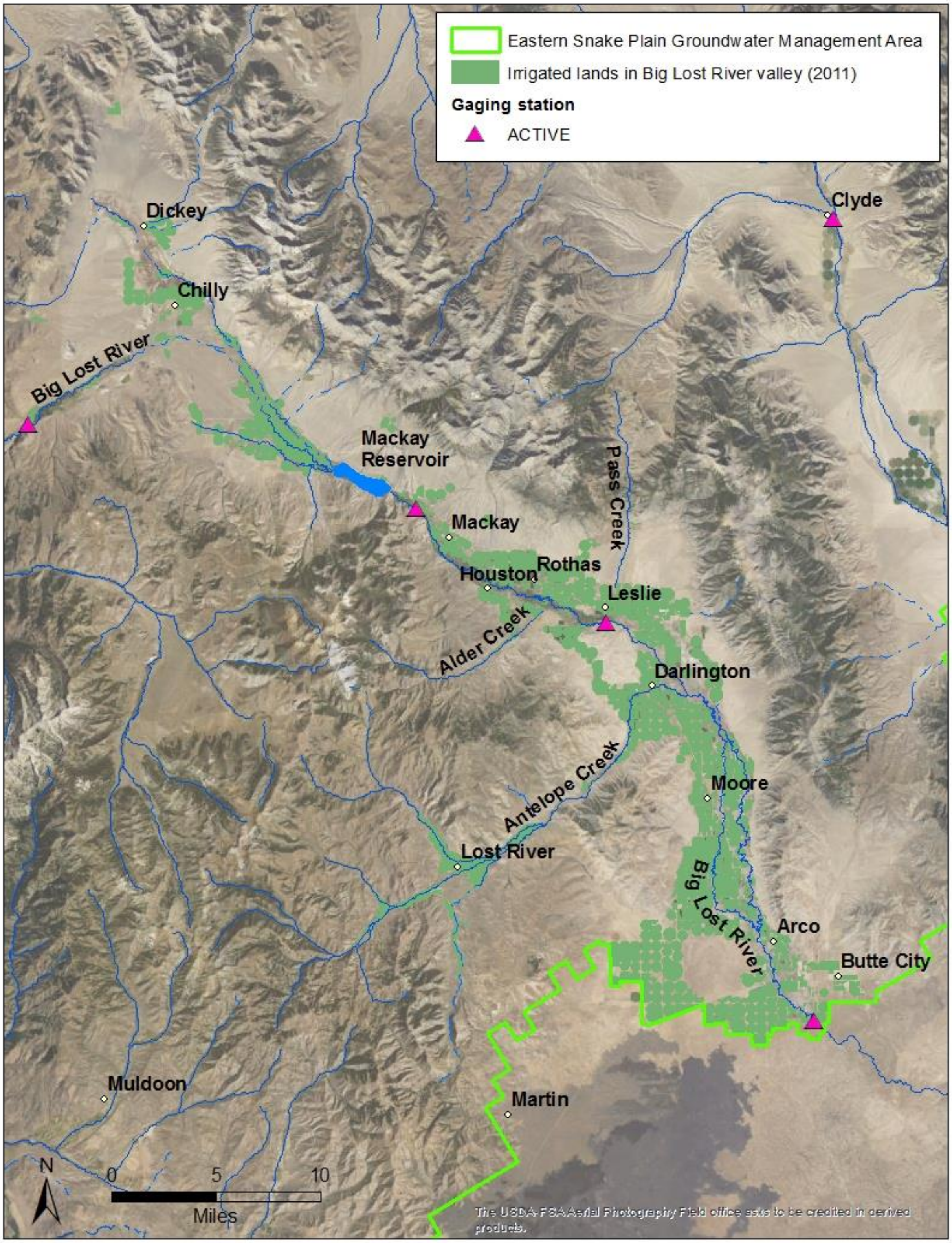

Figure 1. General location map, Big Lost River valley

The geology of Big Lost River valley is discussed in detail by Crosthwaite et al. (1970[2]) and Owsley (2013[3]). The valley is underlain by a thick sequence of valley fill sediments of variable depth, reaching estimated depths of up to 2,000 feet or more at some locations both upstream and downstream of Mackay Dam. The valley fill sediments have considerable capacity to store large volumes of groundwater. The valley is constricted in the vicinity of Mackay Reservoir and much of the groundwater above Mackay Dam is discharged to springs and streams, becoming surface inflow to Mackay Reservoir. Below Leslie, the valley widens, the thickness of sediments increases, and the Big Lost River loses considerable volumes of water to the aquifer (Crosthwaite et al., 1970).

In the southern portion of the Big Lost River valley, the valley fill sediments are interbedded with basalt and the hydraulic gradient steepens as the Big Lost River valley aquifer transitions into the Eastern Snake Plain aquifer. Conditions in the southern portion of the valley were described by Owsley (2013), "*The sedimentary aquifer system in the Big Lost River valley north of Arco is over 2,000 feet thick (Crosthwaite et.al, 1970). Clay layers range from 5 to over 50 feet thick and act locally as confining beds separating saturated zones of sand and gravel as well as perching unconfined zones. The clay units were deposited during flood events when streams were dammed by the encroachment of basalt flows from the south (Crosthwaite et. al, 1970). The encroachment occurred during several episodes forming lakes which deposited clays. The clay deposits have since been eroded and reworked by the Big Lost River, resulting in a series of disconnected clay lenses. The areal extent of individual clay lenses is unknown, but in the Arco area, the clay and basalt sequences are laterally extensive and strongly influence lateral movement of ground water (Crosthwaite et. al, 1970). Additionally, data from well logs suggest that the clay lenses confine or influence the vertical movement of water."* While the discontinuous clay lenses influence lateral and vertical movement of groundwater on a local scale, water level data from wells at different depths and locations within the aquifer system show similar temporal trends. Water level data suggest the Big Lost River valley aquifer system generally functions hydrologically as a single system with a downward gradient.

Crosthwaite et al. (1970) estimated an average annual water budget for the Big Lost River basin for the period of 1944 through 1968. During this period, average basin precipitation was estimated to be approximately 1.5 million acre-feet per year (AF/yr) and natural evapotranspiration was estimated to be approximately 1.0 million AF/yr. The total basin water yield (stream runoff plus infiltration of precipitation to groundwater) was estimated to be approximately 474,000 AF/yr. Approximately 23% of the water yield (109,000 AF/yr) was consumed within the basin by

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[2] Crosthwaite, E.G., C.A. Thomas, and K.L. Dyer, 1970. *Water Resources in the Big Lost River Basin, South-Central Idaho*, U.S. Geological Survey Open-File Report 70-93, 109 p., https://pubs.er.usgs.gov/publication/ofr7093.

[3] Owsley, D., 2013. *Application for Transfer No. 77610 in the Name of Parkinson Farms*, Idaho Department of Water Resources, memorandum to James Cefalo, Hearing Officer, 20 p.

irrigation[4] and wetlands. Approximately 11% of the water yield (54,000 AF/yr) left the basin as surface flow in the Big Lost River south of Arco. The remaining 66% of the water yield (311,000 AF/yr) left the basin as groundwater underflow to the Eastern Snake Plain.

Crosthwaite et al. (1970) assumed there was not a significant net change in aquifer storage (and aquifer water levels) between 1944 and 1968. Average aquifer discharge was assumed to equal the average aquifer recharge. Available water level data (Appendix A) suggest this was a reasonable assumption prior to the late 1970s, but that average aquifer discharge has exceeded average aquifer recharge since the late 1970s. Water level trends are discussed in more detail later in this memorandum.

The volume of water leaving the Big Lost River basin as surface flow south of Arco varies significantly from year to year. During periods of high snowmelt, surface flow in the Big Lost River channel may exceed riverbed seepage and some water may be transmitted south of Arco before being lost to the Eastern Snake Plain aquifer as riverbed seepage. Historically, the Big Lost River has also gained water at times from the Big Lost River valley aquifer between the Arco diversion and the Arco gage (Owsley, 2013). Figure 2 shows the relationship between mean annual and mean August discharge of the Big Lost River near Arco and spring groundwater level measurements in selected wells from 1950 through 2015.

[4] Crosthwaite apparently assumed full irrigation of 75,500 acres during all years between 1944 and 1968 when calculating the average consumptive use within the basin. Because much of the supplemental groundwater supply for mixed source lands was developed after 1968, it is likely the consumptive use estimated by Crosthwaite was not achieved during the drier years of his study period.

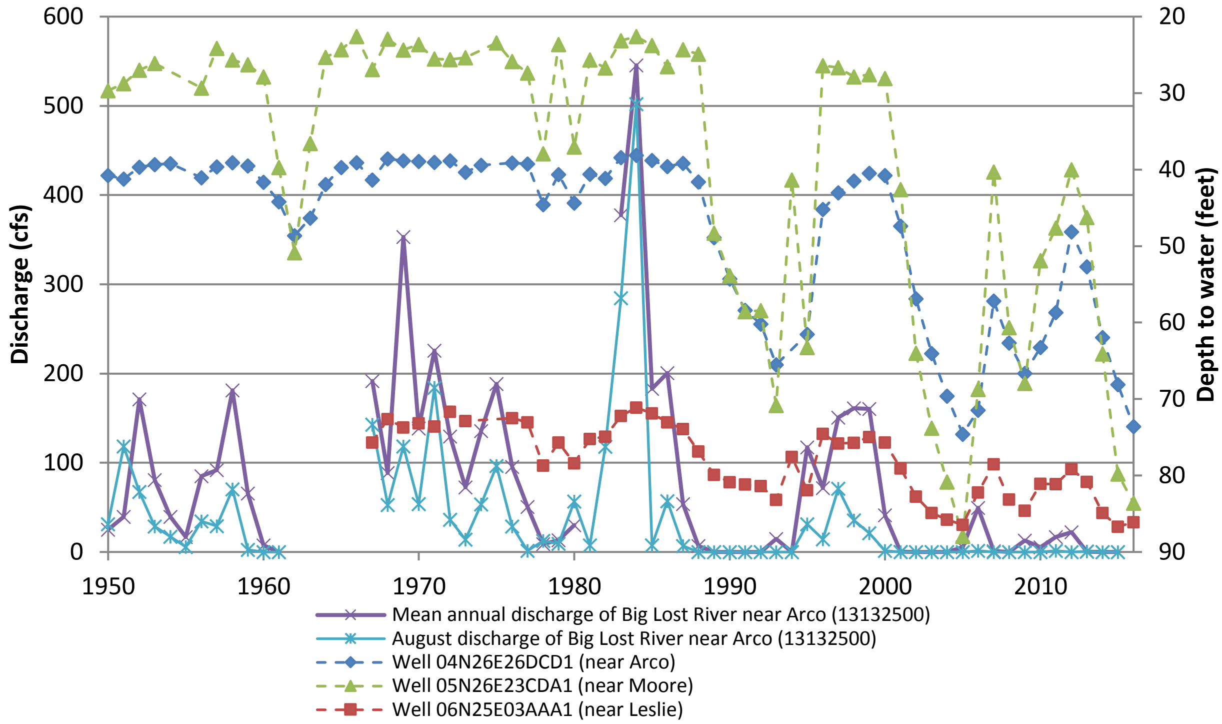

Figure 2. Discharge in the Big Lost River near Arco and spring groundwater level measurements

Net aquifer recharge and discharge in the Big Lost River valley below Mackay Dam between 1985 and 2010 were simulated in the Enhanced Snake Plain Aquifer Model Version 2.1 (ESPAM2.1[5,6,]). While ESPAM2.1 does not explicitly model the interchange of water between the aquifer and the Big Lost River, aquifer recharge (including seepage from the Big Lost River) was calculated for input to the model, and the model does simulate groundwater underflow to the Eastern Snake Plain at the mouth of the Big Lost River valley. The net aquifer recharge (aquifer recharge less groundwater consumed by irrigated crops and wetlands) simulated in the model within the Big Lost valley between 1985 and 2010 averaged approximately 187,000 AF/yr, including approximately 66,000 AF/yr of groundwater inflow in the vicinity of Mackay Dam. The annual net recharge was highly variable, ranging from approximately 71,000 AF in 1988 to approximately 345,000 AF in 2006 (Figure 3). Simulated groundwater outflow to the Eastern Snake Plain at the mouth of the Big Lost Valley averaged 204,000 AF/yr between 1985 and 2010. Annual groundwater outflow was much less variable than the annual net recharge, ranging from approximately 197,000 AF in 1988 to approximately 213,000 AF in 1997 (Figure 3).

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[5] IDWR, 2013. *Enhanced Snake Plain Aquifer Model Version 2.1 Final Report*, Idaho Department of Water Resources with guidance from the Eastern Snake Hydrologic Modeling Committee, 99 p., http://www.idwr.idaho.gov/Browse/WaterInfo/ESPAM/ESPAM_2_Final_Report/.

[6] Wylie, 2013, *ESPAM2.1 Model Validation*, Idaho Department of Water Resources, 29 p., http://www.idwr.idaho.gov/Browse/WaterInfo/ESPAM/ESPAM_2_Scenarios/ESPAM21Validation/.

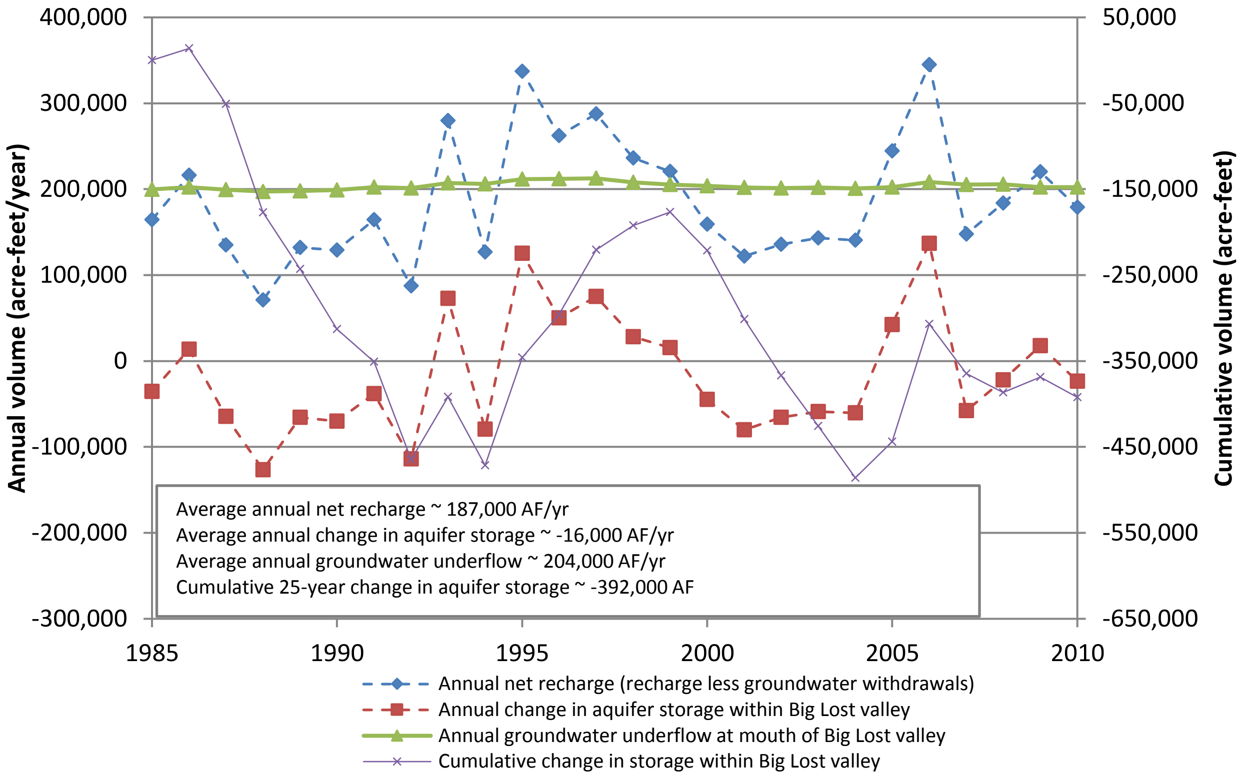

Figure 3. Change in aquifer storage within the Big Lost River valley simulated using the ESPAM2.1 groundwater flow model

The annual and cumulative changes in aquifer storage simulated using ESPAM2.1 are shown in Figure 3. During wet years, net recharge exceeds groundwater outflow to the Eastern Snake Plain and groundwater levels rise, increasing the volume of groundwater stored in the Big Lost River valley. During dry years, groundwater outflow to the Eastern Snake Plain exceeds net recharge and groundwater levels decline, decreasing the volume of groundwater stored in the Big Lost River valley. Aquifer storage may fluctuate by more than 100,000 AF in extremely wet or extremely dry years. Between 1985 and 2010, there was a net decrease in aquifer storage. The cumulative decrease in aquifer storage simulated using ESPAM2.1 was approximately 392,000 AF, an average annual decrease of approximately 16,000 AF/yr. While there is some uncertainty in the calibration of modeled aquifer storage characteristics and the simulated volume of decline in aquifer storage, the simulated trend in aquifer storage change is consistent with trends in measured groundwater levels (Figure 4). Groundwater level trends are discussed further in the following section of this memorandum.

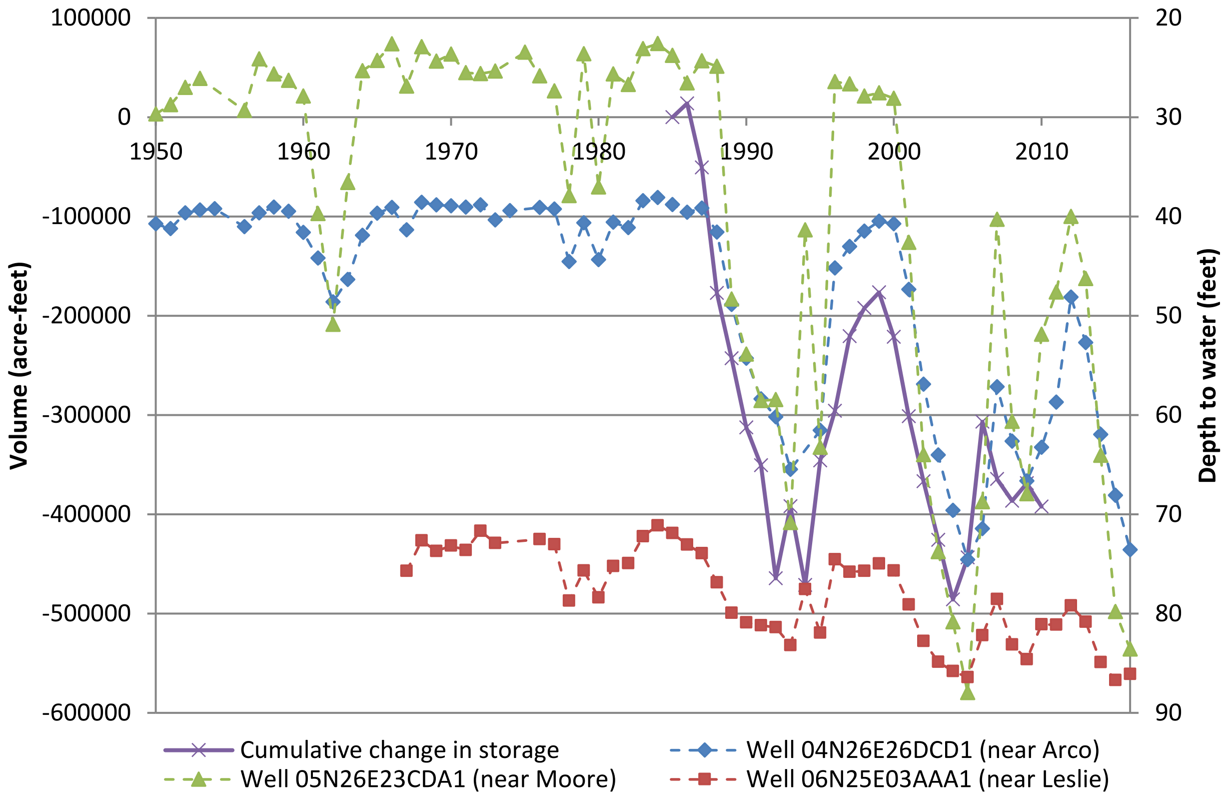

Figure 4. Simulated change in aquifer storage and measured groundwater levels

The average volume of groundwater underflow at the mouth of the Big Lost River valley between 1985 and 2010 simulated using ESPAM2.1 (204,000 AF/yr) is considerably less than the average volume of 311,000 AF/yr between 1944 and 1968 estimated by Crosthwaite et al. (1970). Part of the difference is because Crosthwaite's water budget includes roughly 50,000 AF/yr of estimated surface inflow from Alder Creek and estimated groundwater inflow along the west front of the Lost River Range and from the Antelope Creek basin. These components were not included in the water budget for ESPAM2.1 (Contor, 2009[7]). However, the 53,000 AF/yr of groundwater underflow at Mackay Dam estimated by Crosthwaite et al. (1970) was lower than the value of 66,000 AF/yr estimated for the calibrated ESPAM2.1 model.

In both water budgets, estimated groundwater underflow in the vicinities of Mackay Dam, Antelope Creek, and the west front of the Lost River Range contribute uncertainty to the total volume of groundwater inflow into the Big Lost River basin. The inflow from Antelope Creek, which was estimated by correlating streamflow measured between 1913 and 1922 with streamflow measured in the Big Lost River below Mackay Reservoir, contributes to the uncertainty of total

[7] Contor, Bryce, 2009. *IESW005 Diversions and Perched Seepage in Big Lost*, memorandum to Stacey Taylor and Greg Moore dated August 13, 2009, Idaho Water Resources Research Institute, 7 p.

water availability in the basin. Because groundwater outflow at the Big Lost River valley is calculated based on the estimated inflows, the uncertainty in the volume of estimated inflows to the basin results in uncertainty in the estimated outflow. Therefore, comparing the outflow volumes estimated by Crosthwaite et al. (1970) and ESPAM2.1 to assess long term changes in groundwater outflow from the Big Lost River basin is not recommended. Changes in groundwater levels, which are measured directly, provide greater insight into changes in groundwater conditions.

Groundwater level trends

Groundwater level trends were evaluated using water level measurements collected at 25 wells in the Big Lost River valley between 1950 and 2016 (Figure 5). Two of the wells are located above Mackay Dam. The other 23 wells are located below Mackay Dam. Water level hydrographs for each well are shown in Appendix A. Trend analyses were performed using the regional Kendall test and Mann Kendall test as described in Helsel, et al. (2006[8]). The regional Kendall statistical test was developed by the U.S. Geological Survey (USGS) to analyze trends where observations have been made annually at multiple locations, such as water wells, to determine whether the same trend is evident across those locations. The computer code and documentation are freely available from the USGS[8].

[8] Helsel, D.R., D.K. Mueller, and J.R. Slack, 2006. *Computer Program for the Kendall Family of Trend Tests*, U.S. Geological Survey Scientific Investigations Report 2005-5275, 4 p., https://pubs.usgs.gov/sir/2005/5275/.

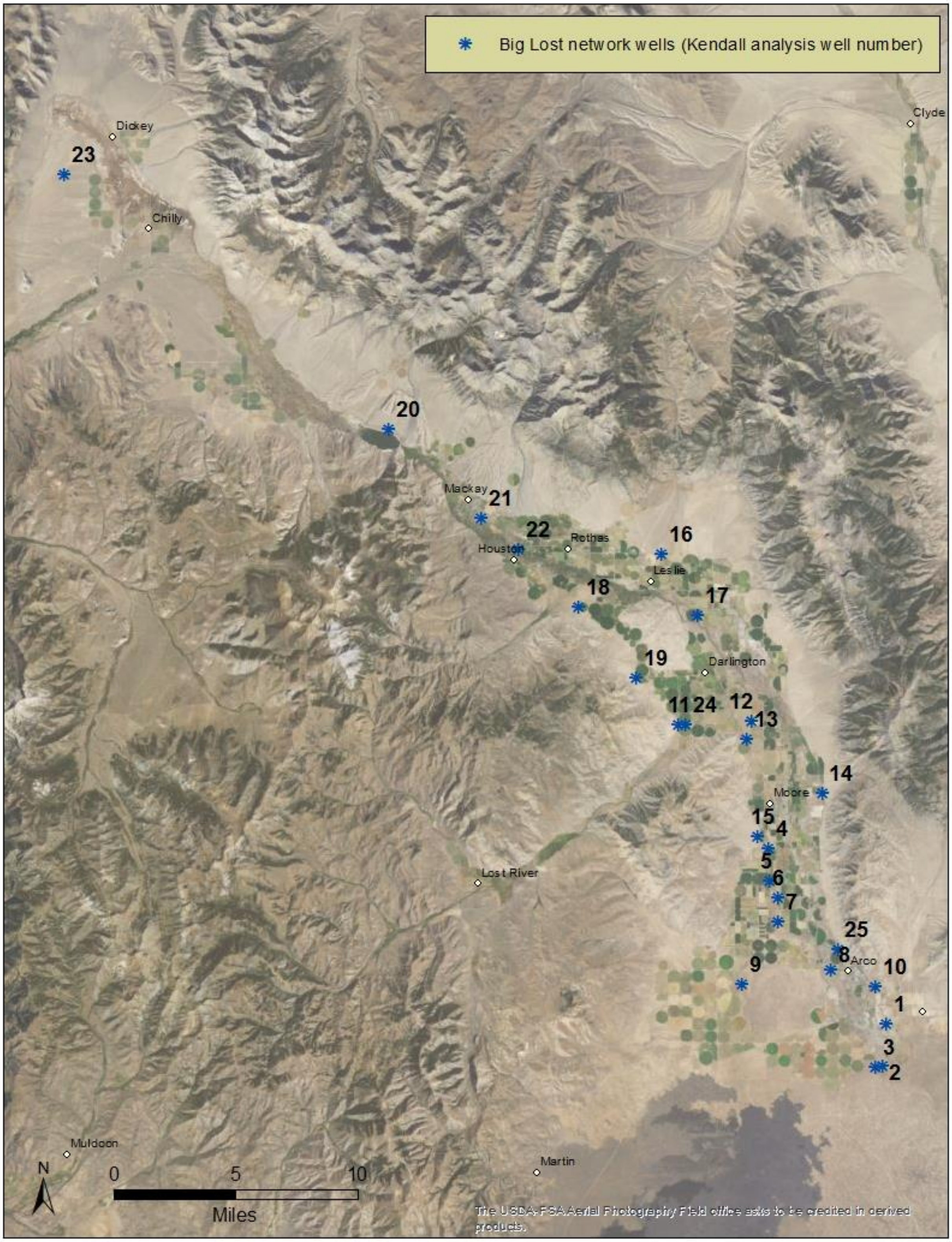

Figure 5. Well locations, Big Lost groundwater level monitoring network

Regional Kendall trend analyses were performed on water level data collected from the 23 wells below Mackay Dam. Spring water levels measured in March or April were used in the analyses. If a well was measured more than once in March or April of a given year, the measurement collected closest to April 1 was selected as the spring measurement for that year. Trends were evaluated for two time periods: spring 1950 through spring 1977, and spring 1977 through spring 2016. Both time periods include years with above average surface water supply and periods of drought (Figure 6). During the first time period, 11 of the 27 years (41%) had below average surface water supply. Drought was more prevalent during the second time period, when 26 of the 39 years (67%) had below average surface water supply. Groundwater use was also more widespread during the second time period. Between 1950 and 1977, groundwater appropriations increased from 1% to approximately 80% of the currently appropriated groundwater rights.

Between 1950 and 1977, there was a statistically significant trend of increasing water levels of 0.09 feet per year. This is equivalent to a regional increase in water level of approximately 2.4 feet over 27 years. Between 1977 and 2016, there was a statistically significant trend of decreasing water levels of 0.4 feet per year. This is equivalent to a regional decrease in water level of approximately 15.5 feet over 39 years.

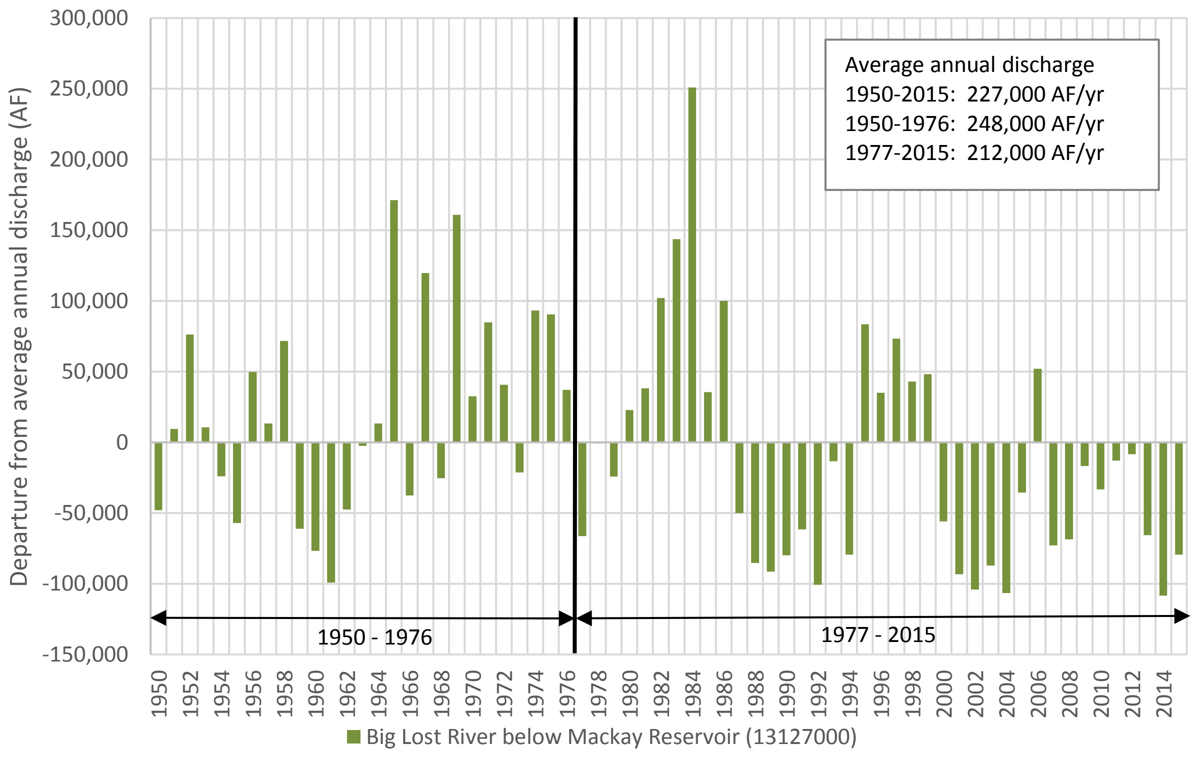

Figure 6. Departure from average annual discharge in the Big Lost River below Mackay Reservoir as an indicator of surface water supply

Individual Mann Kendall trend analyses were performed on spring water level measurements collected at each well between 1977 and 2016. Statistically significant trends are shown in Figure 7. Below Mackay Dam, statistically significant water level trends were observed in 15 of 23 wells. Statistically significant trends ranged from decreasing water levels of less than 0.1 foot per year in two wells near the town of Mackay to decreasing water levels of 1.3 feet per year in three wells near Moore. Thirteen of the wells had decreasing water level trends between 0.3 and 1.3 feet per year, equivalent to water level declines between 12 and 50 feet over 39 years. There is not an apparent correlation between depth and the magnitude of water level decline. Many of the wells did not have a spring water level measurement for every year between 1977 and 2016. Some of the differences in the magnitude of decline may be due to the different periods of record available for each well. Eight wells did not have statistically significant water level trends because of too few measurements or large fluctuations in measurements, but water levels in these wells also appear to generally be declining over time (Appendix A).

Above Mackay Dam, a statistically significant trend was observed in a well northwest of Chilly between spring 1977 and spring 2016. A decreasing water level trend of 0.1 feet per year, equivalent to a decline of approximately 4 feet over 39 years, was observed. The other well above Mackay Dam is located adjacent to Mackay Reservoir and spring water level measurements appear to be influenced by reservoir stage rather than regional groundwater conditions. The water level trend was not statistically significant in this well.

Trend analyses performed on spring water level measurements in five wells located on the Eastern Snake Plain near the mouth of the Big Lost River valley (Figure 8) show statistically significant water level trends similar to the regional water level trend in the Big Lost Valley below Mackay Dam. Between spring 1951 and 1977, water levels increased by 0.07 feet per year. Between spring 1977 and spring 2016, water levels decreased by 0.3 feet per year (approximately 12 feet over 39 years).

Comparison of the regional water level trends within the Big Lost River valley (-0.4 feet per year) and in wells located on the Eastern Snake Plain near the mouth of the Big Lost Valley (-0.3 feet per year) suggests water levels are declining at similar rates in both areas. The slightly higher rate of decline within the Big Lost River valley suggests there may have been some decline in groundwater underflow at the mouth of the Big Lost River valley between 1977 and 2016. Because the difference in regional groundwater level declines is small compared to the steep hydraulic gradient in the lower Big Lost River basin[9], the decline in groundwater underflow at the mouth of the Big Lost River valley has likely been small relative to the total volume of underflow.

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[9] Bassick, M.D. and M.L. Jones, 1992. *Aquifer-Test Results, Direction of Ground-Water Flow, and 1984-90 Annual Ground-Water Pumpage for Irrigation, Lower Big Lost River Valley, Idaho*, U.S. Geological Survey Water Resources Investigation Report 92-4006, 1 pl., https://pubs.er.usgs.gov/publication/wri924006.

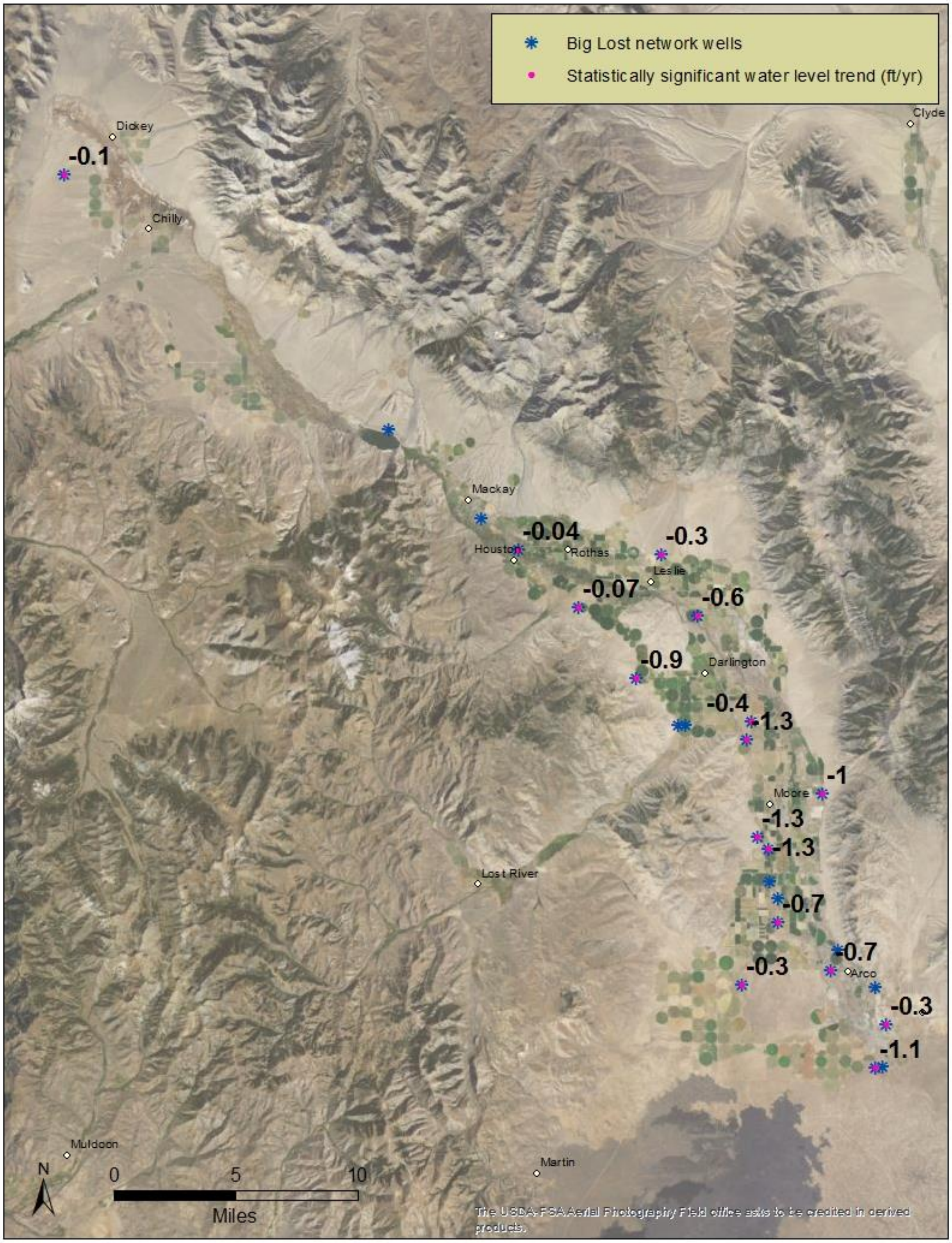


Figure 7. Statistically significant groundwater level trends in the Big Lost River valley (1977-2016)

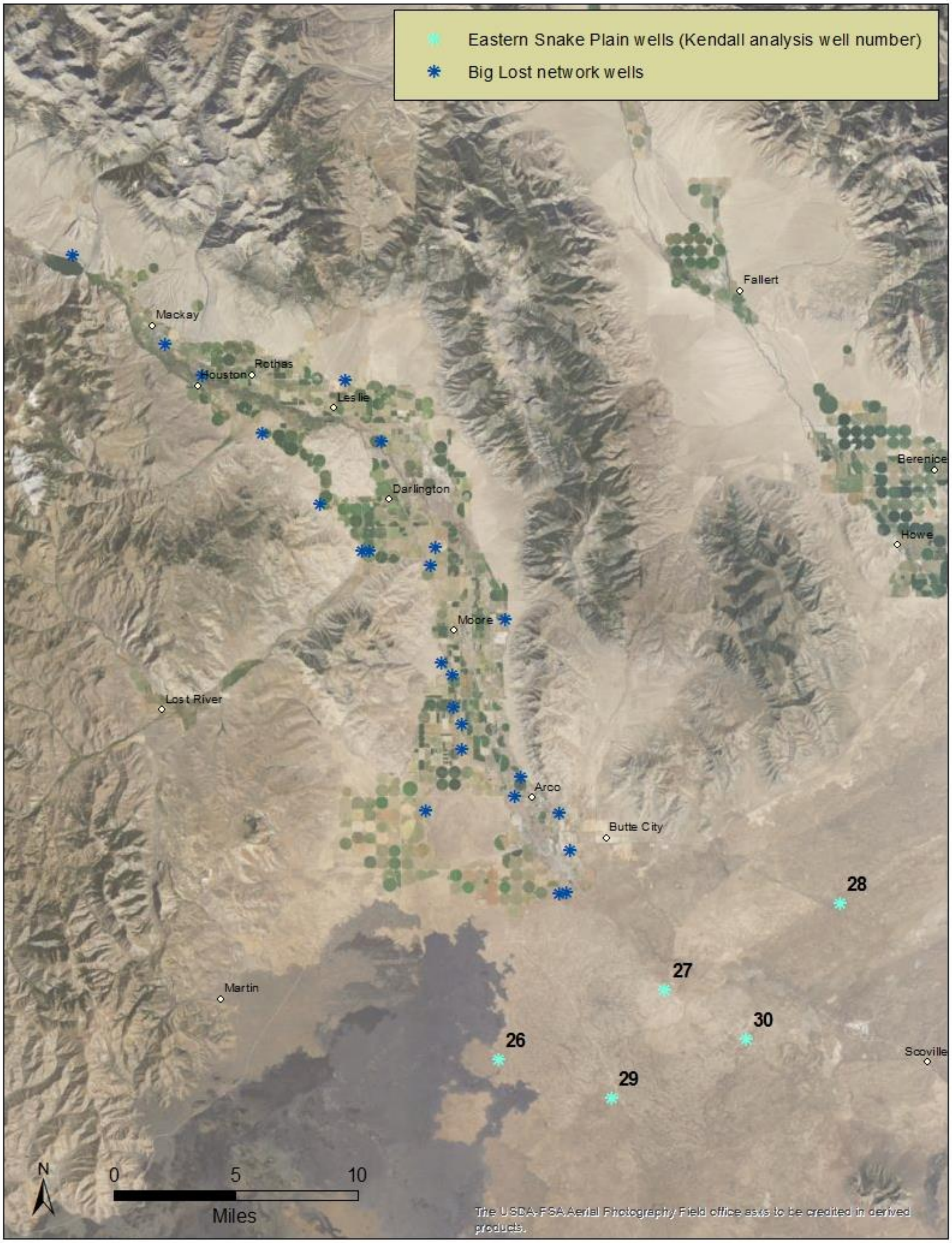


Figure 8. Location of Eastern Snake Plain water level monitoring wells near the mouth of the Big Lost valley

Water use for irrigation

Irrigation water in the Big Lost River valley is obtained from surface water and groundwater sources. As of October 2016, IDWR water right place of use records indicate approximately 76,000 acres are covered by irrigation water right places of use in the Big Lost Valley. Because the permissible place of use described by a water right may be larger than the acreage authorized to be irrigated in a single irrigation season, the authorized irrigated area may be less than 76,000 acres. Above Mackay Dam, water right places of use encompass approximately 18,000 acres, including 15,100 acres with only surface water rights, 1,300 acres with only groundwater rights and 1,600 acres with both surface and groundwater rights. Below Mackay Dam, water right places of use encompass approximately 58,200 acres, including 8,300 acres with only surface water rights, 6,700 acres with only groundwater rights and 43,200 acres with both surface and groundwater rights. The area covered by water right places of use is similar to the irrigated area noted by Crosthwaite et al. (1970).

Irrigated land status has been evaluated by IDWR GIS analysts using satellite and aerial imagery for nine years (1986, 1996, 2000, 2002, 2006, 2008, 2009, 2010, and 2011). Based on these analyses, the total area irrigated in a given year varied from 52,700 acres to 67,400 acres. Much of the fluctuation was in the area irrigated with only surface water sources, which ranged from approximately 13,900 to 23,400 acres. The area irrigated with only groundwater sources varied little, ranging from approximately 6,100 to 6,800 acres. The area irrigated with mixed sources varied from approximately 31,800 to 37,900 acres. The average irrigated area for the nine years evaluated was approximately 58,100 acres.

Site-specific irrigation season evapotranspiration (ET) estimates calculated using remote sensing data are available for the Big Lost River valley below Mackay Dam for ten years (1986, 1996, 2000, 2006, 2008, 2009, 2010, 2011, 2013, and 2014). Irrigation season (April through October) ET on irrigated lands below Mackay Dam varied considerably, ranging from approximately 99,000 AF in 2008 to 157,000 AF in 2014. The average irrigation season ET below Mackay Dam was 126,000 AF. After accounting for precipitation and winter season ET, the annual consumptive use on irrigated lands below Mackay Dam ranged from approximately 53,000 AF in 2010 to 112,000 AF in 2014, averaging 81,000 AF.

For the area above Mackay Dam, ET estimates calculated using remote sensing data are available for seven years (1996, 2000, 2006, 2008, 2009, 2010, and 2011). Irrigation season (April through October) ET on irrigated lands above Mackay Dam ranged from approximately 13,000 AF in 2008 to approximately 26,000 AF in 2011. After accounting for precipitation and winter season ET, the annual irrigation consumptive use on irrigated lands above Mackay Dam ranged from approximately 5,000 AF in 2010 to 15,000 AF in 2011, averaging 9,000 AF.

Figure 9 compares the annual volume of irrigation consumptive use with the annual volume of surface water diversions in the Big Lost River below Mackay Dam. The lack of correlation between surface water diversions and consumptive use for irrigation below Mackay Dam (Figure 10) suggests there is significant reliance on groundwater resources to meet crop irrigation requirements below Mackay Dam. While surface water availability likely has some influence on the total irrigation consumptive use in the valley, other factors such as temperature, precipitation, crop mix, and/or crop management appear to have more influence on irrigation consumptive use.

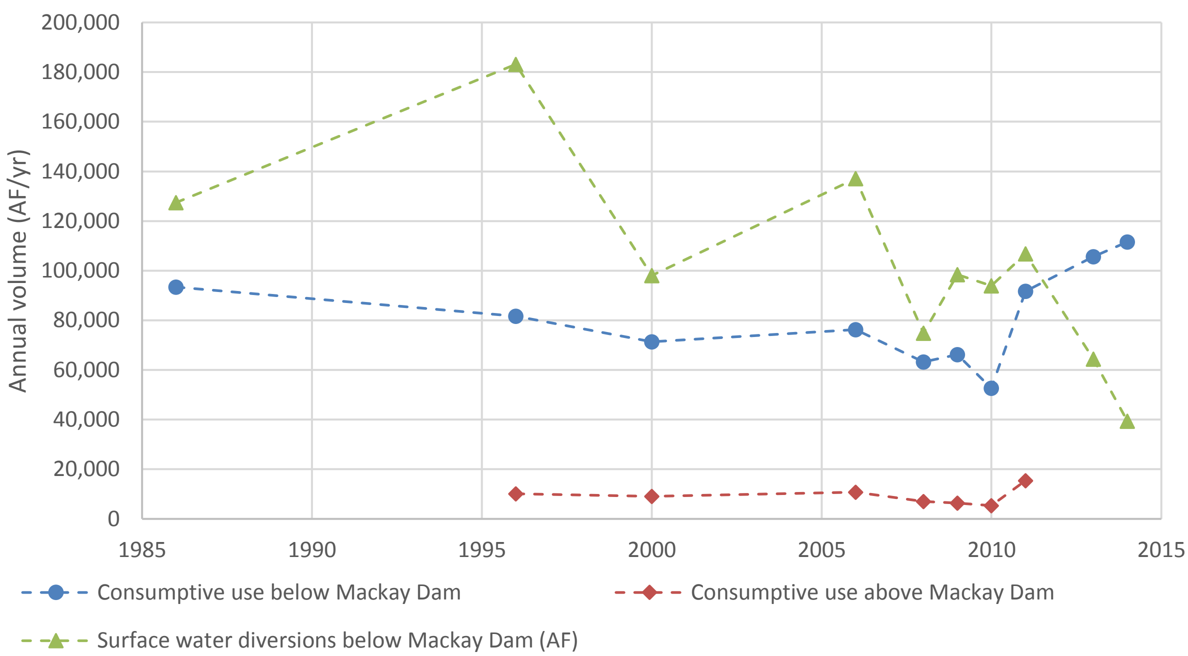


Figure 9. Irrigation consumptive use (crop irrigation requirement) and Big Lost River discharge

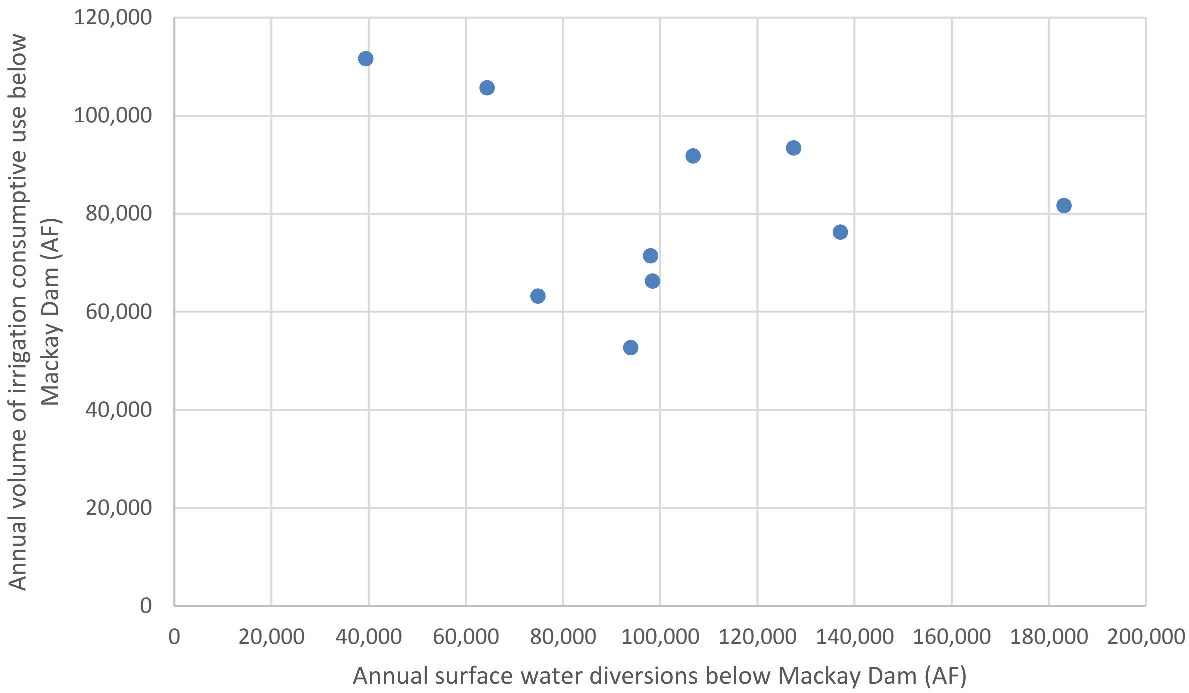


Figure 10. Irrigation consumptive use vs. surface water diversions below Mackay Dam

Based on water right priority dates, approximately 42% of the current groundwater rights (by diversion rate) were appropriated after 1968. The number of irrigation wells increased from approximately 175 (Crosthwaite et al., 1970) to approximately 450 in 2016. While there does not appear to be a significant increase in the total irrigated area in the Big Lost Valley since the Crosthwaite et al. (1970) study, the increase in development of groundwater for irrigation appears to be significant.

Surface water diversion data from Johnson et al. (1991[10]) shows surface water diversions generally decreased between the mid-1960s and 1990, as appropriation of groundwater increased (Figure 11). Surface water diversion data from the IDWR water right accounting database shows surface water diversions have continued to be low from 1994 to 2016 relative to surface water diversion prior to the mid-1960s. Comparison of surface water diversions with flow in the Big Lost River at Mackay shows relatively low surface water diversions even in very wet years in the early 1980s (Figure 12). Measured groundwater pumping data are generally not available, but the reduction in surface water diversions during wet years and the increase in groundwater appropriations suggests an increasing reliance on groundwater for irrigation between the mid-1960s and 1990.

[10] Johnson, G.S., D.R. Ralston, and L.L. Mink, 1991. *Ground-water pumping impacts on surface water irrigation diversions from Big Lost River*, Idaho Water Resources Research Institute, University of Idaho, 54 p.

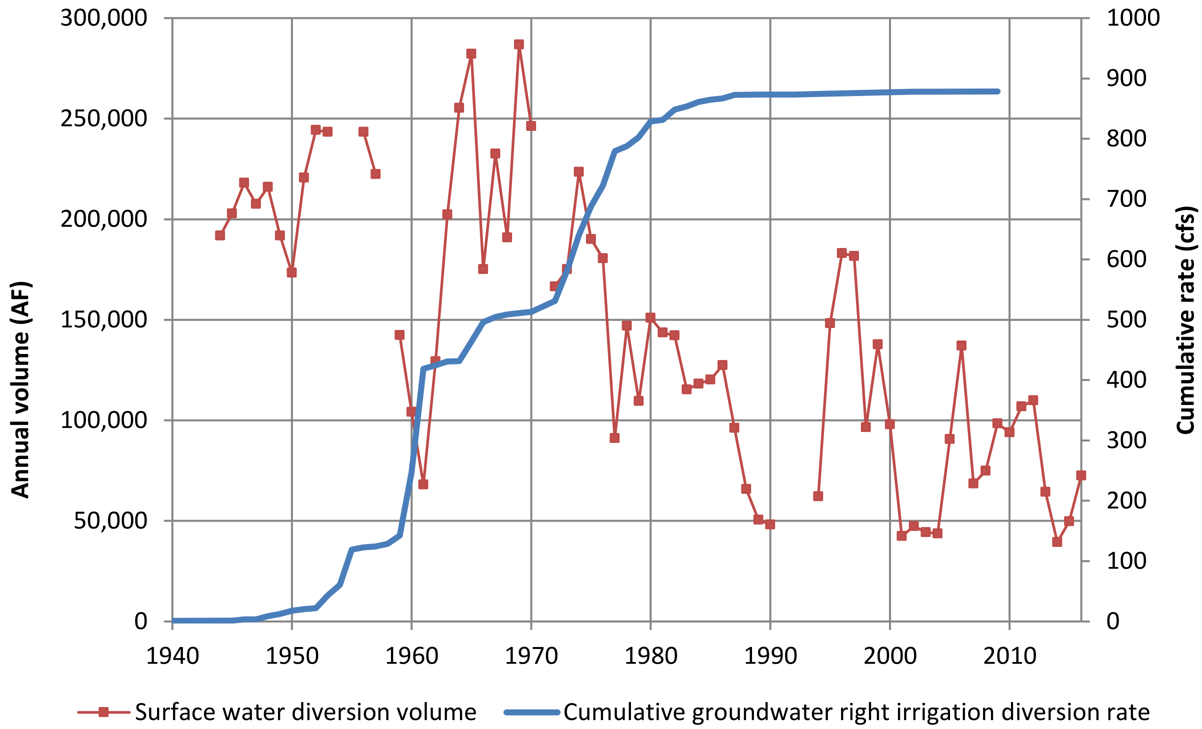


Figure 11. Recorded surface water diversions and appropriation of groundwater

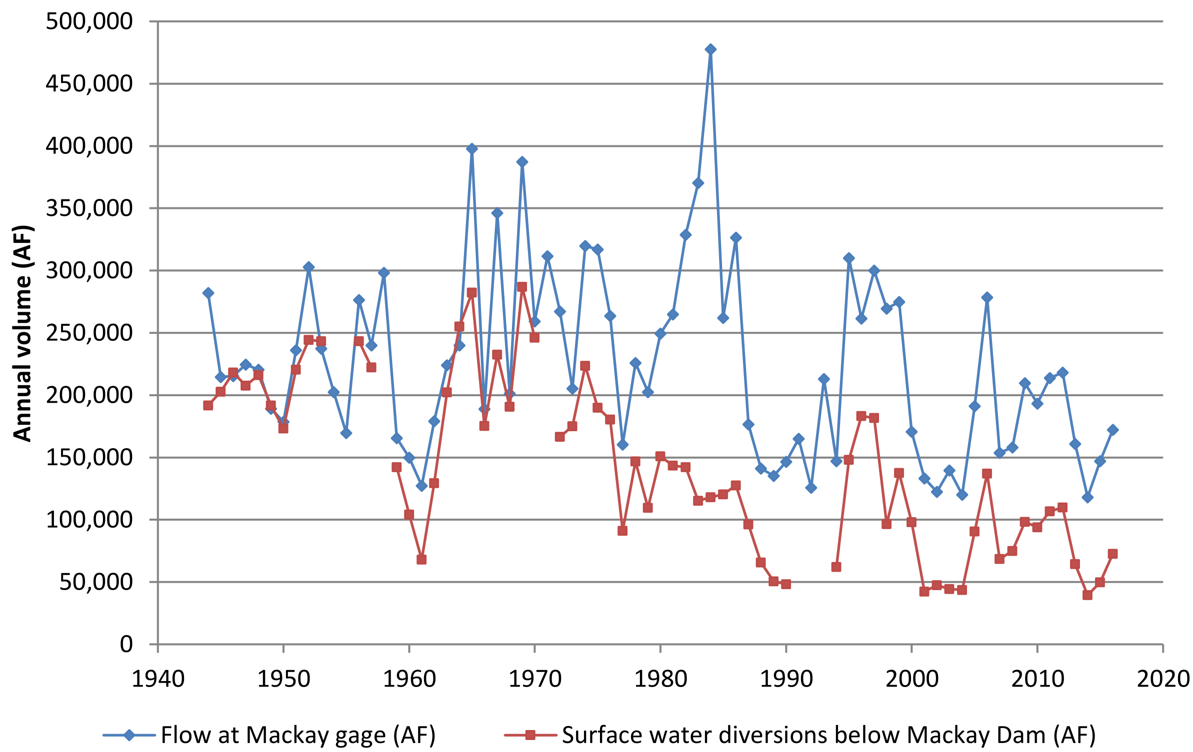


Figure 12. Surface water diversions and streamflow in the Big Lost River near Mackay

Measured groundwater diversions recorded by Water District 34 are available for 2014 and 2015. Below Mackay Dam, approximately 109,000 AF of groundwater were diverted in 2014 and approximately 85,000 AF were diverted in 2015. Surface water diversions and discharge in the Big Lost River below Mackay Dam were low in 2014 and 2015 (Figure 12). Groundwater diversions comprised 73% of total diversions in 2014 and 63% of total diversions in 2015. Because the efficiency of delivering groundwater is generally higher than the efficiency of delivering surface water, the portion of the irrigation consumptive use supplied by groundwater is likely greater than 70%. For example, assuming a groundwater delivery and irrigation efficiency of 0.85 and a surface water delivery and irrigation efficiency of 0.5, groundwater supplied an estimated 82% of the crop irrigation requirement in 2014 and 74% of the crop irrigation requirement in 2015.

Above Mackay Dam, approximately 5,000 AF of groundwater were diverted in both 2014 and 2015. Groundwater diversions above Mackay Dam were approximately 5% of the recorded groundwater diversions in the Big Lost River valley.

Figure 13 compares depth to groundwater at three locations with surface water diversions and flow in the Big Lost River at Mackay. Prior to the mid-1980s, groundwater levels declined somewhat during dry years, but recovered fully during wet years. Beginning in the mid-1980s, groundwater levels decline more dramatically during dry periods and do not fully recover during wet periods. These data suggest the prevalence of below average water years and the ability to intercept groundwater to achieve a full irrigation supply for mixed source lands, even during extended periods of drought, have resulted in a long-term trend of declining groundwater levels over the last four decades.

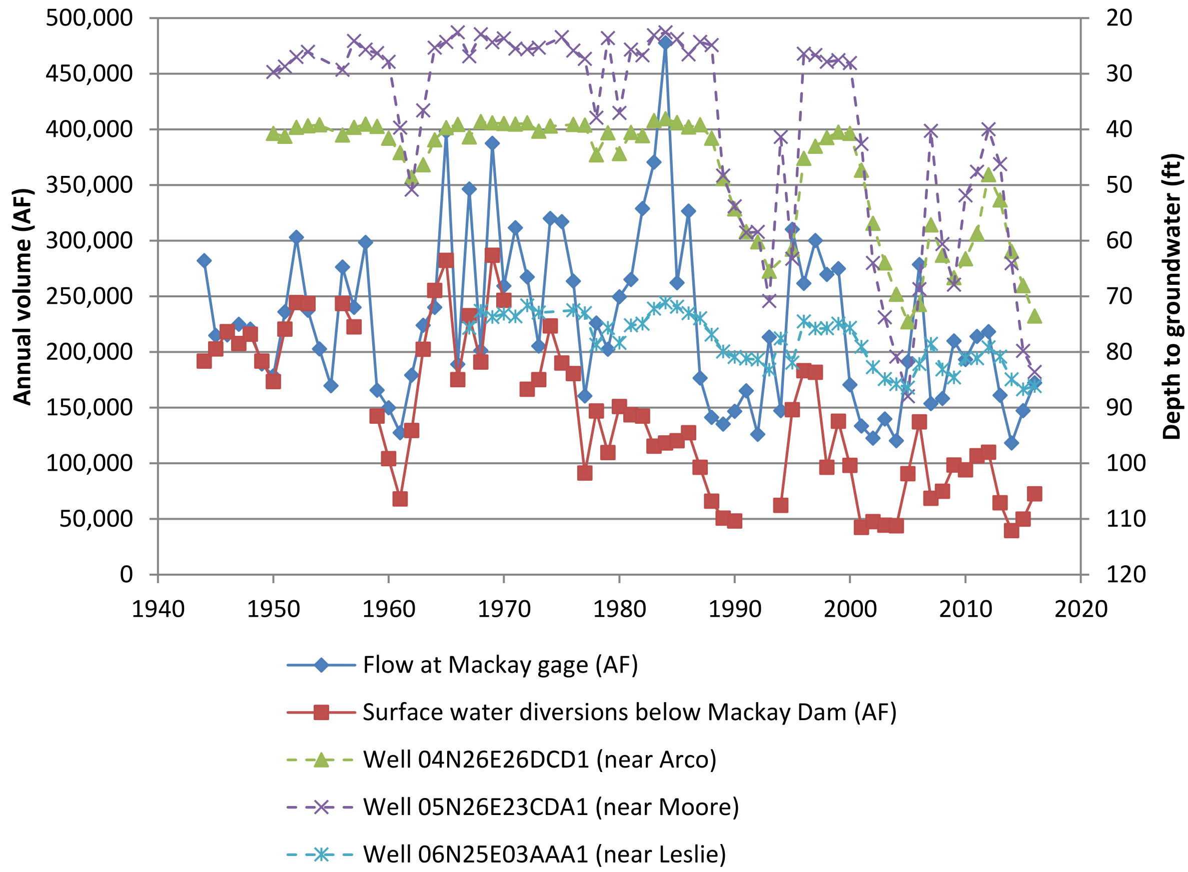


Figure 13. Spring groundwater levels and surface water diversions

<u>Conclusions</u>

Groundwater level trend analyses demonstrate regional groundwater levels within the Big Lost River valley below Mackay Dam were generally stable between 1950 and 1977. Between the spring of 1977 and the spring of 2016, groundwater levels below Mackay Dam have declined approximately 0.4 ft/yr (approximately 16 feet of total decline over a 39-year period). Similar groundwater level trends were observed in wells located on the Eastern Snake Plain near the mouth of the Big Lost River valley. Since 1977, regional water level declines in the Big Lost River valley are slightly greater than groundwater level declines in the Eastern Snake Plain aquifer south of Arco, where water levels declined approximately 0.3 ft/yr between the spring of 1977 and the spring of 2016 (approximately 12 feet of total decline over a 39-year period). Because the difference in regional groundwater level declines is small compared to the steep hydraulic gradient in the lower Big Lost River basin, the decline in groundwater underflow at the mouth of the Big Lost River valley has likely been small relative to the total volume of underflow.

Prior to the 1980s, groundwater levels in the Big Lost River valley declined somewhat during drought periods, but recovered fully during wet periods. Beginning in the 1980s, groundwater levels have declined more dramatically during drought periods and have not fully recovered during wet periods. The change in response to climatic conditions results primarily from the use of groundwater to sustain crop consumptive use during drought periods. Prior to widespread use of groundwater, irrigation consumptive use would have been significantly lower than average during drought periods. Recent diversion data indicate groundwater currently supplies approximately 70% to 80% of the crop irrigation requirement below Mackay Dam during low water years. The annual crop irrigation requirement below Mackay Dam, which was estimated for 10 years between 1986 and 2014, averaged 81,000 AF/yr. The annual crop irrigation requirement above Mackay Dam, which was estimated for 7 years between 1996 and 2011, averaged 9,000 AF/yr.

Comparison of surface water diversion records, Big Lost River discharge below Mackay Dam, and groundwater levels suggests that as groundwater development increased, diversion and use of surface water was not maximized during years with above average surface water supply. The reduction in surface water diversions likely resulted in reduced canal seepage and incidental recharge at locations distant from the Big Lost River channel, and altered the spatial distribution of aquifer recharge within the valley during wet years. While the practice of not maximizing surface water diversions in above average water years likely had little impact on regional water level declines, it may have had localized impacts to shallow or perched groundwater levels and discharge to the Big Lost River near Arco.

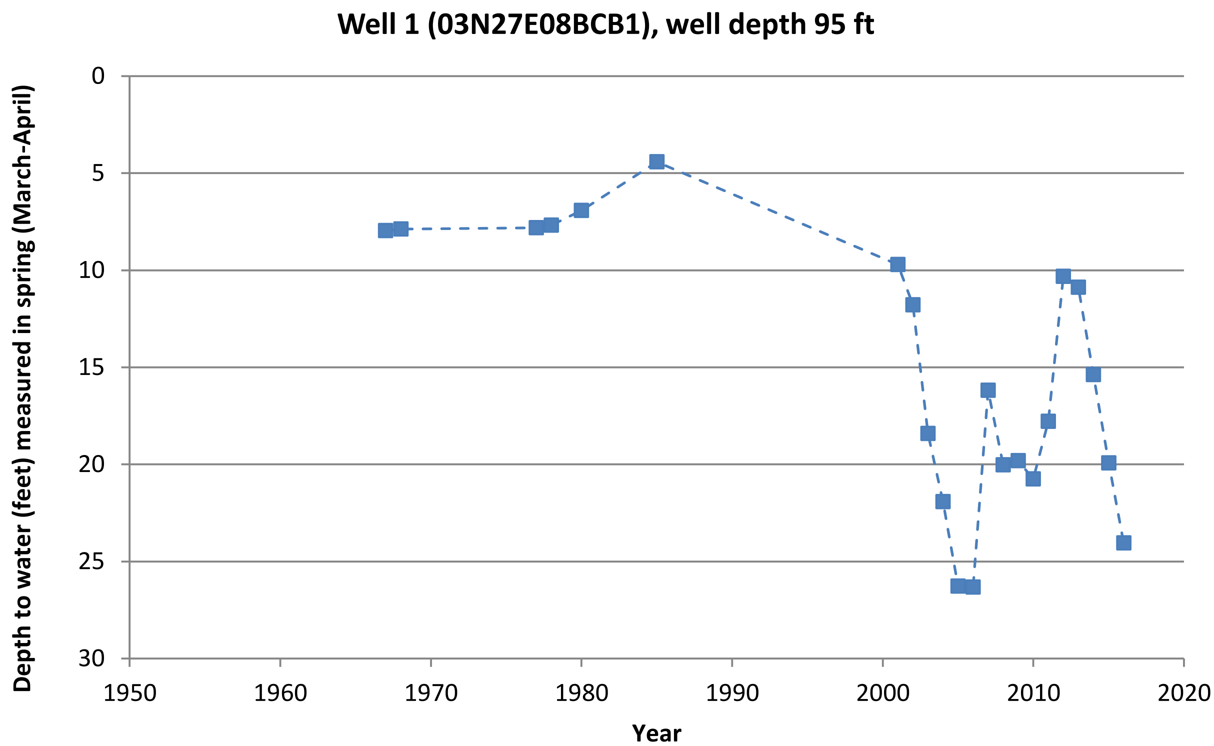
Regional groundwater level declines over several decades demonstrate that long-term aquifer discharge in the Big Lost River valley exceeds long-term aquifer recharge. Aquifer recharge during wet years has not been sufficient for groundwater levels to recover fully from the use of groundwater to maintain crop consumptive use during dry years. Because the Big Lost River valley aquifer system is hydraulically connected to the Eastern Snake Plain aquifer, which also has declining groundwater levels, it is difficult to quantify the aquifer water budget deficit within the Big Lost River valley. The best available estimate is the average aquifer storage change within the Big Lost River valley simulated using the ESPAM2.1 groundwater flow model, which was approximately 16,000 AF/yr between 1985 and 2010. This is approximately 18% of the estimated average annual irrigation consumptive use of 90,000 AF per year (including both groundwater and surface water sources).

APPENDIX A. GROUNDWATER LEVEL TREND

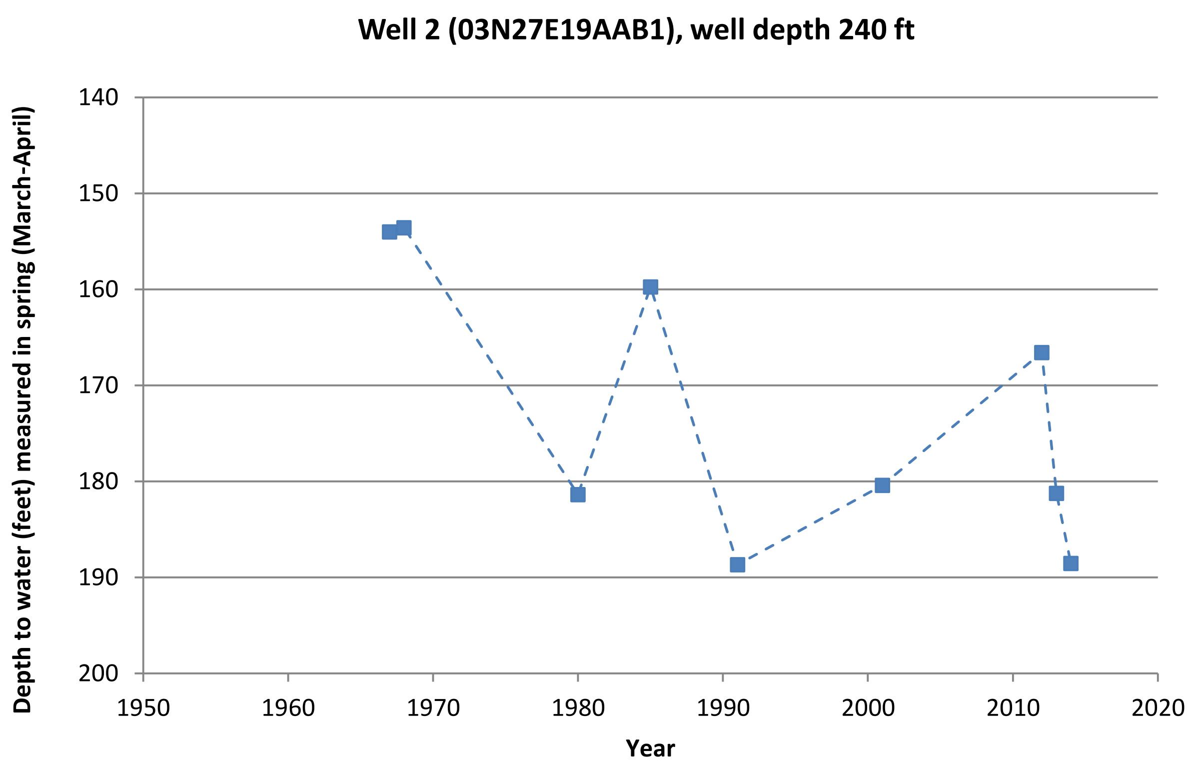
ANALYSES AND HYDROGRAPHS

Summary of Kendall regional trend analyses and individual Mann-Kendall trend anaylses for Big Lost Network wells and nearby Eastern Snake Plain wells

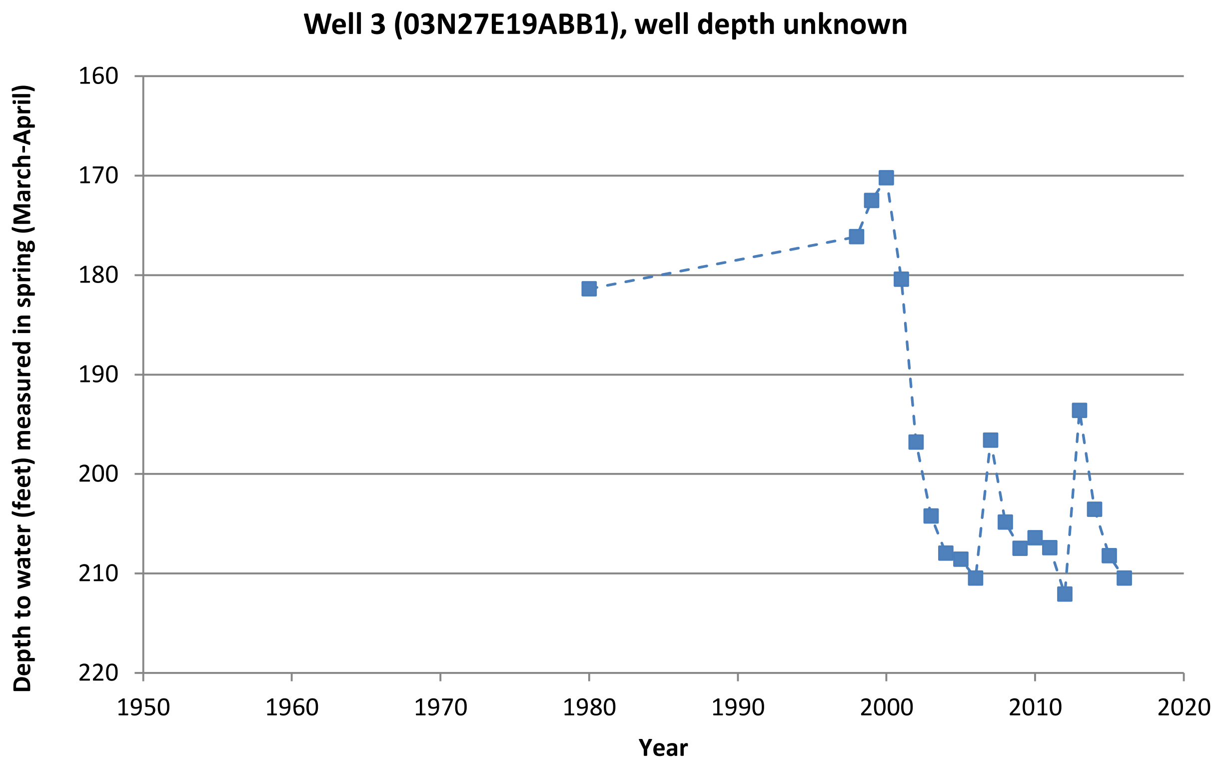
Well(s)	Water level trend (ft/yr)	p-value	Stastical significance (p<0.05)
1, 1977-2016	-0.3309	0.0410	Significant
2, 1980-2014	-0.2106	0.7690	Not Significant
3, 1980-2016	-1.113	0.0043	Significant
4, 1980-2016	-1.256	0.0278	Significant
5, 2015-2016	-1.960	1.0000	Not Significant
6, 1980-2016	-0.3417	0.4954	Not Significant
7, 1977-2016	-0.7427	0.0000	Significant
8, 1977-2016	-0.6900	0.0000	Significant
9, 1977-2016	-0.2848	0.0000	Significant
10, 1980-2016	-0.0869	0.1978	Not Significant
11, 1999-2016	-0.3400	0.9212	Not Significant
12, 1985-2016	-0.4079	0.0037	Significant
13, 1985-2016	-1.2660	0.0133	Significant
14, 1977-2016	-0.9973	0.0000	Significant
15, 1985-2016	-1.2570	0.0343	Significant
16, 1977-2016	-0.2635	0.0000	Significant
17, 1980-2016	-0.6161	0.0095	Significant
18, 1980-2016	-0.0686	0.0273	Significant
19, 1980-2016	-0.9454	0.0071	Significant
20, 1991-2016	-1.5400	0.4524	Not Significant
21, 1985-2016	-0.0491	0.1179	Not Significant
22, 1980-2016	-0.0408	0.0164	Significant
23, 1977-2016	-0.1024	0.0001	Significant
24, 1985-2001	-1.2010	0.1329	Not Significant
25, 1977-2013	-0.5075	0.0736	Not Significant
19 wells blw dam, 1950-1977	0.0894	0.0005	Significant
23 wells blw dam, 1977-2016	-0.3986	0.0000	Significant
5 ESPA wells, 1951-1977	0.0667	0.0326	Significant
5 ESPA wells, 1977-2016	-0.3181	0.0000	Significant
26, 1977-2016	-0.2767	0.0000	Significant
27, 1977-2016	-0.3152	0.0000	Significant
28, 1977-2016	-0.3648	0.0000	Significant
29, 1982-2016	-0.3029	0.0000	Significant
30, 1977-2016	-0.3200	0.0000	Significant



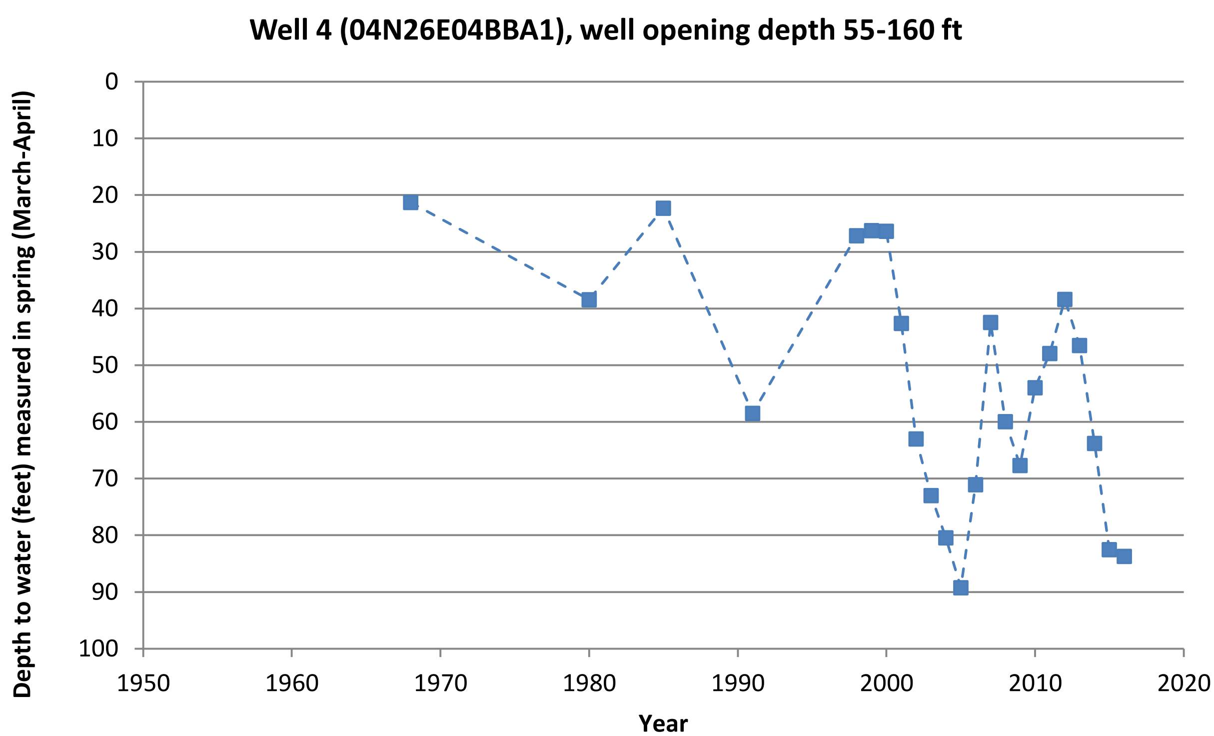
Well 1 (03N27E08BCB1), well depth 95 ft
Depth to water (feet) measured in spring (March-April)
0
5
10
15
20
25
30
1950
1960
1970
1980
1990
2000
2010
2020
Year



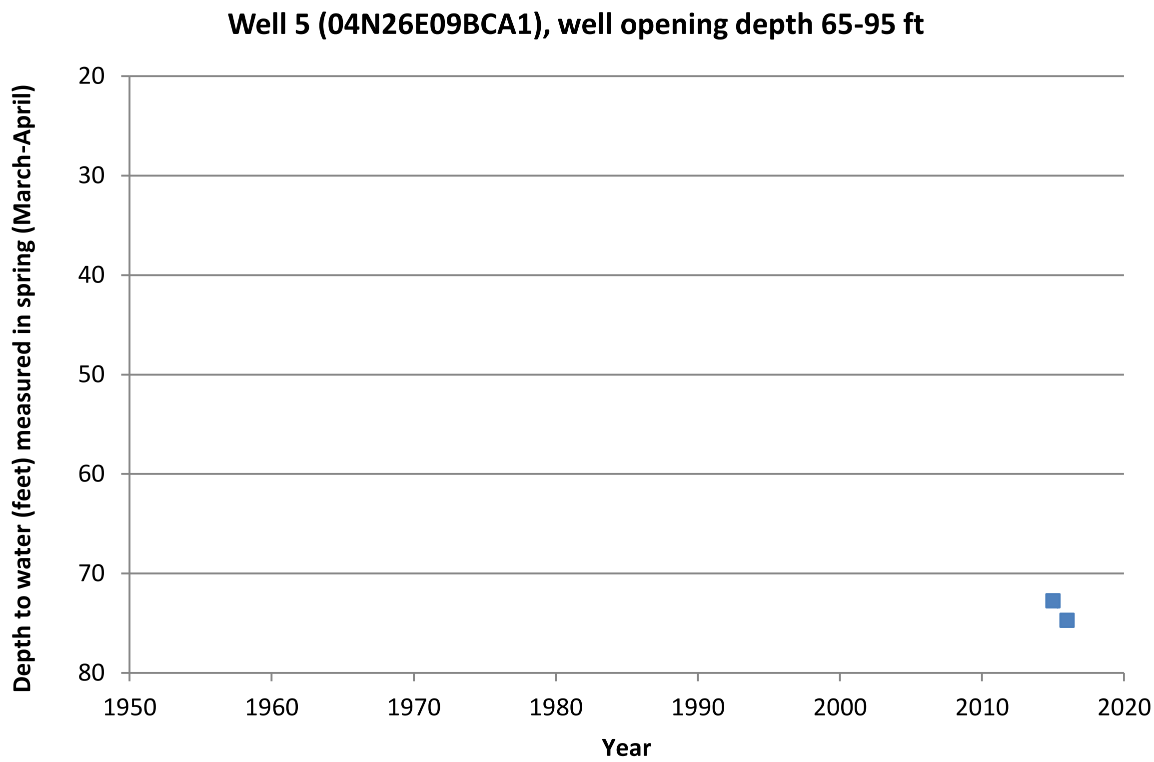
Well 2 (03N27E19AAB1), well depth 240 ft
Depth to water (feet) measured in spring (March-April)
140
150
160
170
180
190
200
1950
1960
1970
1980
1990
2000
2010
2020
Year

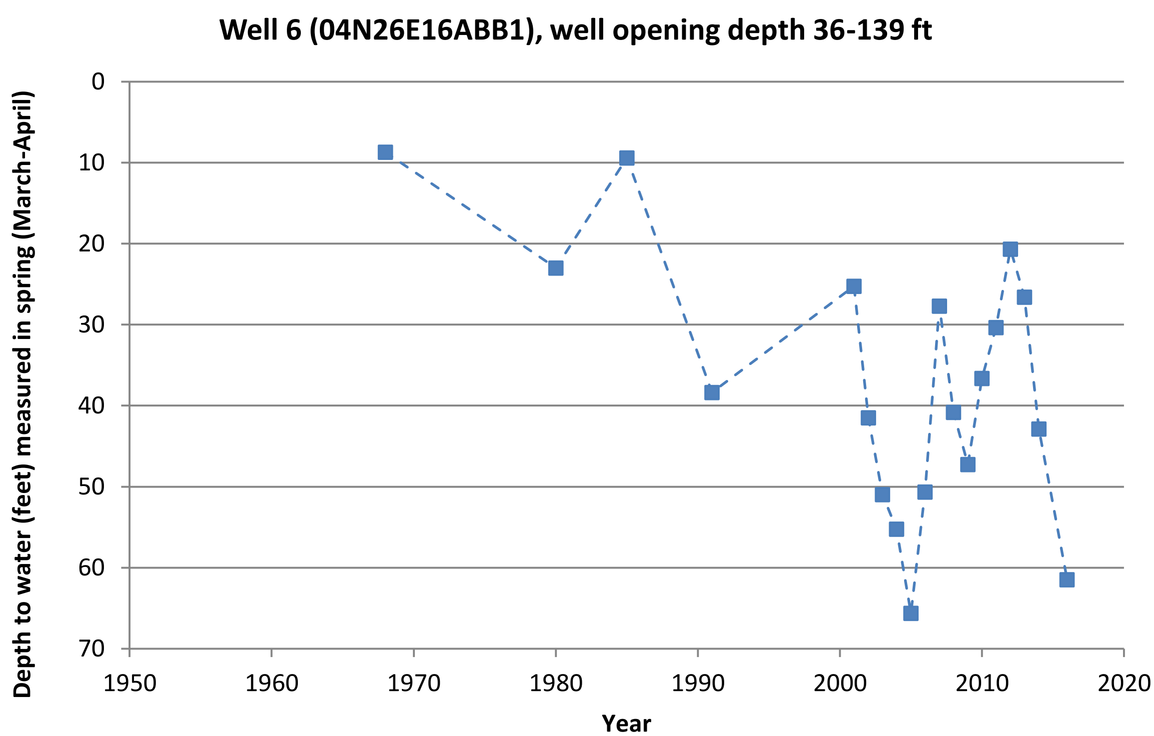


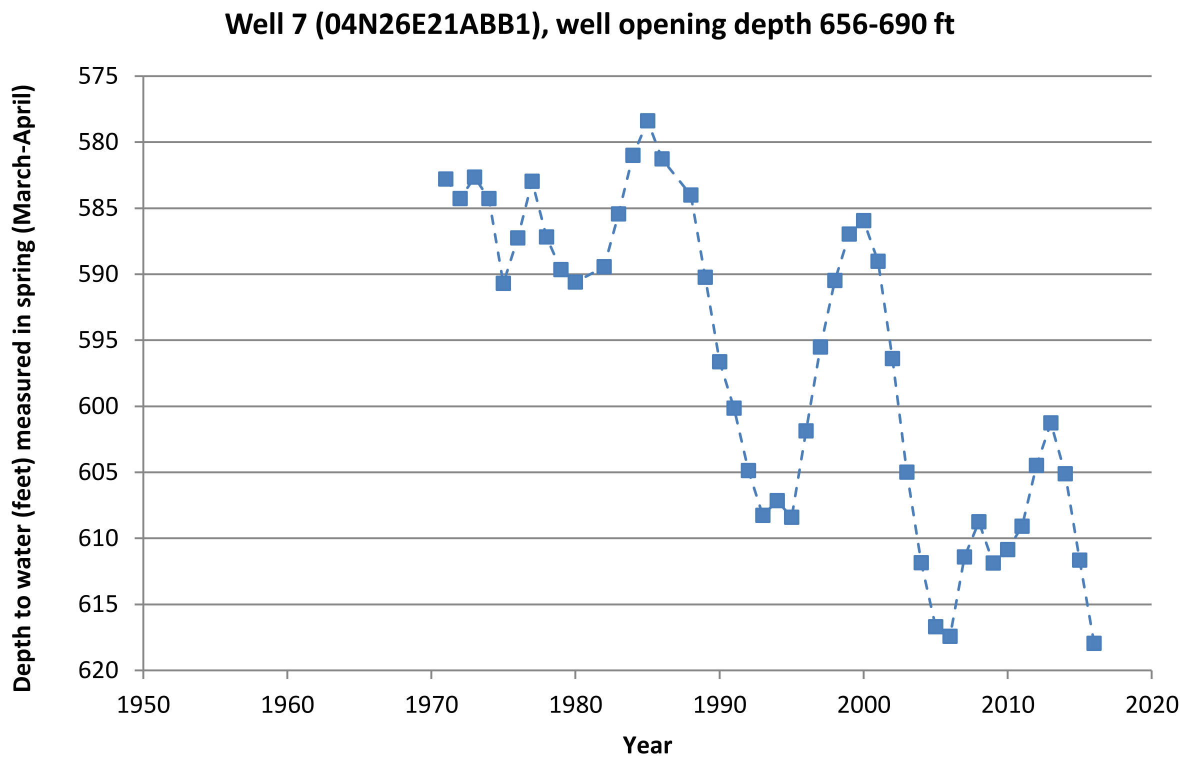
Well 3 (03N27E19ABB1), well depth unknown
Depth to water (feet) measured in spring (March-April)
160
170
180
190
200
210
220
1950
1960
1970
1980
1990
2000
2010
2020
Year



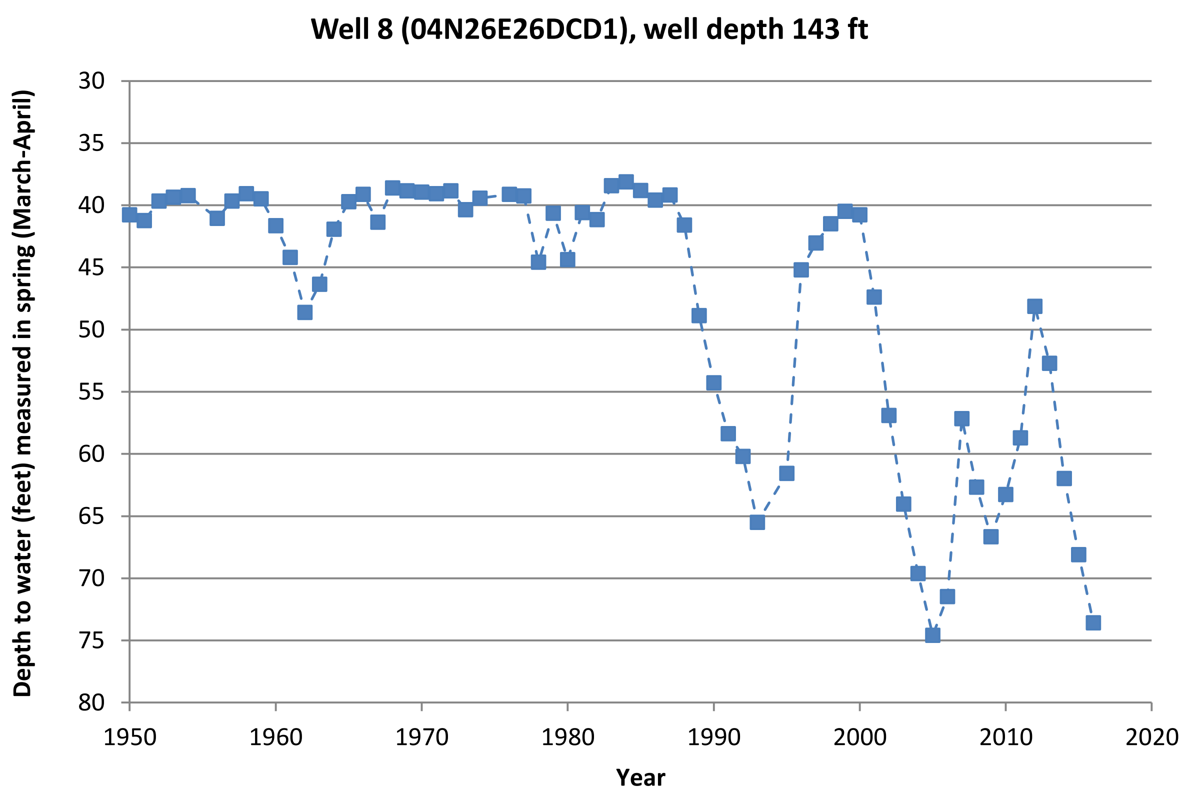
Well 4 (04N26E04BBA1), well opening depth 55-160 ft
Depth to water (feet) measured in spring (March-April)
0
10
20
30
40
50
60
70
80
90
100
1950
1960
1970
1980
1990
2000
2010
2020
Year


Well 5 (04N26E09BCA1), well opening depth 65-95 ft
Depth to water (feet) measured in spring (March-April)
20
30
40
50
60
70
80
1950
1960
1970
1980
1990
2000
2010
2020
Year

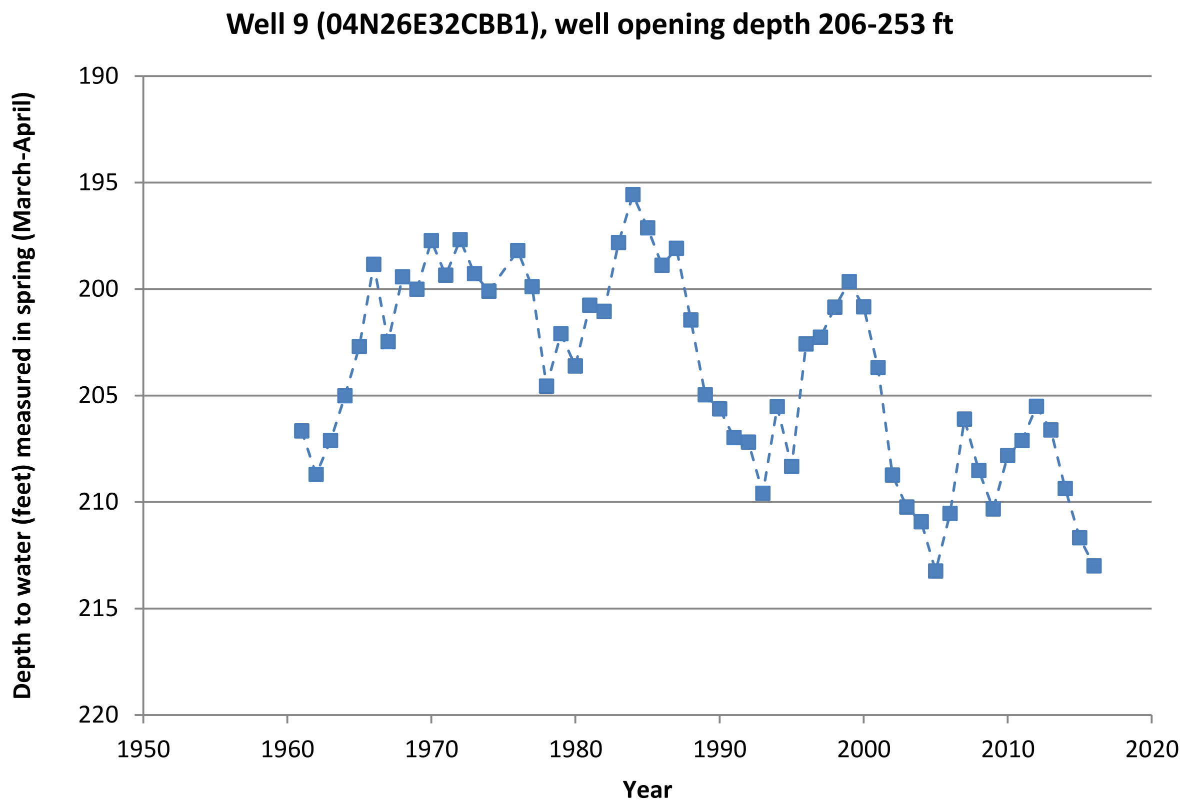

Well 6 (04N26E16ABB1), well opening depth 36-139 ft
Depth to water (feet) measured in spring (March-April)
0
10
20
30
40
50
60
70
1950
1960
1970
1980
1990
2000
2010
2020
Year

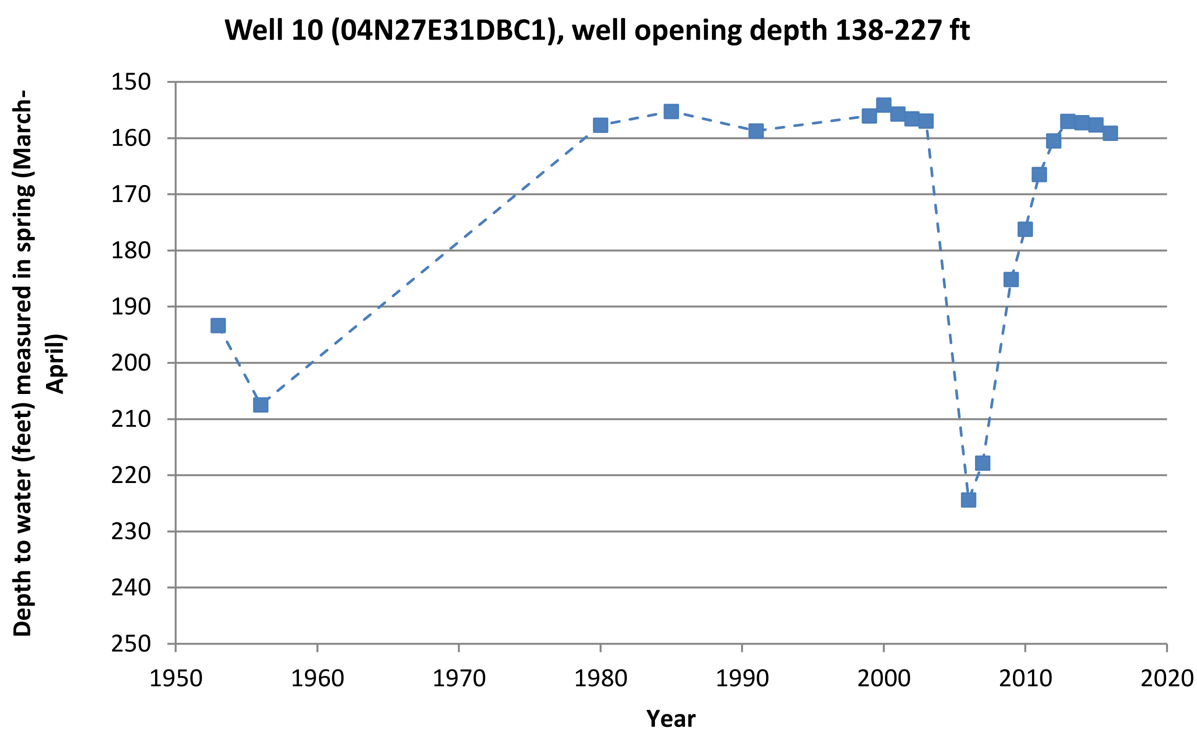


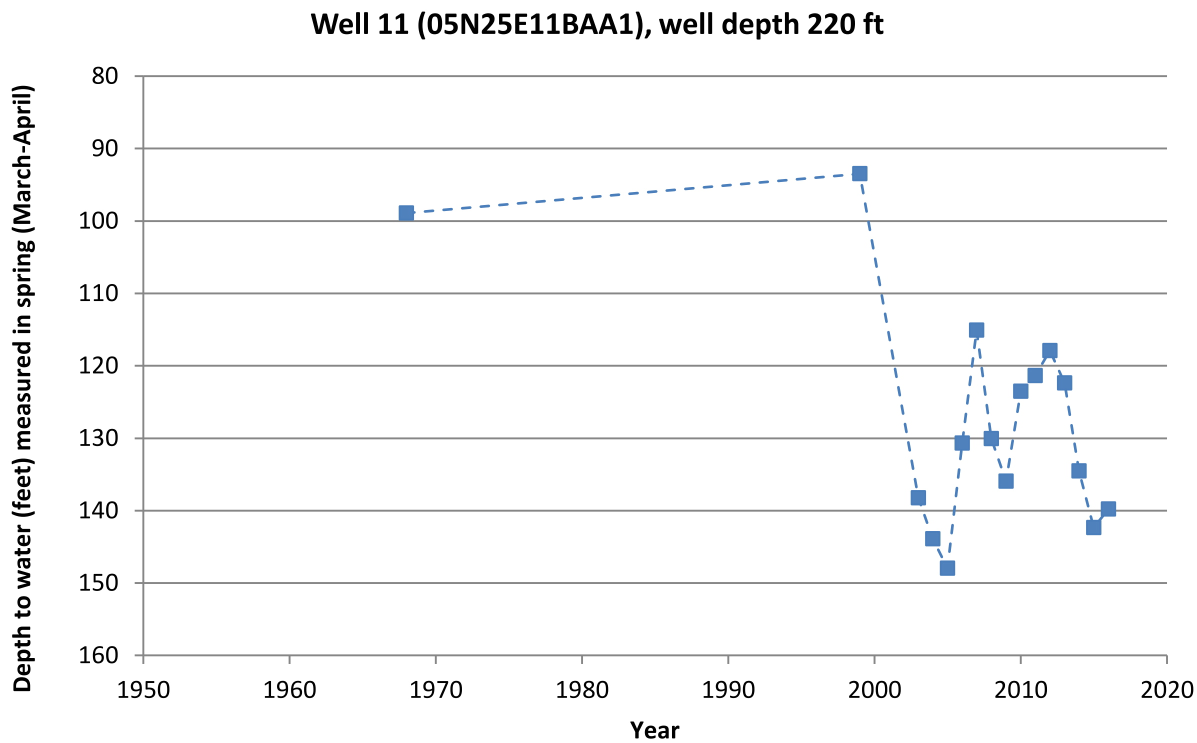
Well 7 (04N26E21ABB1), well opening depth 656-690 ft
Depth to water (feet) measured in spring (March-April)
575
580
585
590
595
600
605
610
615
620
1950
1960
1970
1980
1990
2000
2010
2020
Year

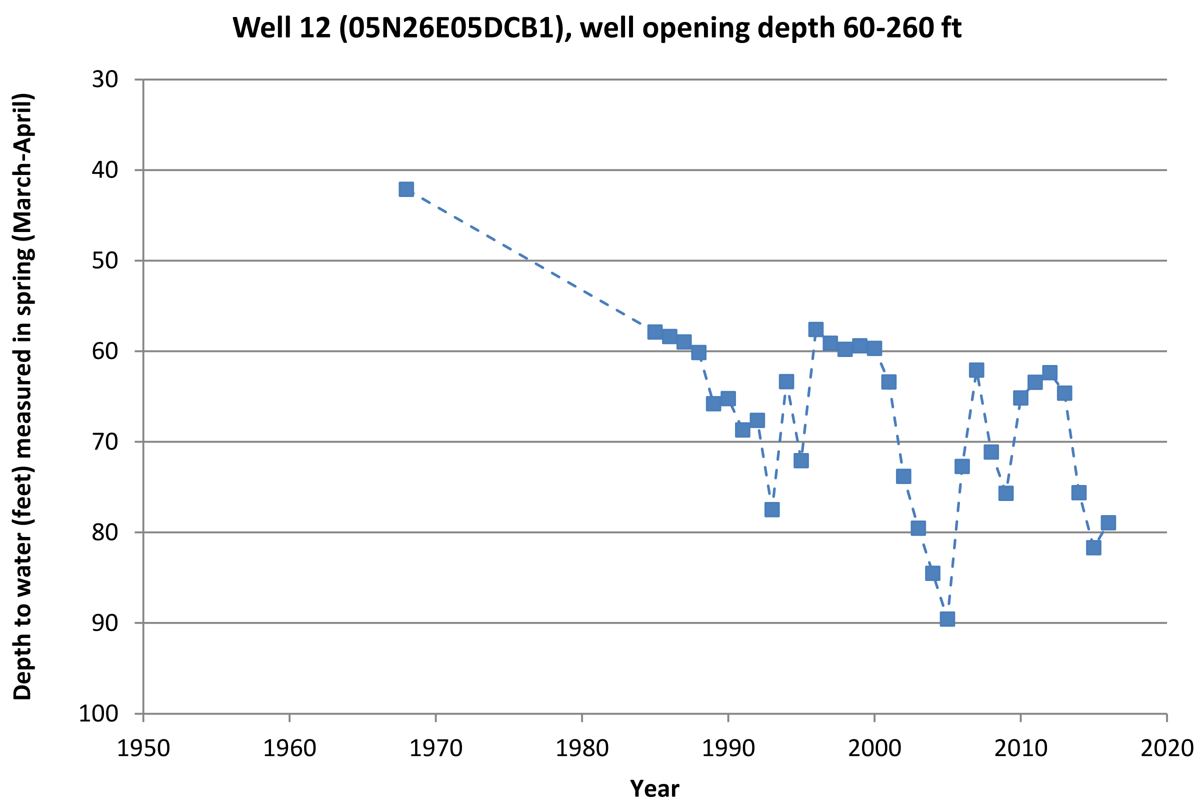


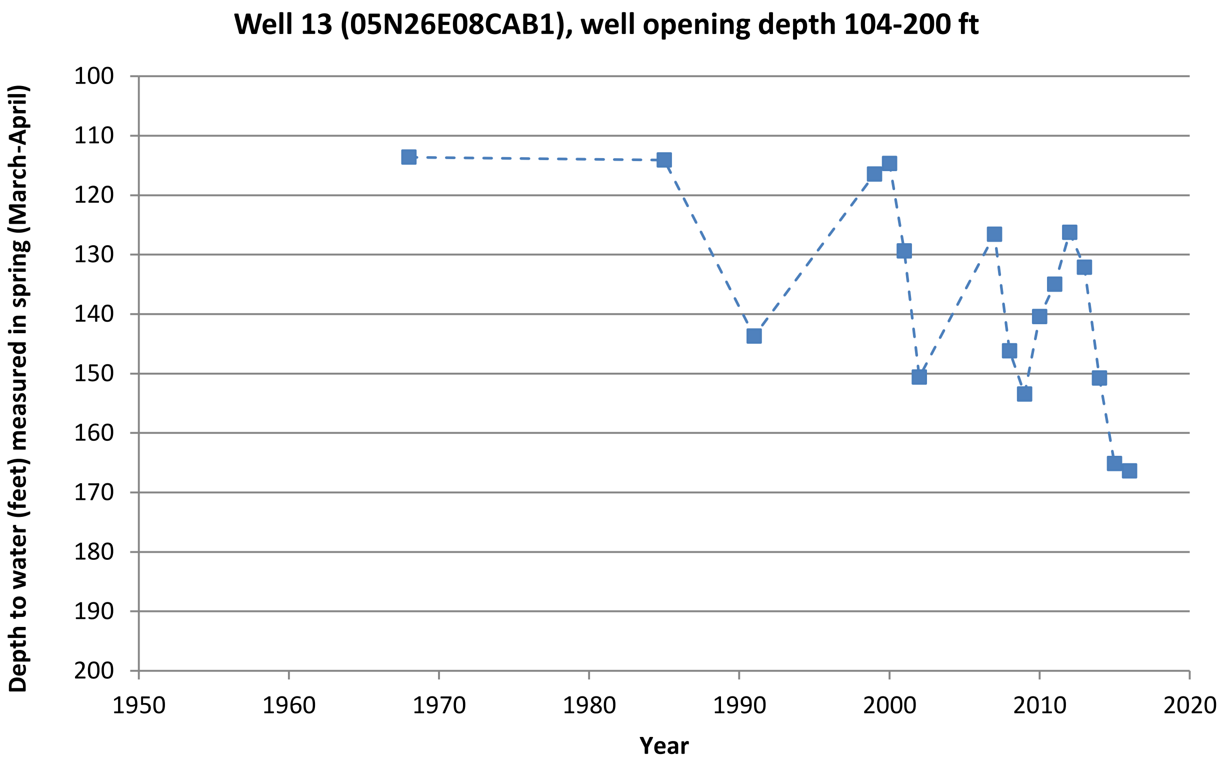
Well 8 (04N26E26DCD1), well depth 143 ft
Depth to water (feet) measured in spring (March-April)
30
35
40
45
50
55
60
65
70
75
80
1950
1960
1970
1980
1990
2000
2010
2020
Year

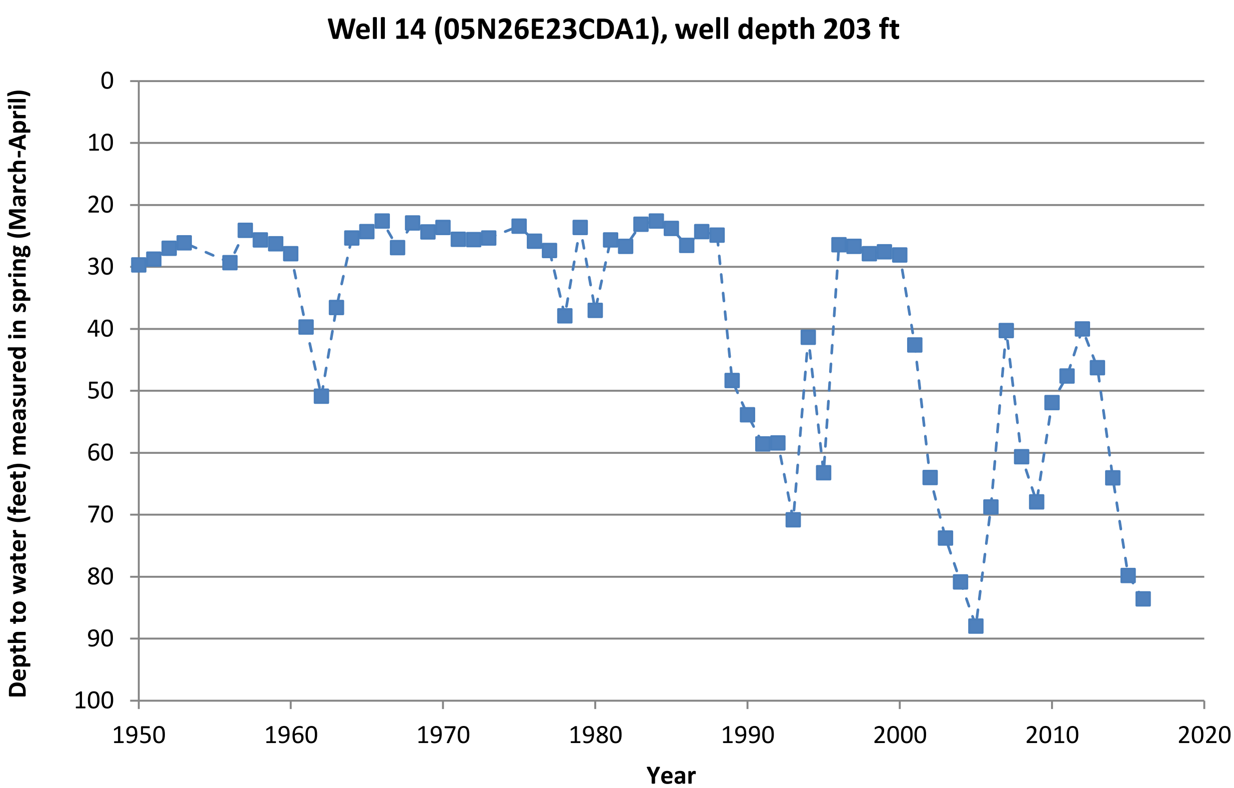

Well 9 (04N26E32CBB1), well opening depth 206-253 ft
Depth to water (feet) measured in spring (March-April)
190
195
200
205
210
215
220
1950
1960
1970
1980
1990
2000
2010
2020
Year

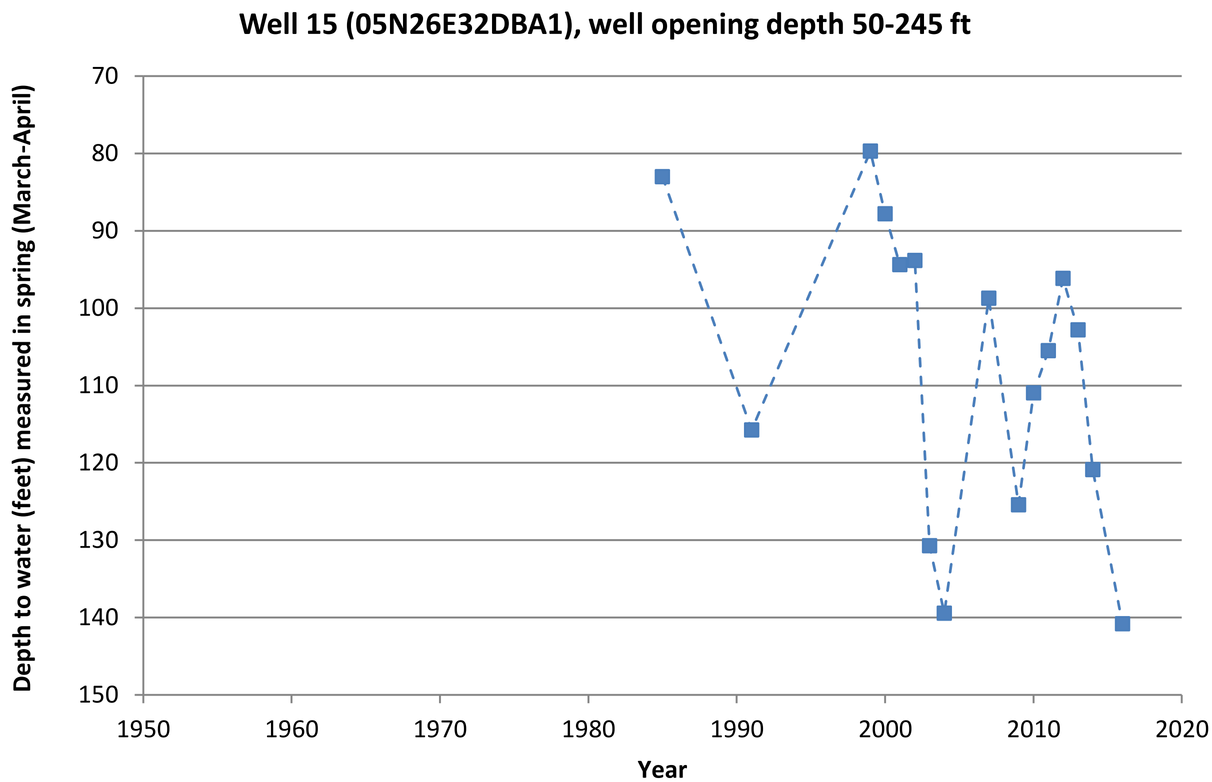

Well 10 (04N27E31DBC1), well opening depth 138-227 ft
Depth to water (feet) measured in spring (March-April)
150
160
170
180
190
200
210
220
230
240
250
1950
1960
1970
1980
1990
2000
2010
2020
Year

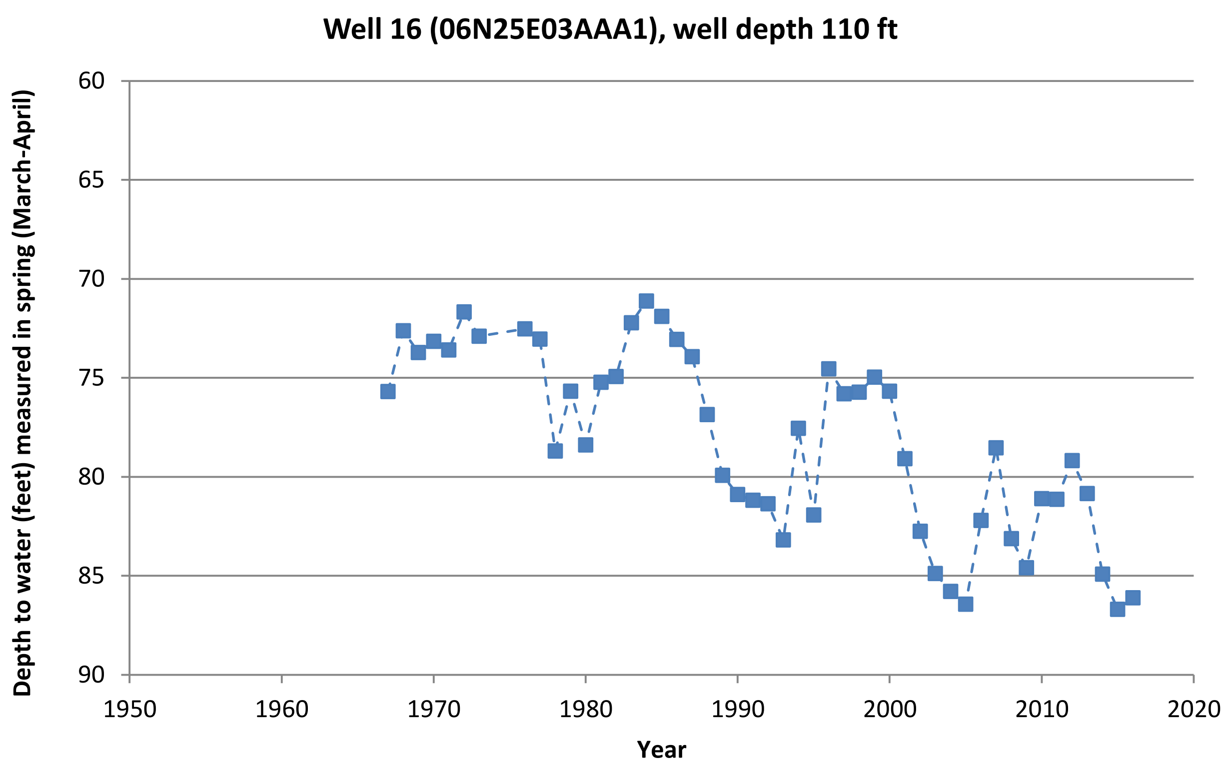

Well 11 (05N25E11BAA1), well depth 220 ft
Depth to water (feet) measured in spring (March-April)
80
90
100
110
120
130
140
150
160
1950
1960
1970
1980
1990
2000
2010
2020
Year

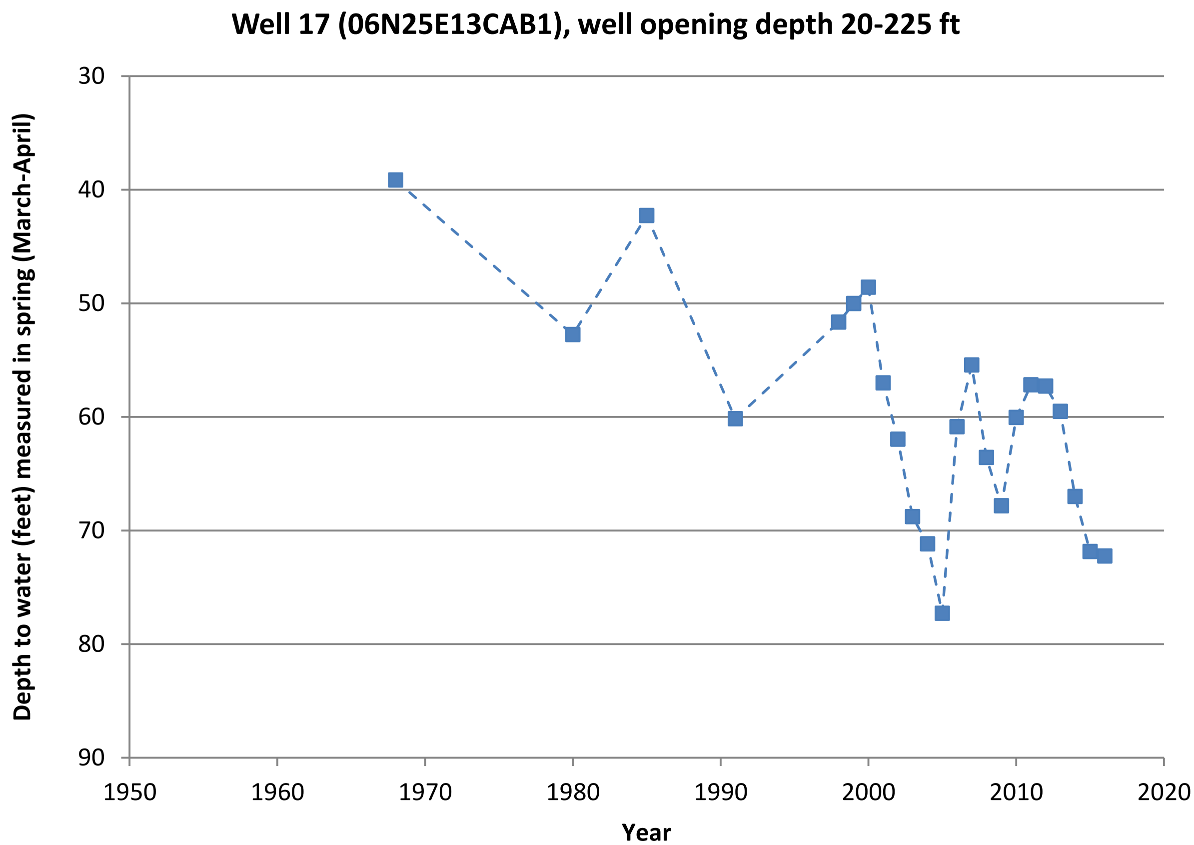

Well 12 (05N26E05DCB1), well opening depth 60-260 ft
Depth to water (feet) measured in spring (March-April)
30
40
50
60
70
80
90
100
1950
1960
1970
1980
1990
2000
2010
2020
Year

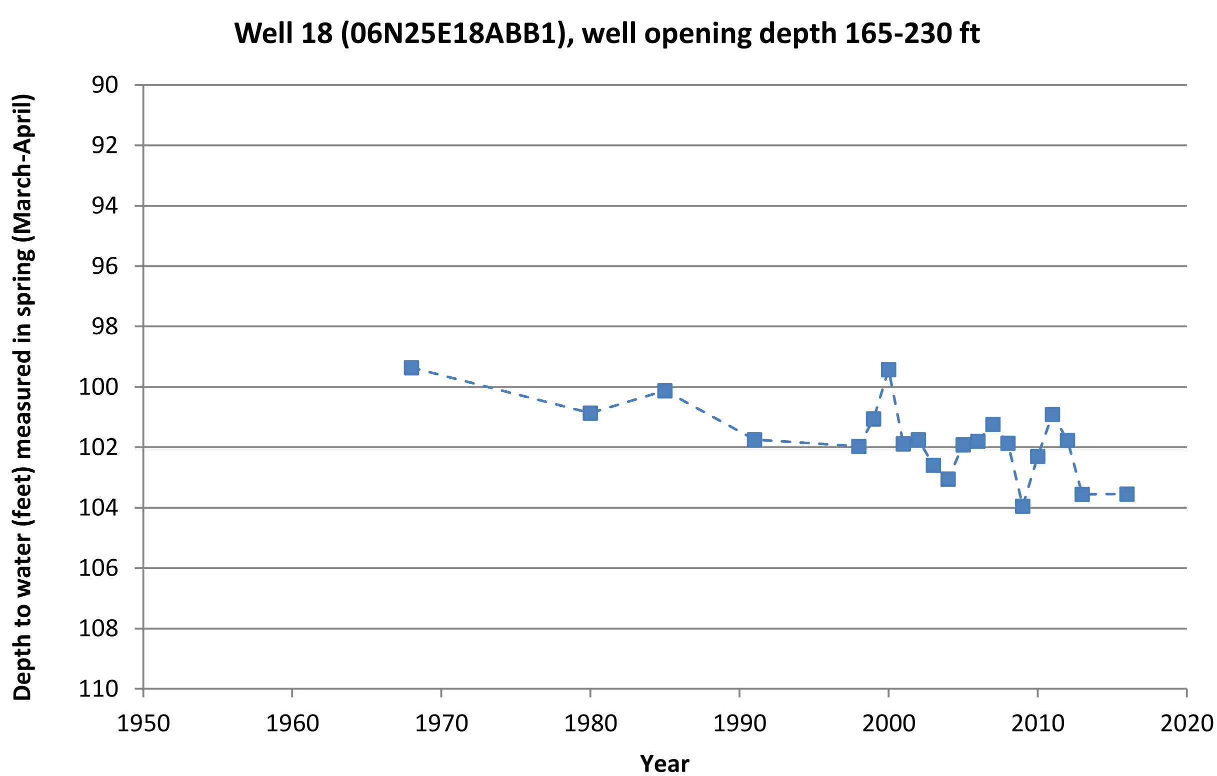

Well 13 (05N26E08CAB1), well opening depth 104-200 ft
Depth to water (feet) measured in spring (March-April)
100
110
120
130
140
150
160
170
180
190
200
1950
1960
1970
1980
1990
2000
2010
2020
Year

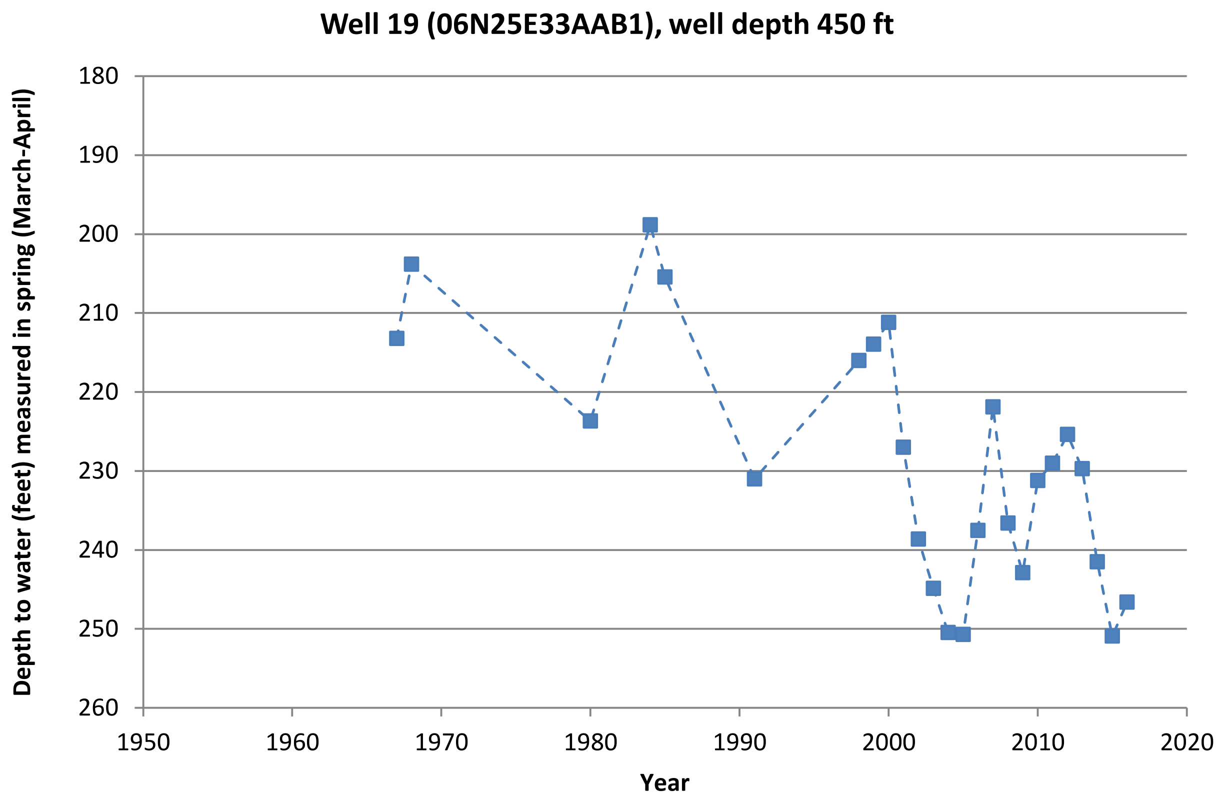

Well 14 (05N26E23CDA1), well depth 203 ft
Depth to water (feet) measured in spring (March-April)
0
10
20
30
40
50
60
70
80
90
100
1950
1960
1970
1980
1990
2000
2010
2020
Year

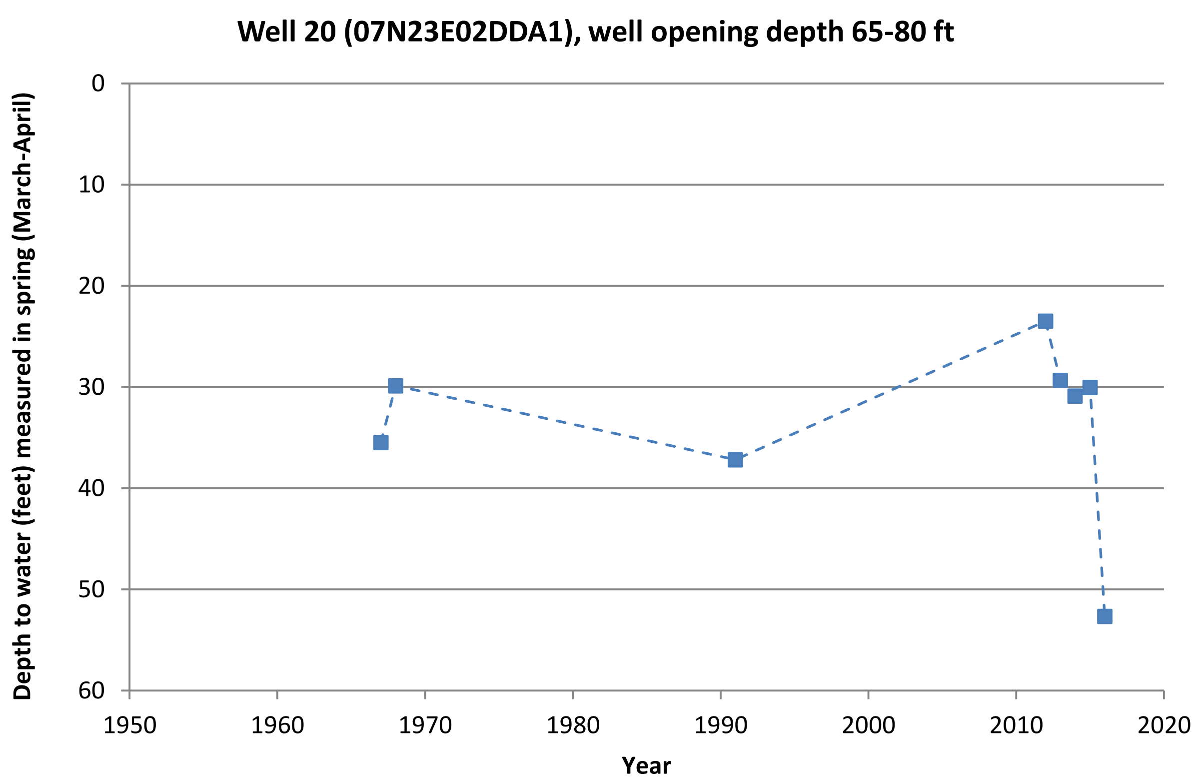

Well 15 (05N26E32DBA1), well opening depth 50-245 ft
Depth to water (feet) measured in spring (March-April)
70
80
90
100
110
120
130
140
150
1950
1960
1970
1980
1990
2000
2010
2020
Year

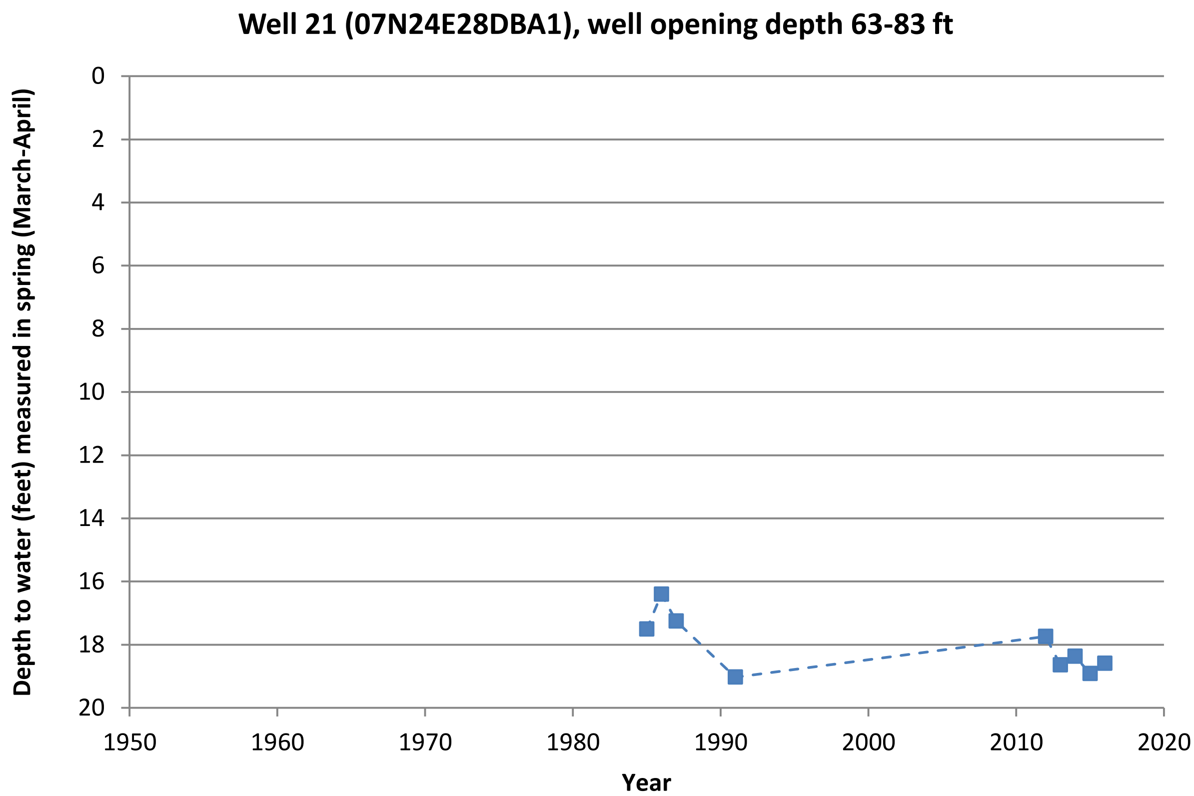

Well 16 (06N25E03AAA1), well depth 110 ft
Depth to water (feet) measured in spring (March-April)
60
65
70
75
80
85
90
1950
1960
1970
1980
1990
2000
2010
2020
Year

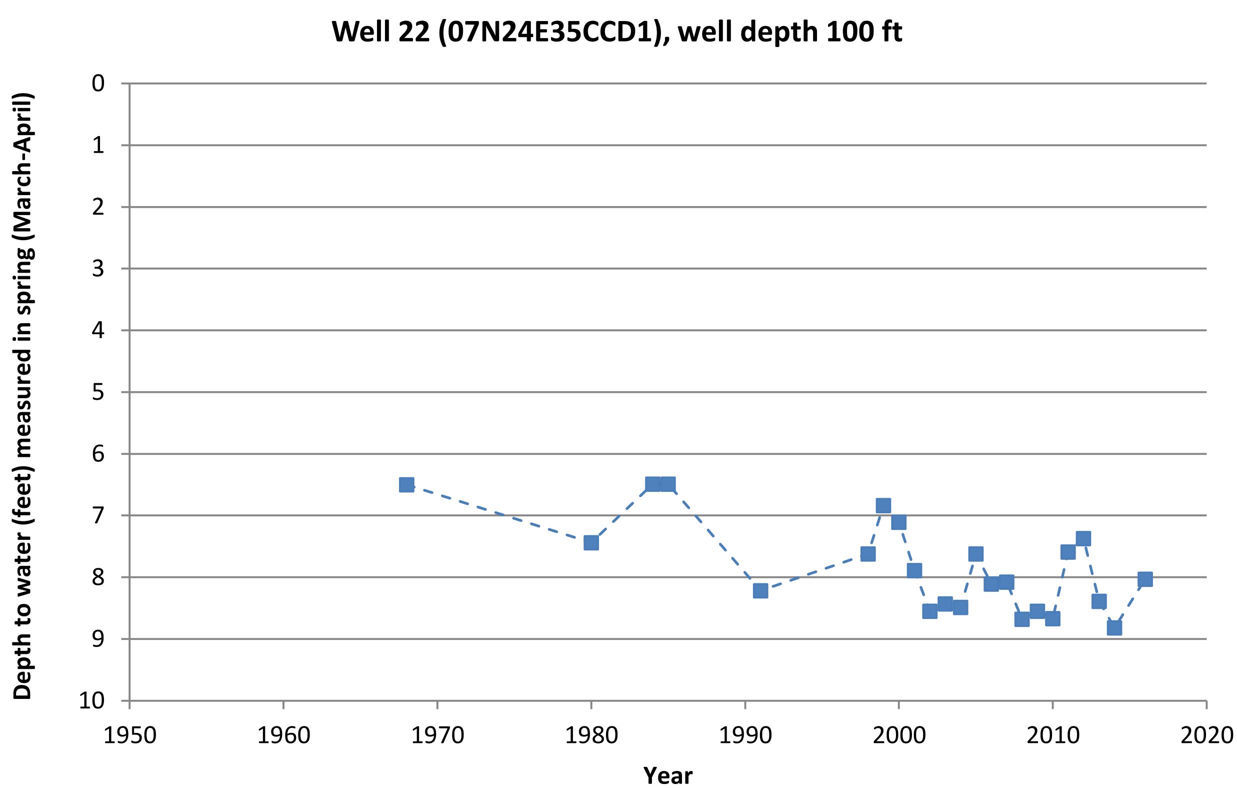

Well 17 (06N25E13CAB1), well opening depth 20-225 ft
Depth to water (feet) measured in spring (March-April)
30
40
50
60
70
80
90
1950
1960
1970
1980
1990
2000
2010
2020
Year


Well 18 (06N25E18ABB1), well opening depth 165-230 ft
Depth to water (feet) measured in spring (March-April)
90
92
94
96
98
100
102
104
106
108
110
1950
1960
1970
1980
1990
2000
2010
2020
Year

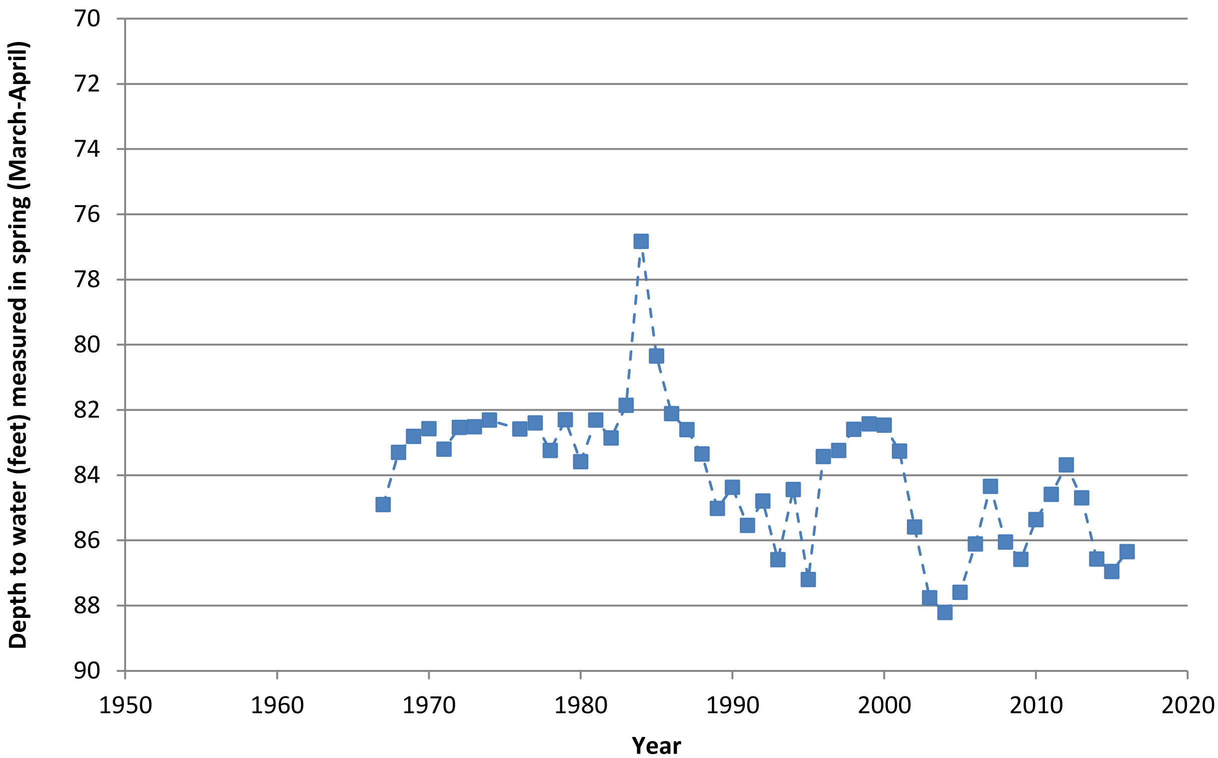

Well 19 (06N25E33AAB1), well depth 450 ft
180
190
200
210
220
230
240
250
260
1950
1960
1970
1980
1990
2000
2010
2020
Year
Depth to water (feet) measured in spring (March-April)


Well 20 (07N23E02DDA1), well opening depth 65-80 ft
0
10
20
30
40
50
60
1950
1960
1970
1980
1990
2000
2010
2020
Year
Depth to water (feet) measured in spring (March-April)

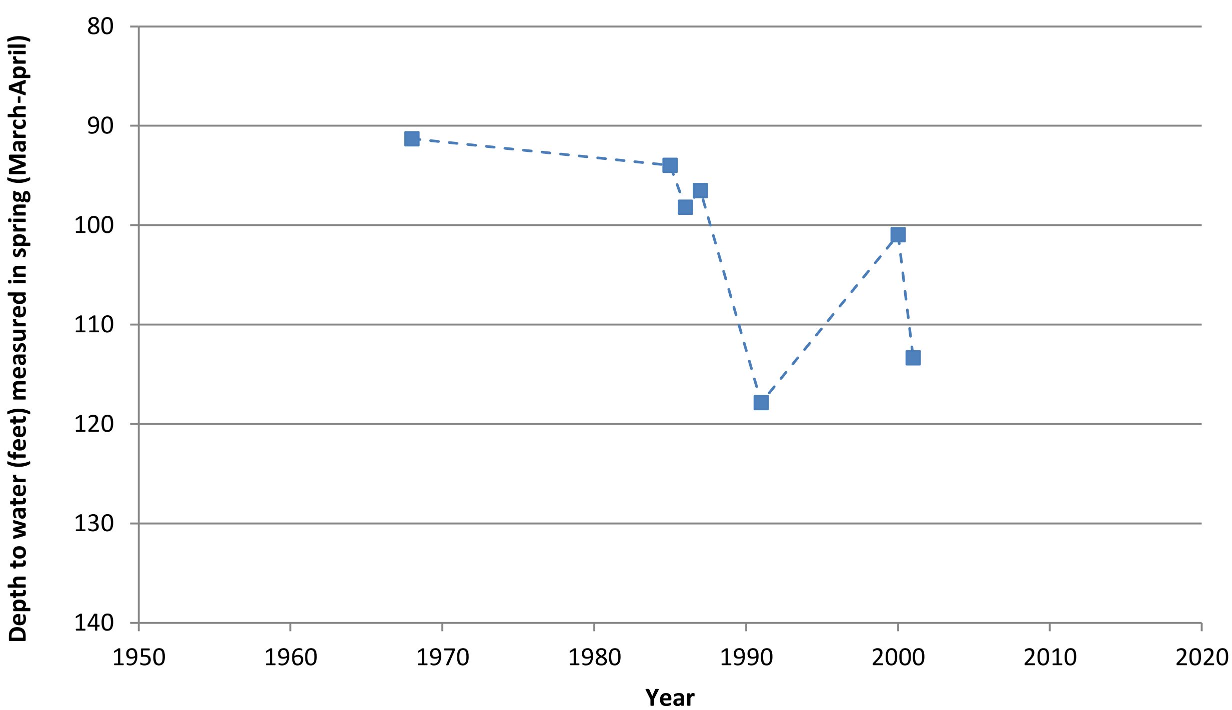

Well 21 (07N24E28DBA1), well opening depth 63-83 ft
Depth to water (feet) measured in spring (March-April)
0
2
4
6
8
10
12
14
16
18
20
1950
1960
1970
1980
1990
2000
2010
2020
Year

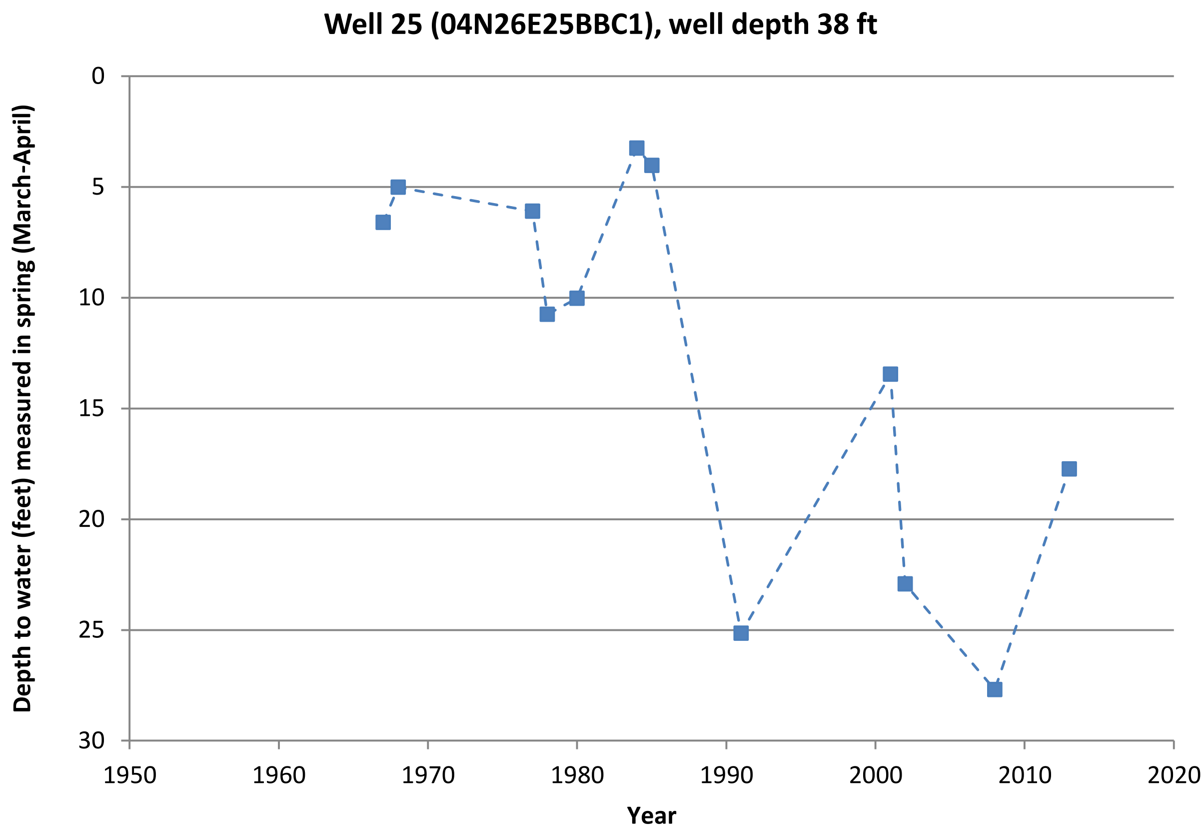

Well 22 (07N24E35CCD1), well depth 100 ft
Depth to water (feet) measured in spring (March-April)
0
1
2
3
4
5
6
7
8
9
10
1950
1960
1970
1980
1990
2000
2010
2020
Year

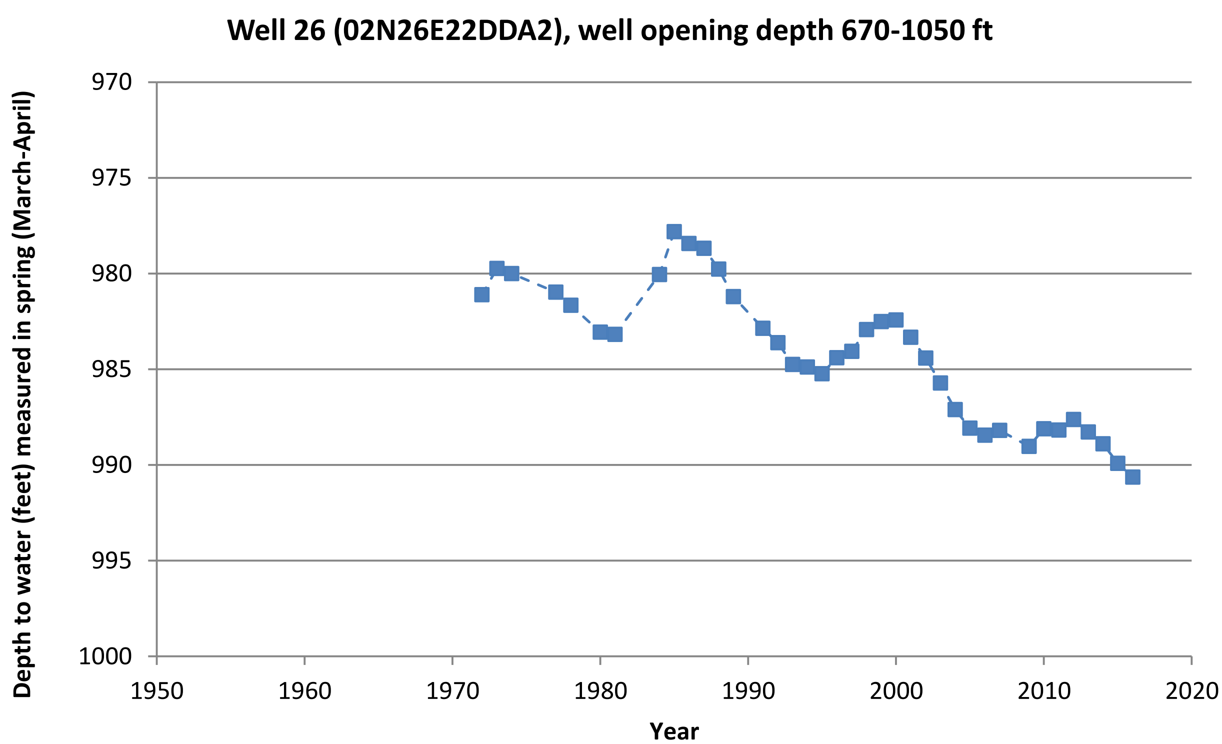
Well 23 (09N21E14BBC1), well opening depth 167-267 ft

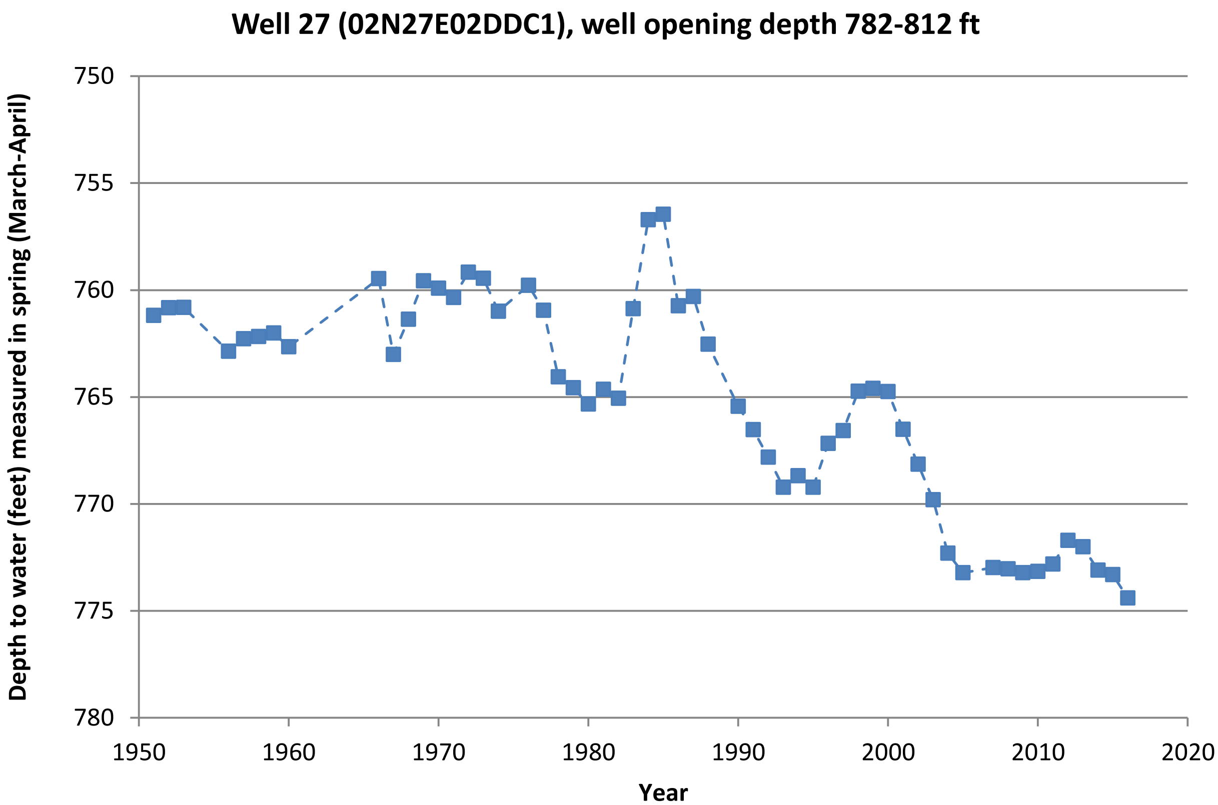


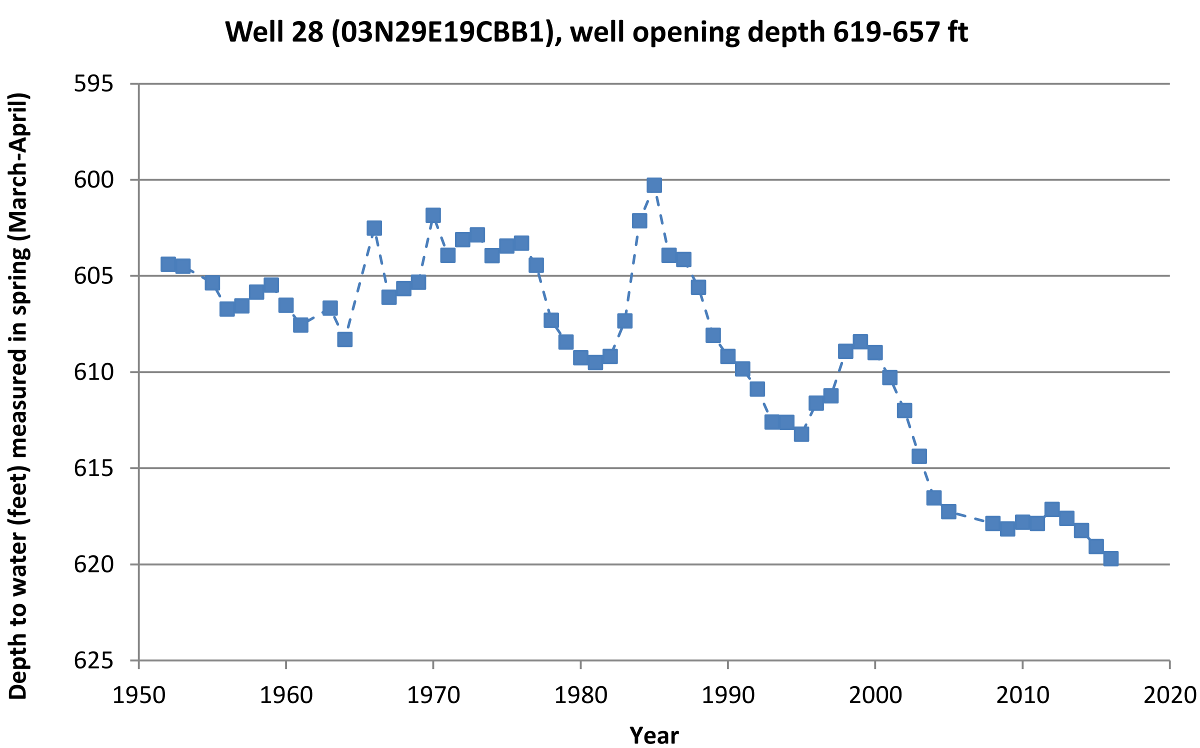
Well 24 (05N25E02DCD1), well opening depth 115-210 ft

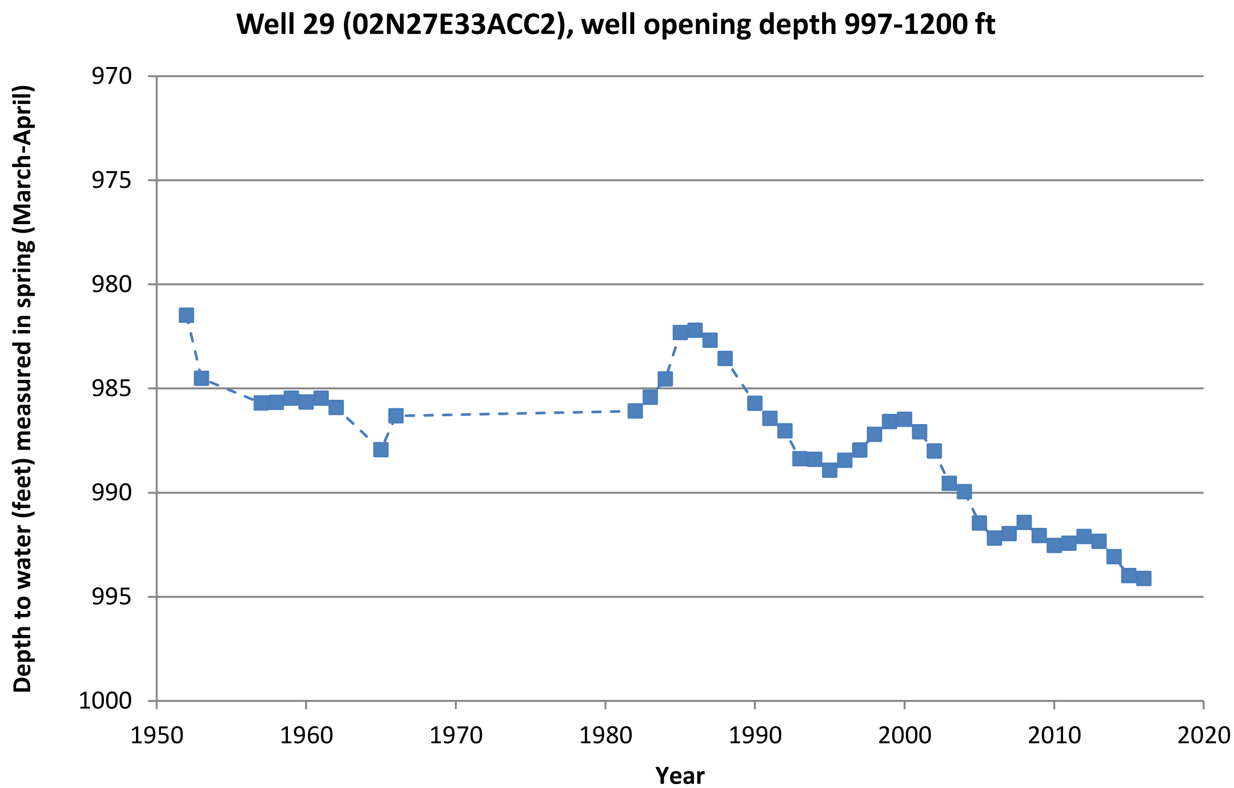



Well 25 (04N26E25BBC1), well depth 38 ft
Depth to water (feet) measured in spring (March-April)
0
5
10
15
20
25
30
1950
1960
1970
1980
1990
2000
2010
2020
Year

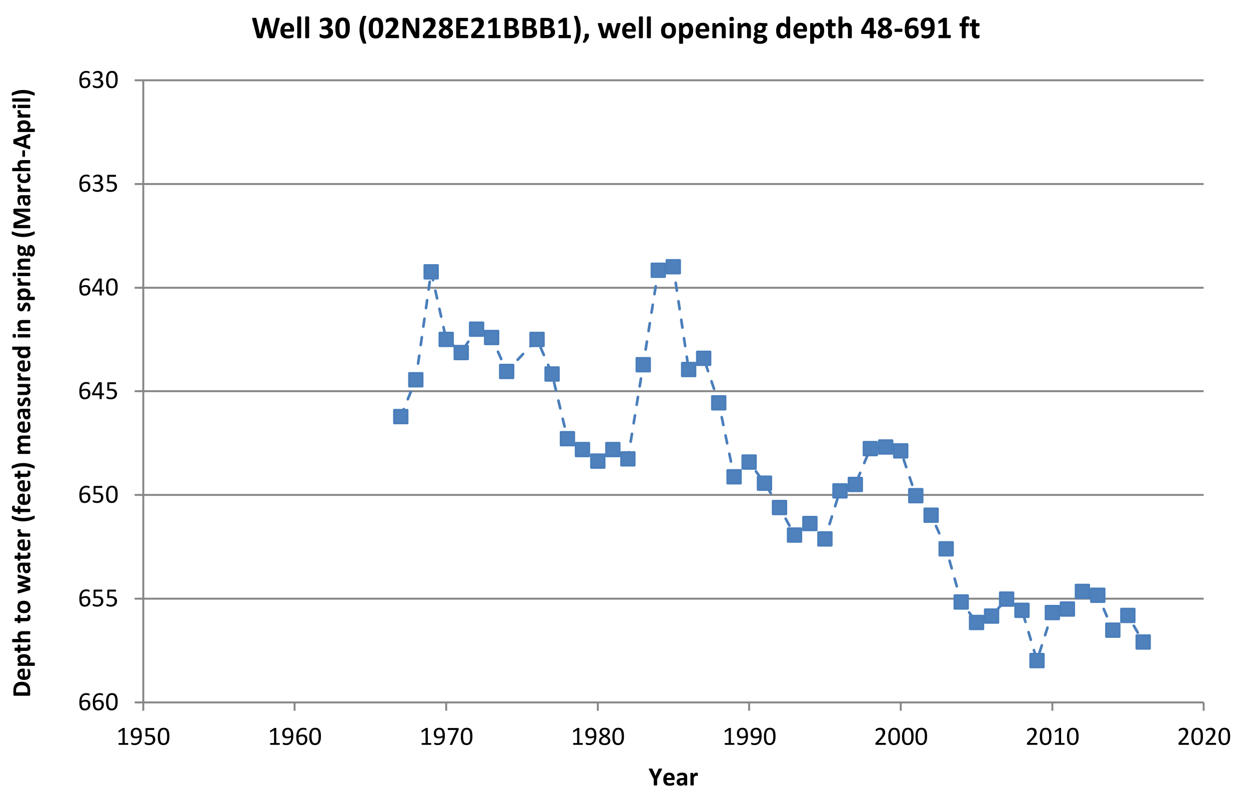

Well 26 (02N26E22DDA2), well opening depth 670-1050 ft
Depth to water (feet) measured in spring (March-April)
970
975
980
985
990
995
1000
1950
1960
1970
1980
1990
2000
2010
2020
Year


Well 27 (02N27E02DDC1), well opening depth 782-812 ft
Depth to water (feet) measured in spring (March-April)
750
755
760
765
770
775
780
1950
1960
1970
1980
1990
2000
2010
2020
Year


Well 28 (03N29E19CBB1), well opening depth 619-657 ft
Depth to water (feet) measured in spring (March-April)
595
600
605
610
615
620
625
1950
1960
1970
1980
1990
2000
2010
2020
Year



Well 29 (02N27E33ACC2), well opening depth 997-1200 ft
Depth to water (feet) measured in spring (March-April)
970
975
980
985
990
995
1000
1950
1960
1970
1980
1990
2000
2010
2020
Year



Well 30 (02N28E21BBB1), well opening depth 48-691 ft
Depth to water (feet) measured in spring (March-April)
630
635
640
645
650
655
660
1950
1960
1970
1980
1990
2000
2010
2020
Year