UPDATE ON GROUNDWATER MONITORING AND HYDROLOGIC INVESTIGATIONS IN THE BIG LOST RIVER VALLEY

IDAHO DEPARTMENT OF
WATER RESOURCES

Open File Report
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Introduction

This open file report was prepared in response to a request to update a previous hydrologic review of groundwater in the Big Lost River valley dated February 6, 2017. The updated review was requested to assist with the evaluation of a petition requesting the designation of a Ground Water Management Area in the Big Lost River basin. Water users have expressed concerns about declining groundwater levels, declining streamflow in the Big Lost River, low intermittent streamflow in the Big Lost River near Arco, and drought.

In response to water user concerns raised in 2016, the Idaho Department of Water Resources (IDWR) and Idaho Water Resource Board (IWRB) have invested considerable resources into hydrologic studies and monitoring of the water resources in the Big Lost River basin. Since completion of the 2017 memorandum, IDWR has increased monitoring of groundwater and surface water in the Big Lost basin and conducted hydrologic investigations, in partnership with the U.S. Geological Survey (USGS) and Idaho Geological Survey (IGS), to improve the characterization of surface and groundwater hydrology. These efforts and their contribution to IDWR's understanding of groundwater resources in the Big Lost basin are summarized in this report. The USGS is currently developing a groundwater flow model of the Big Lost River valley aquifer system, which is scheduled to be completed in June 2025.

This report also updates the water-level trend analyses and water use discussion from the 2017 memorandum using data collected by IDWR, USGS, and Water District 34 through water year 2023. Figure 1 shows the location of geographic features referenced in this report.

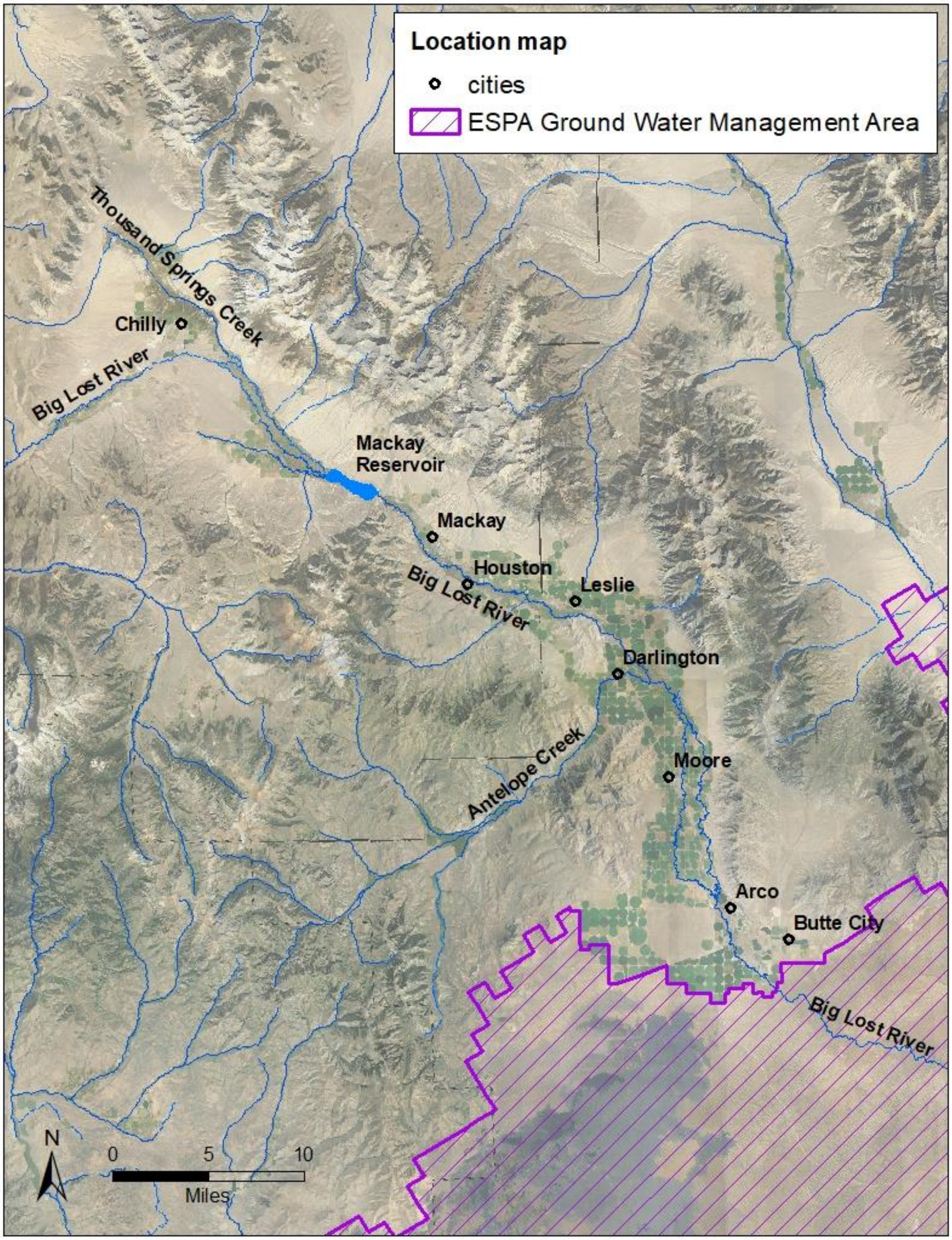


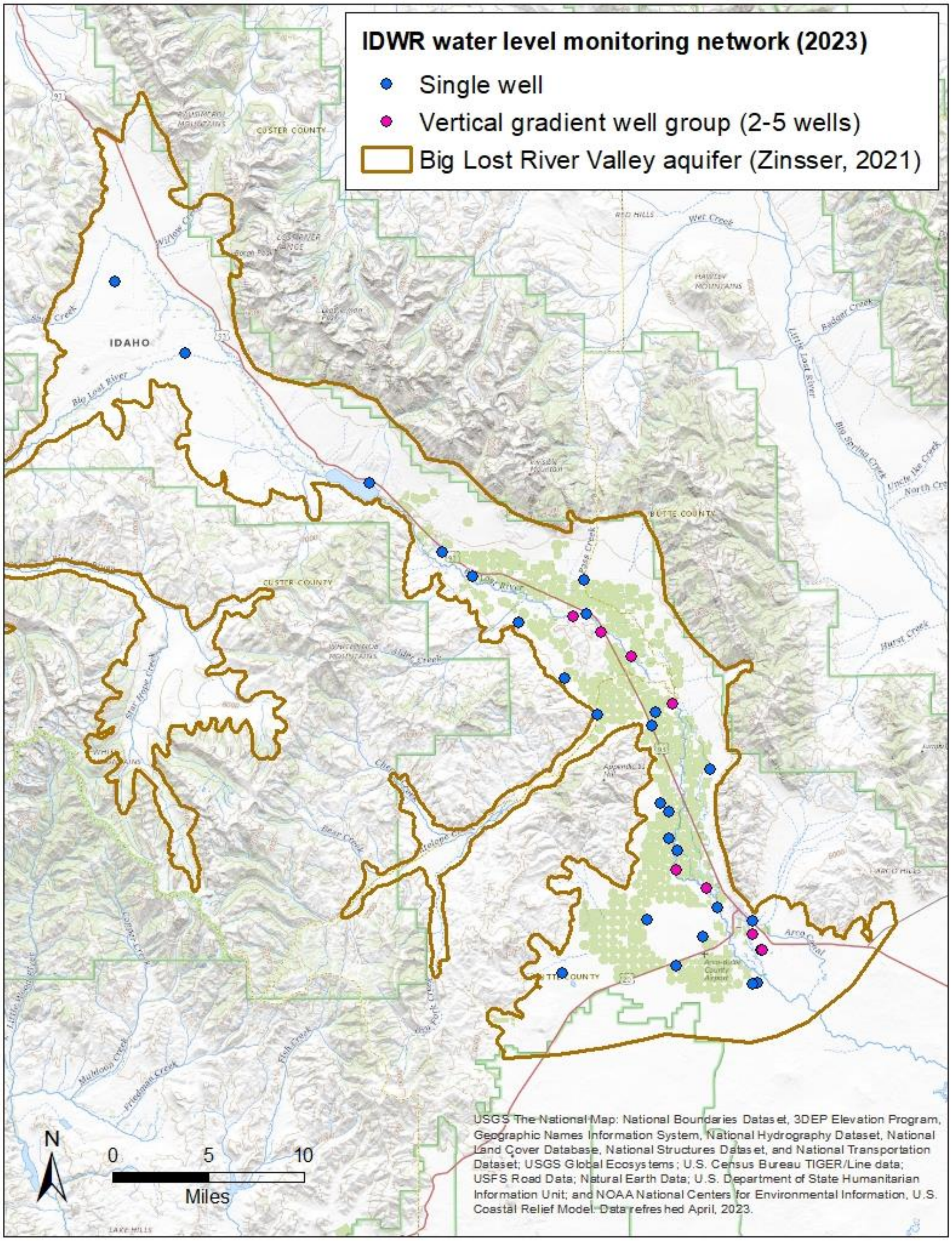
Figure 1. General location map, Big Lost River valley

Expansion of monitoring networks

IDWR expanded the water-level monitoring network in the Big Lost River valley to 50 wells. The current water-level monitoring network is shown in Figure 2. IDWR installed 22 water-level monitoring wells at seven locations near the Big Lost River to investigate vertical hydraulic gradients near the river. IDWR also installed two additional monitoring wells and began monitoring a third privately constructed well to improve understanding of hydraulic gradients at the mouth of the Big Lost valley. Well construction for 23 of the new wells is documented in a well installation completion report (Owsley, 2022). Well construction documentation for the other two wells is included in Appendix A. IDWR also began monitoring one additional well north of Mackay Reservoir in December 2016 and is pursuing adding two additional wells north of Mackay Reservoir to the water-level monitoring network. IDWR has deployed pressure transducers and data loggers for continuous recording of water levels in 39 of the 50 wells in the current monitoring network.

In cooperation with IDWR, the USGS installed new streamflow gaging stations on the Big Lost River below the Moore Diversion and at Sunset Road west of Arco, and on four tributary streams including Thousand Springs Creek, Warm Springs Creek, Lower Cedar Creek, and Antelope Creek. The USGS also installed a streamflow gaging station on the Big Lost River near Leslie in cooperation with Water District 34 and IDWR. The current USGS streamflow gaging network is shown in Figure 3. Station numbers and periods of record for the gaging stations are listed in Table 1.

In September 2019, the United States Bureau of Reclamation installed an Agrimet weather station approximately two miles north of Moore in cooperation with IDWR (Figure 4). Agrimet stations provide precipitation, evapotranspiration, and barometric data essential to the basin water budget and other monitoring efforts. The station installation expanded the Agrimet network to a location near the centroid of irrigated lands within the Big Lost River valley. An Agrimet station located south of Arco has recorded evapotranspiration data since 2014, but the location at the mouth of the Big Lost River valley is likely not representative of relevant weather parameters such as wind speed and humidity in the relatively narrow valley where much of the irrigated land is situated.



USGS The National Map: National Boundaries Dataset, 3DEP Elevation Program, Geographic Names Information System, National Hydrography Dataset, National Land Cover Database, National Structures Dataset, and National Transportation Dataset; USGS Global Ecosystems; U.S. Census Bureau TIGER/Line data; USFS Road Data; Natural Earth Data; U.S. Department of State Humanitarian Information Unit; and NOAA National Centers for Environmental Information, U.S. Coastal Relief Model. Data refreshed April, 2023.

Figure 2. Big Lost water-level monitoring network in 2023

USGS The National Map: National Boundaries Dataset, 3DEP Elevation Program, Geographic Names Information System, National Hydrography Dataset, National Land Cover Database, National Structures Dataset, and National Transportation Dataset; USGS Global Ecosystems; U.S. Census Bureau TIGER/Line data; USFS Road Data; Natural Earth Data; U.S. Department of State Humanitarian Information Unit; and NOAA National Centers for Environmental Information, U.S. Coastal Relief Model. Data refreshed April, 2023.

Figure 3. Active USGS streamflow gaging stations in the Big Lost River basin

Table 1. Active USGS streamflow gaging stations in the Big Lost River basin

Site number	**Site name**	**Period of record**
13120000	North Fork Big Lost River at Wild Horse near Chilly, ID	1944 - present
13120500	Big Lost River at Howell Ranch near Chilly, ID	1904 - present
13122000	Thousand Springs Creek near Chilly, ID	2019 – present
13124265	Warm Springs Creek below diversion near Mackay, ID	2019 – present
13126000	Mackay Reservoir near Mackay, ID (storage content)	1919 – present
13127000	Big Lost River below Mackay Reservoir near Mackay, ID	1904 – present
13128900	Lower Cedar Creek above diversions near Mackay, ID	2019 – present
13130300	Big Lost River near Leslie, ID	2022 - present
13131000	Antelope Creek near Darlington, ID	2017 – present
13132100	Big Lost River below Moore Diversion near Moore, ID	2019 – present
13132373	Big Lost River at Sunset Road at Arco, ID	2019 – present
13132500	Big Lost River near Arco, ID	1946 – present
13132513	INL diversion at head near Arco, ID	1984 – present
13132520	Big Lost River below INL diversion near Arco, ID	1984 – present
13132535	Big Lost River at Lincoln Boulevard near Atomic City, ID	1984 – present
13132565	Big Lost River above Big Lost River Sinks near Howe, ID	1996 – present

Figure 4. Agrimet weather station installed north of Moore in September 2019.

Recent hydrologic investigations

In cooperation with IDWR and IGS, the USGS published an updated characterization of water resources in the Big Lost basin. The characterization included three chapters, a hydrogeologic framework (Zinsser, 2021), surface-water and groundwater interactions (Dudunake and Zinsser, 2021), and groundwater budgets for 2000-2019 (Clark, 2022). Field studies performed in support of the updated characterization included four seepage surveys quantifying groundwater interaction with the Big Lost River in March 2019, October 2019, October 2020, and March 2021 (Dudunake and Zinsser, 2021). The characterization studies are discussed further in subsequent sections of this report.

The USGS and IDWR performed two synoptic water-level measurement events during the spring (April 4 through 8) and fall (October 30 through November 4) of 2022 (Ducar and Zinsser, 2023). Agency staff measured depth to groundwater in 153 wells in the spring and 156 wells in the fall. South of road 2900 North (approximately 2 miles south of Moore), the USGS delineated three discrete water-bearing units, shallow, intermediate, and deep. North of road 2900 North, the shallow aquifer is the main water-bearing unit and deeper units were not identified. The USGS published spring and fall 2022 potentiometric surface maps for the three discrete water-bearing units, and maps showing change in water level between spring and fall of 2022, spring of 1968 and spring of 2022, and spring of 1991 and 2022.

IDWR performed a water quality study in the Big Lost River Basin in September 2020 (Womeldorph and Steimke, 2022). Water samples were collected from 50 wells and eight surface water sites. The purpose of the study was to characterize current groundwater and surface water quality conditions in the basin and provide a baseline if additional water quality studies are performed in the future. Samples were analyzed for physical properties (temperature, dissolved oxygen, pH, specific conductance, total dissolved solids, and alkalinity), major ions and metals, nutrients, and stable isotopes. Elevated nitrate levels were found in water samples from several wells, but nitrate concentrations in all samples were below the U.S. Environmental Protection Agency's Maximum Contaminant Level of 10 mg/L.

Hydrogeologic framework

An updated hydrogeologic framework of the Big Lost River valley is presented in detail by Zinsser (2021). The updated framework includes a conceptual description of hydrogeologic units, a three-dimensional hydrogeologic framework model representing the spatial distribution of hydrogeologic units, and a description of groundwater occurrence and movement. Quaternary-age unconsolidated basin-fill sediments in the valley are the most important hydrogeologic unit and are the main source of groundwater in the Big Lost River basin. Quaternary-age basalt underlies and is interbedded with the sediments in the southern end of the valley, where the basalt units comprise several important water-bearing zones. Paleozoic-age sedimentary rock units, primarily carbonate rocks, contribute subsurface recharge to the Quaternary-age unconsolidated sediments along the valley margins. Tertiary-age volcanic rocks provide a source of water in localized faulted and fracture zones.

Zinsser (2021) developed a three-dimensional hydrogeologic framework model describing the spatial distribution of hydrogeologic units based on lithology data from 608 wells. The framework model provides insights into hydrogeologic controls on water movement and observed interactions between groundwater and surface water. Zinsser notes, *"Historically losing reaches of the Big Lost River in the Chilly and Darlington Sinks are associated with valley widening and coarse unconsolidated sediment subunits (sand and gravel). Historically gaining reaches of the Big Lost River are associated with valley narrowing (above and below the Mackay Reservoir, above the Moore Diversion and near Arco), recharge from surface water and irrigation (above the Moore Diversion and near Arco), and confining layers (near Arco) in the Quaternary unconsolidated sediments hydrogeologic unit."*

The Zinsser (2021) three-dimensional hydrogeologic framework does not fully represent bedrock geometry or the depth of the basin-fill sediments because most wells are completed in the upper 250 feet of the aquifer and lithologic data are very limited at greater depths. Crosthwaite, et al. (1970) performed gravity surveys, seismic surveys, and resistivity soundings to estimate depth to bedrock and thickness of basin-fill sediments in the Big Lost valley. Based on those surveys, the valley is underlain by sediments of variable depth, ranging from less than 100 feet to estimated depths of up to 2,000 feet or more at some locations both upstream and downstream of Mackay Dam. 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. South of 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).

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) 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 irrigation[1] 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 Aquifer (ESPA).

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 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 report.

Clark (2022) estimated an average annual water budget for the Big Lost River aquifer system for the period of 2000 through 2019. During this period, average basin precipitation was estimated to be approximately 1.6 million AF/yr. Clark (2022) did not estimate total basin water yield, but did estimate average annual aquifer recharge of approximately 439,000 AF/yr. Aquifer recharge is less than total basin water yield because it does not include the portion of streamflow consumed during irrigation with surface water or the portion of streamflow leaving the basin at the Big Lost River near Arco gage[2]. Clark (2022) estimated average annual groundwater withdrawals and discharge to surface water of approximately 112,000 AF/yr. The estimated residual difference between aquifer recharge and discharge of approximately 327,000 AF/yr includes groundwater underflow to the ESPA, decline in aquifer storage between 2000 and 2019, and error in the estimates of water budget components.

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[1] 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.

[2] The average streamflow leaving the basin at the Big Lost River near Arco gage during water years 2000 through 2019 was 17,000 AF/yr.

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 5 shows the relationship between mean annual and mean August discharge of the Big Lost River near Arco and spring water levels in selected wells from 1950 through 2023. Since 2000, August streamflow in the Big Lost River has been minimal, even in wetter years with partial groundwater recovery.

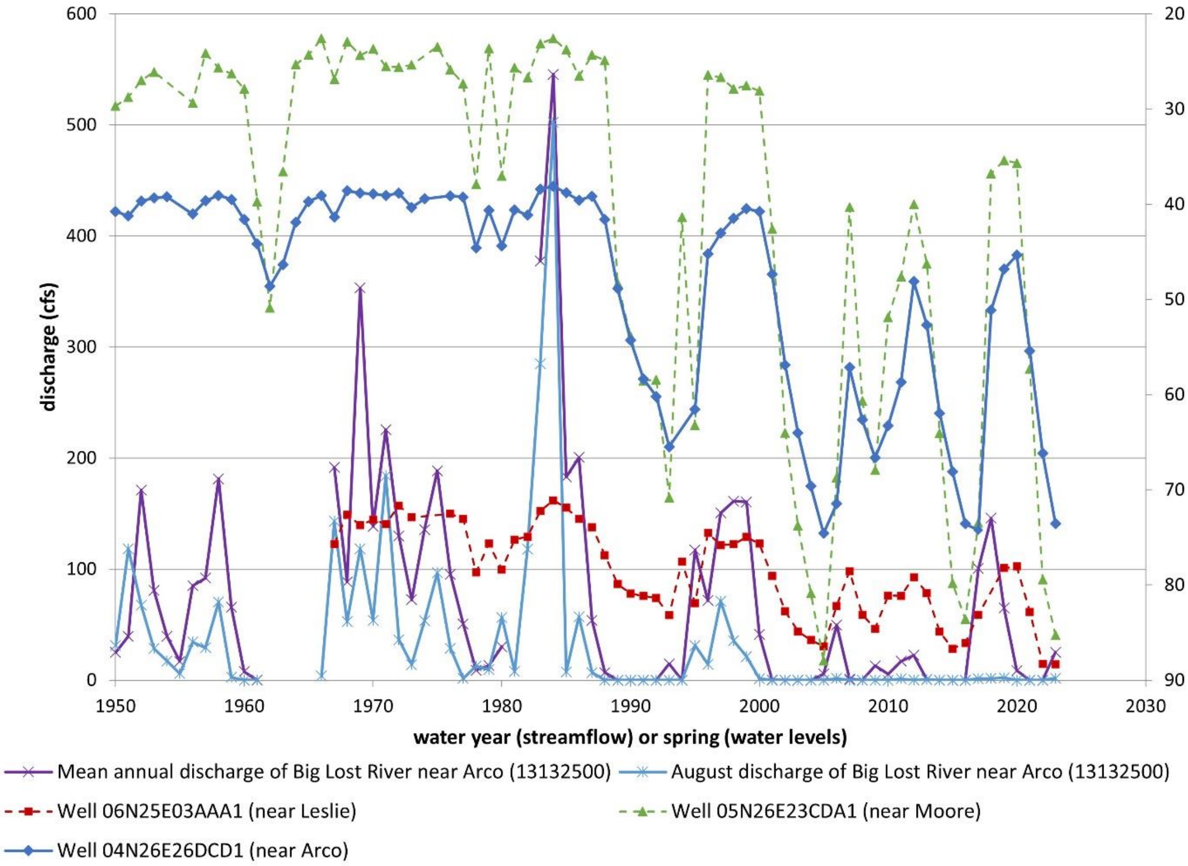


Figure 5. Discharge in the Big Lost River near Arco and spring water levels

Net aquifer recharge and discharge in the Big Lost River valley below Mackay Dam between 1985 and 2018 were simulated in the Eastern Snake Plain Aquifer Model Version 2.2 (ESPAM2.2). While ESPAM2.2 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 2018 averaged approximately 208,000 AF/yr, including approximately 55,000 AF/yr of groundwater inflow in the vicinity of Mackay Dam and 25,000 AF/yr of groundwater inflow in the vicinity of Antelope Creek. The annual net recharge was highly variable, ranging from approximately 88,000 AF in 2014 to approximately 452,000 AF in 2017 (Figure 6). Simulated groundwater outflow to the Eastern Snake Plain at the mouth of the Big Lost Valley averaged 214,000 AF/yr between 1985 and 2018. Annual groundwater outflow was much less variable than the annual net recharge, ranging from approximately 203,000 AF in 2015 to approximately 226,000 AF in 1998 (Figure 6). Better estimates of the volume and variability of annual net recharge and annual groundwater outflow are expected to be available when the USGS completes the Big Lost River Basin groundwater flow model, scheduled for June 2025.

The annual and cumulative changes in aquifer storage simulated using ESPAM2.2 are shown in Figure 6. During wet years, net recharge (aquifer recharge less groundwater consumed by irrigated crops and wetlands) exceeds groundwater outflow to the Eastern Snake Plain and water 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 (aquifer recharge less groundwater consumed by irrigated crops and wetlands) and water 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 October 1984 and September 2018, there was a net decrease in aquifer storage. The cumulative decrease in aquifer storage simulated using ESPAM2.2 was approximately 207,000 AF, an average annual decrease of approximately 6,000 AF/yr. Better estimates of aquifer storage change are expected to be available when the USGS completes the Big Lost River Basin groundwater flow model, scheduled for June 2025. While there is 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 water levels (Figure 7). Water-level trends are discussed further in the following section of this report. Changes in water levels, which can be measured directly, provide greater insight into changes in groundwater conditions than estimated changes in aquifer storage.

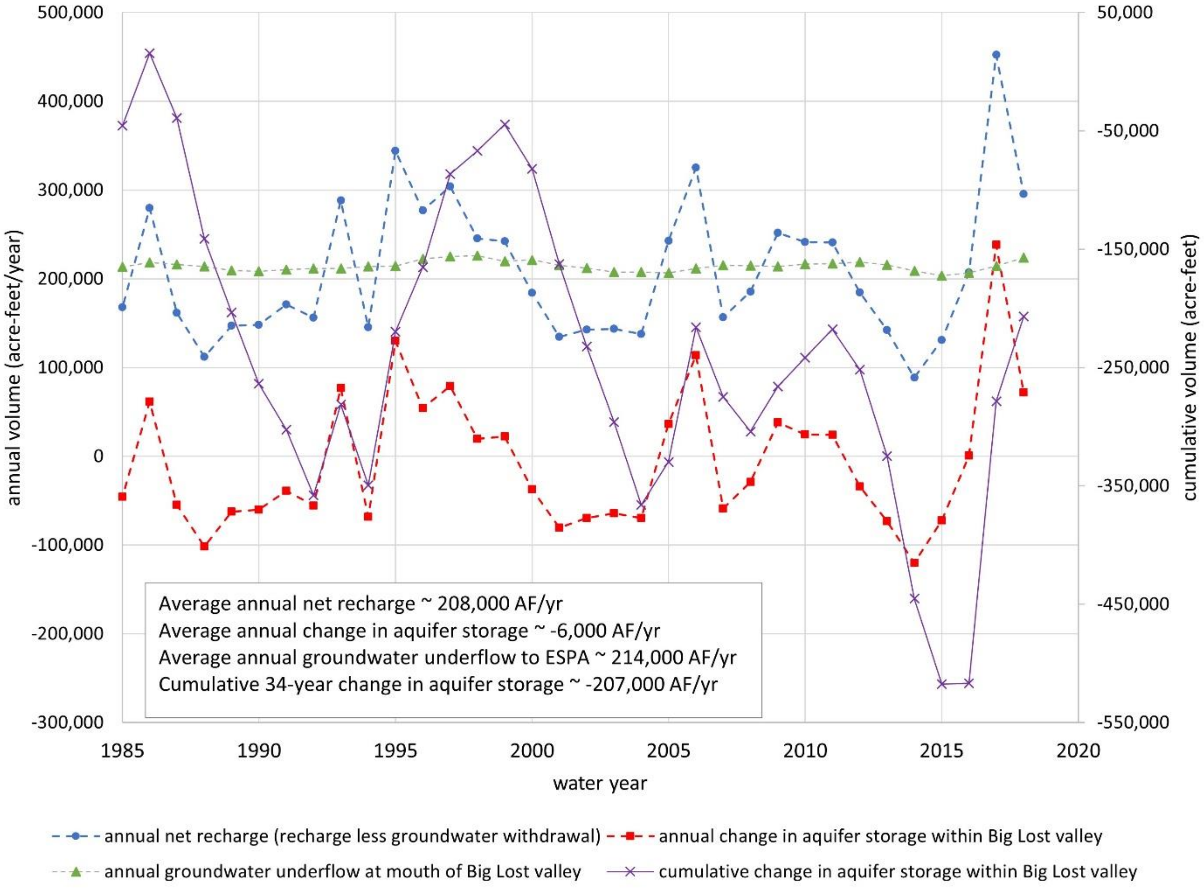


Figure 6. Change in aquifer storage within the Big Lost River valley below Mackay Dam simulated using the ESPAM2.2 groundwater flow model

The average volume of groundwater underflow at the mouth of the Big Lost River valley between 1985 and 2018 simulated using ESPAM2.2 (214,000 AF/yr) is considerably less than the average volume of 311,000 AF/yr between 1944 and 1968 estimated by Crosthwaite et al. (1970) and the average water budget residual of 326,000 AF/yr for 2000 to 2019 estimated by Clark (2022). Much of the difference appears to be in estimates of tributary underflow to the Big Lost valley aquifer below Mackay Dam. IDWR is currently implementing revisions to tributary underflow based on Clark (2022) for development of the next version of ESPAM. Following completion of the USGS Big Lost River Basin groundwater flow model, ESPAM representation of groundwater discharge from the Big Lost valley aquifer to the ESPA should be re-evaluated to incorporate findings from the Big Lost modeling effort.

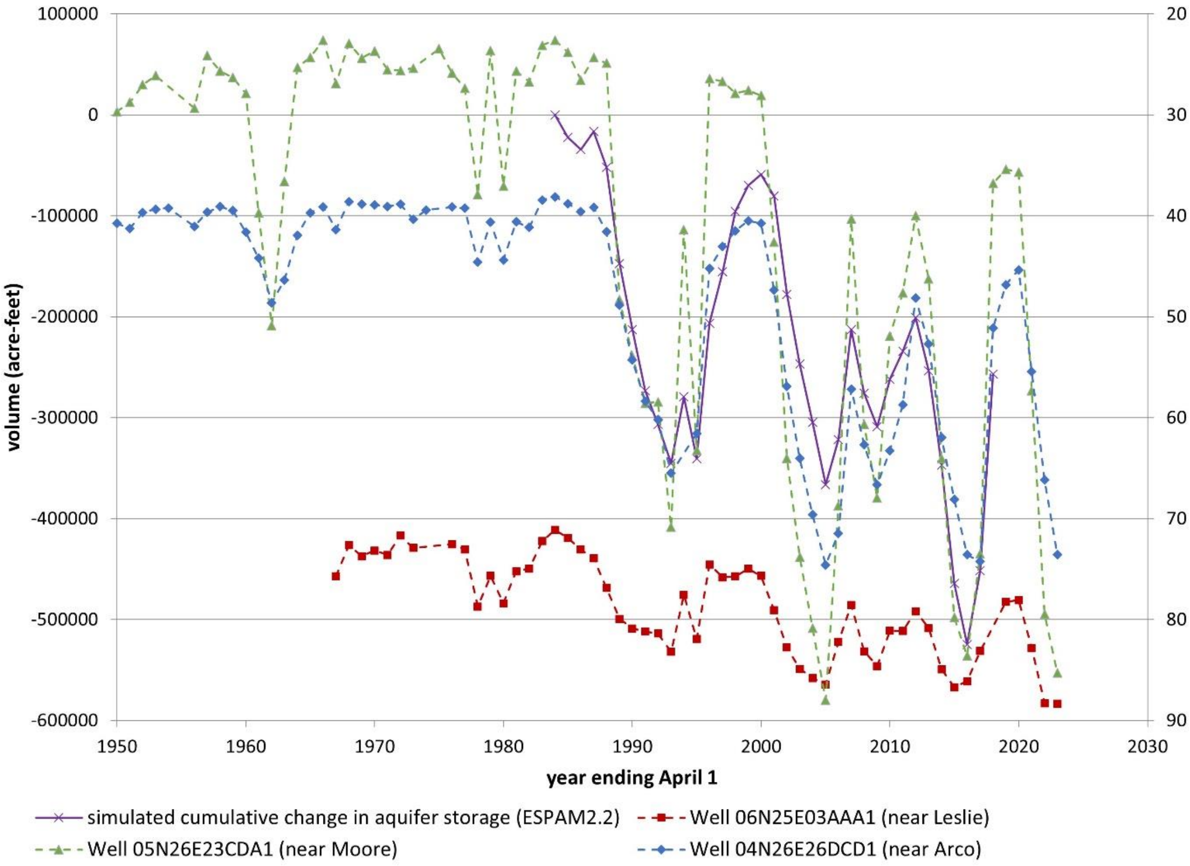


Figure 7. Simulated change in aquifer storage and measured water levels

<u>Groundwater and surface water interaction</u>

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.*"

Zinsser (2021) noted that changes in the width of the Big Lost River valley are "*likely the primary control on the volume of the Quaternary unconsolidated sediments and subsequently affect river gains and losses, although depth may be more important to aquifer geometry in the narrow valley near Mackay*". Streamflow losses to groundwater in the Chilly Sinks occur in coarse-grained sediments where the valley widens as the upper Big Lost River and Thousand Springs Creek flow into the main valley. Streamflow gains from groundwater occur upstream and downstream of Mackay Reservoir where the valley is relatively narrow and bedrock is relatively shallow.

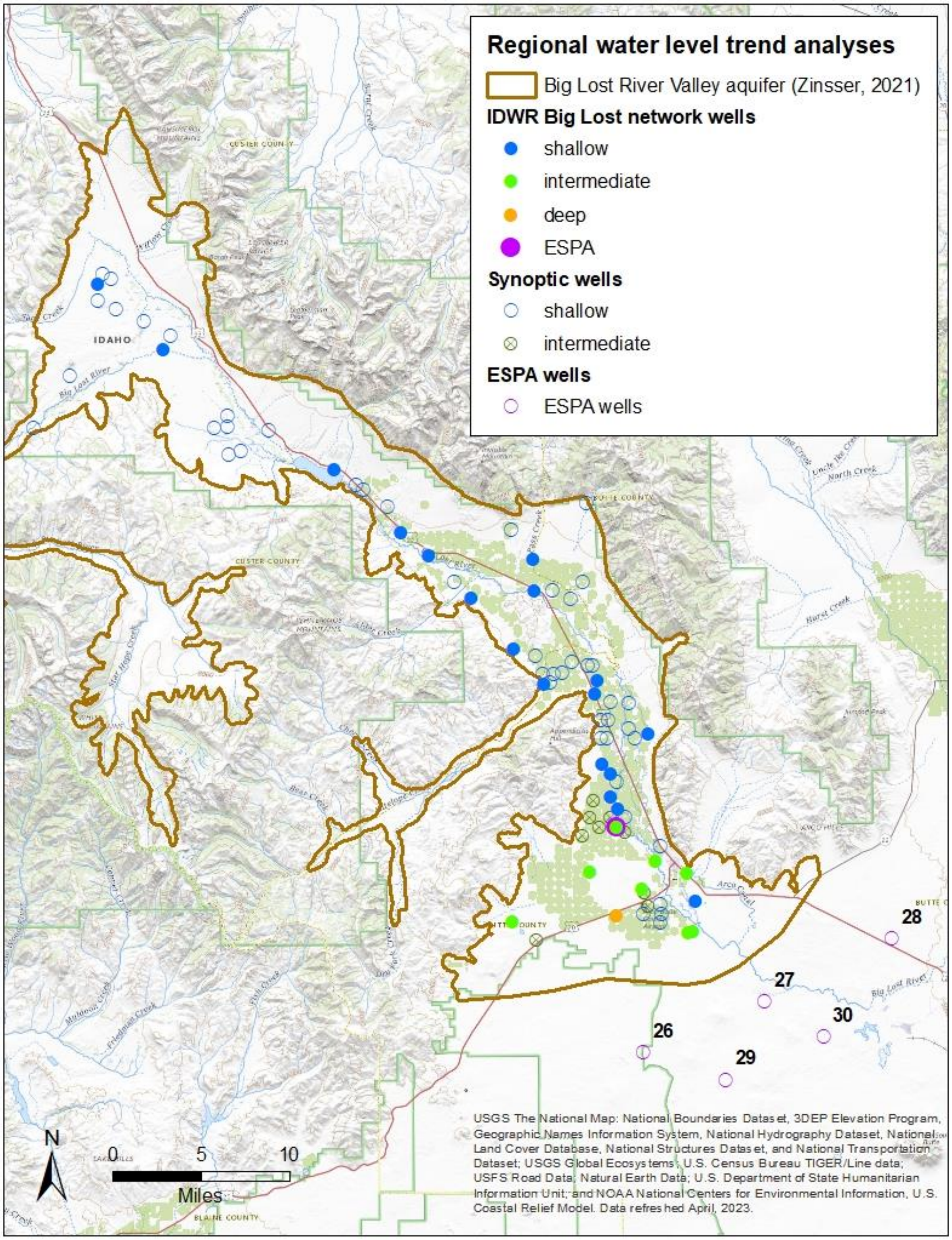
Streamflow losses to groundwater in the Darlington Sinks occur in a wider part of the valley with coarse-grained sediments. Streamflow gains from the aquifer also occur intermittently where the valley narrows upstream from the Moore Diversion and near Arco.

Dudunake and Zinsser (2021) quantified streamflow gains and losses in the Big Lost River below Mackay Dam during four measurement events. Streamflow and diversions were measured by USGS and IDWR personnel during two-day events in March 2019, October 2019, October 2020, and March 2021. Gains and losses were analyzed for three river reaches, from the below Mackay Reservoir gage to the near Leslie gage (upper reach), from the near Leslie gage to below the Moore Diversion (middle reach), and from below the Moore Diversion to the near Arco gage (lower reach). Gains and losses were also analyzed for shorter subreaches within each of the three river reaches. Observed gains and losses were generally consistent with historic observations. The quantification of reach gains and losses at specific times and locations will provide useful calibration targets for development of the Big Lost River Basin groundwater flow model.

During March 2019 and October 2019, the Big Lost River flowed past Arco and streamflow gains and losses were quantified by Dudunake and Zinsser (2021) from the below Mackay Reservoir gage to the near Arco gage. During October 2020, the entire remaining flow of the Big Lost River was diverted at Moore and the river was dry below the Moore Diversion. Streamflow gains and losses were quantified from the below Mackay Reservoir gage to the Big Lost River below Moore Diversion for October 2020. A very small streamflow gain of 0.4 cfs was observed in the Big Lost River between the Arco-Minidoka Road and Highway 20 crossings in October 2020. During March 2021, the Big Lost River was dry at the 3350 North road crossing (less than 2 river miles below the Moore Diversion). Streamflow gains and losses were quantified from the below Mackay Reservoir gage to the 3350 North road crossing for March 2021. The Big Lost River was dry between the 3350 North road crossing and the near Arco gage during the March 2021 measurement event.

Water-level trends

Water-level trends were evaluated on a regional basis and at individual wells. Regional water-level trends were evaluated using water levels measured at 82 wells in the Big Lost River valley between 1950 and 2023 (Figure 8), including 16 wells located above Mackay Dam and 66 wells located below Mackay Dam. Trend analyses were performed using the regional Kendall test and Mann Kendall test as described in Helsel, et al. (2006). 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.



USGS The National Map: National Boundaries Dataset, 3DEP Elevation Program, Geographic Names Information System, National Hydrography Dataset, National Land Cover Database, National Structures Dataset, and National Transportation Dataset; USGS Global Ecosystems; U.S. Census Bureau TIGER/Line data; USFS Road Data; Natural Earth Data; U.S. Department of State Humanitarian Information Unit; and NOAA National Centers for Environmental Information, U.S. Coastal Relief Model. Data refreshed April, 2023.

Figure 8. Wells used in regional water-level trend analyses

The trend analyses included analysis of water-level trends in two individual wells above Mackay Dam and 26 individual wells below Mackay Dam that are (or were) included in IDWR's water-level monitoring network. An additional 14 wells above Mackay Dam and 40 wells below Mackay Dam with less frequent measurements were included in some of the regional trend analyses. Trend analyses were also performed for five wells located in the ESPA south of the mouth of the Big Lost Valley for comparison with water-level trends in the Big Lost River basin.

Spring water levels measured in March or April were used in the trend 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 2023. Both time periods include years with above average surface water supply and periods of drought (Figure 9). 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 30 of the 46 years (65%) 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.

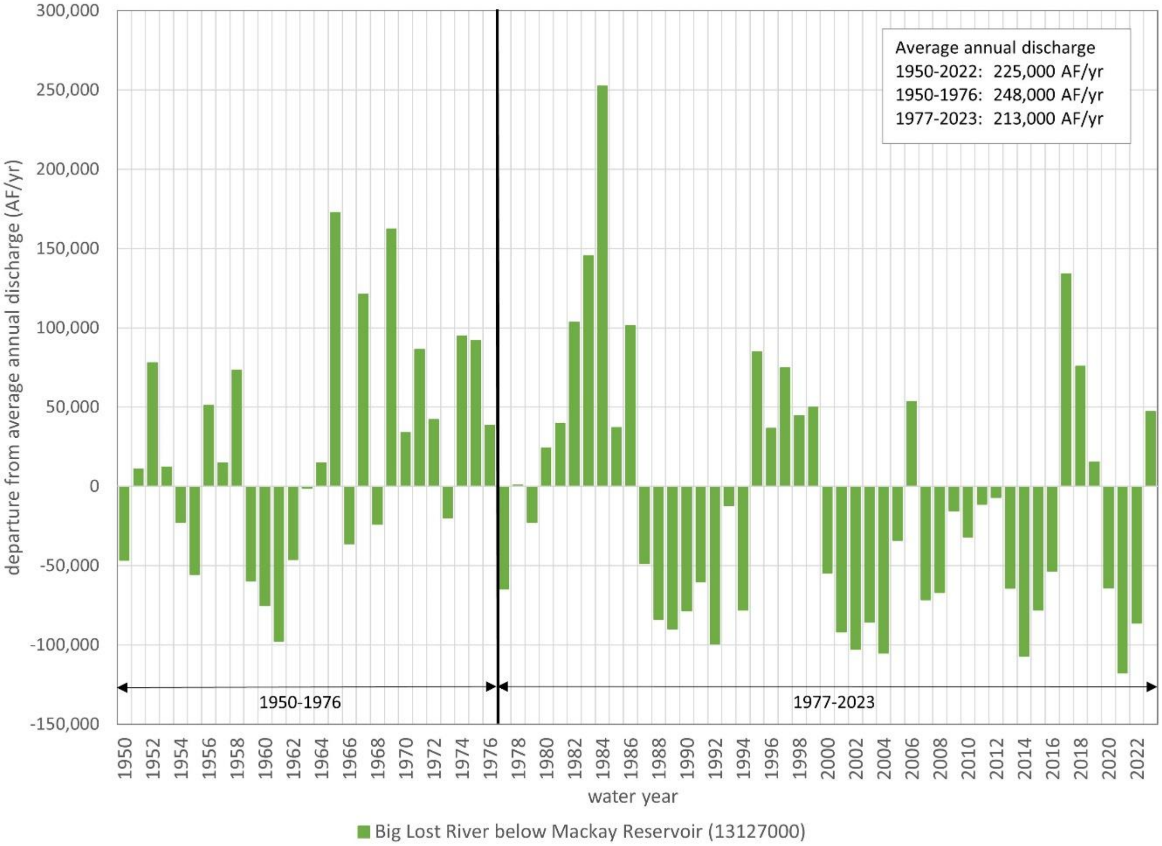


Figure 9. Departure from average annual discharge in the Big Lost River below Mackay Reservoir as an indicator of surface water supply

Calculating a linear water-level trend is a simple way to describe long-term water-level changes, but calculated trends may not be meaningful if only a few measurements are available or if data are only available for a short period of time. Statistical assessments can be helpful in determining the level of confidence in calculated trends. For the regional Kendall and individual Mann Kendall analyses discussed in this report, the level of statistical significance is indicated by the p-value. Low p-values indicate high confidence in the calculated trend (a p-value of 0.05 represents a 95% confidence interval), high p-values indicate low confidence in the calculated trend (a p-value of 0.95 represents a 5% confidence interval). Regional Kendall analyses indicated high confidence in water levels trends calculated for the regional aquifer. Confidence intervals varied for the individual Mann Kendall analyses, largely because of variations in the period of record and amount of data available for each well. Appendix B provides a table with p-values for all analyses discussed in this report and hydrographs of spring water-level data in the network wells.

Regional Kendall analyses were performed on water-level data collected from 26 network wells below Mackay Dam. Between 1950 and 1977, there was a statistically significant trend of increasing water levels of 0.09 feet per year. Between 1977 and 2023, there was a statistically significant trend of decreasing water levels of 0.27 feet per year. Regional analyses of 1977-2023 water-level data from wells assigned to the shallow and intermediate aquifer units delineated by Ducar and Zinsser (2023) resulted in similar statistically significant declining trends of 0.24 feet per year for 16 wells in the shallow unit and 0.25 feet per year for 7 wells in the intermediate unit.

Regional Kendall analyses were also performed using additional wells included in the recent synoptic measurement (Ducar and Zinsser, 2023). A regional analysis of water-level data from 16 wells above Mackay Dam resulted in a statistically significant trend of increasing water levels of 0.14 feet per year between 1967 and 1977 and a statistically significant trend of decreasing water levels of 0.10 feet per year between 1977 and 2023. A regional analysis of water-level data from 66 wells below Mackay Dam resulted in a statistically significant trend of declining water levels of 0.28 feet per year between 1977 and 2023.

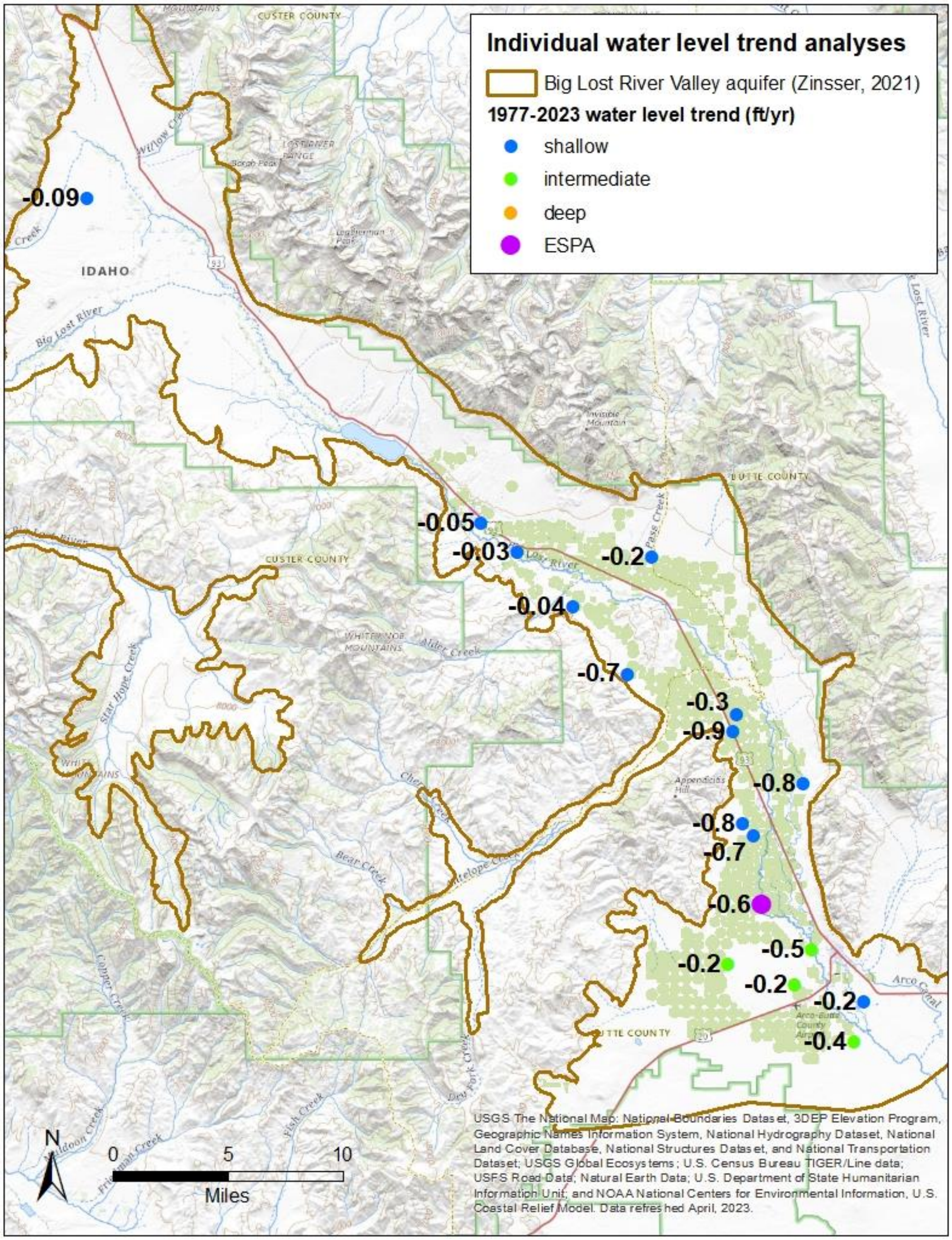
Individual Mann Kendall trend analyses were performed on spring water levels measured at each well between 1977 and 2023. Statistically significant trends are shown in Figure 10. Below Mackay Dam, statistically significant water-level trends with a p-value of less than 0.05 (confidence interval greater than 95%) were observed in 13 of 26 wells. Statistically significant trends ranged from decreasing water levels of less than 0.1 foot per year in three wells near the town of Mackay to decreasing water levels of 0.9 feet per year in a well near Moore. Statistically significant declining water-level trends with p-values between 0.05 and 0.20 (confidence interval between 80% and 95%) were observed in four wells. A statistically significant decreasing trend of 0.4 feet per year was observed between 2019 and 2023 in a well recently added to the monitoring network, but this observation period is short and the trend reflects short-term climate fluctuation.

Eight wells did not have statistically significant water-level trends because of too few measurements or large fluctuations in measurements.

Above Mackay Dam, a statistically significant decreasing water-level trend of 0.09 foot per year was observed in a well northwest of Chilly between spring 1977 and spring 2023. A statistically significant decreasing trend of 4.6 feet per year was observed between 2017 and 2023 in a well recently added to the monitoring network, but this observation period is short, and the trend reflects short-term climate fluctuation.

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 2023, water levels decreased by 0.28 foot per year. Comparison of the regional water-level trends within the Big Lost River valley (-0.27 foot per year) and in wells located on the Eastern Snake Plain near the mouth of the Big Lost Valley (-0.28 foot per year) suggests water levels are declining at similar rates in both areas.

Comparison of 1977-2023 calculated trends with 1977-2016 calculated trends (Sukow, 2017) shows a decrease in the magnitude of long-term water-level decline with the addition of seven years of observations. In general, water-level measurements in 22 wells with periods of record extending from at least 2005 to 2023 show similarly low water levels during recent droughts. The lowest spring water level observed in half of these wells occurred in 2022 or 2023. While water levels observed since 2005 generally appear to be fluctuating within a consistent range, further long-term water level declines are possible pending future climate and water management. Without changes in water management and groundwater use, water levels during future droughts can be expected to drop to levels similar to the low levels observed between 2005 and 2023, if not lower.



USGS The National Map: National Boundaries Dataset, 3DEP Elevation Program, Geographic Names Information System, National Hydrography Dataset, National Land Cover Database, National Structures Dataset, and National Transportation Dataset; USGS Global Ecosystems; U.S. Census Bureau TIGER/Line data; USFS Road Data; Natural Earth Data; U.S. Department of State Humanitarian Information Unit; and NOAA National Centers for Environmental Information, U.S. Coastal Relief Model. Data refreshed April, 2023.

Figure 10. Water-level trends in the Big Lost River valley (1977-2023)

Irrigation diversion records

Irrigation water in the Big Lost River valley is obtained from surface water and groundwater sources. 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.

As of October 2016, IDWR water right place of use records indicated 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. Based on recent irrigated lands delineations, Clark (2022) reported the active irrigated area between 2000 and 2019 averaged approximately 12,400 acres above Mackay Dam and 55,000 acres below Mackay Dam. Crop irrigation requirement reported by Clark (2022) for 2000 to 2019 ranged from approximately 80,000 AF/yr to over 160,000 AF/yr, averaging 1.7 AF/yr per acre.

Diversion data from Johnson et al. (1991) shows surface water diversions from the Big Lost River below Mackay Dam generally decreased between the mid-1960s and 1990, as appropriation of groundwater increased (Figure 11). Diversion data from the IDWR water right accounting database and recent Water District 34 reports show surface water diversions have continued to be low from 1994 to 2023 relative to surface water diversions 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 prior to 2014, 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.

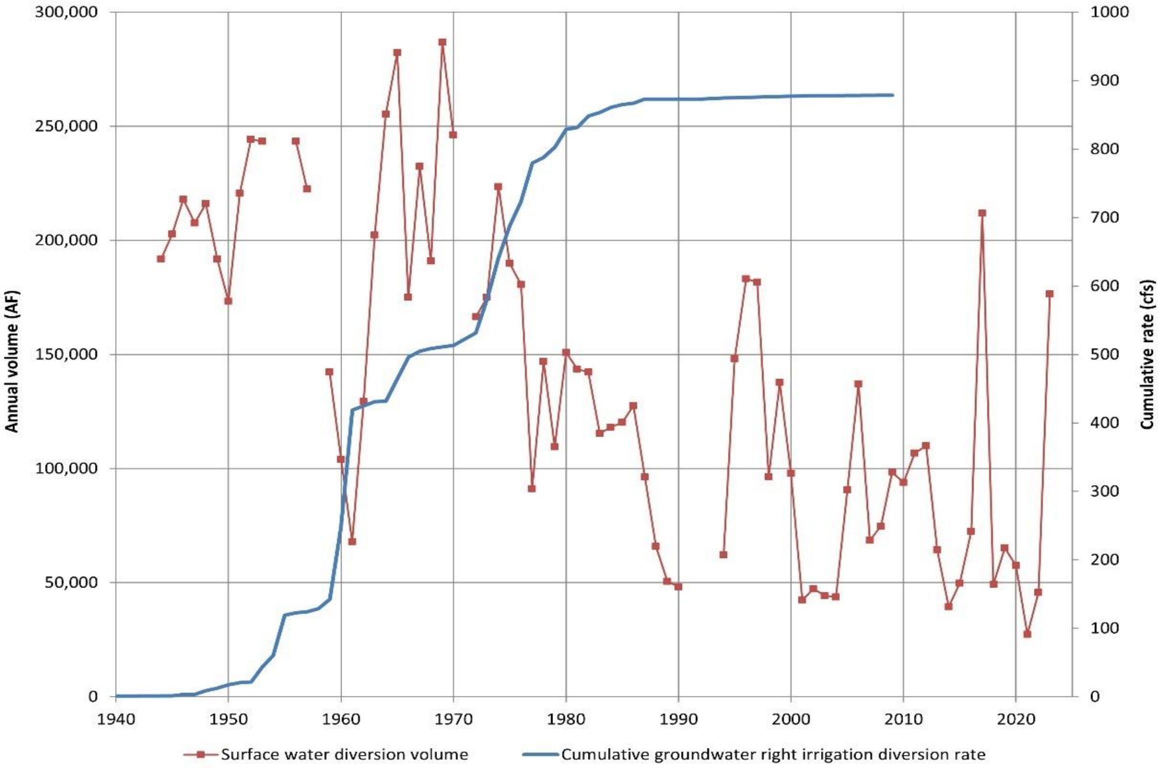


Figure 11. Recorded surface water diversions and appropriation of groundwater

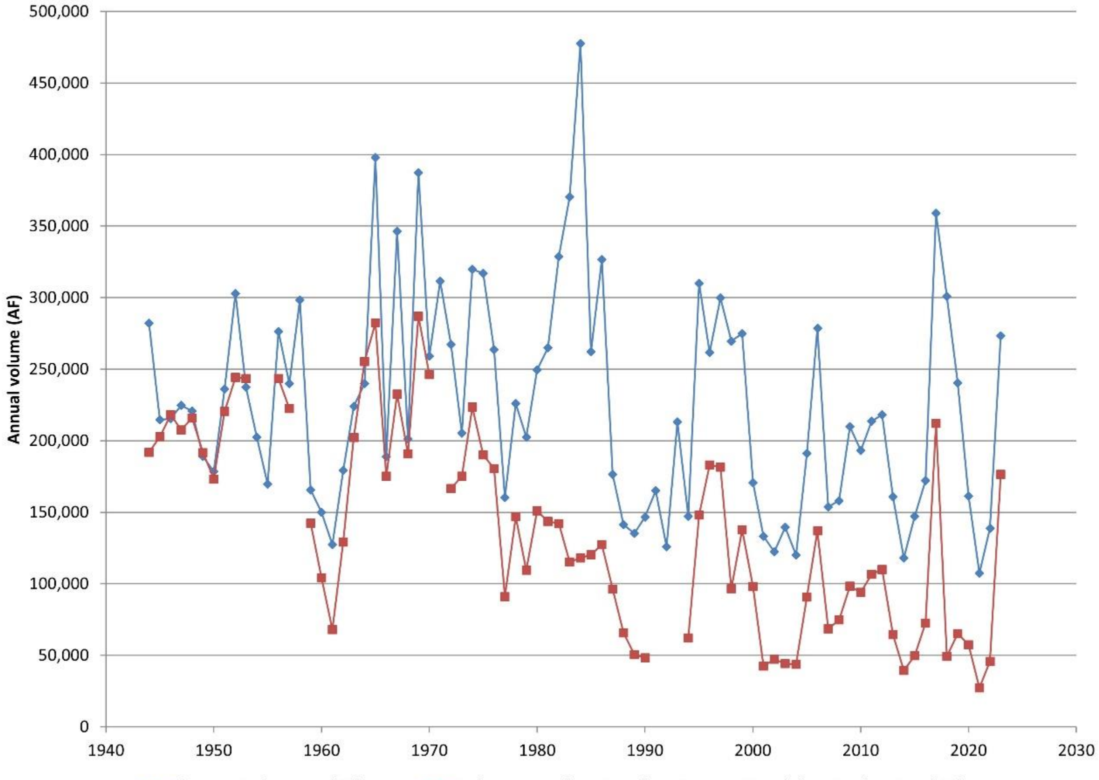


Figure 12. Surface water diversions and streamflow in the Big Lost River near Mackay

Groundwater diversions reported by Water District 34 are available for 2014 through 2023. Below Mackay Dam, reported annual groundwater diversions ranged from 50,000 AF in 2017 to 115,000 AF in 2021, averaging approximately 81,000 AF/yr. Reported surface water diversions varied significantly between 2014 and 2023 (Figure 12) and generally have an inverse relationship to groundwater diversions (Figure 13 and Figure 14). Because many of the groundwater rights in the Big Lost River valley are supplemental to surface water rights, less groundwater is diverted for irrigation in years with higher surface water supply. Based on the regression in Figure 14, this appears to explain roughly 60% of the variation in groundwater diversions. Crop irrigation demand, which varies with climate, crop type, and crop management, will also affect the volume of groundwater diverted.

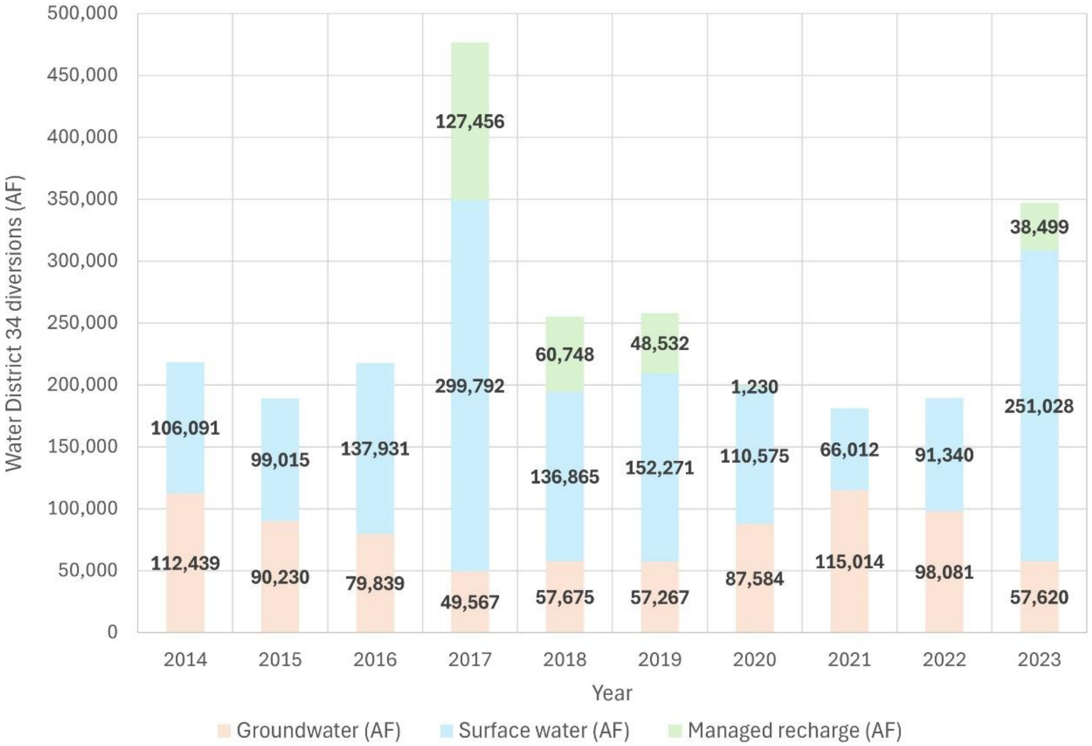


Figure 13. Diversions reported by Water District 34[3]

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[3] Surface water diversions include diversions from the Big Lost River and tributary creeks (Warm Springs, Rock, Lone Cedar, Lower Cedar, Alder, Pass, Antelope, Champagne).

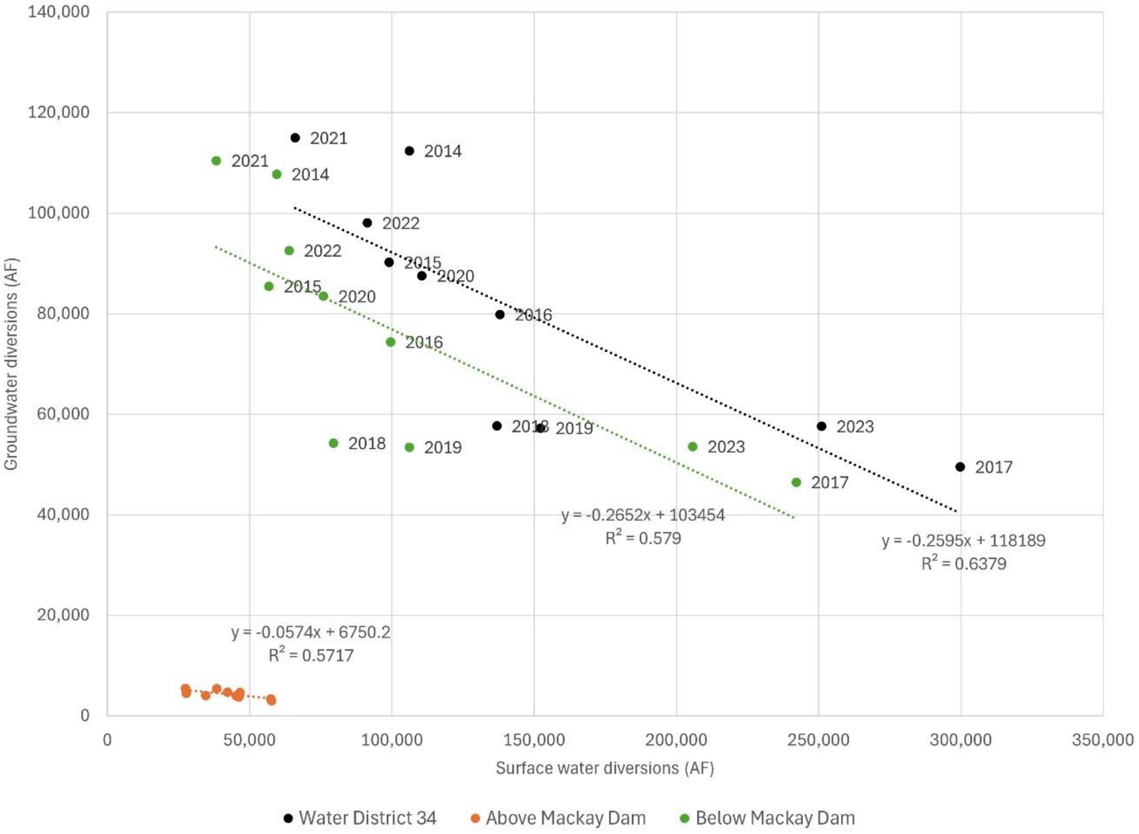

Figure 14. Relationship between groundwater and surface water diversions

The high volume of surface water diverted in 2023 may have been in part due to the failure of gates that control the release of water from Mackay Reservoir (Jones, 2023; Giorgi, 2023). Regardless, Figure 14 suggests that the relationship between surface water and groundwater diversions in 2023 was similar to other recent years.

Approximately 95% of groundwater diversions in the Big Lost River basin occur in the valley south of Mackay Dam. Between 2014 and 2023, groundwater diversions above Mackay Dam ranged from 3,000 to 5,500 AF/yr (5% to 17% of total diversions above Mackay Dam), while groundwater diversions below Mackay Dam ranged from 47,000 to 110,000 AF/yr (16% to 74% of total diversions below Mackay Dam). On average, groundwater diversions comprised approximately 10% of total diversions above Mackay Dam and approximately 50% of total diversions below Mackay Dam[4].

Figure 15 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, water levels declined somewhat during dry years, but recovered fully during wet years. Beginning in the mid-1980s, water 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 water levels over the last five decades.

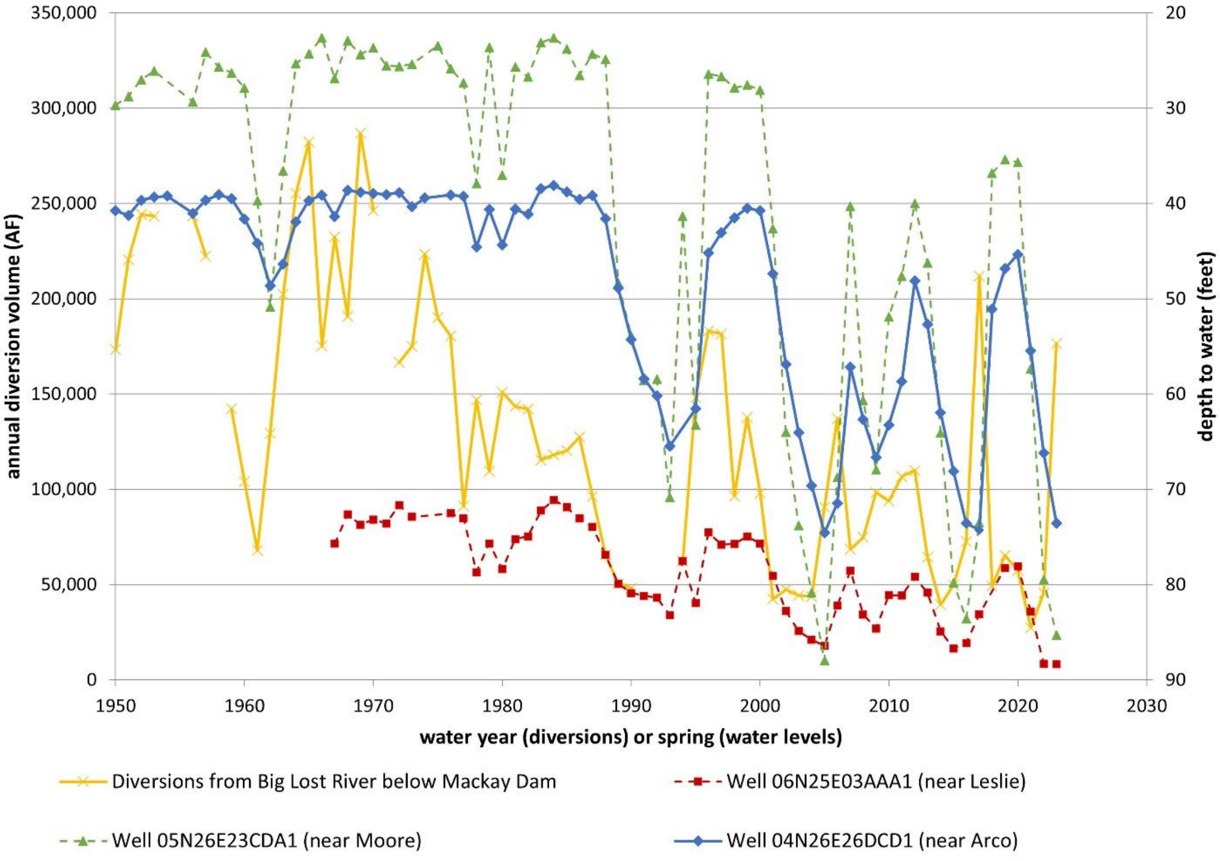

Figure 15. Spring water levels and recorded surface water diversions from Big Lost River

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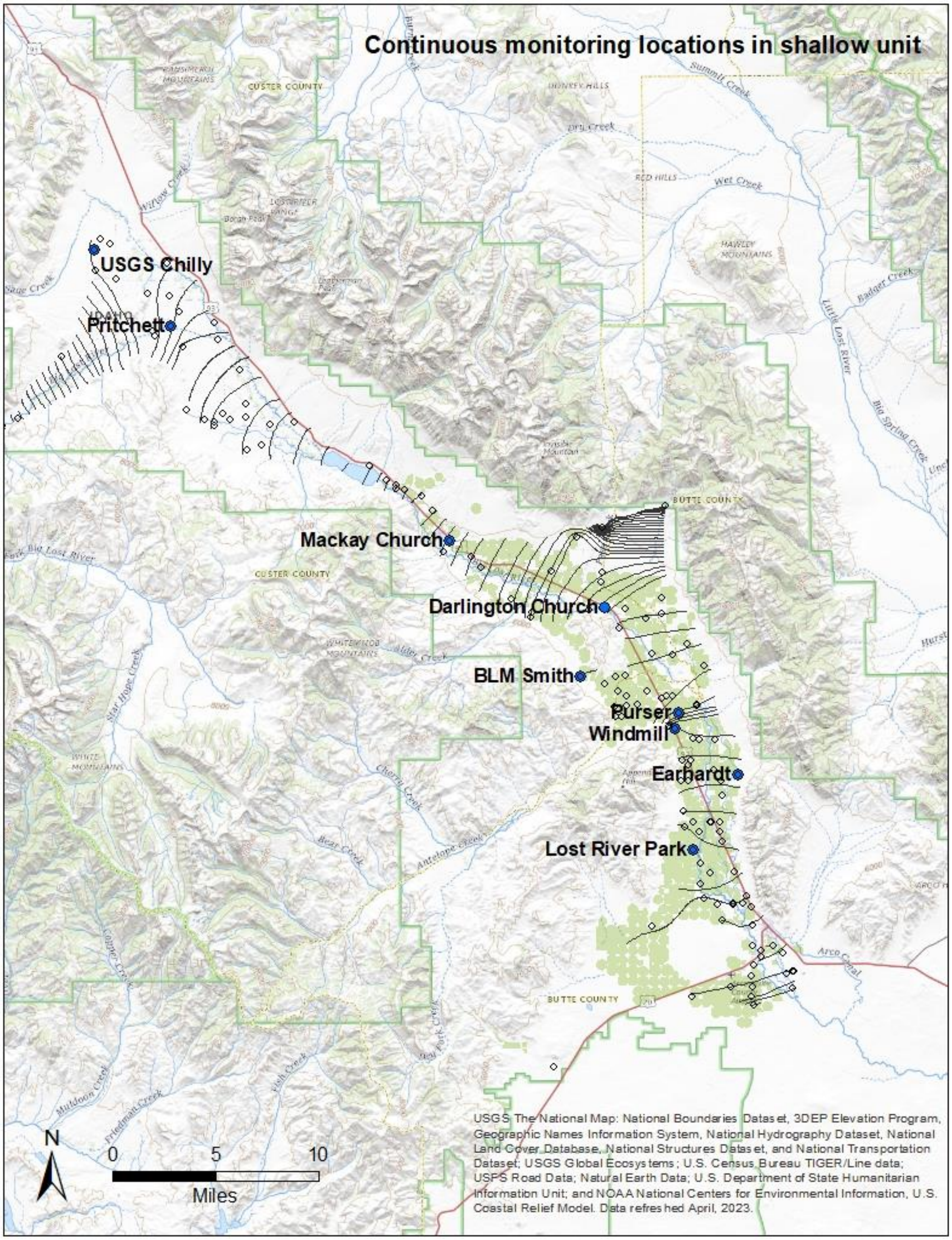
[4] Managed recharge diversions shown on Figure 13 were not included in the total diversions discussed in this paragraph.

Continuous water-level monitoring

As of 2023, IDWR has installed pressure transducers with dataloggers that record water levels at least twice daily in 39 of the 50 wells in the monitoring network. Twenty-one of the wells are shallow monitoring wells installed between 2019 and 2021 to evaluate vertical gradients at seven locations near the Big Lost River (Figure 2). Hydrographs of the vertical gradient observation well groups are provided in Appendix C. The shallow observation well groups included three shallow wells completed to depths of approximately 20 feet, 40 or 50 feet, and 50, 60 or 100 feet. The 20-foot-deep wells were generally dry during part or all of the 2019 to 2023 monitoring period. When water levels declined during 2021 and 2022, some of the deeper wells also went dry for part of the monitoring period. The observed vertical gradients were downward throughout the monitoring period at six of the seven sites.

At the Barnes well group, a slight upward vertical gradient was observed between the 60-foot deep and 40-foot between August 2019 and April 2020, but the vertical gradient transitioned to a downward gradient as water levels declined during the 2020 irrigation season. A downward vertical gradient was observed at the Barnes site between July 2020 and October 2023, even after water levels increased during the 2023 irrigation season. Dudunake and Zinsser (2021) observed the adjacent reach of the Big Lost River between Darlington Road and above the East Side and Moore diversions gained water from the aquifer in March 2019 and October 2019, and lost water to the aquifer in October 2020 and May 2021. The October 2019 observations followed three years of above average surface water supply and below average groundwater pumping, while water years 2020 through 2022 had below average surface water supply and above average groundwater pumping. While water year 2023 had above average surface water supply and low groundwater pumping, the vertical gradient observations at the Barnes well through October 2023 indicate a single season of above average surface water supply and lower groundwater pumping did not result in enough recovery of aquifer storage to restore an upward vertical gradient at this location.

Other wells equipped with continuous monitoring include two wells completed in the shallow aquifer unit above Mackay Reservoir and seven in the shallow aquifer unit below Mackay dam (Figure 16). Hydrographs of continuous monitoring above Mackay Reservoir are shown in Figure 17. Water level in the USGS Chilly well, located approximately 5 miles north of the Big Lost River and 2 miles west of Thousand Springs Creek, responds gradually to annual variations in aquifer recharge with small fluctuations. Water-level elevation may be controlled in part by interaction with Thousand Springs Creek. The Pritchett well, located less than 150 feet south of the Big Lost River, has significantly more fluctuation in water level than the USGS Chilly well. Water-level elevation generally increases during spring runoff, peaks in June, and declines over the summer and winter. During the 2017, 2018, 2019, and 2023 peaks, groundwater elevation was higher in the Pritchett well than in the USGS Chilly well, illustrating how seasonal changes in aquifer stresses and interaction with the Big Lost River can result in seasonal changes in groundwater gradients and flow direction.



USGS The National Map: National Boundaries Dataset, 3DEP Elevation Program, Geographic Names Information System, National Hydrography Dataset, National Land Cover Database, National Structures Dataset, and National Transportation Dataset; USGS Global Ecosystems; U.S. Census Bureau TIGER/Line data; USFS Road Data; Natural Earth Data; U.S. Department of State Humanitarian Information Unit; and NOAA National Centers for Environmental Information, U.S. Coastal Relief Model. Data refreshed April, 2023.

Figure 16. Continuous monitoring locations in shallow aquifer unit

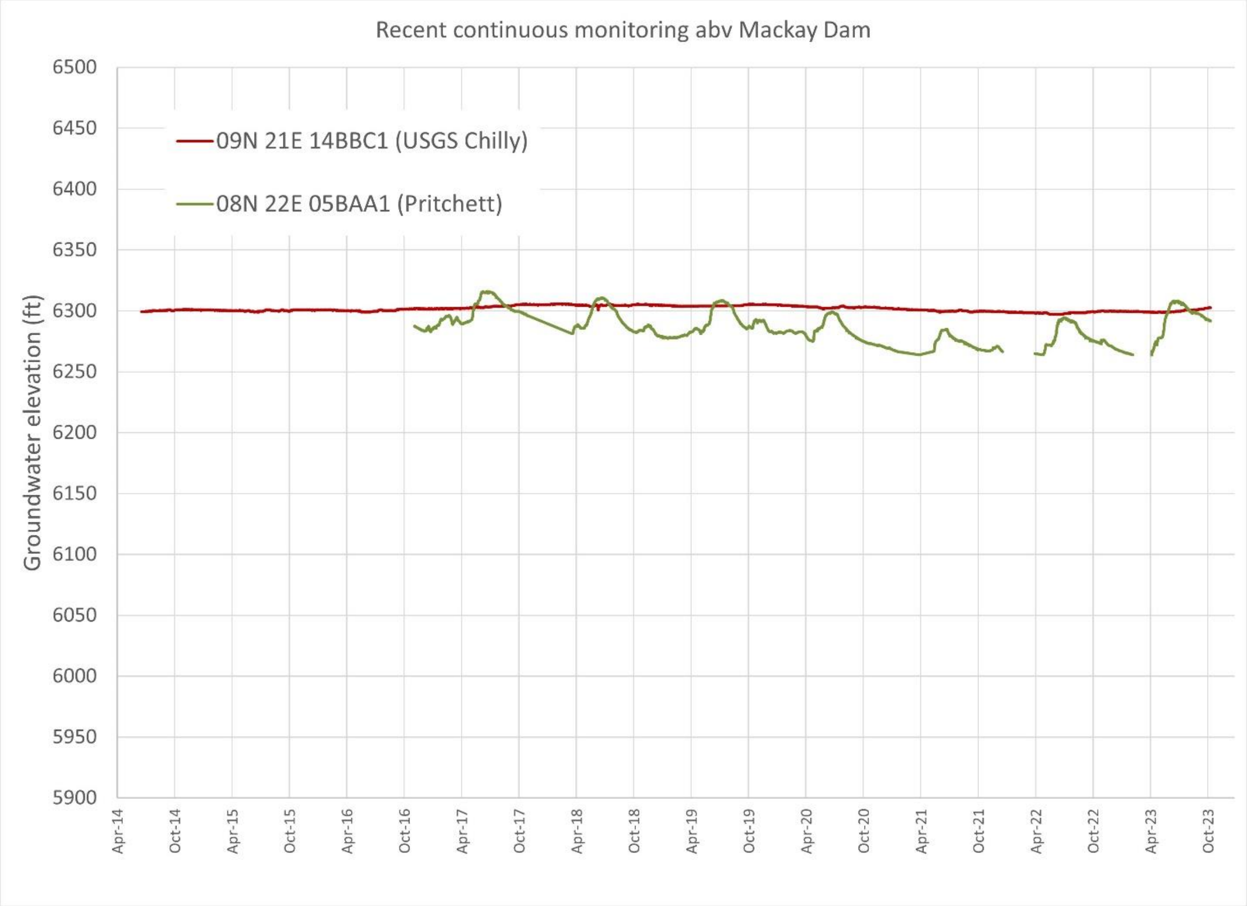


Figure 17. Continuous water-level monitoring above Mackay Reservoir

Hydrographs of continuous monitoring in seven wells completed in the shallow aquifer unit below Mackay Dam are shown in Figure 18. The Mackay Church well is located approximately ½ mile from the Big Lost River between Mackay Dam and Leslie. Zinsser (2021) notes this area is a relatively narrow part of the Big Lost River valley with shallow bedrock. Long-term water-level monitoring and recent continuous monitoring show groundwater elevation fluctuates less in this area than in wells located down-gradient of Leslie, indicating that water-level fluctuations are moderated by interaction with the Big Lost River between Mackay Dam and Leslie. Down-gradient of Leslie, the valley widens and the Big Lost River loses water to the aquifer in the Darlington Sinks. The extent of direct hydraulic connection between the aquifer (the location and length of perched or dry Big Lost River reaches) varies with streamflow and aquifer water level. Long-term groundwater monitoring and recent continuous monitoring show larger fluctuations in groundwater elevation in the shallow aquifer unit down-gradient of Leslie in response to varying aquifer recharge and seasonal groundwater pumping (Figure 18, Darlington Church through River Park wells).

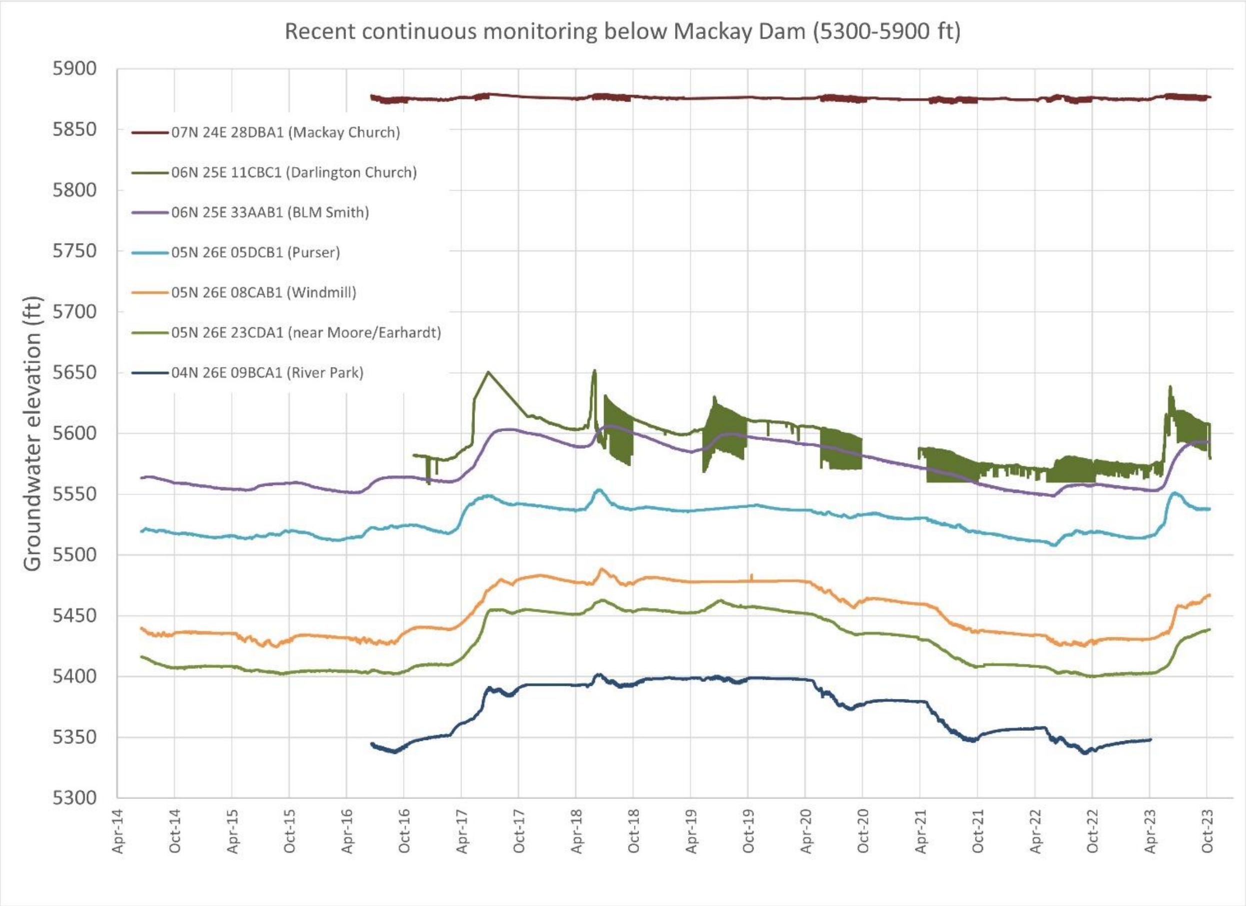


Figure 18. Continuous water-level monitoring in shallow aquifer unit below Mackay Dam

Six wells equipped with continuous monitoring are completed in the intermediate aquifer unit (Figure 19). Hydrographs are shown in Figure 20. The Granite Trust 200 and Trap Club wells are located near the Big Lost River and numerous irrigation wells. Continuous monitoring shows groundwater elevation in this area of the intermediate aquifer unit responds relatively quickly to aquifer recharge during years with higher-than-average surface water supply and to groundwater withdrawals from nearby irrigation wells. The SEP 7 and Hansen wells are located along the margins of the aquifer at the mouth of the Big Lost valley and exhibit less fluctuation in water level and show a gradual response to changes in aquifer recharge and discharge. The BLM South and Telford wells are located adjacent to Lost River Butte at the mouth of the Big Lost Valley and exhibit slightly more fluctuation in water level than the SEP 7 and Hansen wells. The BLM South well shows a gradual response to changes in aquifer recharge and discharge, while water level in the Telford well responds relatively quickly to groundwater pumping in nearby wells during the irrigation season.


Continuous monitoring locations (intermediate unit)

USGS The National Map: National Boundaries Dataset, 3DEP Elevation Program, Geographic Names Information System, National Hydrography Dataset, National Land Cover Database, National Structures Dataset, and National Transportation Dataset; USGS Global Ecosystems; U.S. Census Bureau TIGER/Line data; USFS Road Data; Natural Earth Data; U.S. Department of State Humanitarian Information Unit; and NOAA National Centers for Environmental Information, U.S. Coastal Relief Model. Data refreshed April, 2023.

Figure 19. Continuous water-level monitoring in intermediate aquifer unit

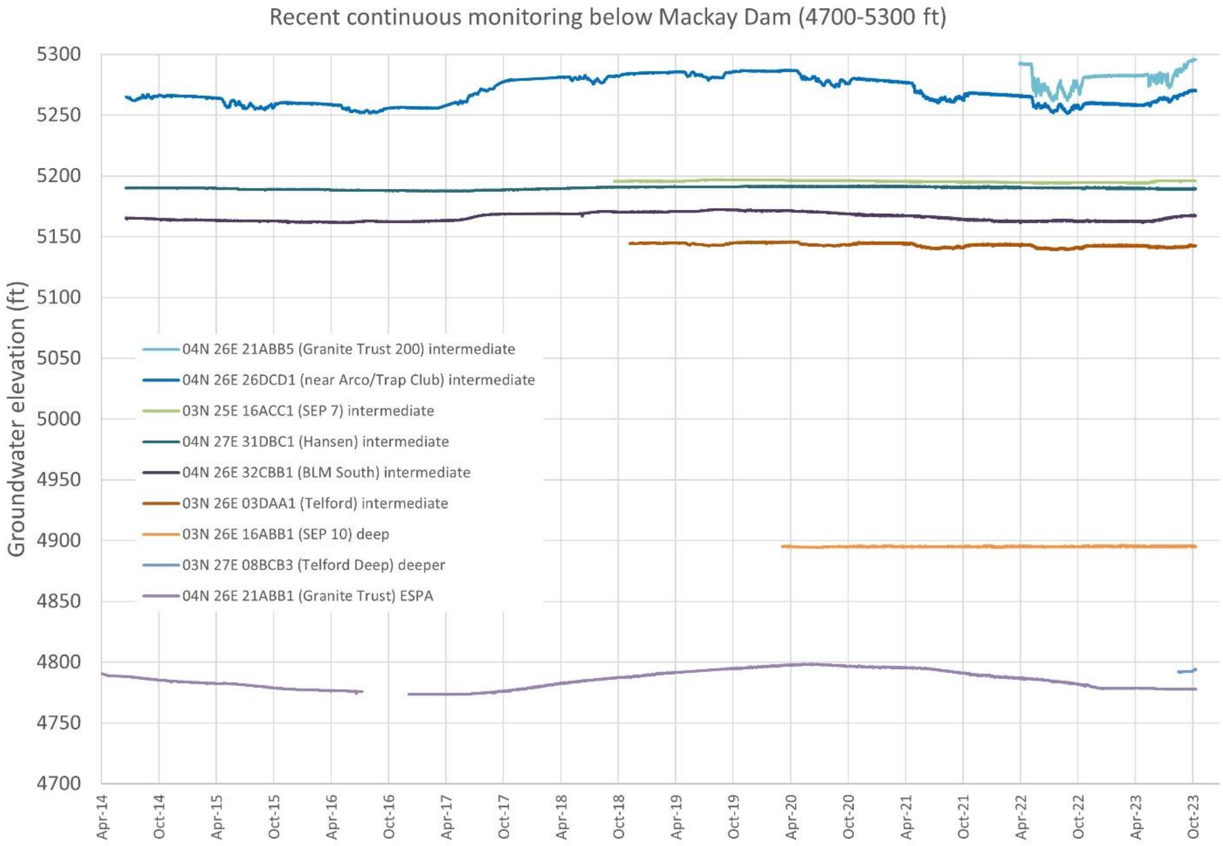
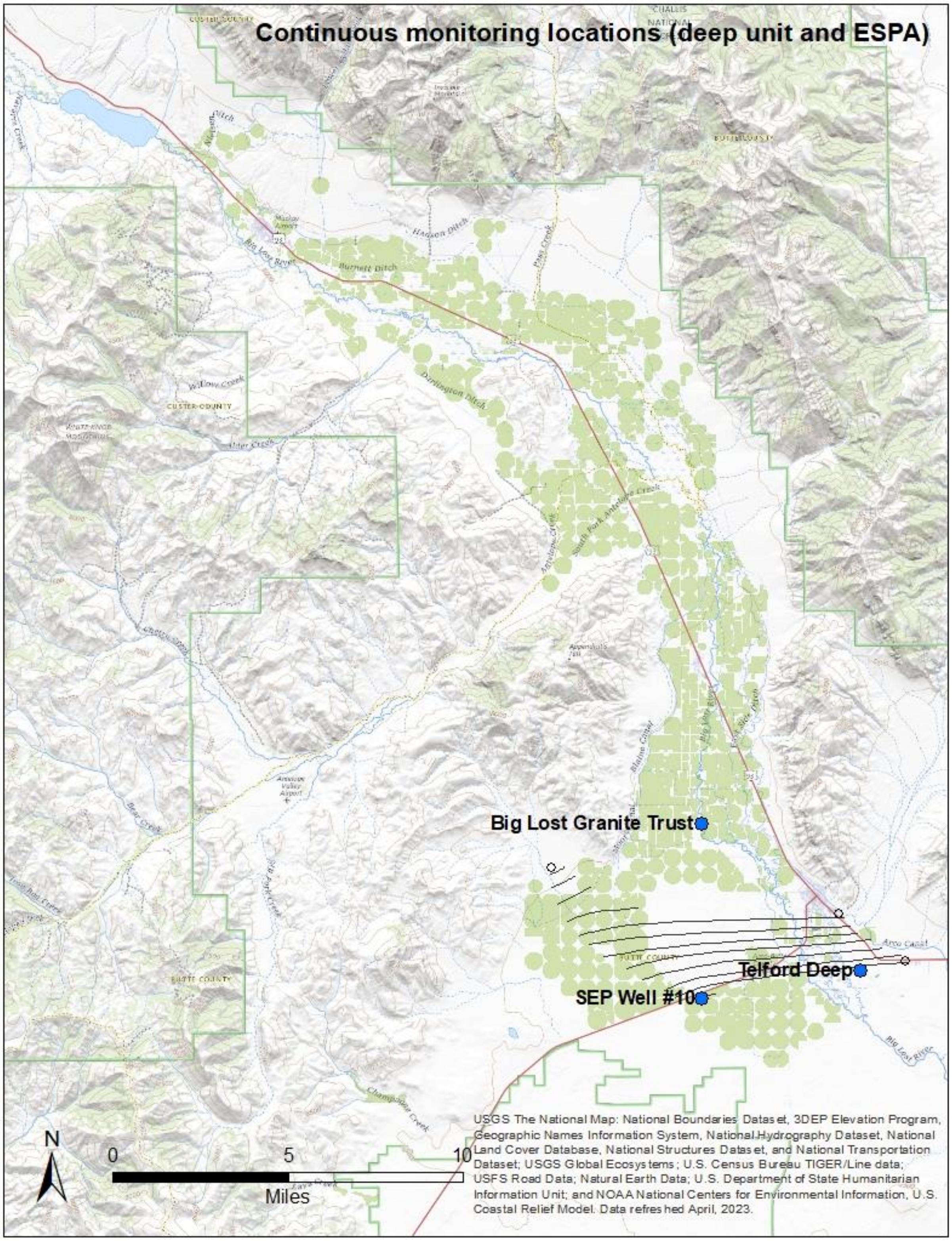


Figure 20. Continuous water-level monitoring in intermediate and deeper aquifer units

Three continuously monitored wells are completed in deeper aquifer units (Figure 21). Hydrographs are shown in Figure 20. One well (SEP 10) is completed in the deep aquifer unit delineated by Ducar and Zinsser (2023). Based on water-level elevations, the Telford Deep well appears to be completed in a deeper aquifer unit overlying the ESPA, and the Granite Trust well appears to be completed in the ESPA. The SEP 10 well exhibited very little fluctuation in water level during the 2020 to 2023 monitoring period. Monitoring of the Telford Deep well began in August 2023 and sufficient data to evaluate water-level fluctuation are not yet available. Groundwater elevation in the Granite Trust well exhibits more fluctuation than in many of the wells located in the intermediate and deep aquifer units near the mouth of the Big Lost valley, but also exhibits a gradual, attenuated response to changes in aquifer recharge and discharge. The water-level response observed in the Granite Trust well suggests a significant portion of the groundwater outflow to the ESPA may occur as downward flow from Big Lost valley aquifer to the ESPA distributed across the lower end of the valley south of road 2900 North.



USGS The National Map: National Boundaries Dataset, 3DEP Elevation Program, Geographic Names Information System, National Hydrography Dataset, National Land Cover Database, National Structures Dataset, and National Transportation Dataset; USGS Global Ecosystems; U.S. Census Bureau TIGER/Line data; USFS Road Data; Natural Earth Data; U.S. Department of State Humanitarian Information Unit; and NOAA National Centers for Environmental Information, U.S. Coastal Relief Model. Data refreshed April, 2023.

Figure 21. Continuous water level monitoring in deeper aquifer units

Conclusions

Water-level trend analyses demonstrate regional water 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 2023, regional water levels below Mackay Dam have declined an average of approximately 0.27 ft/yr. Similar water-level trends were observed in wells located on the Eastern Snake Plain near the mouth of the Big Lost River valley.

Declining water-level trends in individual wells varied from less than 0.1 ft/yr to 0.9 ft/yr. Both long-term water-level monitoring and recent continuous monitoring show groundwater elevation fluctuates less in the area between Mackay Dam and Leslie than in wells located down-gradient of Leslie, indicating that water-level fluctuations are moderated by interaction with the Big Lost River between Mackay Dam and Leslie. The impacts to streamflow in the Big Lost River from groundwater pumping in this area will be more immediate than the impacts to aquifer storage and underflow to the ESPA. Because the Big Lost River loses water to the aquifer downstream of Leslie, reductions in streamflow resulting from pumping up-gradient of Leslie will also impact aquifer recharge and storage down-gradient of Leslie. Down-gradient of Leslie, groundwater pumping will have a more immediate impact on aquifer storage and underflow to the ESPA and a lesser impact on streamflow in the Big Lost River. The Big Lost River Basin groundwater flow model currently being developed by the USGS is expected to provide a valuable tool for analyzing the spatial and temporal distribution of pumping impacts to Big Lost River streamflow, aquifer storage, and underflow to the ESPA.

Prior to the 1980s, aquifer water levels in the Big Lost River valley declined somewhat during drought periods but recovered fully during wet periods. Beginning in the 1980s, water 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 diversions constitute 60% to 75% of total diversions below Mackay Dam during years with low surface water supply. Because surface water diversions typically have higher delivery losses than groundwater diversions, the contribution of groundwater to the crop irrigation requirement during dry years would have been an even higher percentage.

Regional water level declines over several decades demonstrate that long-term aquifer discharge in the Big Lost River valley has exceeded long-term aquifer recharge. Aquifer recharge during wet years has not been sufficient for water levels to recover fully from the use of groundwater to maintain crop consumptive use during dry years. In recent decades, there have been large fluctuations in aquifer storage and aquifer interaction with the Big Lost River. While water levels recover to some extent in response to years with higher surface water supply, periods of recovery have repeatedly been short-lived and followed by substantial decreases in water levels. If recent water management practices continue into future decades, similar fluctuations in water levels and similar impacts to streamflow should be expected in response to future climatic cycles. Without changes in water management and groundwater use, water levels during future droughts can be expected to drop to levels similar to the low levels observed between 2005 and 2023, if not lower.

Recent water-level monitoring and hydrologic studies have provided valuable observations for evaluating these fluctuations and calibrating the Big Lost River Basin groundwater flow model currently being developed by the USGS. Improved estimates of volumetric changes in aquifer storage and groundwater outflow to the ESPA are expected to be available when the USGS model is completed.

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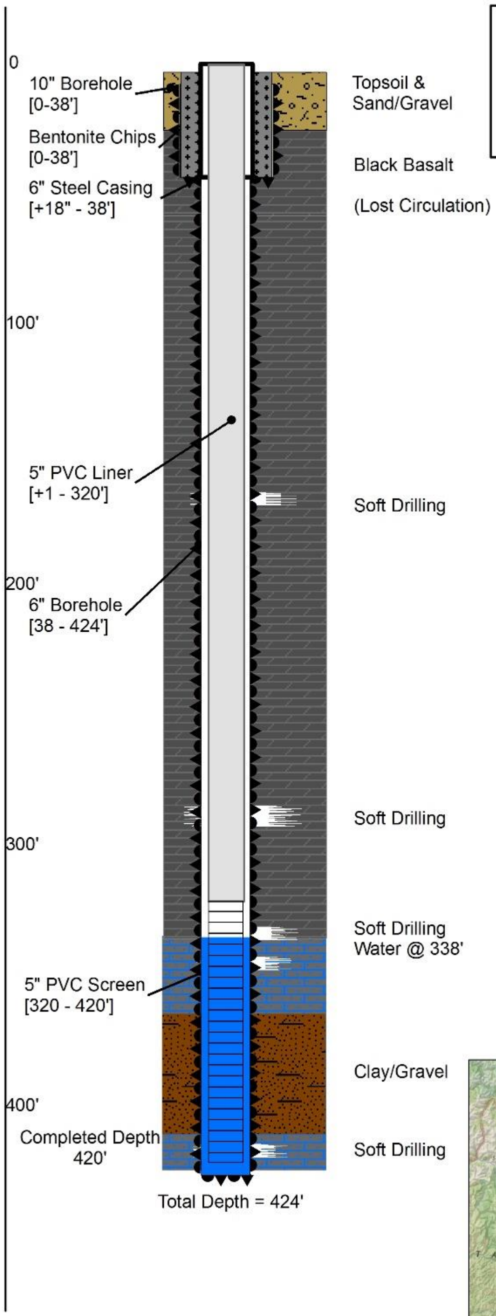
APPENDIX A. WELL CONSTRUCTION LOGS

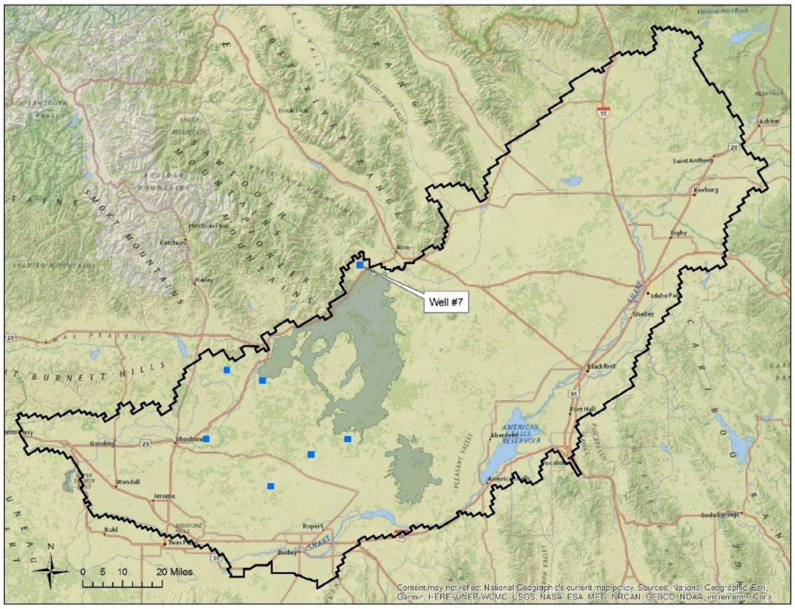
SEP #7 WELL AND TELFORD DEEP WELL

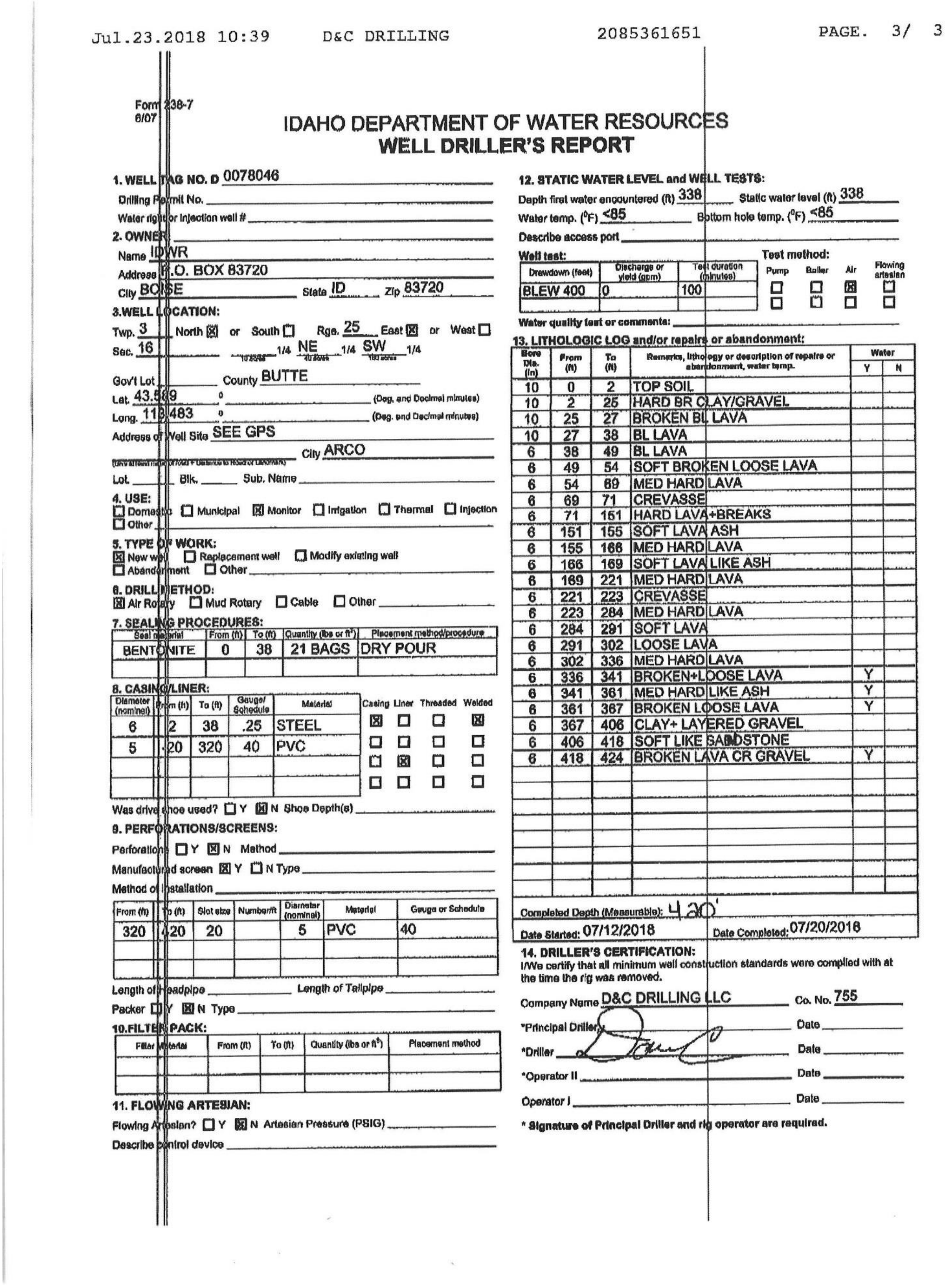


Well #7
03N 25E 16
43.589 -113.483
Start Date: 07/12/2018
End Date: 07/20/2018

Well Tag No. D0078046
County: Butte
Well Location: Blizzard Mountain Road
Well Use: Monitoring

Seal: 3/8 Bentonite Chips (dry pour)
21 bags [0 to 38']
Casing: 6" 0.250" steel
[+18" to 38']
Liner: 5" Schedule 40 PVC
[+20" to 320']
Screen: 5" Schedule 40 PVC
[320 to 420']
Drilling Method: Air Rotary
Well Test: Air (No Return)
DTW = 338'
Driller: D&C Drilling, LLC
Co No. 711





Jul.23.2018 10:39 D&C DRILLING 2085361651 PAGE. 3/ 3

Form 238-7
6/07

IDAHO DEPARTMENT OF WATER RESOURCES
WELL DRILLER'S REPORT

1. WELL TAG NO. D 0078046
Drilling Permit No.
Water right or injection well #

2. OWNER:
Name IDWR
Address P.O. BOX 83720
City BOISE State ID Zip 83720

3.WELL LOCATION:
Twp. 3 North ☒ or South ☐ Rge. 25 East ☒ or West ☐
Sec. 16 1/4 NE 1/4 SW 1/4
10 acres 40 acres 160 acres
Gov't Lot County BUTTE
Lat. 43.5[illegible]9 ° (Deg. and Decimal minutes)
Long. 11[illegible]483 ° (Deg. and Decimal minutes)
Address of Well Site SEE GPS City ARCO
(Give at least name of road + Distance to Road or Landmark)
Lot. Blk. Sub. Name

4. USE:
☐ Domestic ☐ Municipal ☒ Monitor ☐ Irrigation ☐ Thermal ☐ Injection
☐ Other

5. TYPE OF WORK:
☒ New well ☐ Replacement well ☐ Modify existing well
☐ Abandonment ☐ Other

6. DRILL METHOD:
☒ Air Rotary ☐ Mud Rotary ☐ Cable ☐ Other

7. SEALING PROCEDURES:

Seal material	From (ft)	To (ft)	Quantity (lbs or ft³)	Placement method/procedure
BENTONITE	0	38	21 BAGS	DRY POUR

8. CASING/LINER:

Diameter (nominal)	From (ft)	To (ft)	Gauge/ Schedule	Material	Casing	Liner	Threaded	Welded
6	2	38	.25	STEEL	☒	☐	☐	☒
5	20	320	40	PVC	☐	☐	☐	☐
					☐	☒	☐	☐
					☐	☐	☐	☐

Was drive shoe used? ☐ Y ☒ N Shoe Depth(s)

9. PERFORATIONS/SCREENS:
Perforations ☐ Y ☒ N Method
Manufactured screen ☒ Y ☐ N Type
Method of installation

From (ft)	To (ft)	Slot size	Number/ft	Diameter (nominal)	Material	Gauge or Schedule
320	420	20		5	PVC	40

Length of Headpipe Length of Tailpipe
Packer ☐ Y ☒ N Type

10.FILTER PACK:

Filter Material	From (ft)	To (ft)	Quantity (lbs or ft³)	Placement method

11. FLOWING ARTESIAN:
Flowing Artesian? ☐ Y ☒ N Artesian Pressure (PSIG)
Describe control device

12. STATIC WATER LEVEL and WELL TESTS:
Depth first water encountered (ft) 338 Static water level (ft) 338
Water temp. (°F) <85 Bottom hole temp. (°F) <85
Describe access port

Well test:

Drawdown (feet)	Discharge or yield (gpm)	Test duration (minutes)
BLEW 400	0	100

Test method:

Pump	Bailer	Air	Flowing artesian
☐	☐	☒	☐
☐	☐	☐	☐

Water quality test or comments:

13. LITHOLOGIC LOG and/or repairs or abandonment:

Bore Dia. (in)	From (ft)	To (ft)	Remarks, lithology or description of repairs or abandonment, water temp.	Water Y	Water N
10	0	2	TOP SOIL		
10	2	25	HARD BR CLAY/GRAVEL		
10	25	27	BROKEN BL LAVA		
10	27	38	BL LAVA		
6	38	49	BL LAVA		
6	49	54	SOFT BROKEN LOOSE LAVA		
6	54	69	MED HARD LAVA		
6	69	71	CREVASSE		
6	71	161	HARD LAVA+BREAKS		
6	151	155	SOFT LAVA ASH		
6	155	166	MED HARD LAVA		
6	166	169	SOFT LAVA LIKE ASH		
6	169	221	MED HARD LAVA		
6	221	223	CREVASSE		
6	223	284	MED HARD LAVA		
6	284	291	SOFT LAVA		
6	291	302	LOOSE LAVA		
6	302	336	MED HARD LAVA		
6	336	341	BROKEN+LOOSE LAVA	Y	
6	341	361	MED HARD LIKE ASH	Y	
6	361	367	BROKEN LOOSE LAVA	Y	
6	367	406	CLAY+ LAYERED GRAVEL		
6	406	418	SOFT LIKE SANDSTONE		
6	418	424	BROKEN LAVA CR GRAVEL	Y	

Completed Depth (Measurable): 420'
Date Started: 07/12/2018 Date Completed: 07/20/2018

14. DRILLER'S CERTIFICATION:
I/We certify that all minimum well construction standards were complied with at the time the rig was removed.

Company Name D&C DRILLING LLC Co. No. 755
*Principal Driller Date
*Driller Date
*Operator II Date
Operator I Date

*** Signature of Principal Driller and rig operator are required.**

Form 238-7
6/07

IDAHO DEPARTMENT OF WATER RESOURCES
WELL DRILLER'S REPORT

1. WELL TAG NO. D 0081297
Drilling Permit No. D0081297
Water right or injection well # 34-2277

2. OWNER: Mike Telford
Name Mike Telford
Address 1450 w Hwy 24
City Paul State Idaho Zip 83347

3.WELL LOCATION:
Twp. 03 North ☒ or South ☐ Rge. 27 East ☒ or West ☐
Sec. 8 ____ 1/4 (10 acres) sw 1/4 (40 acres) nw 1/4 (160 acres)
Gov't Lot ____ County Butte
Lat. 43 ° 36.3414 (Deg. and Decimal minutes)
Long. 113 ° 16.5774 (Deg. and Decimal minutes)
Address of Well Site Corner of 2300 N. 2900 W.
(Give at least name of road + Distance to Road or Landmark) City Butte City, Arco
Lot. ____ Blk. ____ Sub. Name ____

4. USE:
☐ Domestic ☐ Municipal ☐ Monitor ☒ Irrigation ☐ Thermal ☐ Injection
☐ Other ____

5. TYPE OF WORK:
☐ New well ☒ Replacement well ☐ Modify existing well
☐ Abandonment ☐ Other ____

6. DRILL METHOD:
☒ Air Rotary ☐ Mud Rotary ☒ Cable ☐ Other ____

7. SEALING PROCEDURES:

Seal material	From (ft)	To (ft)	Quantity (lbs or ft³)	Placement method/procedure
Cement	0	145	10 yrds	tremie, pump

8. CASING/LINER:

Diameter (nominal)	From (ft)	To (ft)	Gauge/ Schedule	Material	Casing	Liner	Threaded	Welded
20	+2'	288	.250	steel	☒	☐	☐	☒
18	590	662	.375	steel	☒	☐	☐	☒
					☐	☐	☐	☐
					☐	☐	☐	☐

Was drive shoe used? ☒ Y ☐ N Shoe Depth(s) 288

9. PERFORATIONS/SCREENS:
Perforations ☐ Y ☒ N Method ____
Manufactured screen ☐ Y ☒ N Type ____
Method of installation ____

From (ft)	To (ft)	Slot size	Number/ft	Diameter (nominal)	Material	Gauge or Schedule

Length of Headpipe ____ Length of Tailpipe ____
Packer ☐ Y ☒ N Type ____

10.FILTER PACK:

Filter Material	From (ft)	To (ft)	Quantity (lbs or ft³)	Placement method

11. FLOWING ARTESIAN:
Flowing Artesian? ☐ Y ☒ N Artesian Pressure (PSIG) ____
Describe control device ____

12. STATIC WATER LEVEL and WELL TESTS:
Depth first water encountered (ft) 8' Static water level (ft) 440
Water temp. (⁰F) cold Bottom hole temp. (⁰F) cold
Describe access port ____

Well test:

Drawdown (feet)	Discharge or yield (gpm)	Test duration (minutes)
	400 gpm	

Test method:

Pump	Bailer	Air	Flowing artesian
☒	☐	☐	☐
☐	☐	☐	☐

Water quality test or comments: ____

13. LITHOLOGIC LOG and/or repairs or abandonment:

Bore Dia. (in)	From (ft)	To (ft)	Remarks, lithology or description of repairs or abandonment, water temp.	Water Y	Water N
24"	0	5	soil		n
	5	15	course sand, large gravel	y	
	15	30	course sand and pea gravel	y	
	30	45	sandy clay	y	
	45	61	course sand	y	
	61	75	course sand and clay	y	
	75	84	course sand and pea gravel	y	
	84	102	sandy clay	y	
	102	108	clay		n
	108	145	basalt	y	
20	145	220	sandy clay	y	
	220	240	sand and pea gravel	y	
	240	288	sandy clay		n
	288	330	caving basalt (cemented)		n
	330	439	basalt		n
	439	595	basalt with small fractures	y	
	595	630	red ash sand and clay	y	
	630	640	sand and gravel	y	
18	640	662	sandy clay	y	
	662	800	Basalt with some small fractures	y	

Completed Depth (Measurable): 800
Date Started: 10-20-19 Date Completed: 3-30-2020

14. DRILLER'S CERTIFICATION:
I/We certify that all minimum well construction standards were complied with at the time the rig was removed.
Company Name Vollmer Well Drilling Co. No. 383
*Principal Driller ____ Date 4-13-2020
*Driller ____ Date ____
*Operator II ____ Date ____
Operator I ____ Date ____

*** Signature of Principal Driller and rig operator are required.**

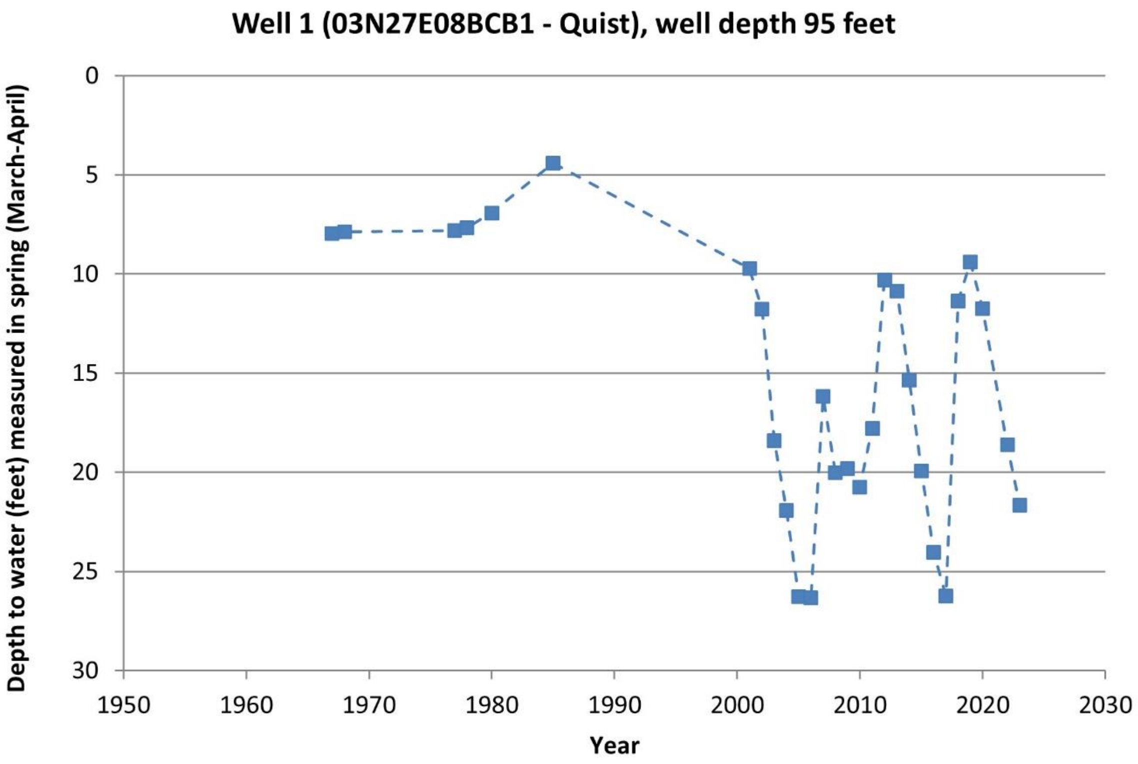
APPENDIX B. WATER-LEVEL TREND ANALYSES AND HYDROGRAPHS

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

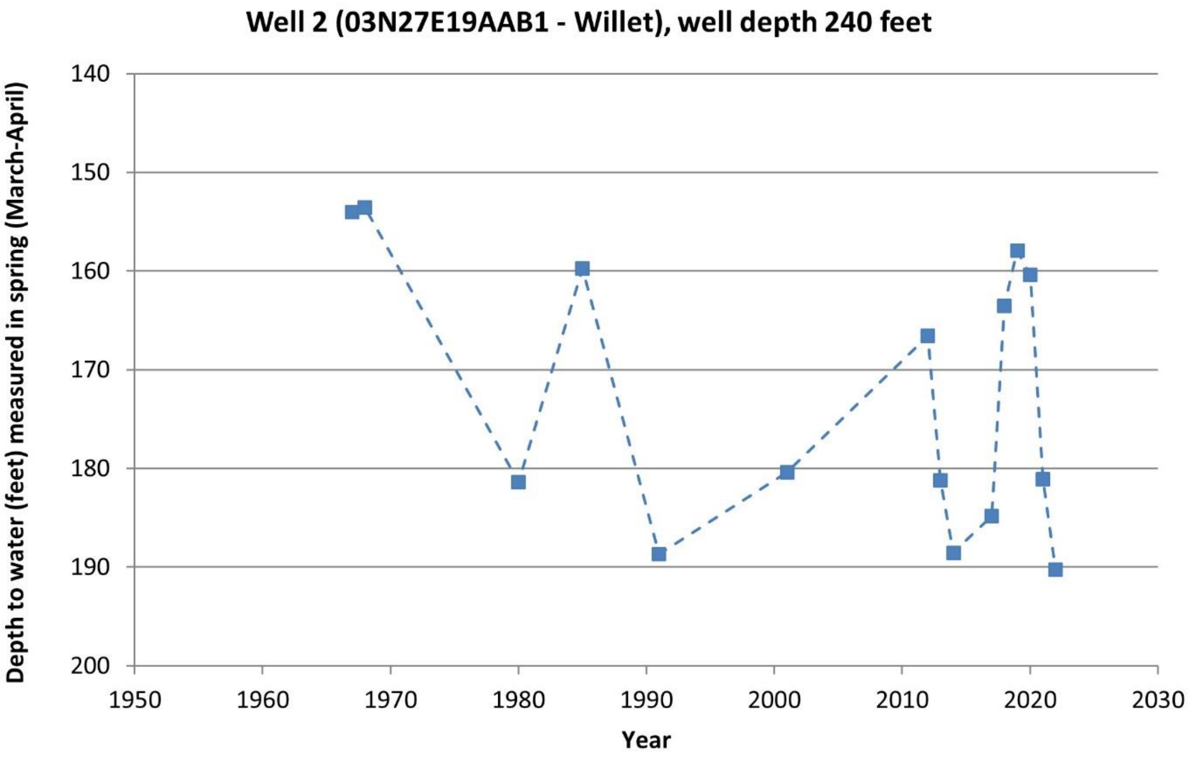
Well(s)	Water-level trend (ft/yr)	p-value	Statistical significance	Well name
network wells				
1 well above dam, 1967-1977	0.1150	0.0073	significant at p<0.05	
19 wells blw dam, 1950-1977	0.0894	0.0005	significant at p<0.05	
14 wells, shallow, 1950-1977	0.1269	0.0230	significant at p<0.05	
5 wells, intermediate, 1950-1977	0.0683	0.0056	significant at p<0.05	
5 ESPA wells, 1951-1977	0.0667	0.0326	significant at p<0.05	
2 wells abv dam, 1977-2023	-0.0935	0.0001	significant at p<0.05	
26 wells blw dam, 1977-2023	-0.2743	0.0000	significant at p<0.05	
16 wells, shallow, 1977-2023	-0.2400	0.0000	significant at p<0.05	
8 wells, intermediate, 1977-2023	-0.2524	0.0000	significant at p<0.05	
5 ESPA wells, 1977-2023	-0.2756	0.0000	significant at p<0.05	
network wells plus synoptic wells				
11 wells abv dam, 1967-1977	0.1375	0.0015	significant at p<0.05	
16 wells abv dam, 1977-2023	-0.0972	0.0000	significant at p<0.05	
66 wells blw dam, 1977-2023	-0.2819	0.0000	significant at p<0.05	
shallow wells above Mackay Reservoir				
09N21E14BBC1 (23), 1977-2023	-0.0911	0.0001	significant at p<0.05	USGS Chilly
08N22E05BAA1 (31), 2017-2023	-4.6360	0.0163	significant at p<0.05, short-term	Pritchett
shallow wells below Mackay Reservoir				
07N24E28DBA1 (21), 1985-2023	-0.0547	0.0079	significant at p<0.05	Mackay Church
07N24E35CCD1 (22), 1980-2023	-0.0325	0.0220	significant at p<0.05	Magee
06N25E03AAA1 (16), 1977-2023	-0.2354	0.0000	significant at p<0.05	Sayer
06N25E11CBC1 (32), 2016-2023	-1.0750	0.9015	not significant, short-term	Darlington Church
06N25E18ABB1 (18), 1980-2023	-0.0396	0.0271	significant at p<0.05	Goff
06N25E13CAB1 (17), 1980-2016	-0.6161	0.0095	significant at p<0.05	discontinued
06N25E33AAB1 (19), 1980-2023	-0.6509	0.0224	significant at p<0.05	BLM Smith
05N25E11BAA1 (11), 1999-2023	0.1572	0.9102	not significant	Pioneer
05N26E05DCB1 (12), 1985-2023	-0.2900	0.0090	significant at p<0.05	Purser
05N26E08CAB1 (13), 1985-2023	-0.8929	0.0447	significant at p<0.05	Windmill
05N26E23CDA1 (14), 1977-2023	-0.8159	0.0000	significant at p<0.05	Earhardt
05N26E32DBA1 (15), 1985-2023	-0.7738	0.0725	significant at p<0.10	Babcock
04N26E04BBA1 (4), 1980-2023	-0.6576	0.0878	significant at p<0.10	Haney
04N26E09BCA1 (5), 2015-2023	0.8857	1.0000	not significant, short-term	River Park
04N26E16ABB1 (6), 1980-2023	-0.1849	0.7614	not significant	Perkes
03N27E08BCB1 (1), 1977-2023	-0.1767	0.1029	significant at p<0.15	Quist

Well(s)	Water-level trend (ft/yr)	p-value	Statistical significance	Well name
intermediate wells below Mackay Reservoir				
04N26E21ABB5 (37), 2022-2023	-9.5960	1.0000	not significant, short-term	Granite Trust 200
04N26E26DCD1 (8), 1977-2023	-0.5193	0.0000	significant at p<0.05	Trap Club
04N26E32CBB1 (9), 1977-2023	-0.2250	0.0000	significant at p<0.05	BLM South
04N27E31DBC1 (10), 1980-2023	-0.0004	1.0000	not significant	Hansen
03N26E03DAA1 (35), 1991-2023	-0.1584	0.0195	significant at p<0.05	Telford
03N25E16ACC1 (33), 2019-2023	-0.4217	0.0864	significant at p<0.10, short-term	SEP Well #7
03N27E19AAB1 (2), 1980-2022	0.0051	0.9514	not significant	Willet
03N27E19ABB1 (3), 1980-2023	-0.4280	0.1648	significant at p<0.20	McDonald
deep wells below Mackay Reservoir				
03N26E16ABB1 (34), 2020-2023	0.0435	1.0000	not significant, short-term	SEP Well #10
03N27E08BCB3 (36)			data collection started 8/2023	Telford Deep
Big Lost network well in ESPA				
04N26E21ABB1 (7), 1977-2023	-0.6068	0.0000	significant at p<0.05	Granite Trust
ESPA wells south of Big Lost network				
02N26E22DDA2 (26), 1977-2023	-0.2353	0.0000	significant at p<0.05	
02N27E02DDC1 (27), 1977-2023	-0.2134	0.0000	significant at p<0.05	
03N29E19CBB1 (28), 1977-2023	-0.3182	0.0000	significant at p<0.05	
02N27E33ACC2 (29), 1982-2023	-0.2637	0.0000	significant at p<0.05	
02N28E21BBB1 (30), 1977-2023	-0.2800	0.0000	significant at p<0.05	

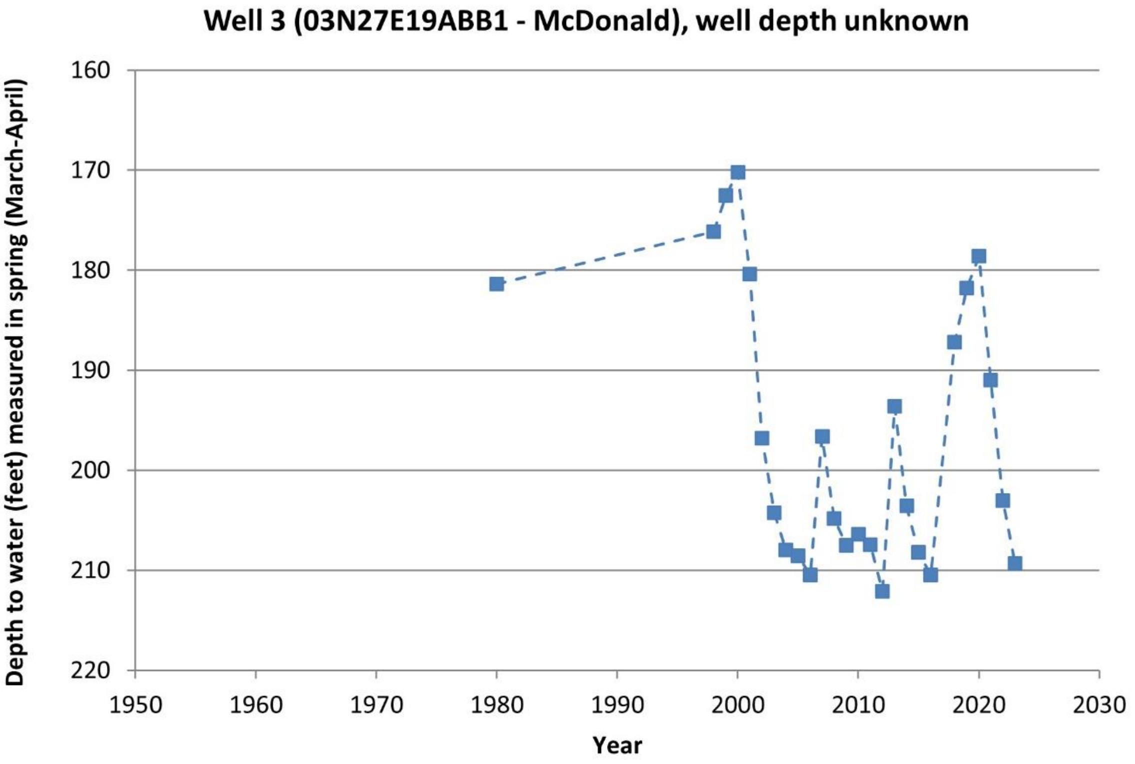
Note: Wells 24 and 25 from the 2017 analysis are not part of the monitoring network, but were included in the synoptic wells for this analysis.

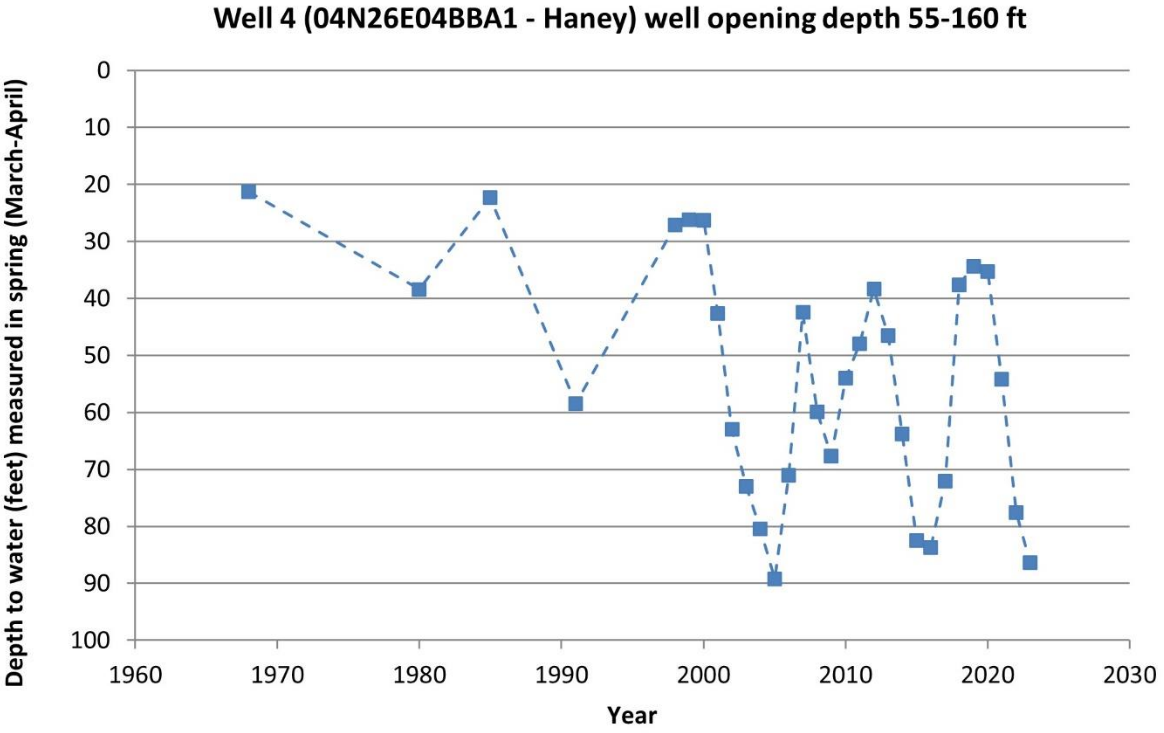


Well 1 (03N27E08BCB1 - Quist), well depth 95 feet

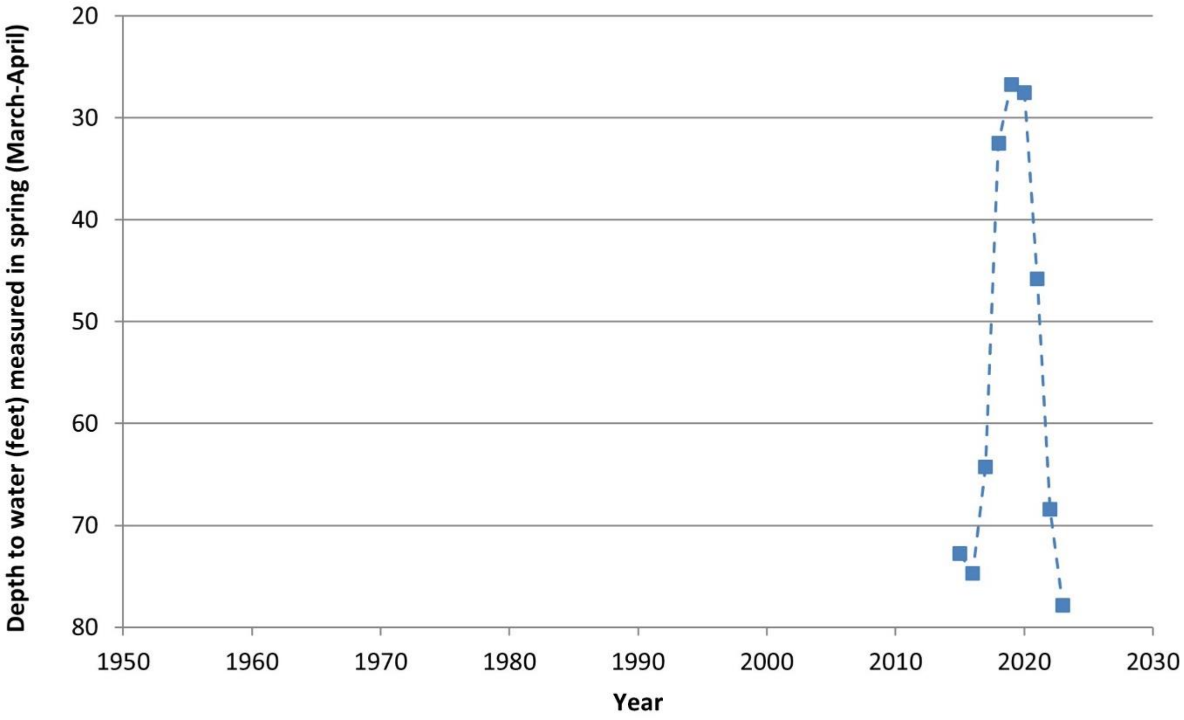


Well 2 (03N27E19AAB1 - Willet), well depth 240 feet

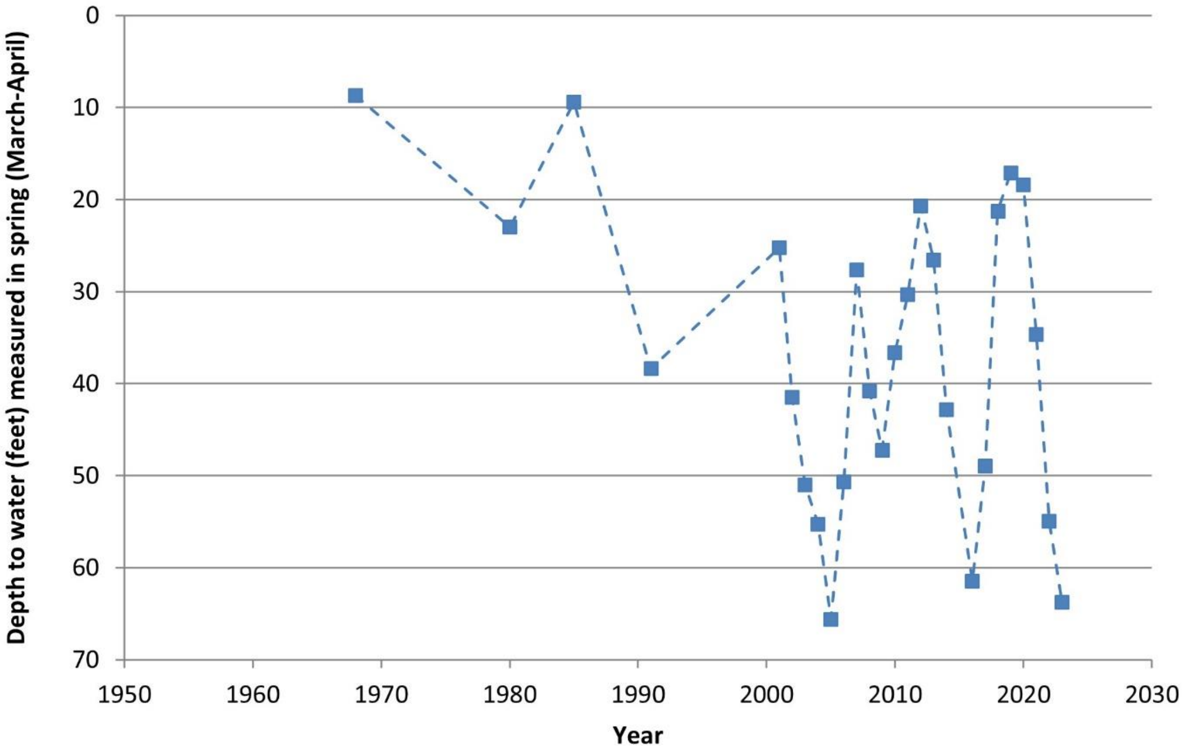

Well 3 (03N27E19ABB1 - McDonald), well depth unknown
Depth to water (feet) measured in spring (March-April)
160
170
180
190
200
210
220
1950
1960
1970
1980
1990
2000
2010
2020
2030
Year

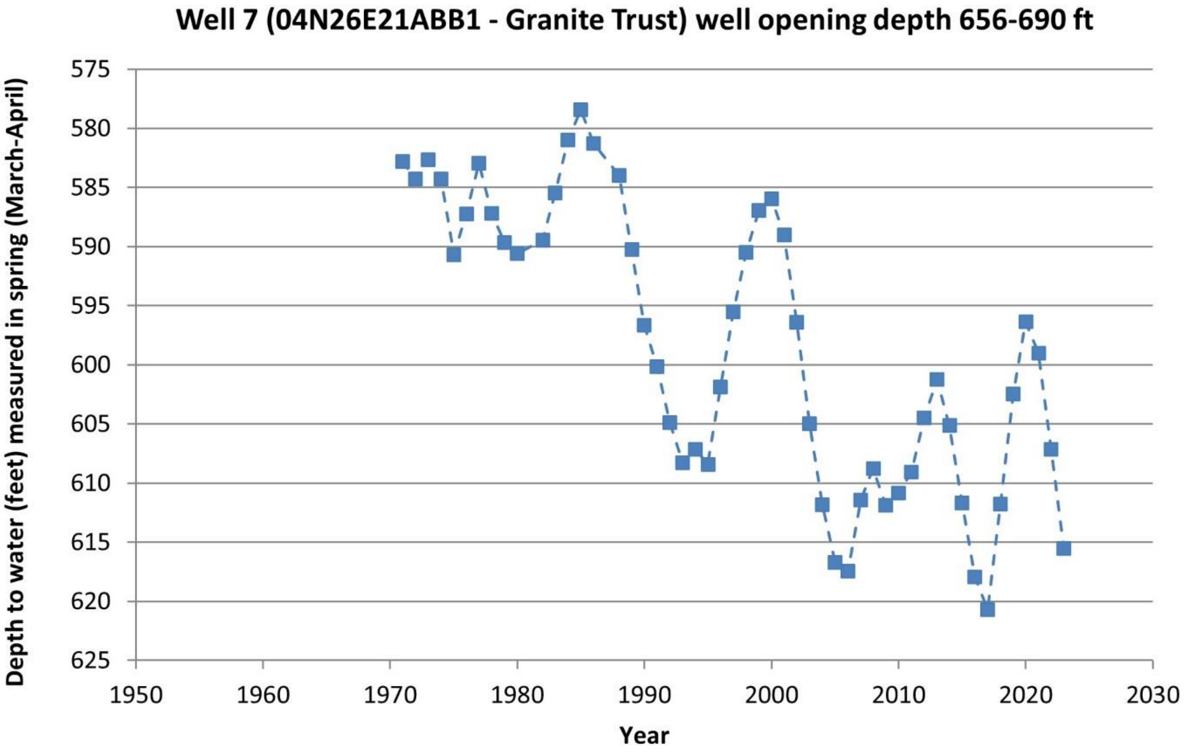

Well 4 (04N26E04BBA1 - Haney) well opening depth 55-160 ft
Depth to water (feet) measured in spring (March-April)
0
10
20
30
40
50
60
70
80
90
100
1960
1970
1980
1990
2000
2010
2020
2030
Year

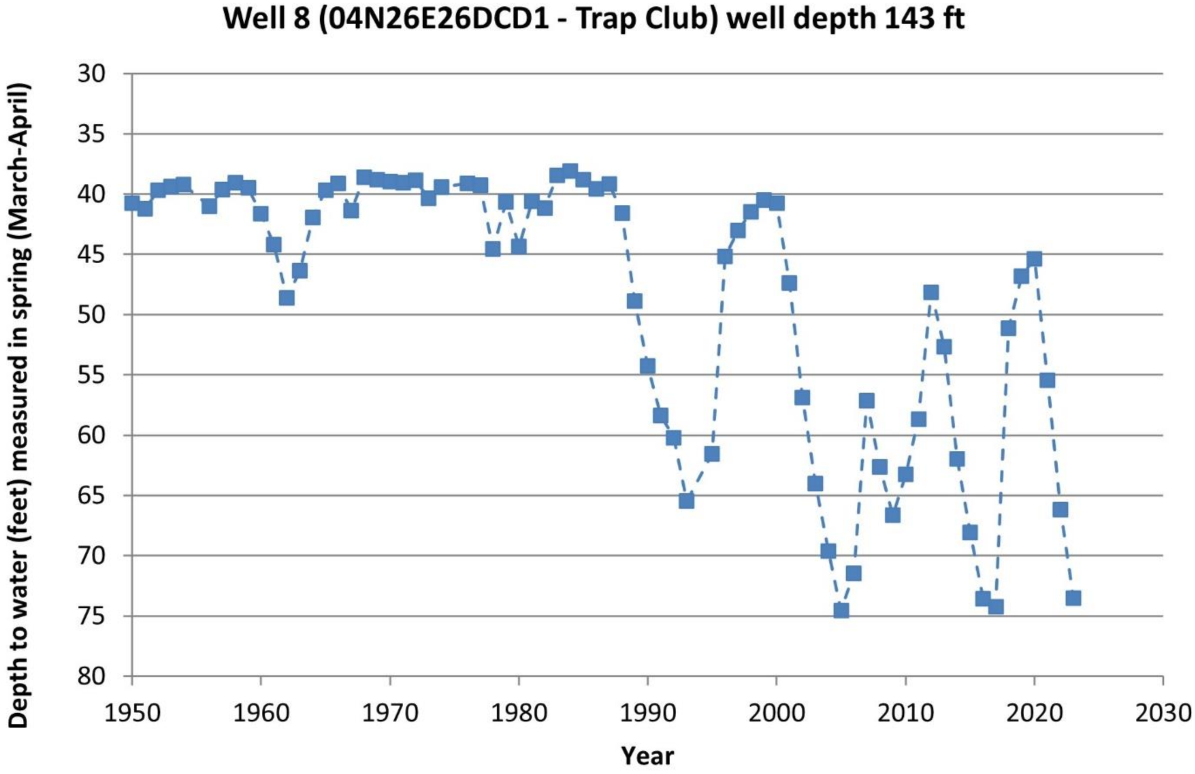
Well 5 (04N26E09BCA1 - Lost River Park), well opening depth 65-95 ft

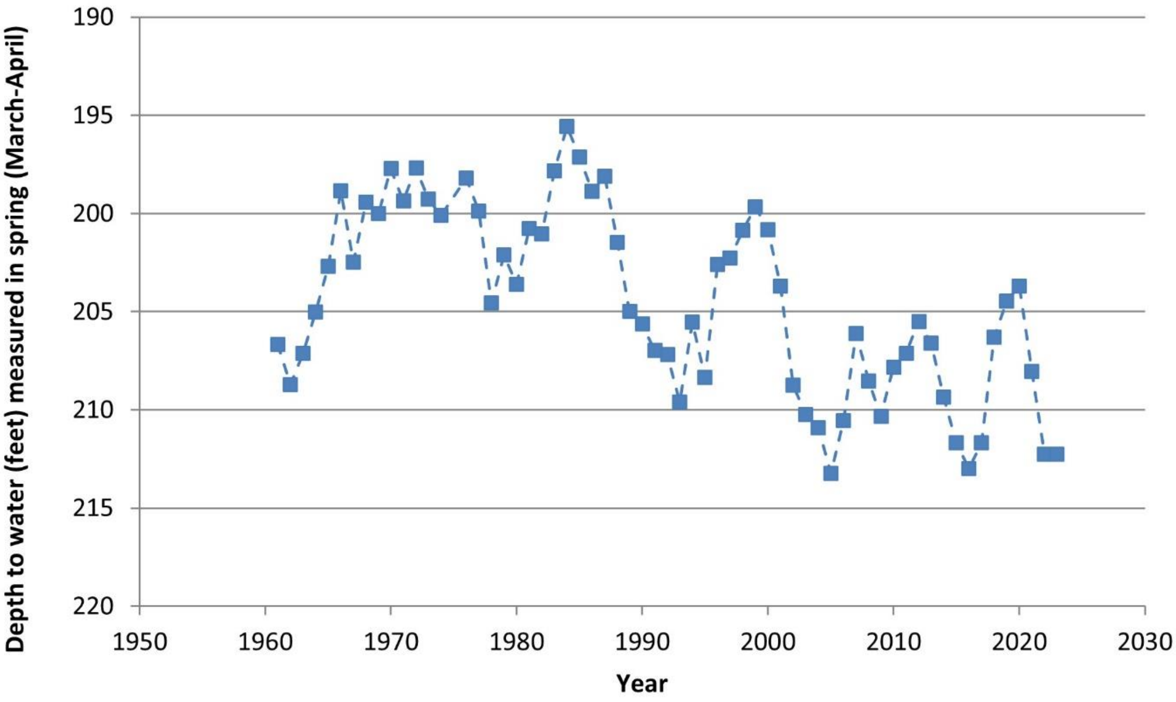


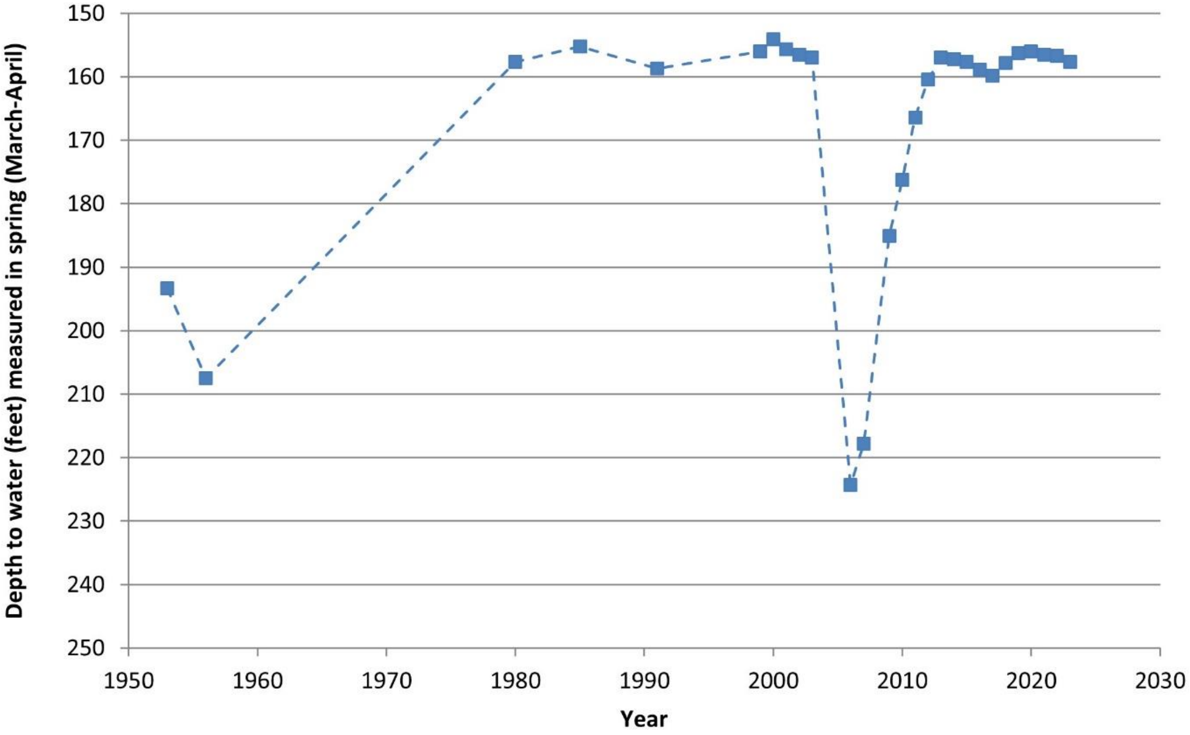
Well 6 (04N26E16ABB1 - Perkes) well opening depth 36-139 ft

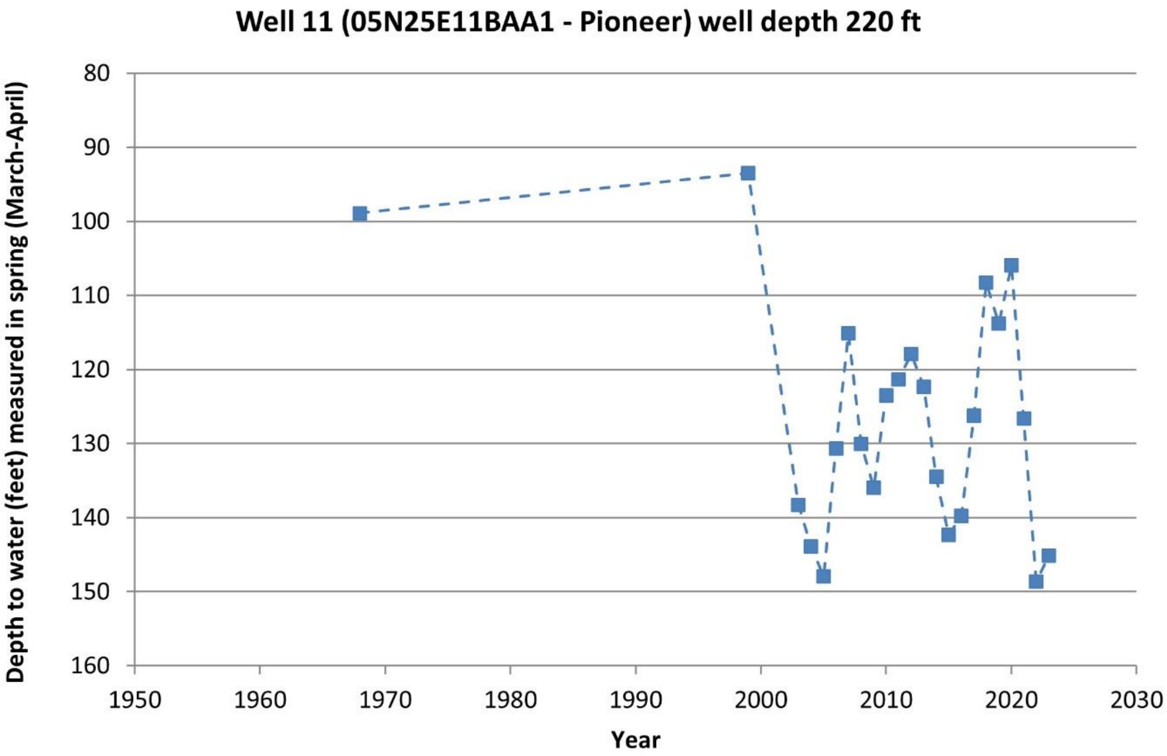


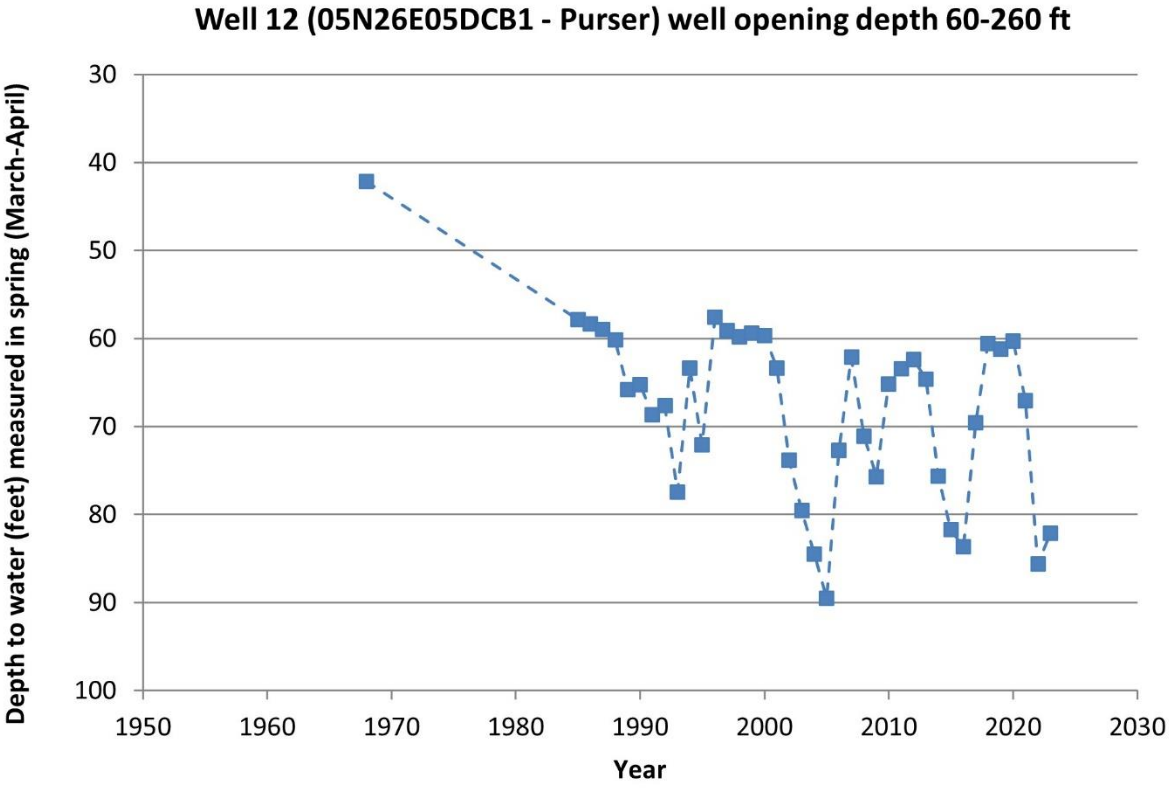

Well 7 (04N26E21ABB1 - Granite Trust) well opening depth 656-690 ft
Depth to water (feet) measured in spring (March-April)
575
580
585
590
595
600
605
610
615
620
625
1950
1960
1970
1980
1990
2000
2010
2020
2030
Year

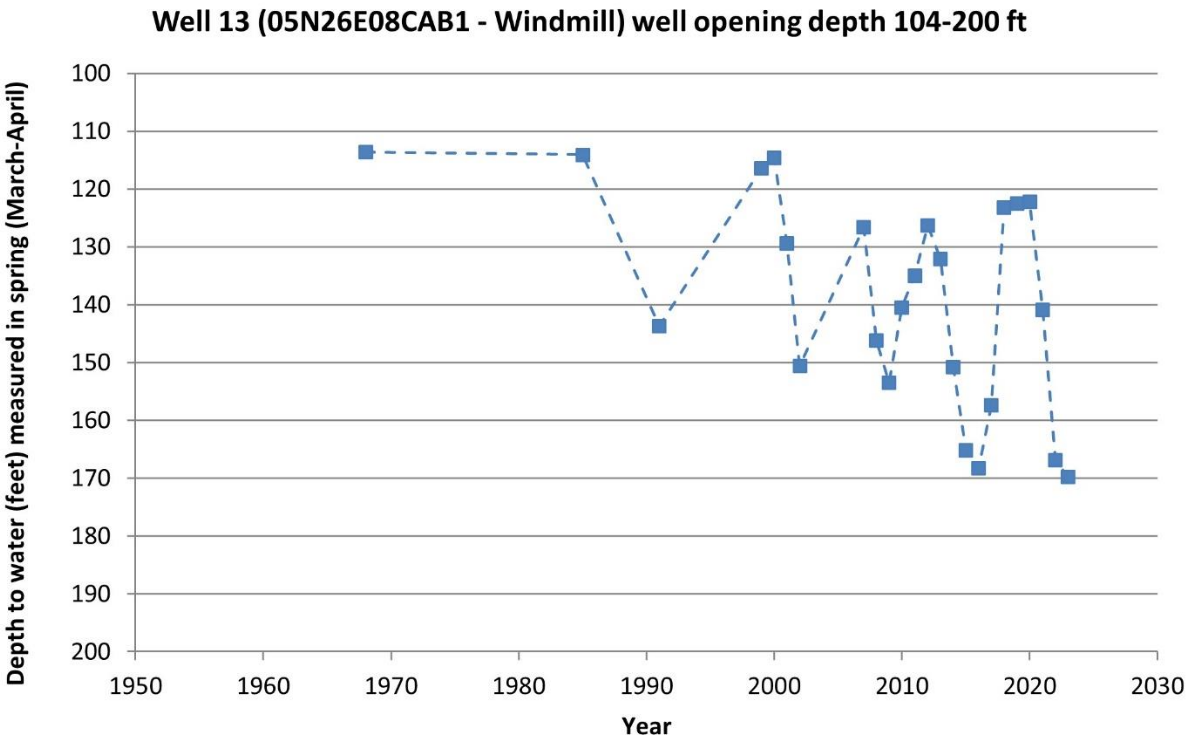

Well 8 (04N26E26DCD1 - Trap Club) well depth 143 ft
Depth to water (feet) measured in spring (March-April)
30
35
40
45
50
55
60
65
70
75
80
1950
1960
1970
1980
1990
2000
2010
2020
2030
Year

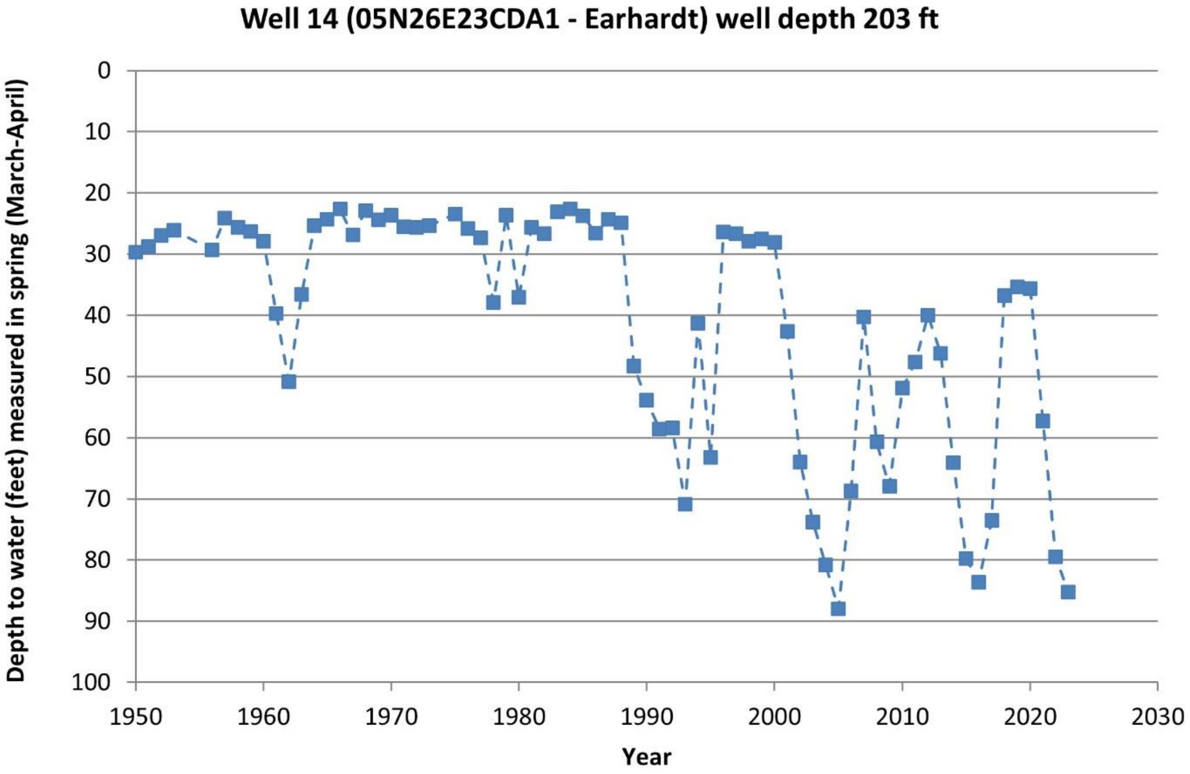

Well 9 (04N26E32CBB1 - BLM South) well opening depth 206-253 ft

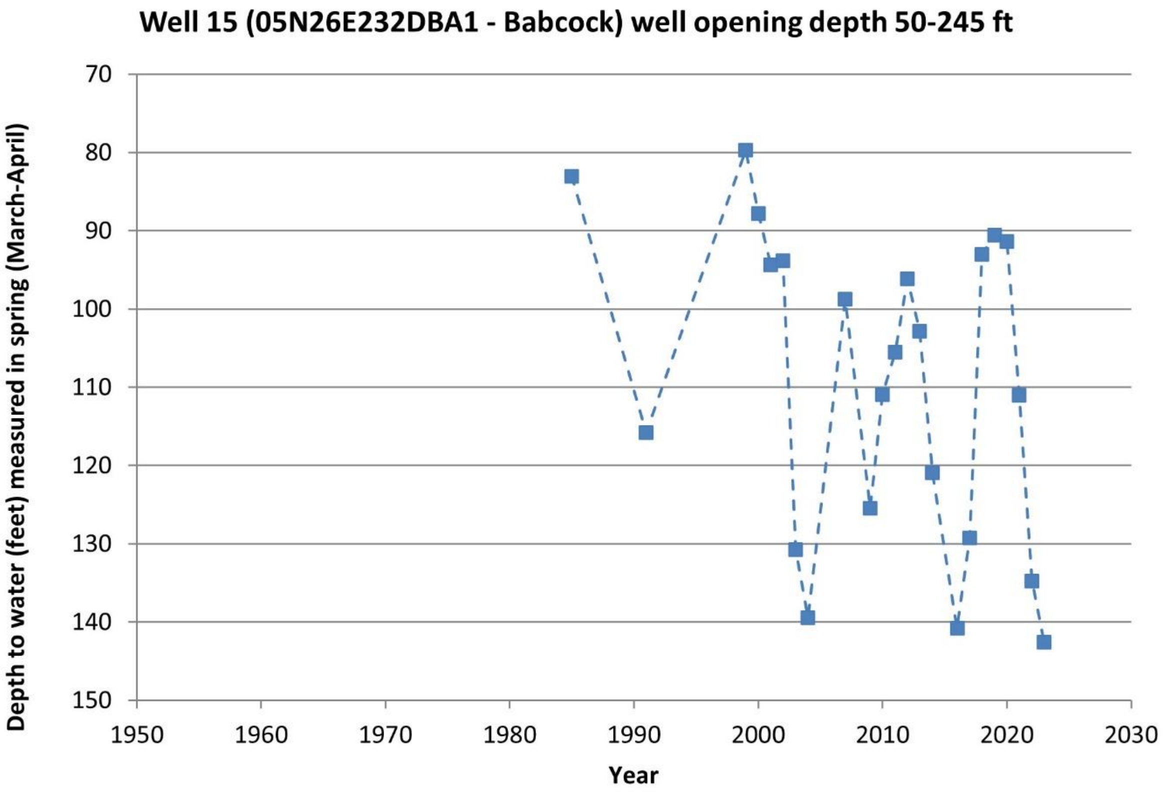

Well 10 (04N27E31DBC1 - Hansen) well opening depth 138-227 ft

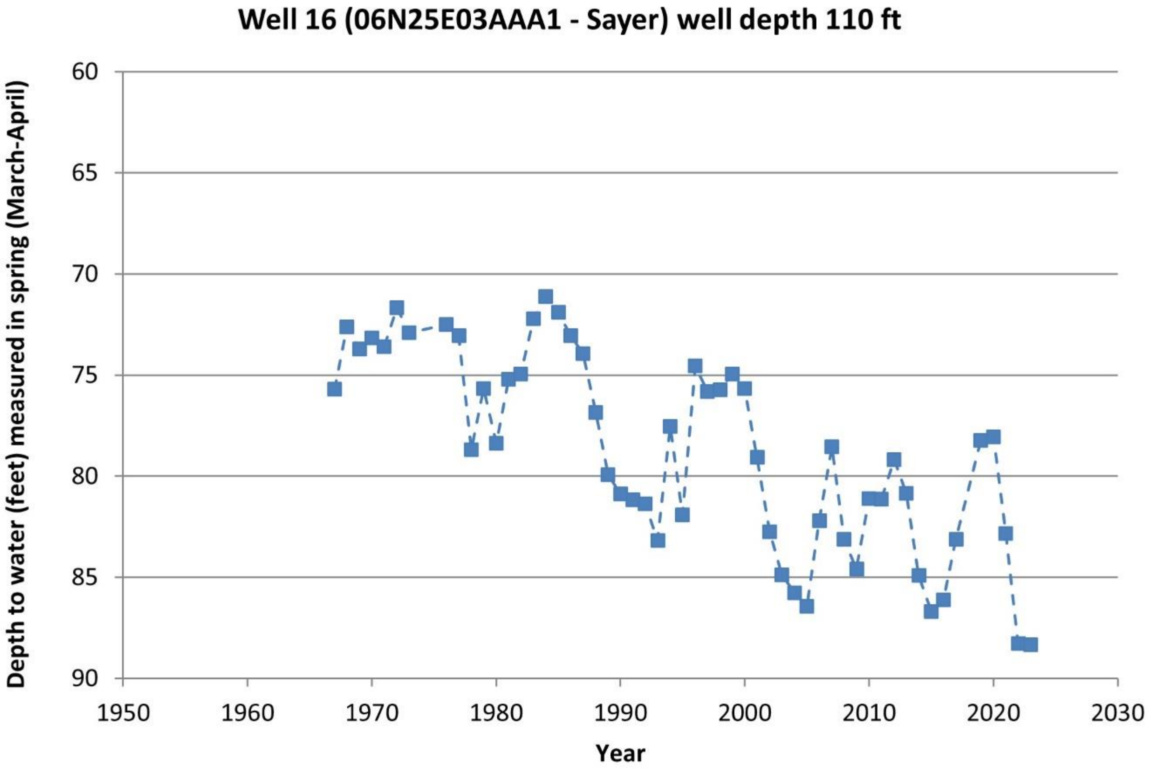

Well 11 (05N25E11BAA1 - Pioneer) well depth 220 ft
Depth to water (feet) measured in spring (March-April)
80
90
100
110
120
130
140
150
160
1950
1960
1970
1980
1990
2000
2010
2020
2030
Year


Well 12 (05N26E05DCB1 - Purser) 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
2030
Year

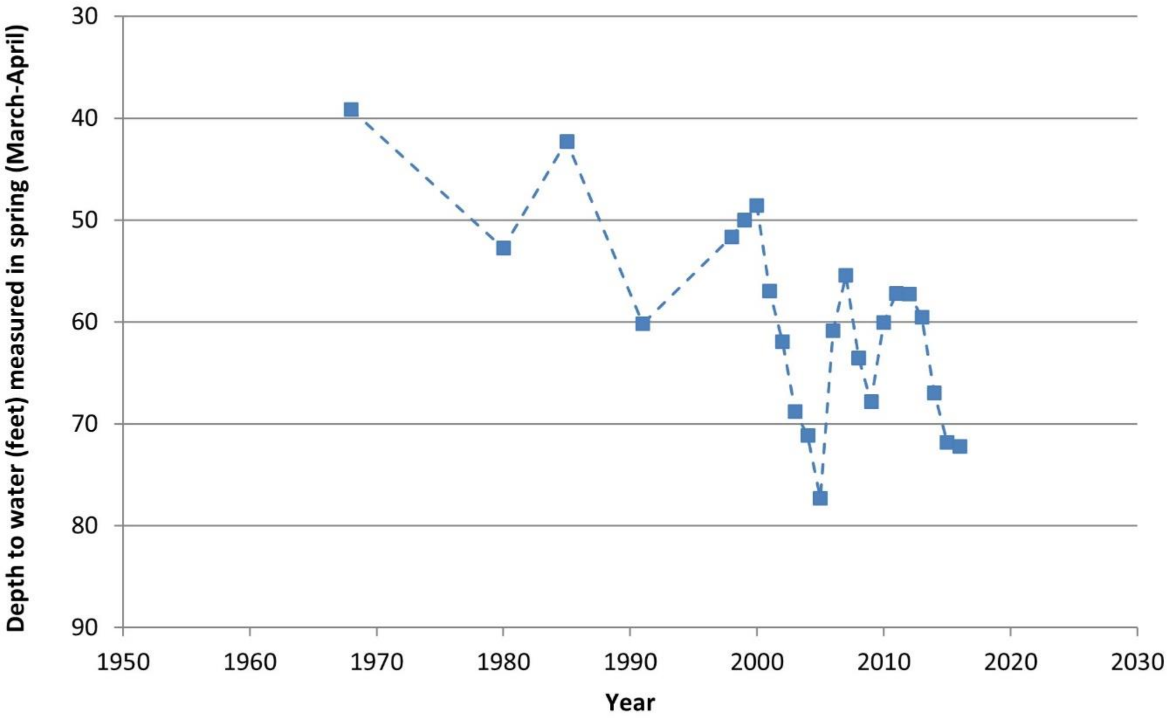

Well 13 (05N26E08CAB1 - Windmill) well opening depth 104-200 ft
Depth to water (feet) measured in spring (March-April)
100
110
120
130
140
150
160
170
180
190
200
1950
1960
1970
1980
1990
2000
2010
2020
2030
Year


Well 14 (05N26E23CDA1 - Earhardt) 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
2030
Year

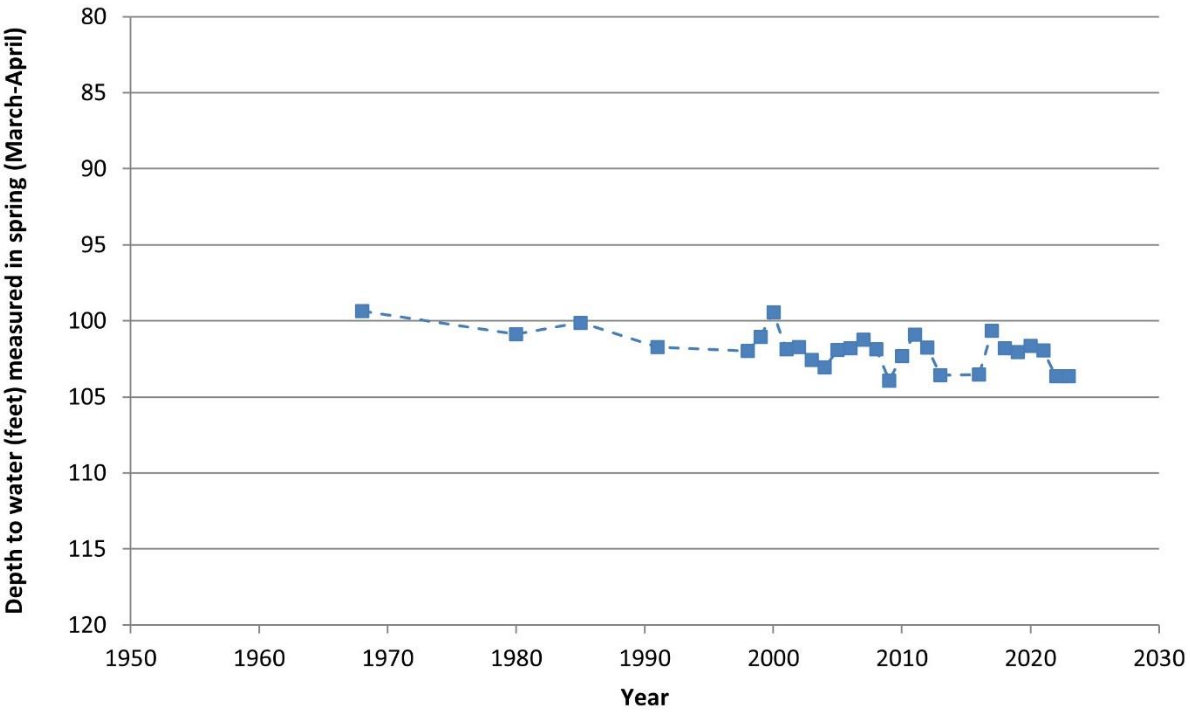

Well 15 (05N26E232DBA1 - Babcock) well opening depth 50-245 ft
Depth to water (feet) measured in spring (March-April)
70
80
90
100
110
120
130
140
150
1950
1960
1970
1980
1990
2000
2010
2020
2030
Year


Well 16 (06N25E03AAA1 - Sayer) 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
2030
Year

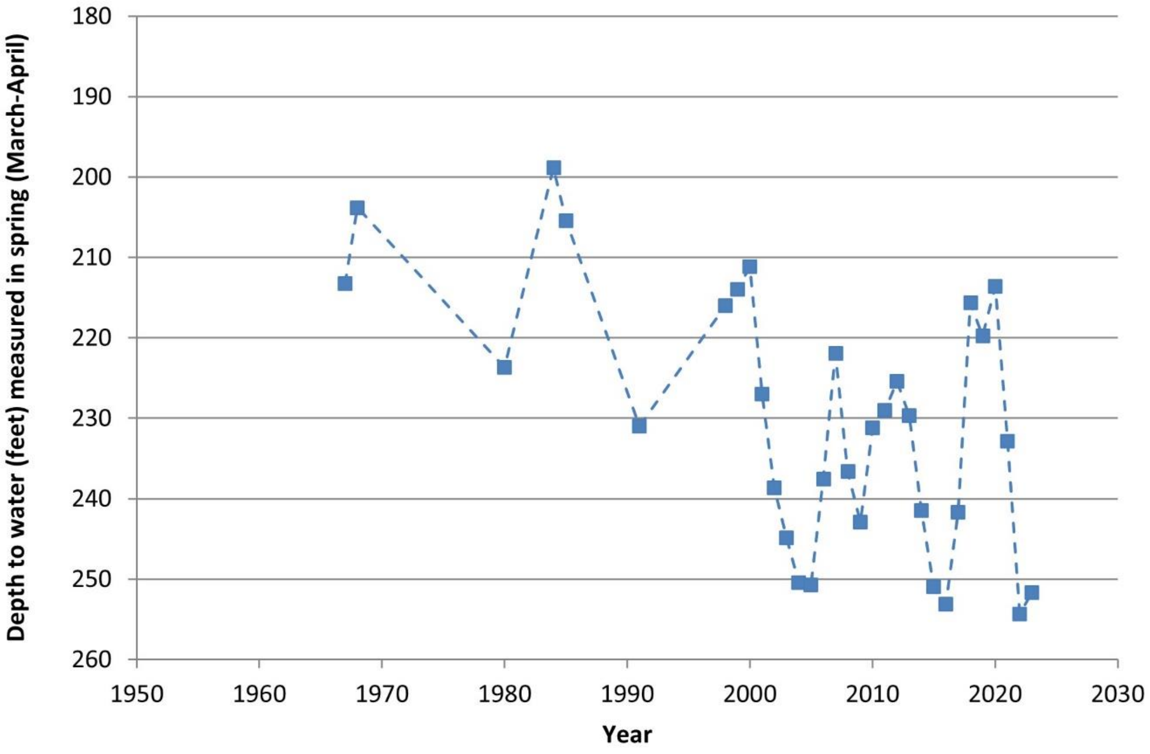
Well 17 (06N25E13CAB1 - discontinued) well opening depth 20-225 ft



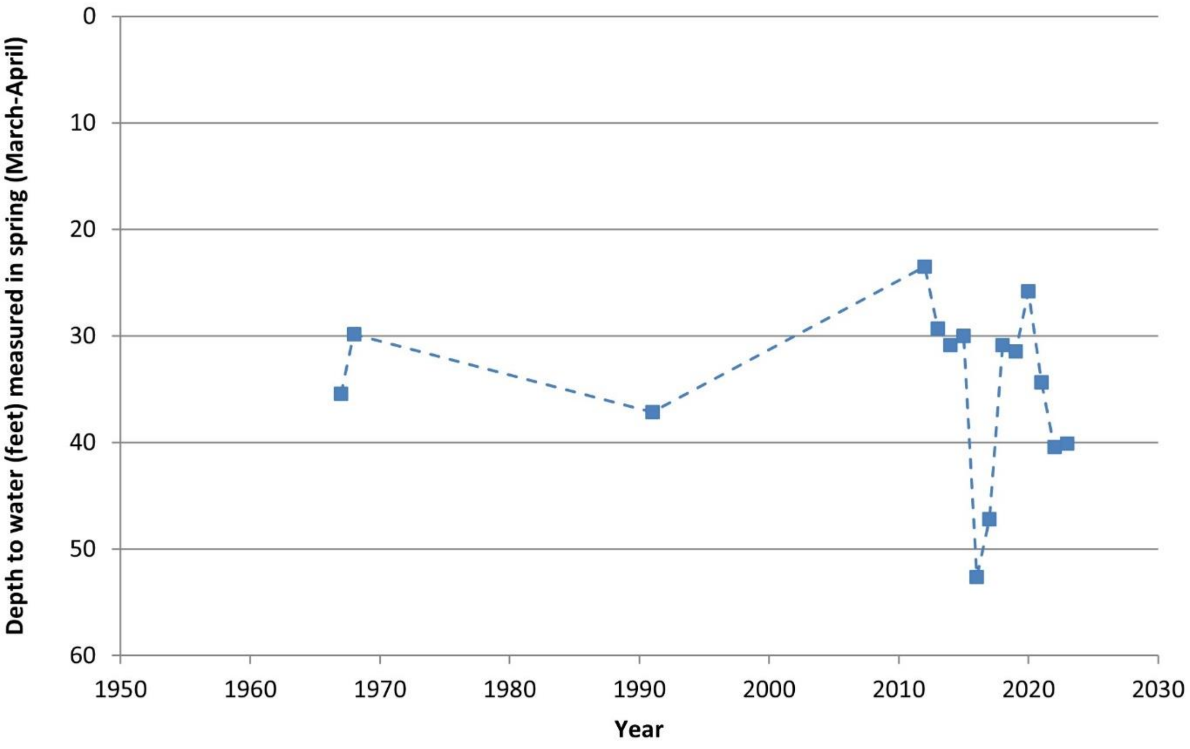
Well 18 (06N25E18ABB1 - Goff) well opening depth 165-230 ft

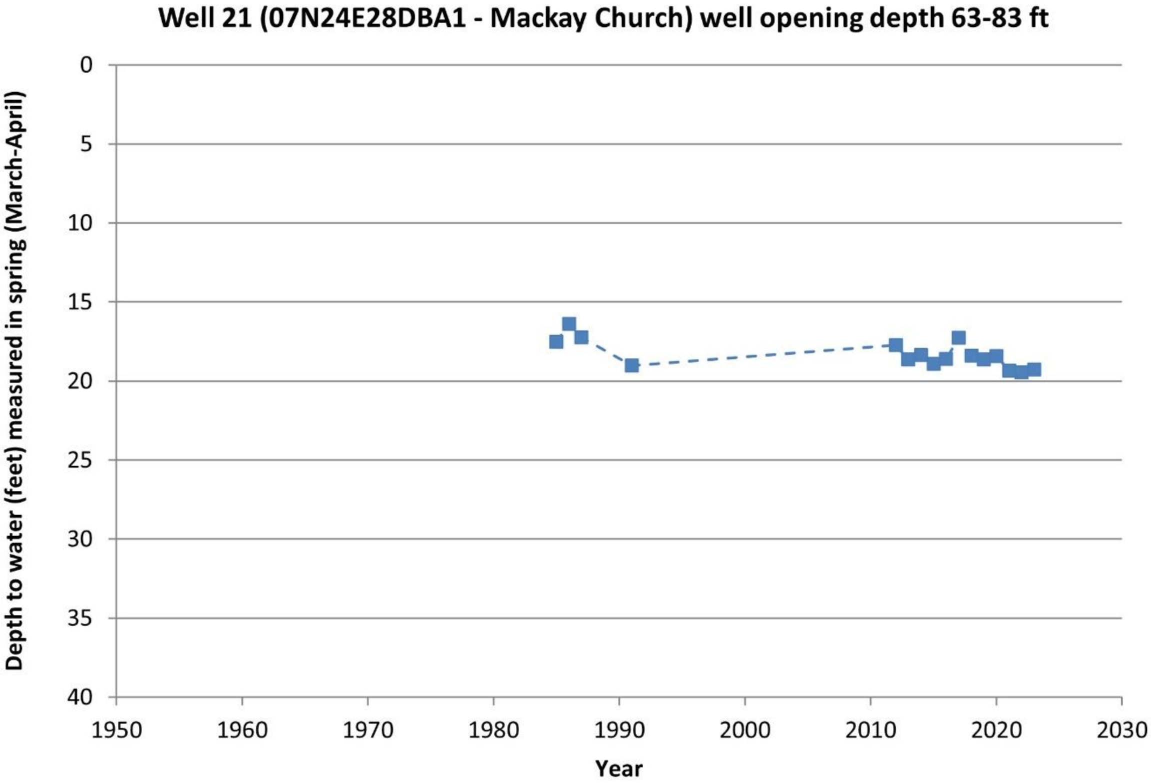


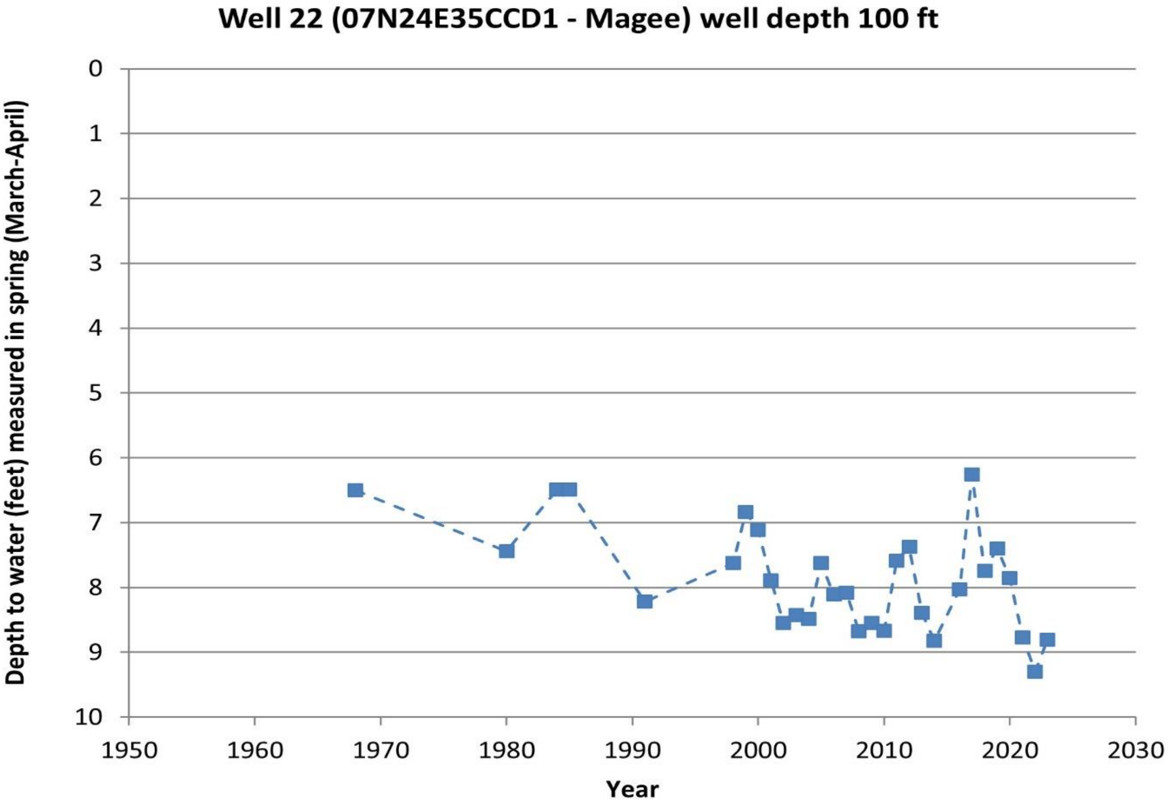
Well 19 (06N25E33AAB1 - BLM Smith) well depth 450 ft

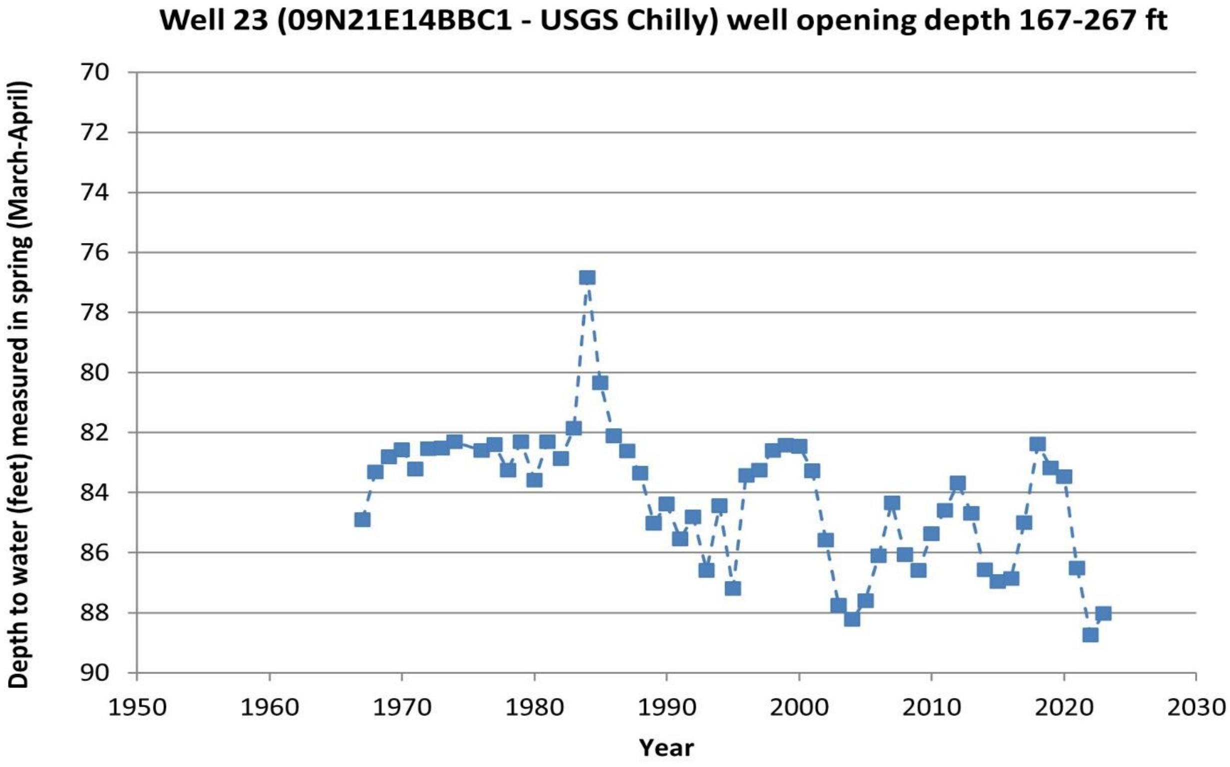


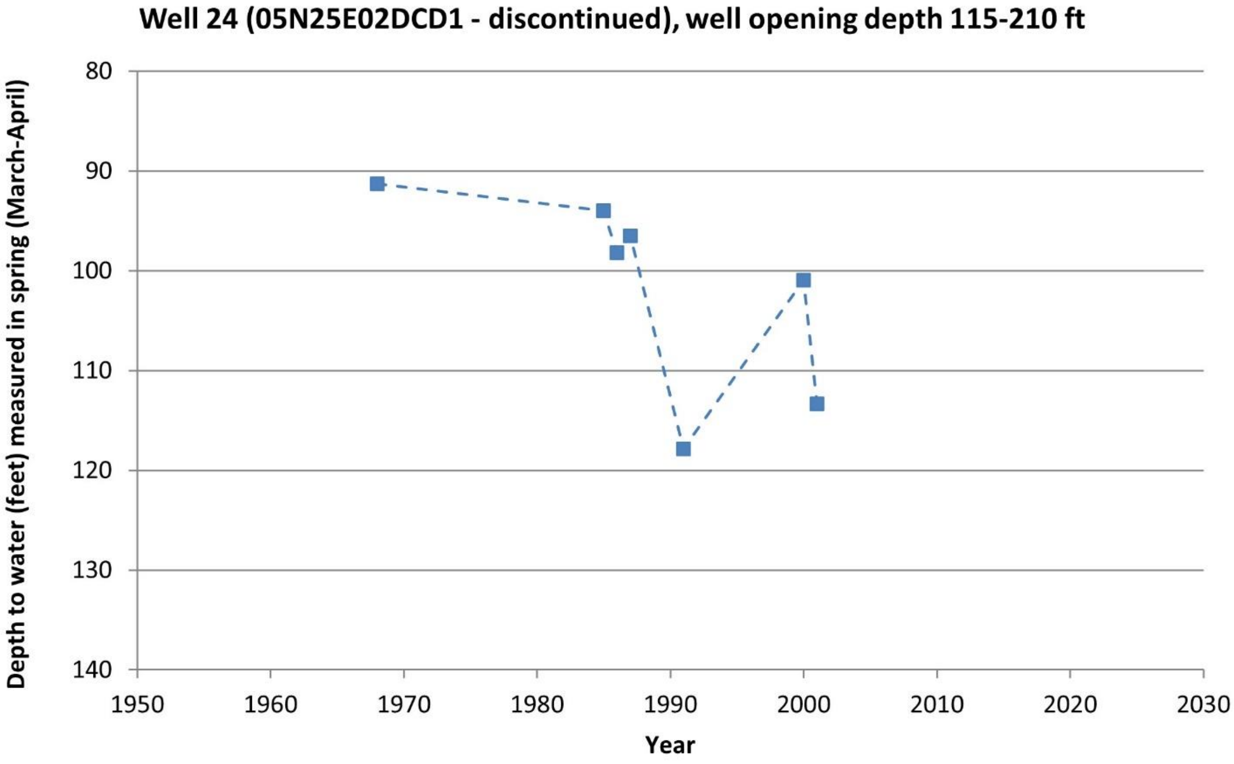
Well 20 (07N23E02DDA1 - BLM Fallini) well opening depth 65-80 ft

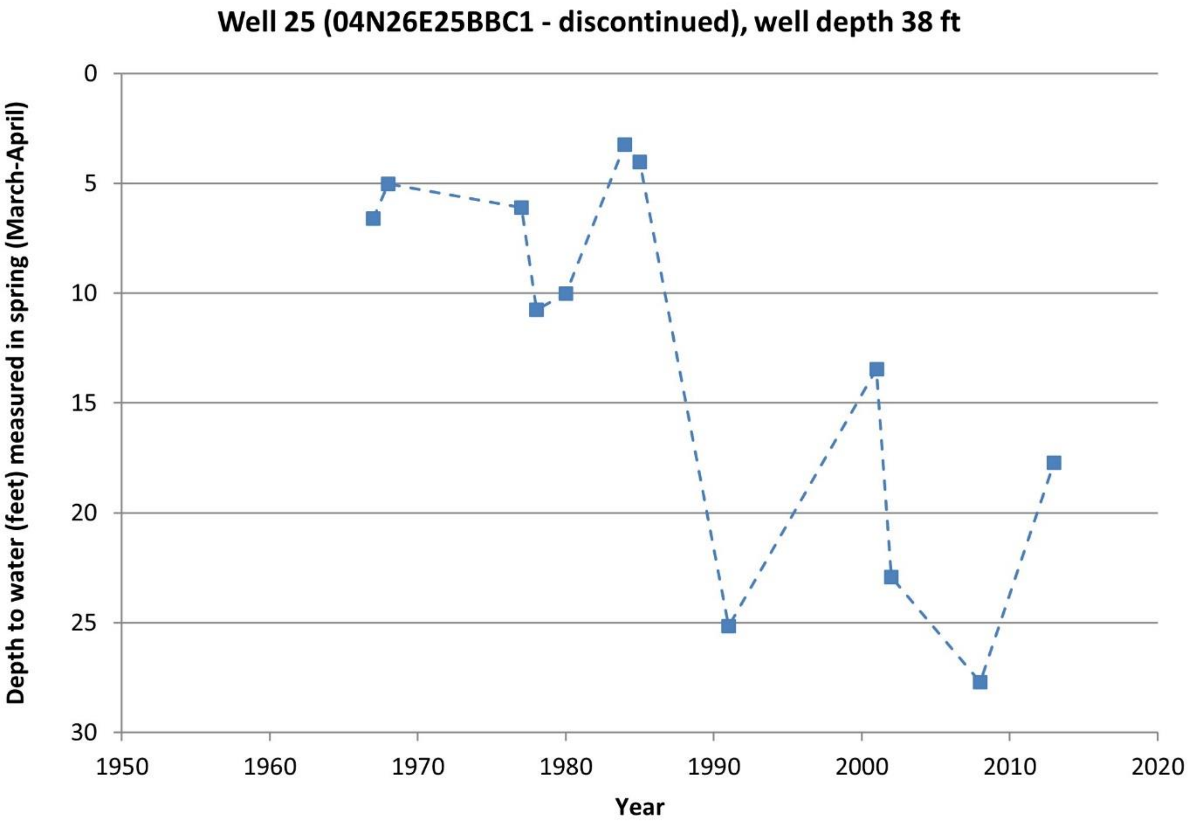


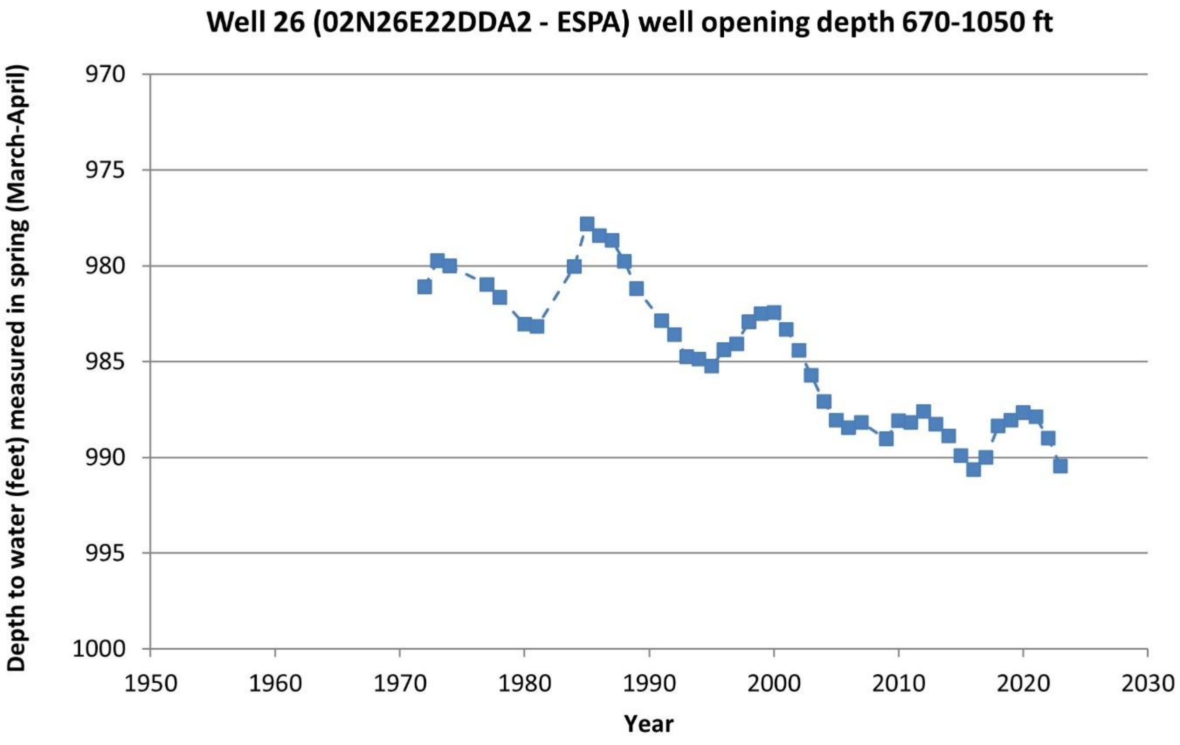

Well 21 (07N24E28DBA1 - Mackay Church) well opening depth 63-83 ft
Depth to water (feet) measured in spring (March-April)
0
5
10
15
20
25
30
35
40
1950
1960
1970
1980
1990
2000
2010
2020
2030
Year

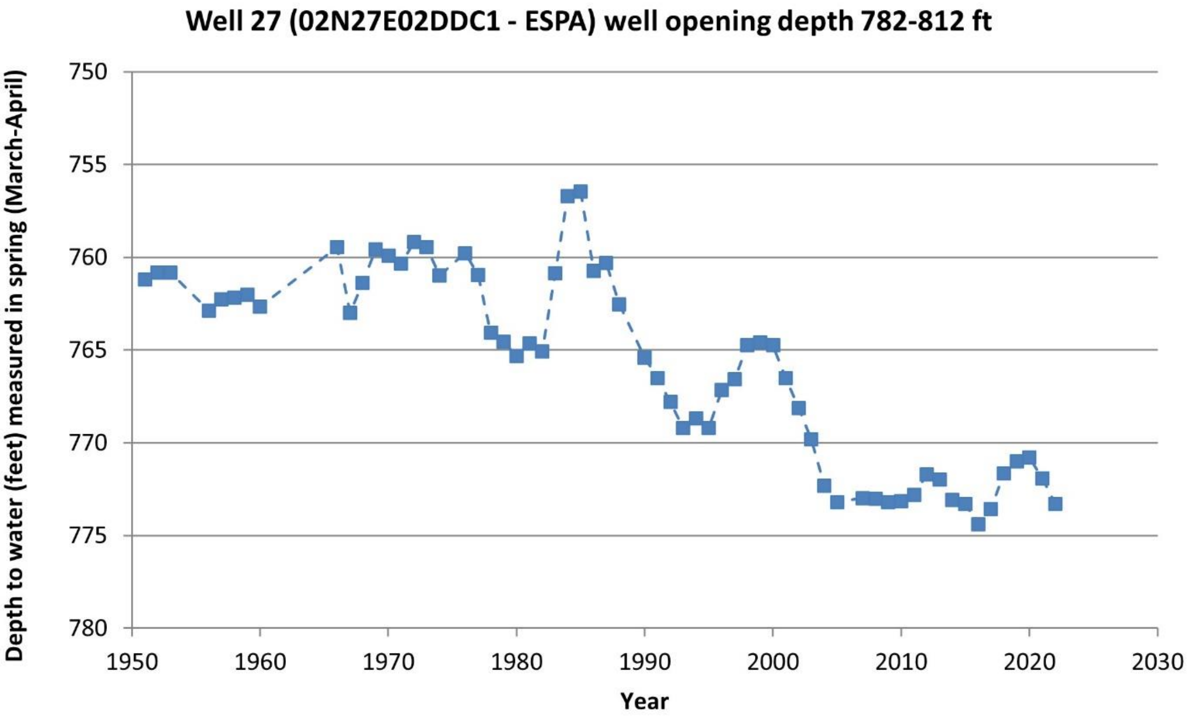

Well 22 (07N24E35CCD1 - Magee) well depth 100 ft
Depth to water (feet) measured in spring (March-April)
0
1
2
3
4
5
6
7
8
9
10
1950
1960
1970
1980
1990
2000
2010
2020
2030
Year

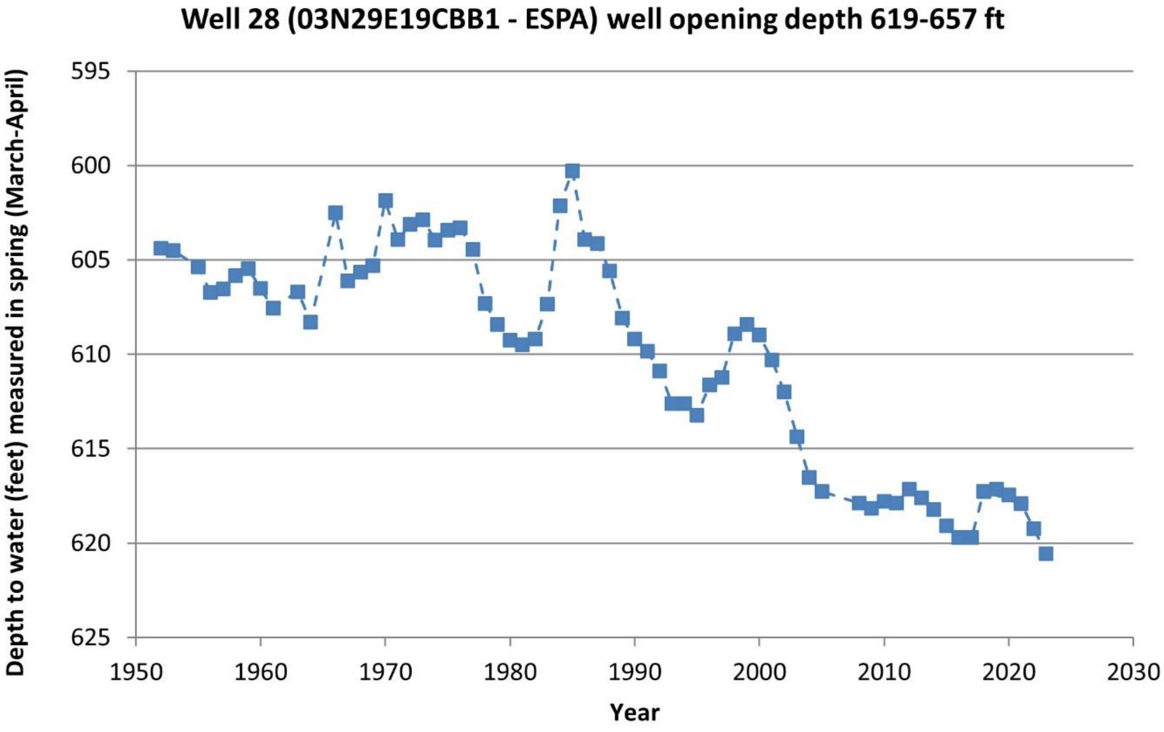

Well 23 (09N21E14BBC1 - USGS Chilly) well opening depth 167-267 ft
Depth to water (feet) measured in spring (March-April)
70
72
74
76
78
80
82
84
86
88
90
1950
1960
1970
1980
1990
2000
2010
2020
2030
Year

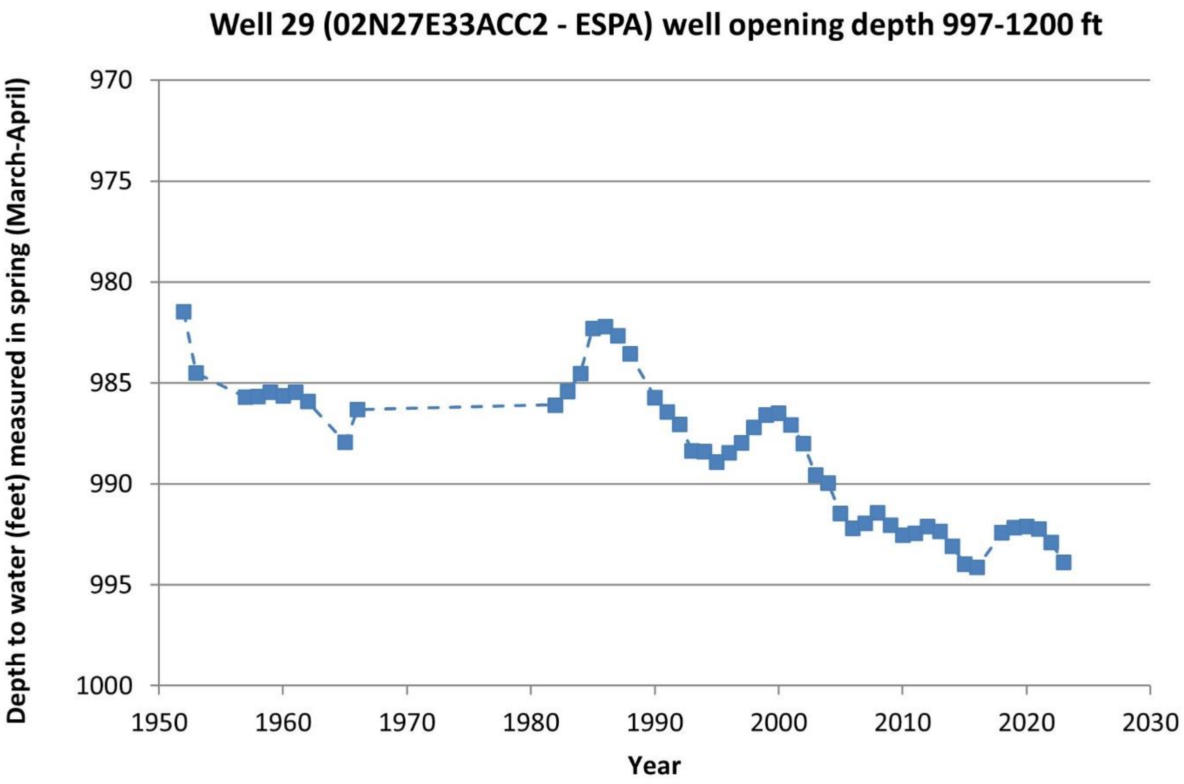

Well 24 (05N25E02DCD1 - discontinued), well opening depth 115-210 ft
Depth to water (feet) measured in spring (March-April)
80
90
100
110
120
130
140
1950
1960
1970
1980
1990
2000
2010
2020
2030
Year

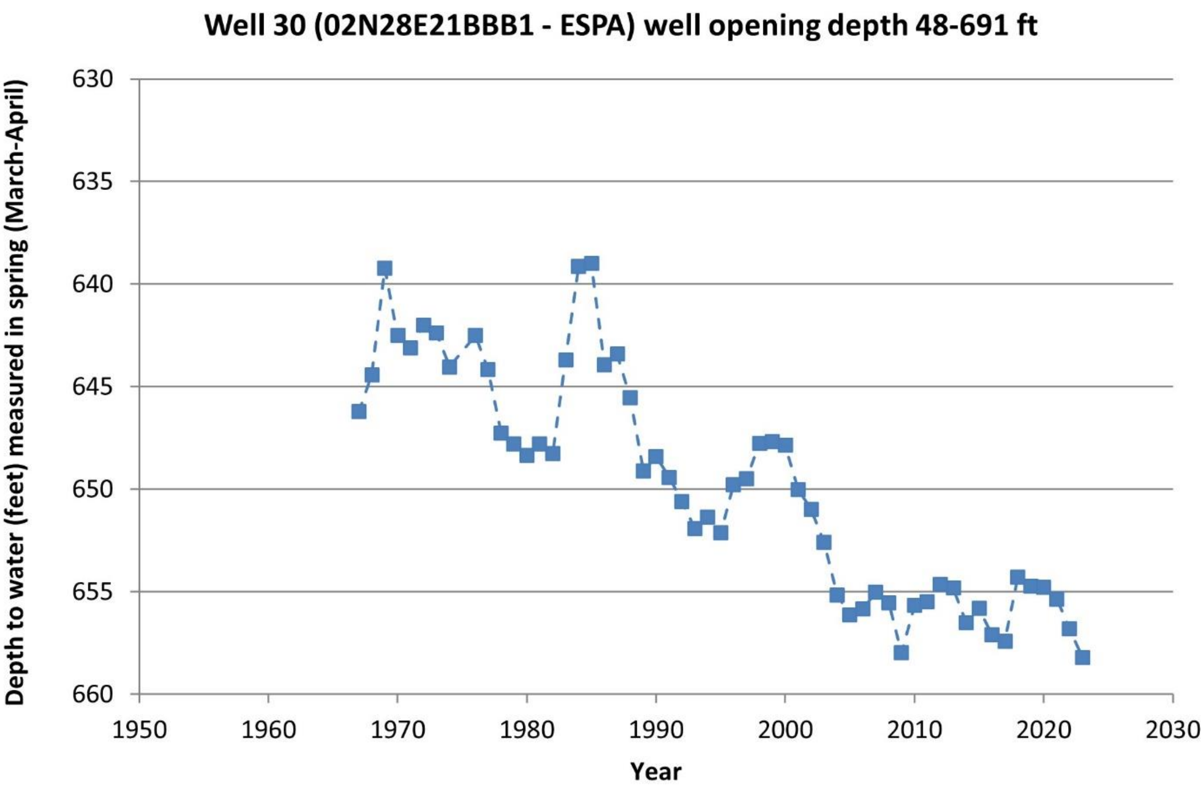

Well 25 (04N26E25BBC1 - discontinued), well depth 38 ft
Depth to water (feet) measured in spring (March-April)
0
5
10
15
20
25
30
1950
1960
1970
1980
1990
2000
2010
2020
Year

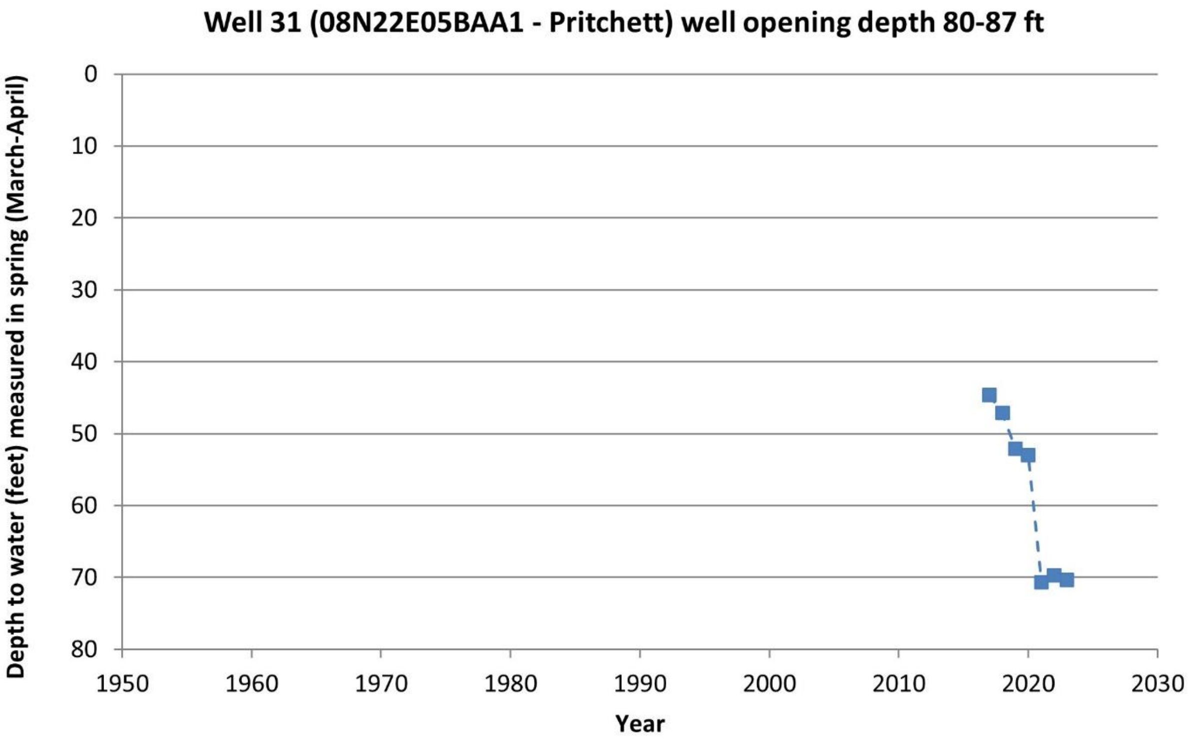

Well 26 (02N26E22DDA2 - ESPA) well opening depth 670-1050 ft
Depth to water (feet) measured in spring (March-April)
970
975
980
985
990
995
1000
1950
1960
1970
1980
1990
2000
2010
2020
2030
Year

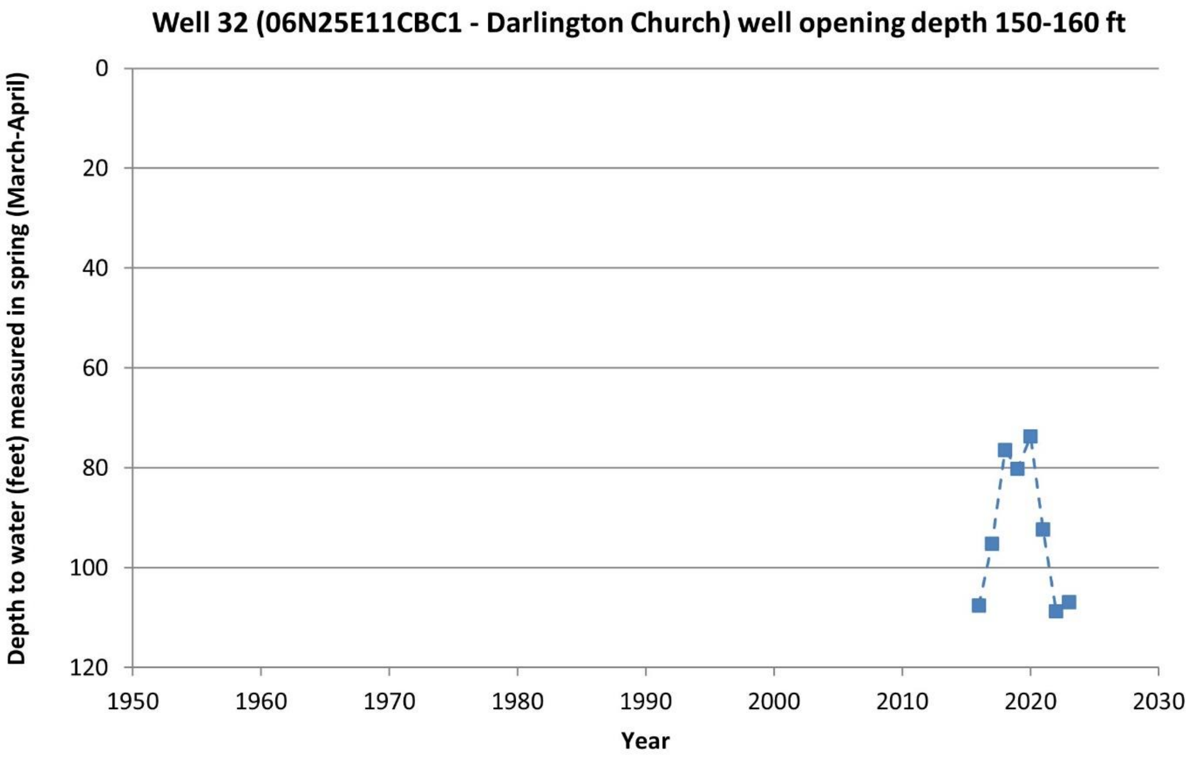

Well 27 (02N27E02DDC1 - ESPA) well opening depth 782-812 ft
Depth to water (feet) measured in spring (March-April)
750
755
760
765
770
775
780
1950
1960
1970
1980
1990
2000
2010
2020
2030
Year

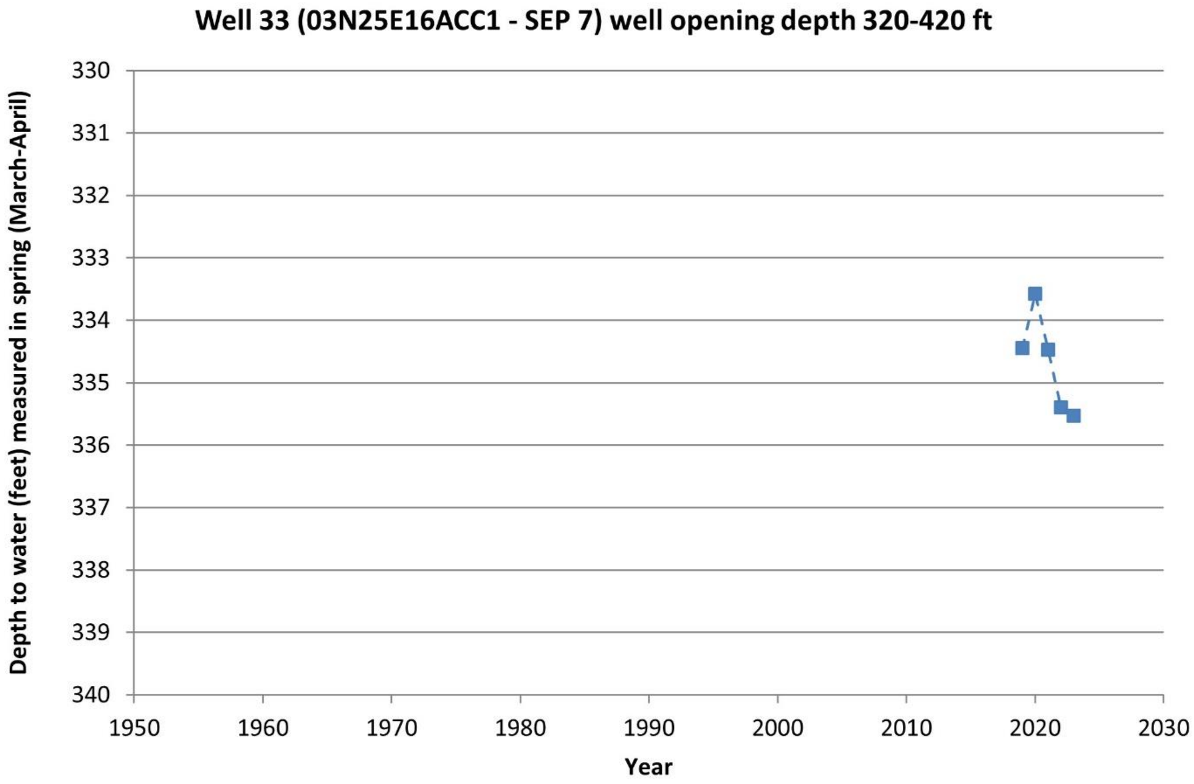

Well 28 (03N29E19CBB1 - ESPA) well opening depth 619-657 ft
Depth to water (feet) measured in spring (March-April)
595
600
605
610
615
620
625
1950
1960
1970
1980
1990
2000
2010
2020
2030
Year

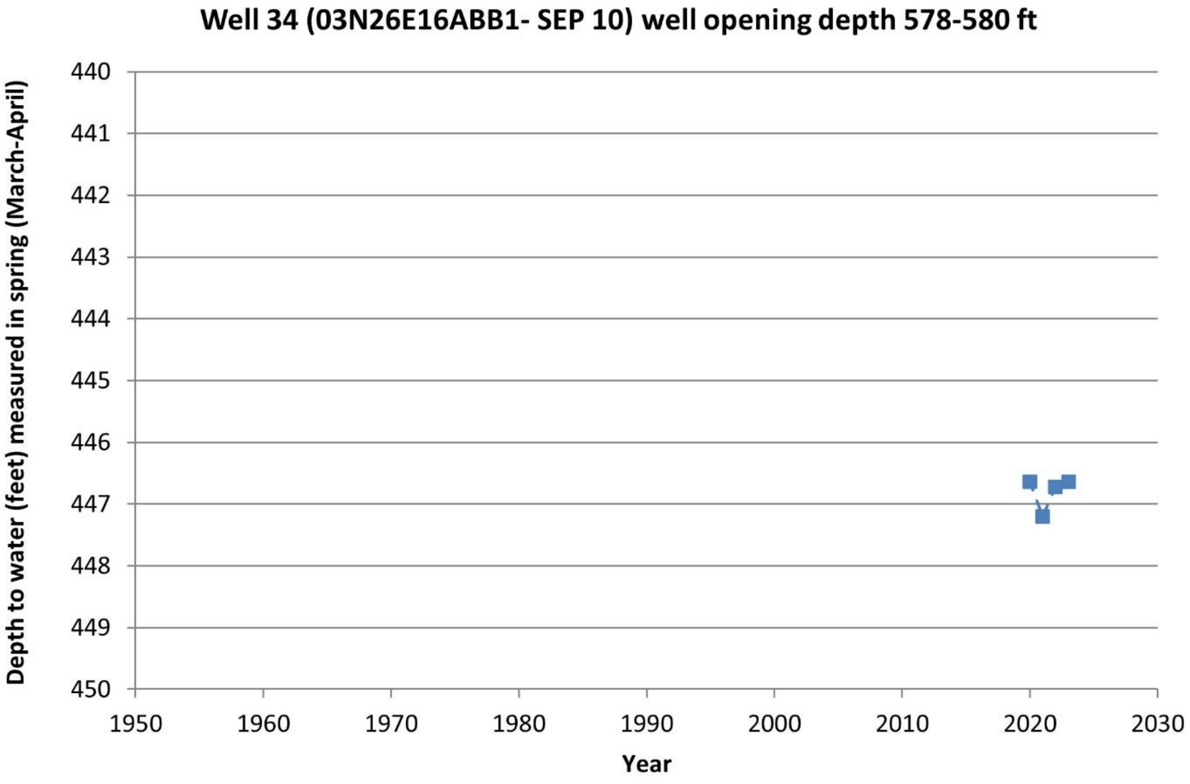

Well 29 (02N27E33ACC2 - ESPA) well opening depth 997-1200 ft
Depth to water (feet) measured in spring (March-April)
970
975
980
985
990
995
1000
1950
1960
1970
1980
1990
2000
2010
2020
2030
Year


Well 30 (02N28E21BBB1 - ESPA) 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
2030
Year

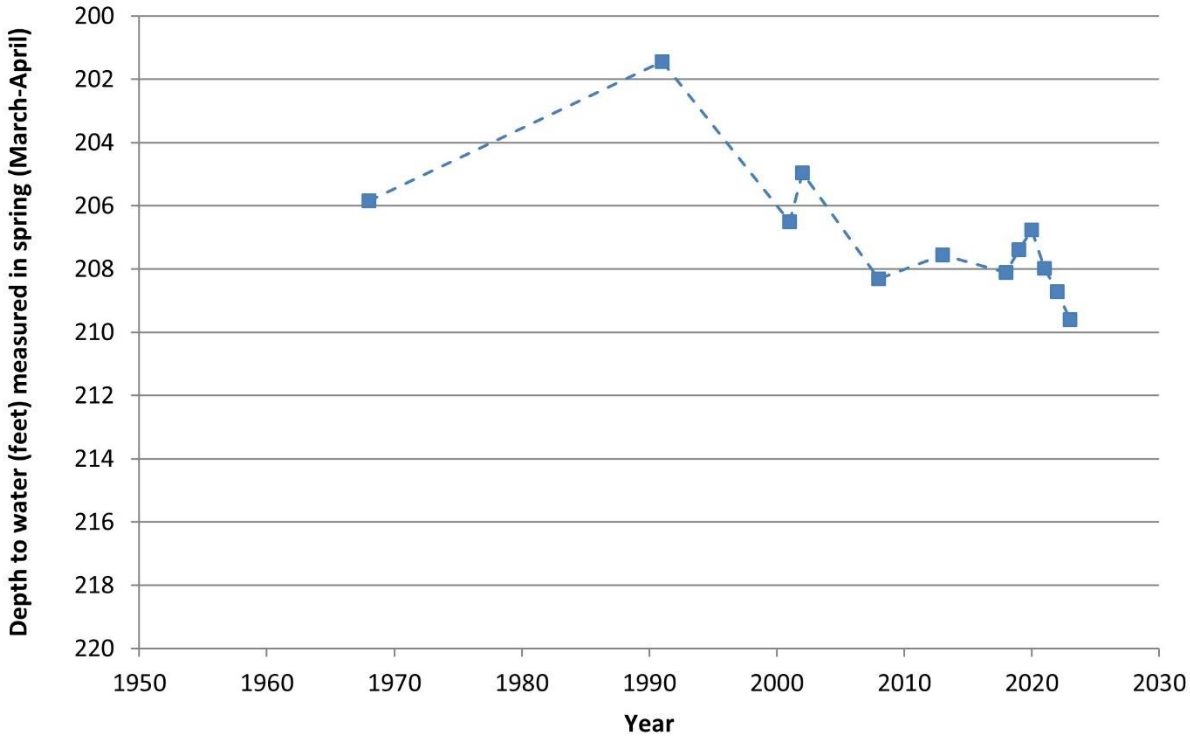

Well 31 (08N22E05BAA1 - Pritchett) well opening depth 80-87 ft


Well 32 (06N25E11CBC1 - Darlington Church) well opening depth 150-160 ft

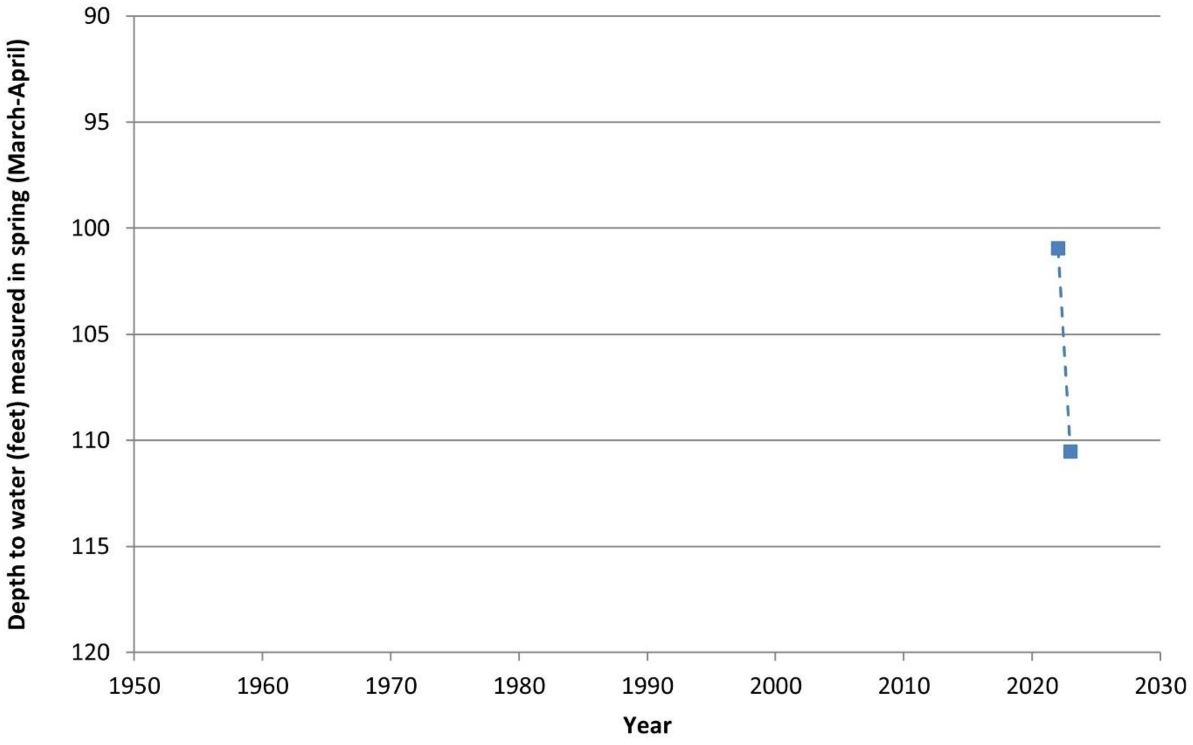

Well 33 (03N25E16ACC1 - SEP 7) well opening depth 320-420 ft
Depth to water (feet) measured in spring (March-April)
330
331
332
333
334
335
336
337
338
339
340
1950
1960
1970
1980
1990
2000
2010
2020
2030
Year


Well 34 (03N26E16ABB1- SEP 10) well opening depth 578-580 ft
Depth to water (feet) measured in spring (March-April)
440
441
442
443
444
445
446
447
448
449
450
1950
1960
1970
1980
1990
2000
2010
2020
2030
Year

Well 35 (03N26E03DAA1 - Telford) well opening depth unknown

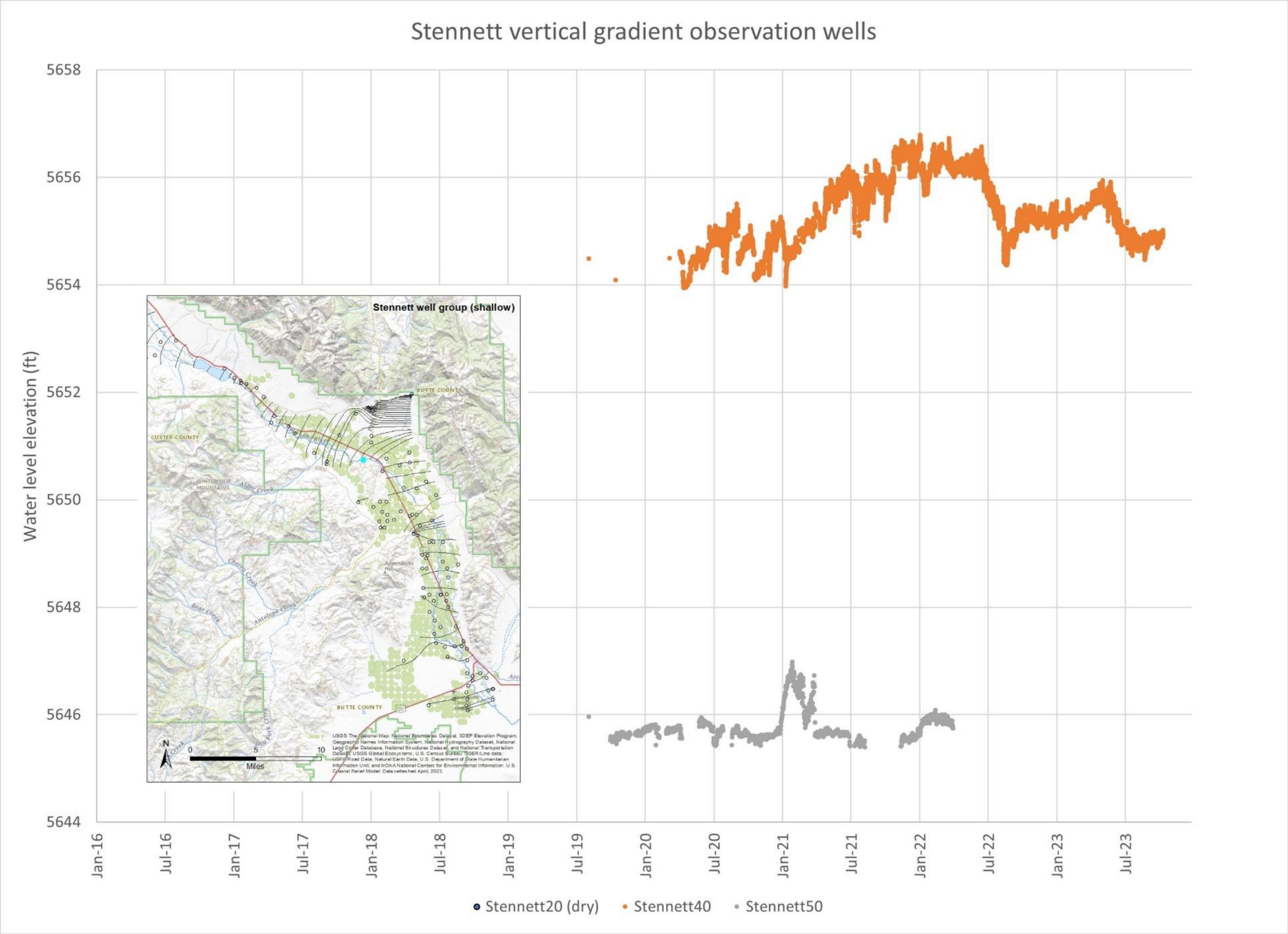


Well 37 (04N26E21ABB5 - Granite Trust 200) well opening depth 192-202 ft

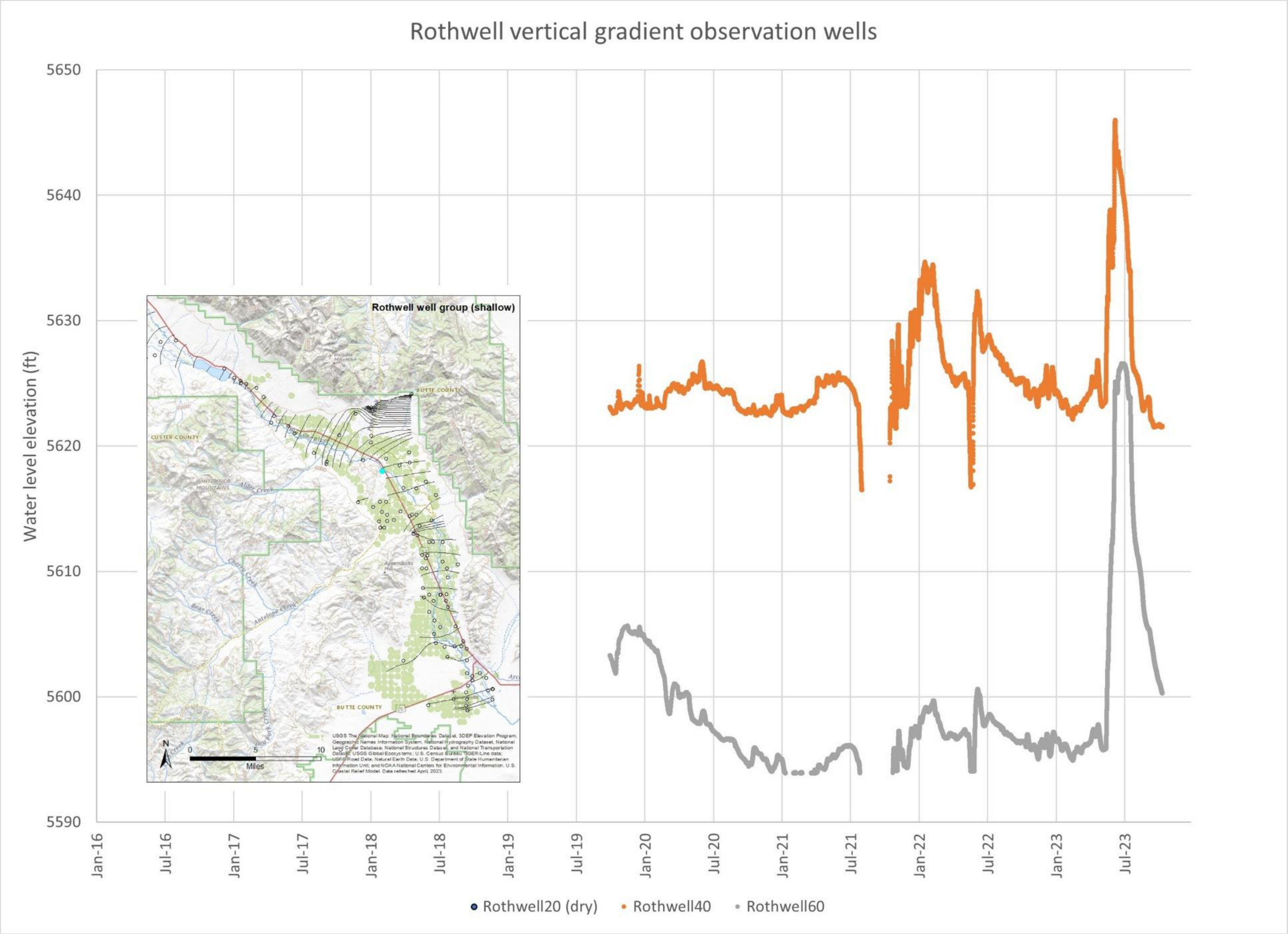


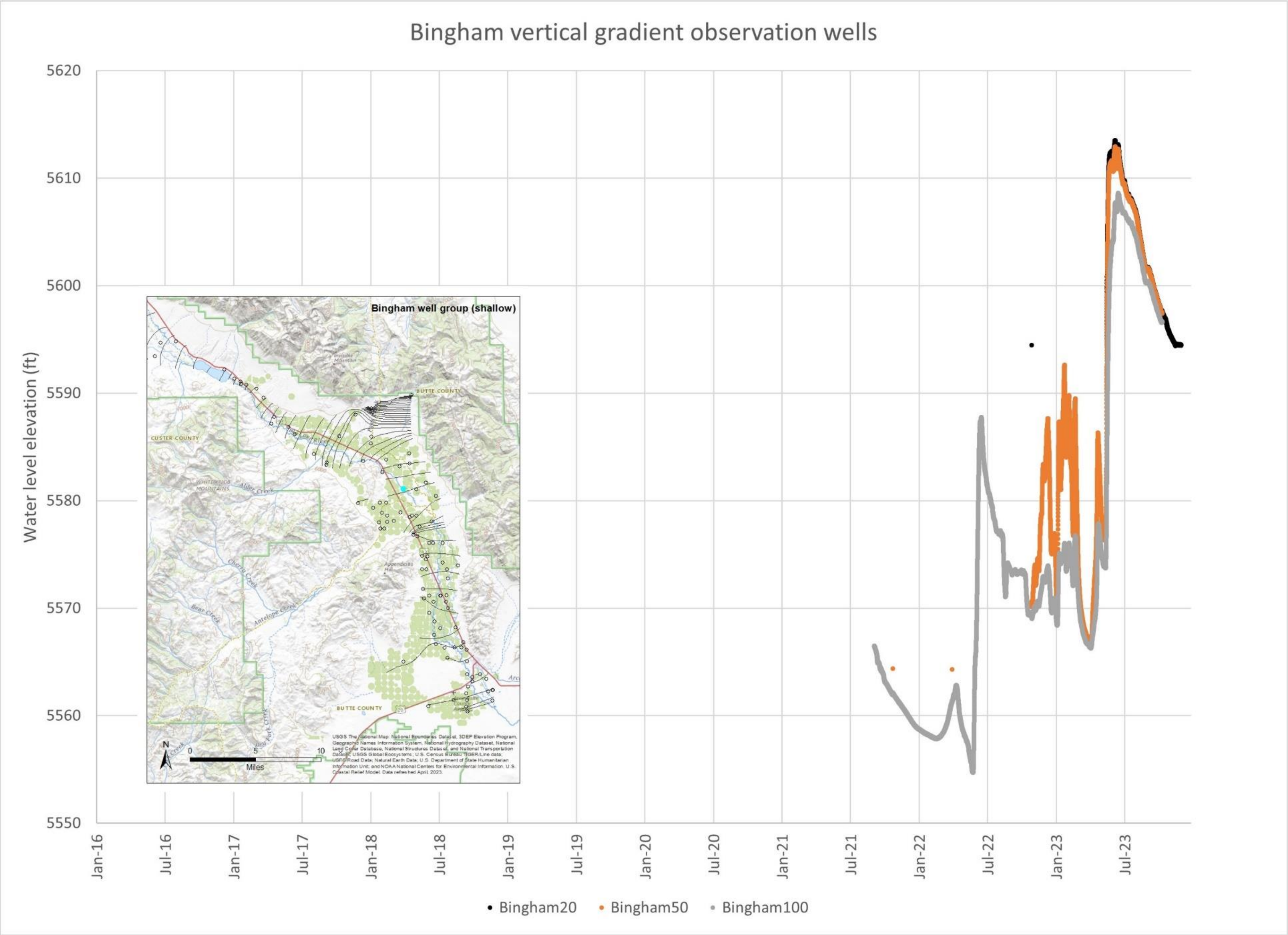
APPENDIX C. HYDROGRPAHS FOR

VERTICAL GRADIENT WELL GROUPS

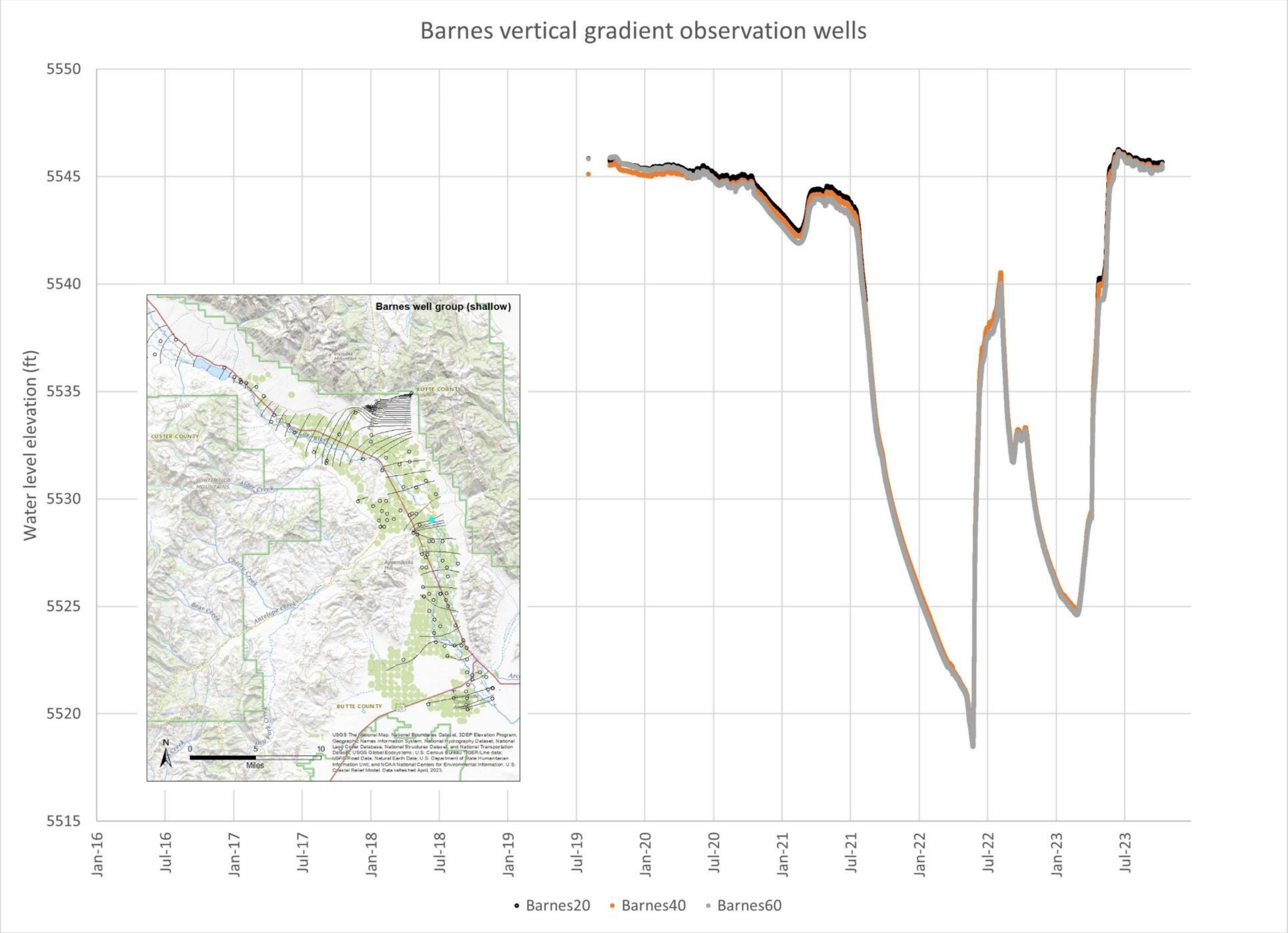


USGS The National Map: National Boundaries Dataset, 3DEP Elevation Program, Geographic Names Information System, National Hydrography Dataset, National Land Cover Database, National Structures Dataset, and National Transportation Dataset; USGS Global Ecosystems; U.S. Census Bureau TIGER/Line data; USFS Road Data; Natural Earth Data; U.S. Department of State Humanitarian Information Unit; and NOAA National Centers for Environmental Information, U.S. Coastal Relief Model. Data refreshed April, 2023.

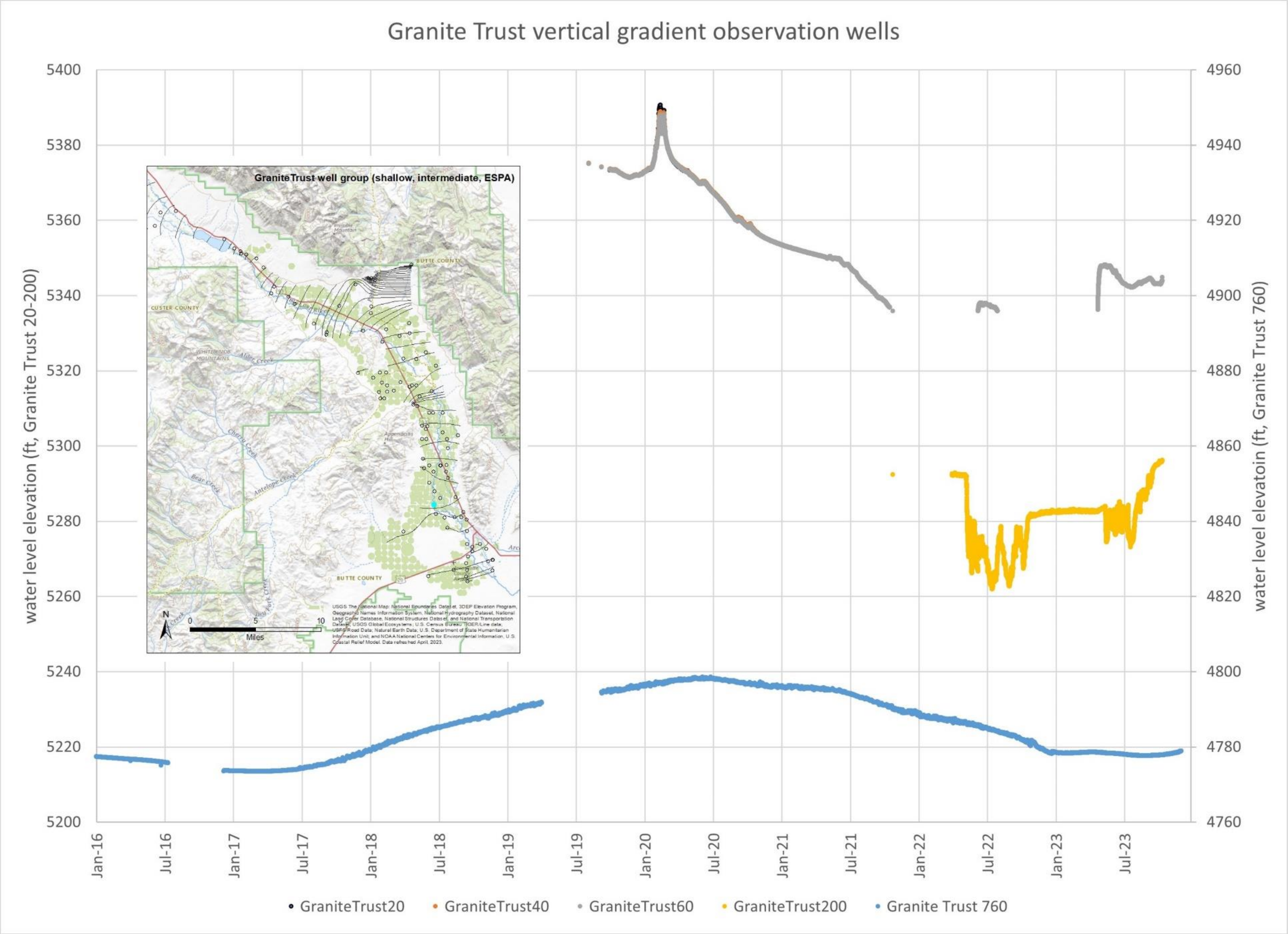

Rothwell vertical gradient observation wells
Water level elevation (ft)
5650
5640
5630
5620
5610
5600
5590
Jan-16
Jul-16
Jan-17
Jul-17
Jan-18
Jul-18
Jan-19
Jul-19
Jan-20
Jul-20
Jan-21
Jul-21
Jan-22
Jul-22
Jan-23
Jul-23
Rothwell well group (shallow)
BUTTE COUNTY
CUSTER COUNTY
Alder Creek
Cherry Creek
Bear Creek
Antelope Creek
Dry Fork Creek
Appendicitis Hill
Arco
20
N
0
5
10
Miles
USGS The National Map: National Boundaries Dataset, 3DEP Elevation Program, Geographic Names Information System, National Hydrography Dataset, National Land Cover Database, National Structures Dataset, and National Transportation Dataset; USGS Global Ecosystems; U.S. Census Bureau TIGER/Line data; USFS Road Data; Natural Earth Data; U.S. Department of State Humanitarian Information Unit; and NOAA National Centers for Environmental Information, U.S. Coastal Relief Model. Data refreshed April, 2023.
● Rothwell20 (dry)
● Rothwell40
● Rothwell60



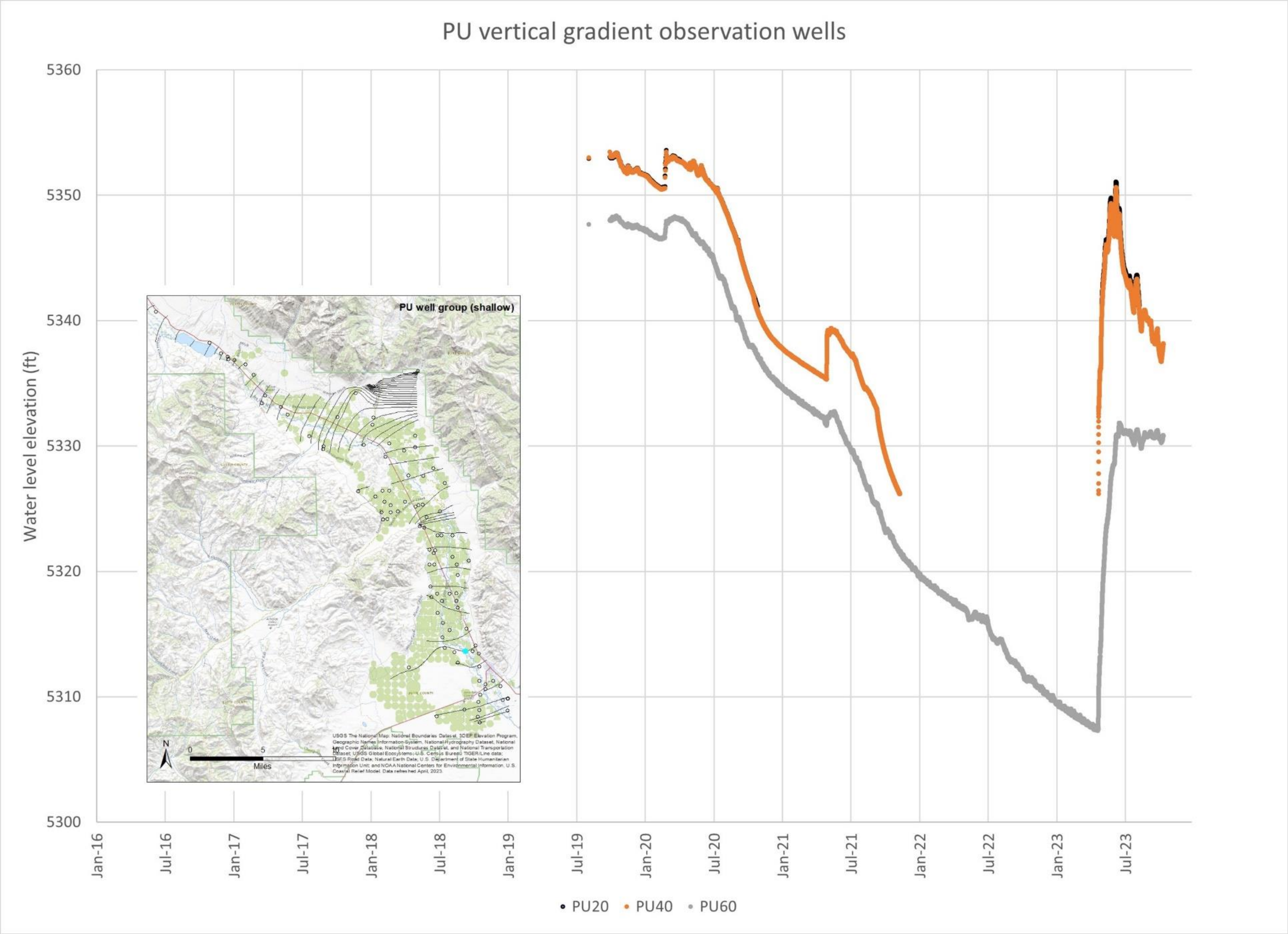
USGS The National Map: National Boundaries Dataset, 3DEP Elevation Program, Geographic Names Information System, National Hydrography Dataset, National Land Cover Database, National Structures Dataset, and National Transportation Dataset; USGS Global Ecosystems; U.S. Census Bureau TIGER/Line data; USFS Road Data; Natural Earth Data; U.S. Department of State Humanitarian Information Unit; and NOAA National Centers for Environmental Information, U.S. Coastal Relief Model. Data refreshed April, 2023.

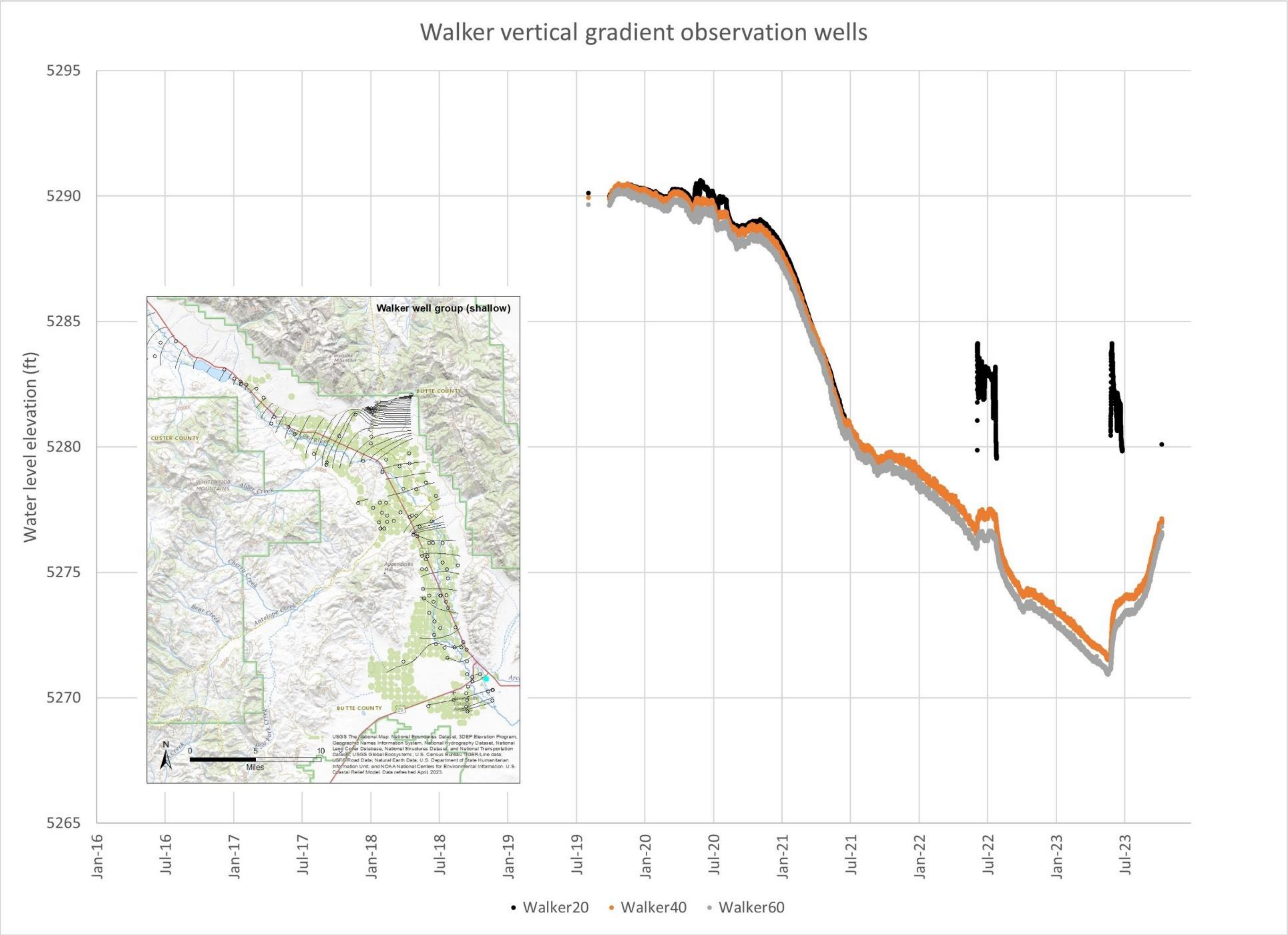


USGS The National Map: National Boundaries Dataset, 3DEP Elevation Program, Geographic Names Information System, National Hydrography Dataset, National Land Cover Database, National Structures Dataset, and National Transportation Dataset; USGS Global Ecosystems; U.S. Census Bureau TIGER/Line data; USFS Road Data; Natural Earth Data; U.S. Department of State Humanitarian Information Unit; and NOAA National Centers for Environmental Information, U.S. Coastal Relief Model. Data refreshed April, 2023.

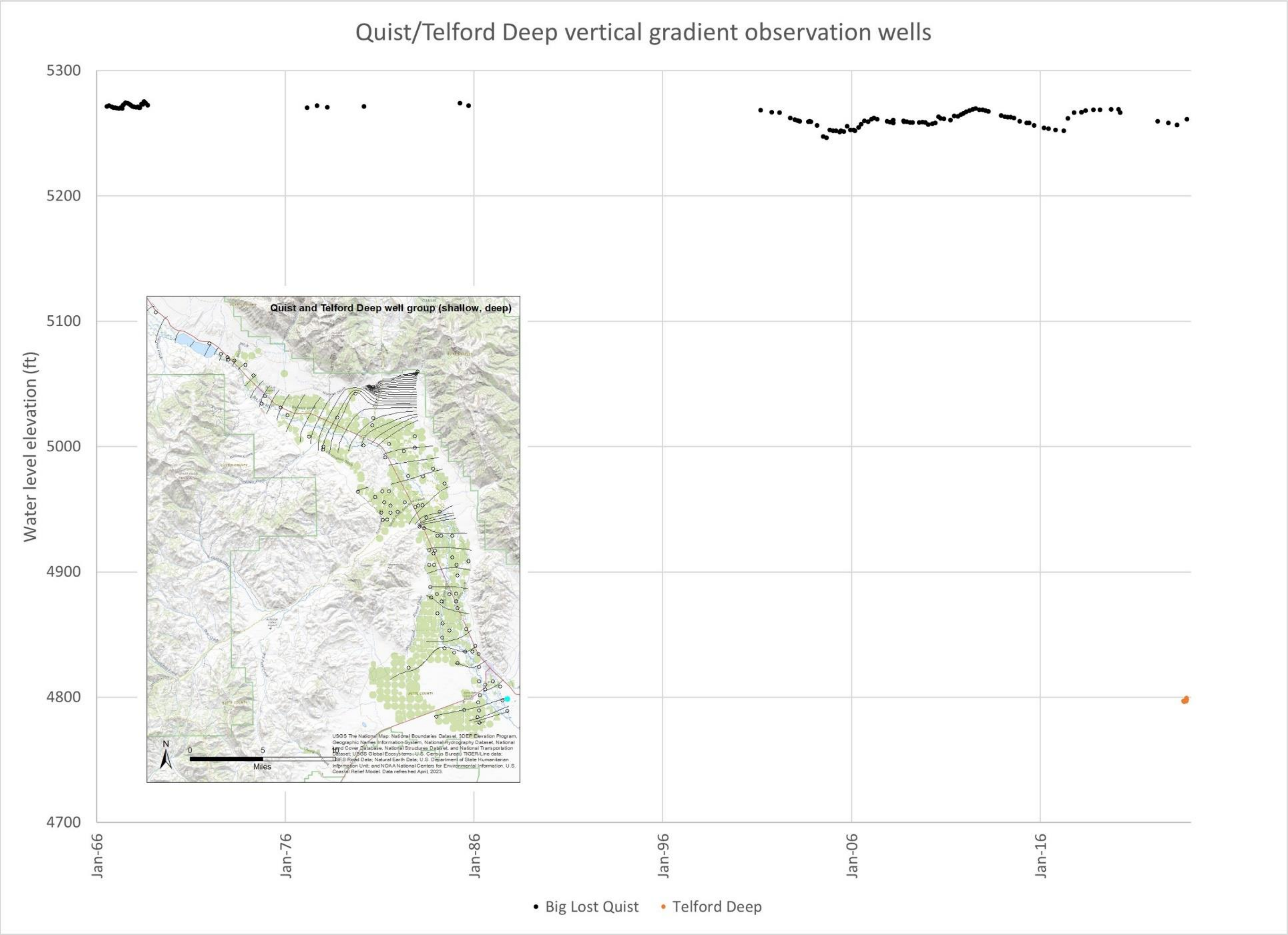


USGS The National Map: National Boundaries Dataset, 3DEP Elevation Program, Geographic Names Information System, National Hydrography Dataset, National Land Cover Database, National Structures Dataset, and National Transportation Dataset; USGS Global Ecosystems; U.S. Census Bureau TIGER/Line data; USFS Road Data; Natural Earth Data; U.S. Department of State Humanitarian Information Unit; and NOAA National Centers for Environmental Information, U.S. Coastal Relief Model. Data refreshed April, 2023.


PU vertical gradient observation wells
Water level elevation (ft)
5360
5350
5340
5330
5320
5310
5300
Jan-16
Jul-16
Jan-17
Jul-17
Jan-18
Jul-18
Jan-19
Jul-19
Jan-20
Jul-20
Jan-21
Jul-21
Jan-22
Jul-22
Jan-23
Jul-23
PU20
PU40
PU60
PU well group (shallow)
N
0
5
10
Miles
BUTTE COUNTY
USGS The National Map: National Boundaries Dataset, 3DEP Elevation Program, Geographic Names Information System, National Hydrography Dataset, National Land Cover Database, National Structures Dataset, and National Transportation Dataset; USGS Global Ecosystems; U.S. Census Bureau TIGER/Line data; USFS Road Data; Natural Earth Data; U.S. Department of State Humanitarian Information Unit; and NOAA National Centers for Environmental Information, U.S. Coastal Relief Model. Data refreshed April, 2023.



USGS The National Map: National Boundaries Dataset, 3DEP Elevation Program, Geographic Names Information System, National Hydrography Dataset, National Land Cover Database, National Structures Dataset, and National Transportation Dataset; USGS Global Ecosystems; U.S. Census Bureau TIGER/Line data; USFS Road Data; Natural Earth Data; U.S. Department of State Humanitarian Information Unit; and NOAA National Centers for Environmental Information, U.S. Coastal Relief Model. Data refreshed April, 2023.



Quist/Telford Deep vertical gradient observation wells

USGS The National Map: National Boundaries Dataset, 3DEP Elevation Program, Geographic Names Information System, National Hydrography Dataset, National Land Cover Database, National Structures Dataset, and National Transportation Dataset; USGS Global Ecosystems; U.S. Census Bureau TIGER/Line data; USFS Road Data; Natural Earth Data; U.S. Department of State Humanitarian Information Unit; and NOAA National Centers for Environmental Information, U.S. Coastal Relief Model. Data refreshed April, 2023.