Update of the Banbury Hot Springs Ground Water Management Area

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Introduction

The Idaho Department of Water Resources (IDWR) maintains a ground water level monitoring network in the Banbury Hot Springs Ground Water Management Area (BGWMA) near Buhl, Idaho (Figure 1). The area overlies a confined, low-temperature geothermal aquifer, defined in Idaho as water with a temperature above 85 and below 212°F (IDAPA, 2009). Wells were first drilled into the geothermal system in the 1970s and development continued into the mid-1980s, providing for power-generation, irrigation, heating, and aquaculture (Street & DeTar, 1987). The development led to declines in artesian pressures, raising concerns about the long-term viability of the resource.

Sustained monitoring of wells in the Banbury Hot Springs area began in the early 1980s. In response to pressure declines revealed by monitoring, the Banbury Hot Springs Ground Water Management Area was designated on April 12, 1983 (IDWR, 1983). Continued declining artesian pressures led to a December 4, 1985, order staying the approval of pending water right applications and suspending further ground water development in the BGWMA, essentially establishing a moratorium on further ground water development (IDWR, 1985).

Due to continued declining artesian pressures, a final order was issued on August 4, 2011, limiting domestic use of low-temperature geothermal water from within the BGWMA to closed loop systems, in which the water is returned or injected into the same source aquifer at a similar pressure and depth (IDWR, 2011).

The BGWMA Monitoring Network consists of 9 wells that are measured in the spring and fall using a pressure gauge or calibrated electric tape (Table 1, Figure 1). All wells are artesian, and each has enough pressure to flow above ground surface, except for 09S 14E 13DDD1. Monitoring in two wells has been discontinued: in 08S 14E 30ACA1 due to leaking water near the measurement point and in 09S 14E 14BDB1 due to well owner request.

Table 1: Banbury GWMA wells monitored by IDWR.

Well Number	Well use	Altitude (ft)	Latitude	Longitude	Total Depth (ft)	Opening Min	Opening Max	Period of Record
08S 14E 30ACA1	Geothermal	2900	42.706	-114.858	760	301	760	1979-2017
08S 14E 30DDB1	Geothermal	2910	42.700	-114.855	480	204	480	1983-2022
08S 14E 31ABBC1	Domestic	2980	42.695	-114.860	360	67	360	2019-2022
08S 14E 32DAA1	Geothermal	2960	42.688	-114.832	645	449	645	1979-2022
08S 14E 33CCA1	Geothermal	2904	42.684	-114.827	513	412	517	1975-2022
09S 14E 04BBD1	Geothermal	2938	42.679	-114.828	700	215	700	1979-2022
09S 14E 09ADC1	Other	3000	42.660	-114.816	850	380	850	1974-2022
09S 14E 13DDD1	Irrigation	3514	42.637	-114.753	900	31	900	1979-2022
09S 14E 14BDB1	Domestic	3127	42.648	-114.787	906	345	906	1980-2005

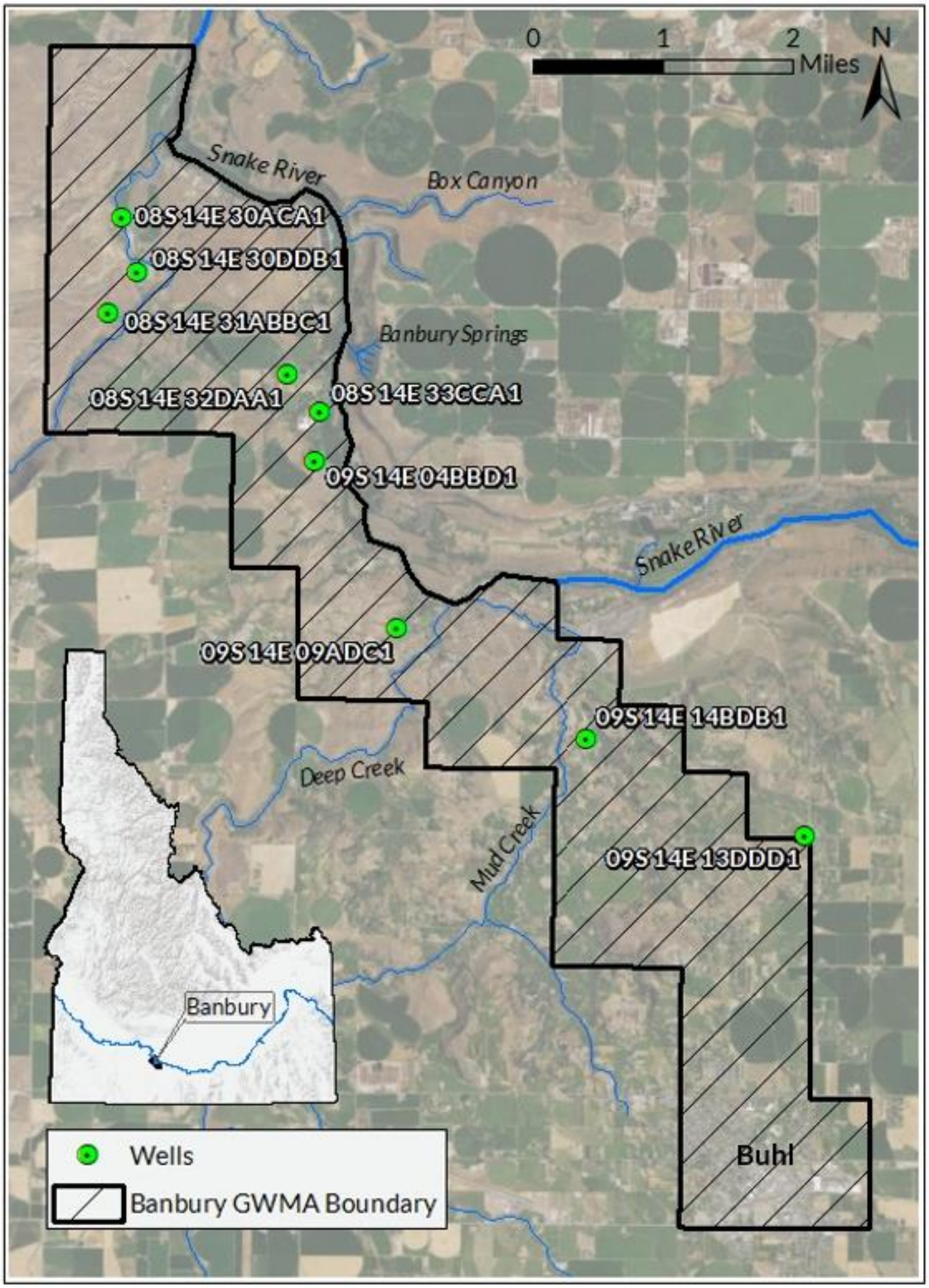

Figure 1: *Banbury GWMA Monitoring Network.*

Geology, Hydrogeology, and Climate

Geology

The BGWMA is located at the southwestern edge of the Eastern Snake Plain, part of a geothermal resource that underlies much of the plain. Tertiary rhyolite and basalt flows dominate the geology of the area (Lewis & Young, 1989). Tertiary rhyolitic lava flows and welded ash-flow tuffs of the Idavada Formation are the oldest rocks in the area. Tertiary olivine basalts of the Banbury Formation, interbedded with sedimentary fluvial sands and gravels and lacustrine clays, silts, and diatomite, overlie the Idavada Formation. Finally, Tertiary and Quaternary olivine basalts of the Glenns Ferry Formation overlie the Banbury Formation.

Hydrogeology

A minor shallow, cold groundwater system is present in the area, likely recharged by precipitation and irrigation infiltration (Lewis & Young, 1989). The confined geothermal aquifer that supplies the springs and wells of the Banbury Hot Springs GWMA stems from the Idavada Formation, likely part of a wider geothermal system in the Twin Falls County area (Lewis & Young, 1982; Street & DeTar, 1987). Storage space in the aquifer results from faulting as the rhyolite cooled following deposition, ash flow and ash fall porosity, and voids in-between flows (Street & DeTar, 1987). Water discharged at the surface from the aquifer has temperatures ranging from 86° to 158° F, increasing to the northwest (Neupane, et al., 2016). Recharge to the system likely occurs in the Cassia Mountains, southeast of the GWMA (Street & DeTar, 1987).

Palmer Drought Severity Index

The Palmer Drought Severity Index (PDSI) uses precipitation and temperature measurements in a physical water-balance model to provide a measure of drought for a given region (Dai, 2019). PDSI is correlated to moisture content and provides a useful snapshot of the natural water availability of a region over time (Dai, Trenberth, & Qian, 2004). The output is a unitless number where more negative values indicate drier conditions and more positive numbers indicate wetter than normal conditions. The Banbury Hot Springs GWMA Monitoring Network is best represented by the climate division for the Idaho Central Plains region (Figure 2; Dai, 2019).

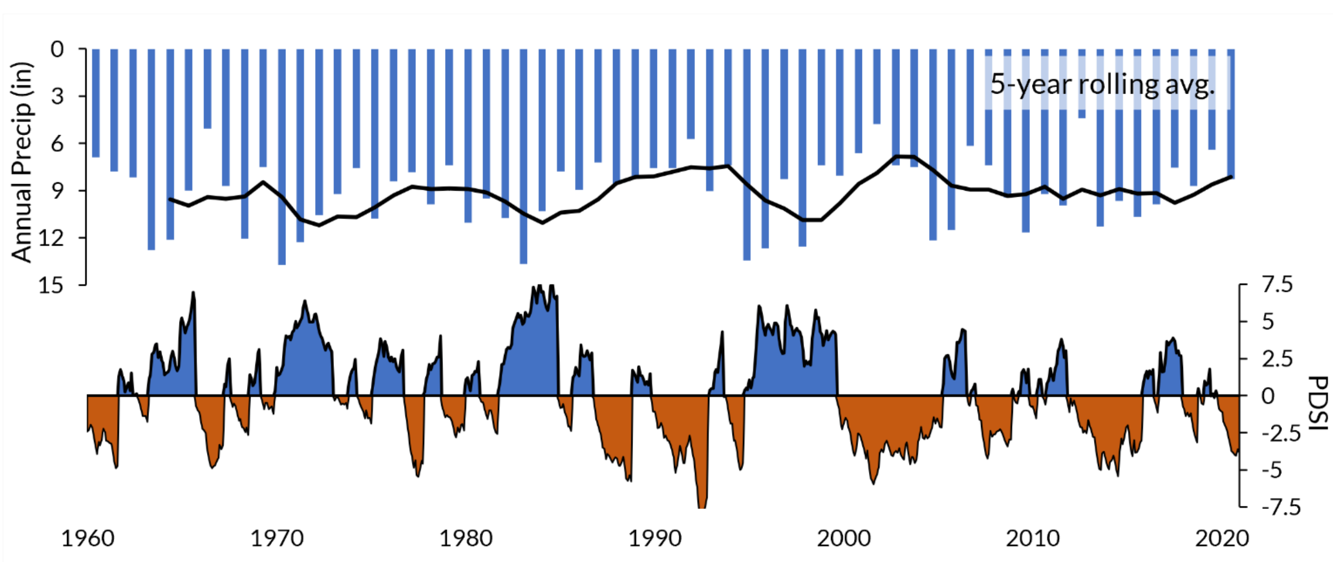

***Figure 2** Palmer Drought Severity Index for Idaho Central Plains region and annual precipitation totals with 5-year moving average in the BGWMA area, Idaho.*

PDSI conditions for the 1986-2022 and 2003-2022 periods are compared in Table 2. The time periods were chosen to examine regional drought conditions since the 1985 moratorium and over the last 20 years. The Banbury region was in drought 46.7% of the time, near normal 32.3% of the time, and wetter than normal the remaining 21% of the time during the 1986-2022 period. The region was in drought conditions 47.7% of the time, near normal 39.6% of the time, and wetter than normal 12.8% of the time during the 2003-2022 period.

Table 2: Network PDSI conditions, 1986-2022.

PDSI condition	PDSI value	1986-2022	2003-2022
Extreme Drought	$x \leq -4$	18.9%	16.2%
Severe Drought	$-4 < x \leq -3$	14.8%	14.0%
Moderate Drought	$-3 < x \leq -2$	13.0%	17.4%
Near Normal	$-2 > x < 2$	32.3%	39.6%
Unusually Moist	$2 \geq x < 3$	6.2%	5.1%
Very Moist	$3 \geq x < 4$	5.9%	6.4%
Extremely Moist	$x \geq 4$	8.9%	1.3%

Water Level Analyses

Hydrographs

Hydrographs for the BGWMA network wells are presented in Appendix A and cover the entire period of measurement for each well. Driller reported water levels were excluded from the hydrographs due to concerns over accuracy. In general, the hydrographs display water level declines over both the long-term and recent periods of record.

Wells in the BGWMA show a seasonal change in water levels, generally reflective of the given well's water use. Wells used for geothermal heating, either for domestic or commercial purposes, exhibit lower water levels in the colder months of the year. Wells used for irrigation exhibit lower water levels during the irrigation season, generally April to October. Season of use for each BGWMA well measurement is indicated in the hydrographs in Appendix A, where the time of year is split into a warm season (April to September) and cold season (October to March).

Trend Analysis

The BGWMA network water level measurements were used to test for ground water level trends using the Mann-Kendall and Regional Kendall computer program described by Helsel et al., 2006. The Mann-Kendall test describes trend over time while providing a measure of the trend's statistical significance (Helsel & Hirsch, 2002). Statistical significance indicates that there is a non-zero trend in the data at the chosen confidence interval, and the calculated trend is assumed to be the best linear representation of changes over time. The Regional Kendall (RMK) test provides a measure of trend over multiple sampling locations in a region, in this case the BGWMA (Helsel & Frans, 2006).

Mann-Kendall tests were implemented using a 95% confidence interval to analyze spring-season measurements in each network well for (1) the entire record, (2) the long-term period (1986-2022), and (3) the recent period (2003-2022), where water level record allowed (Table 3). Negative trends indicate rising water levels, while positive trends indicate declining water levels. Measurements were not used if they were qualified as flowing, recently flowing, pumping, or recovering. Over the entire record, four of nine network wells had statistically significant ($p<0.05$) declines in water levels, one well showed a statistically significant increasing trend, and three wells resulted in a non-significant trend.

Table 3: Mann-Kendall test results for individual BGWMA wells, spring measurements. Shaded trends and p-values highlight wells with statistically significant trends. Negative trends indicate rising water levels.

	Entire Record		1986-2022		2003-2022	
Well Number	**Trend (ft/yr)**	**p-value**	**Trend (ft/yr)**	**p-value**	**Trend (ft/yr)**	**p-value**
08S 14E 30ACA1	**3.27**	**0.000**	**3.39**	**0.000**	**4.41***	**0.023**
08S 14E 30DDB1	**1.23**	**0.001**	**1.30**	**0.001**	**1.39**	**0.008**
08S 14E 31ABBC1	0.01	1	0.01	1	--**	--
08S 14E 32DAA1	-1.67	0.462	-1.67	0.462	--	--
08S 14E 33CCA1	**0.25**	**0.035**	0.17	0.242	0.21	0.463
09S 14E 04BBD1	1.28	0.051	-0.30	0.602	0.29	0.368
09S 14E 09ADC1	**-0.28**	**0.002**	**-0.25**	**0.008**	**-0.3984**	**0.025**
09S 14E 13DDD1	**0.49**	**0**	**0.52**	**0**	**0.31**	**0.000**
09S 14E 14BDB1	--	--	--	--	--	--

*Period of record for 08S 14E 30ACA1 ends after 2017. **No results indicate insufficient data.

RMK tests were implemented using a 95% confidence interval to analyze spring measurements in BGWMA wells over the entire record, the long-term period, and the recent period (Table 4). Wells were used in the RMK tests if they had four or more spring measurements, and measurements were not used if they were qualified as flowing, recently flowing, pumping, or recovering. All test intervals resulted in statistically significant trends showing declining water levels indicating an ongoing, regional decline in the spring season.

Well number 09S 14E 14BDB1 was excluded from the Regional Kendall tests, as 114 of the 124 total measurements were qualified as flowing or recently flowing, resulting in fewer than four usable spring-season measurements and suggesting that most measurements were not taken under static aquifer conditions.

Table 4: Regional Mann-Kendall test results for all BGWMA wells with at least four spring-season measurements, excluding 09S 14E 14BDB1. Positive trends indicate declining water levels. All results are statistically significant with a p-value <0.05

Entire Record		1986-2022		2003-2022	
Trend (ft/yr)	**p-value**	**Trend (ft/yr)**	**p-value**	**Trend (ft/yr)**	**p-value**
0.44	**0.000**	**0.43**	**0.000**	**0.23**	**0.005**

Water Table Change Maps

Change maps were created to visualize water level differences over time in the BGWMA network wells. Two maps show the spring water table elevation change in select wells from 1986 to 2022 (Figure 3A) and from 2003 to 2022 (Figure 3B). The span of years was chosen to best capitalize on the period of record available for each well to investigate changes since the 1985 moratorium (IDWR, 1985) as well as changes over the past 20 years. Due to inconsistent data collection among the BGWMA network wells, the maps only provide changes for four network wells, a caveat to be considered when drawing conclusions.

The water-level change maps reveal a pattern in the BGWMA; both periods show significant water level declines in the northwest portion of the area, moderate declines in the southeast, and slight declines or

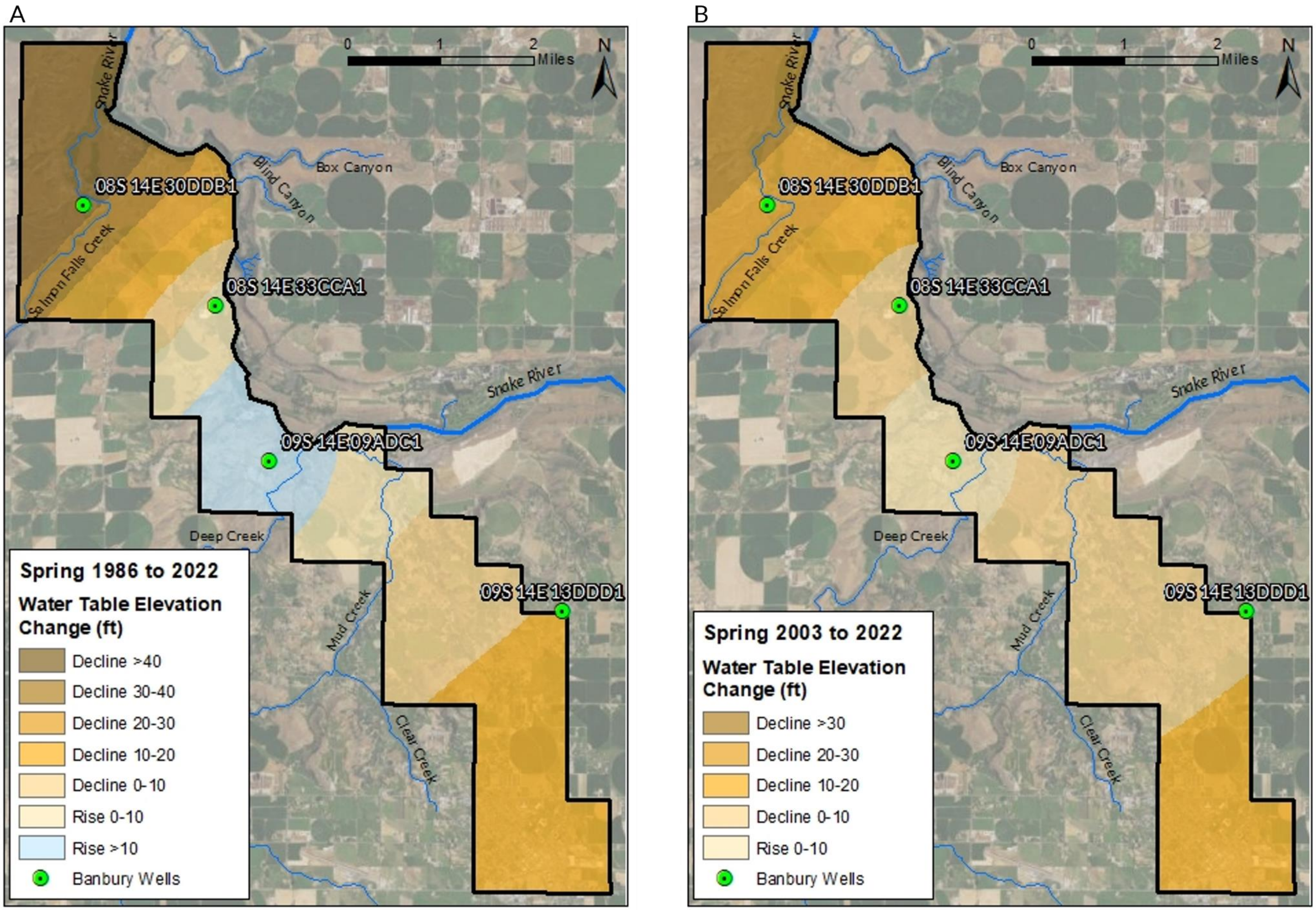

Figure 3*: Water table elevation change in the BGWMA from spring 1986 to 2022 (A) and spring 2003 to 2022 (B).*

rises in the central portion of the area. Although the northwest and southeast portions have experienced over 20 feet of change, the recent period (2003-2022) shows less of a decline than for the long-term period (1986-2022). However, the limitations of the change maps are evident, as they do not include several network wells with clear records of declining water levels, such as 09S 14E 04BBD1 and 08S 14E 30ACA1.

Discussion and Recommendations

Wells in the BGWMA network show significant water level declines since development in the late 1970s to early 1980s. In the initial years following the original moratorium order in late 1985, water level declines continued. The past 20 years reveal a more nuanced picture, with evidence of moderation or steadying of previous declines in some wells, such as 09S 14E 13DDD1, while others continue to show increasing declines, such as 08S 14E 30ACA1 and 08S 14E 30DDB1.

The inconsistent periods of measurement from well-to-well pose problems for the analysis of network water levels over time and for conducting future monitoring. For example, the two wells in the BGWMA with the greatest water level declines, 08S 14E 30ACA1 and 09S 14E 14BDB1, are no longer measured as part of the network.

Overall, the BGWMA continues to experience declining water levels, indicating the potential for continued impacts to the confined geothermal aquifer. IDWR recommends continuing biannual monitoring of the BGWMA network and adding new wells to better monitor the geothermal system's declining status.

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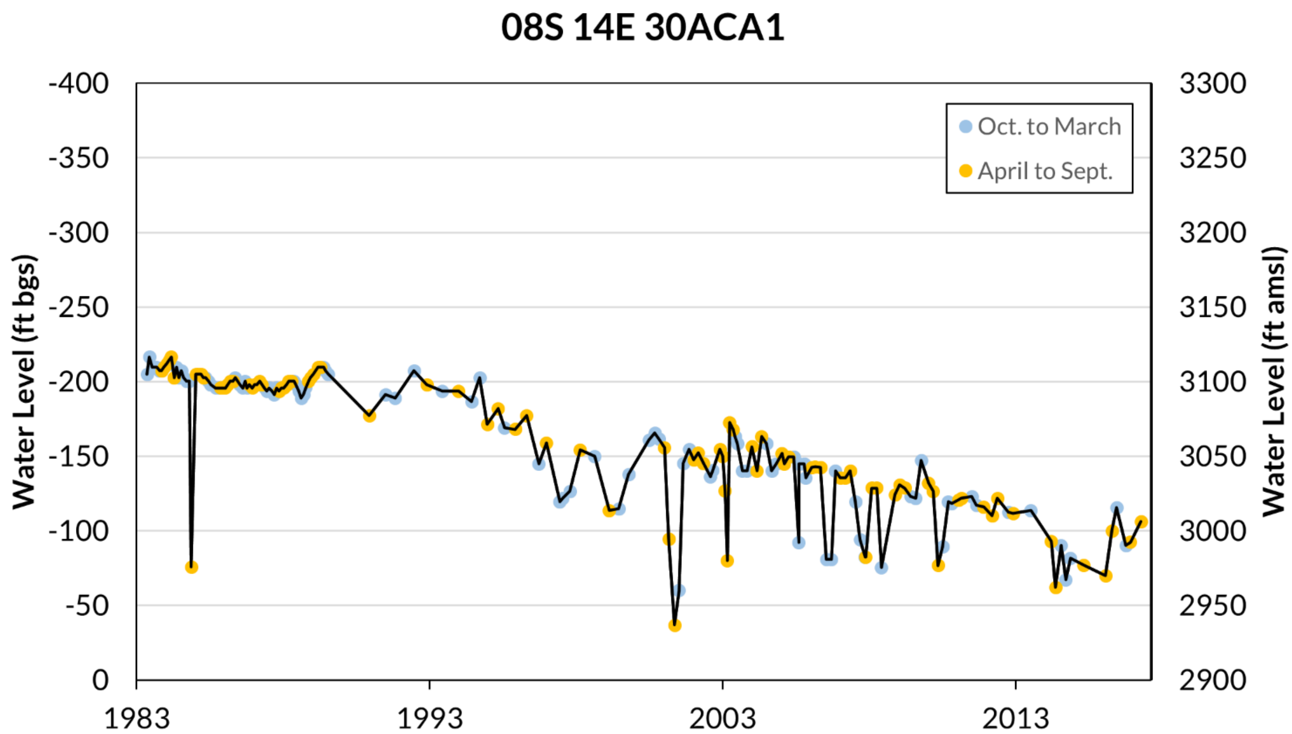
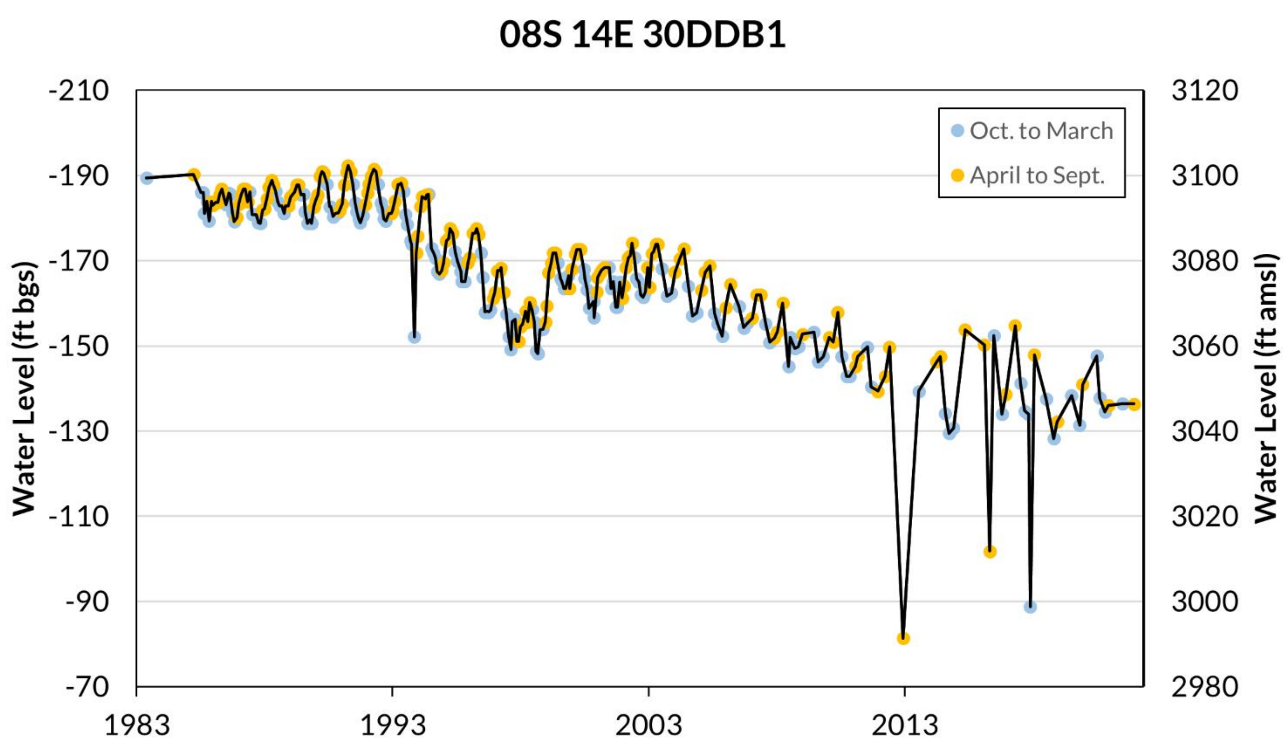
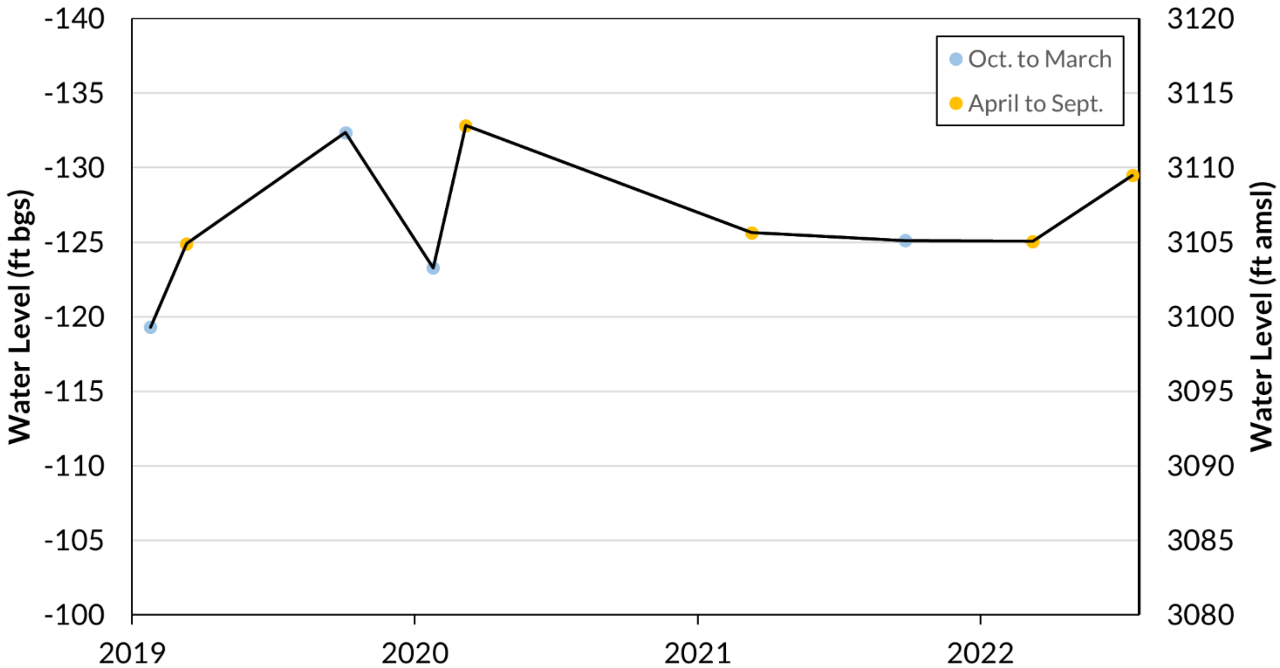
Appendix A – Hydrographs with seasonal water level changes

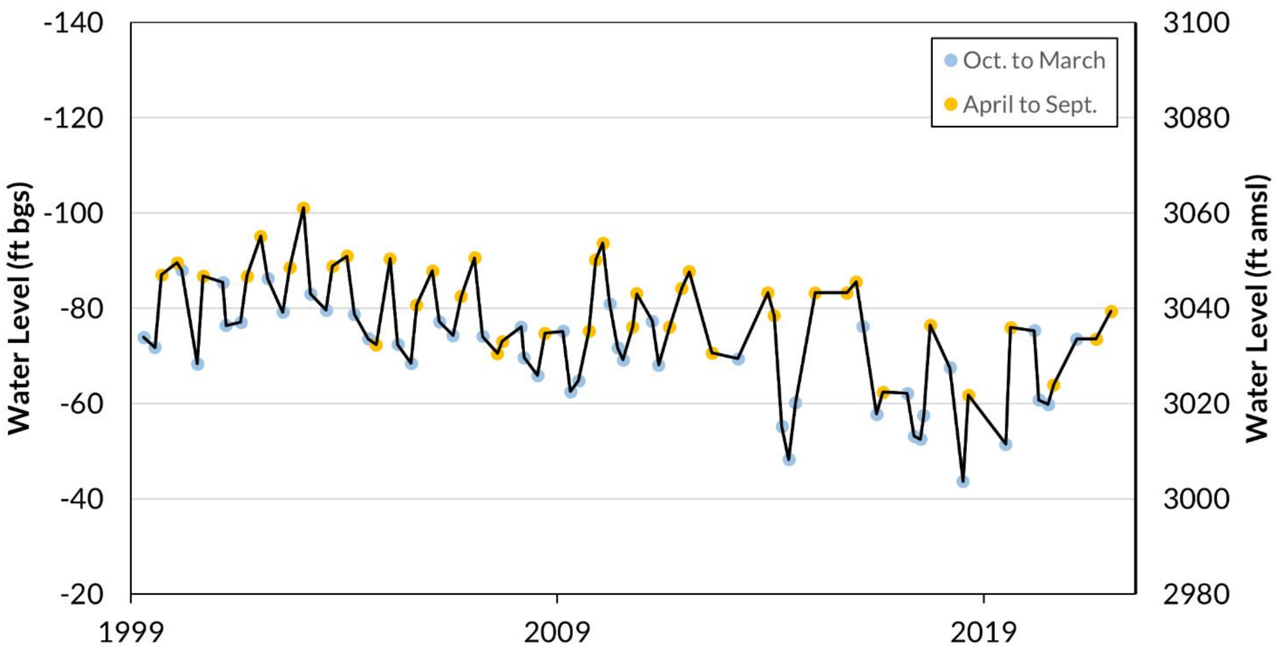




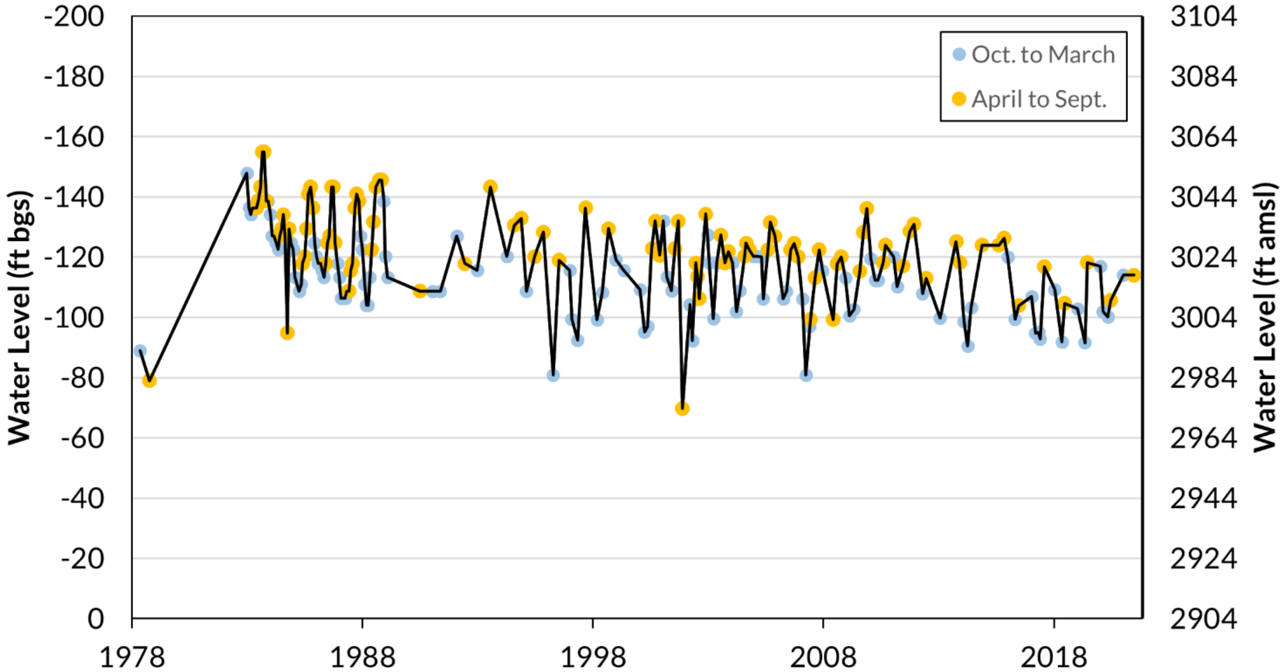
08S 14E 31ABBC1



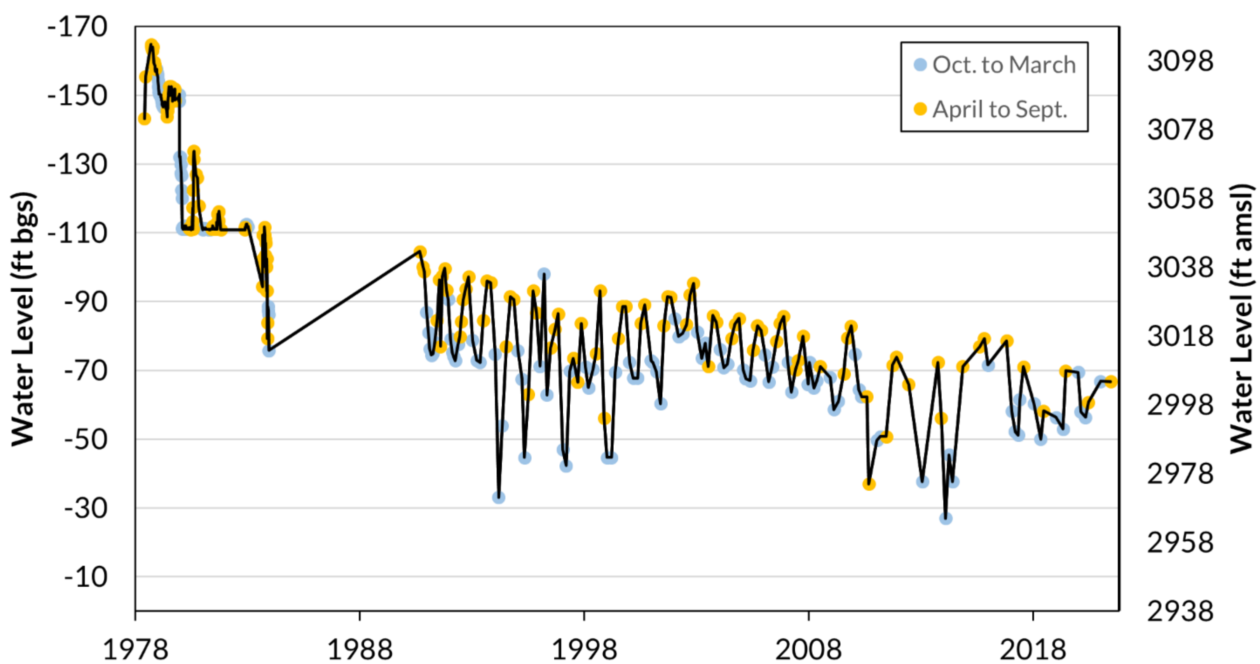
08S 14E 32DAA1

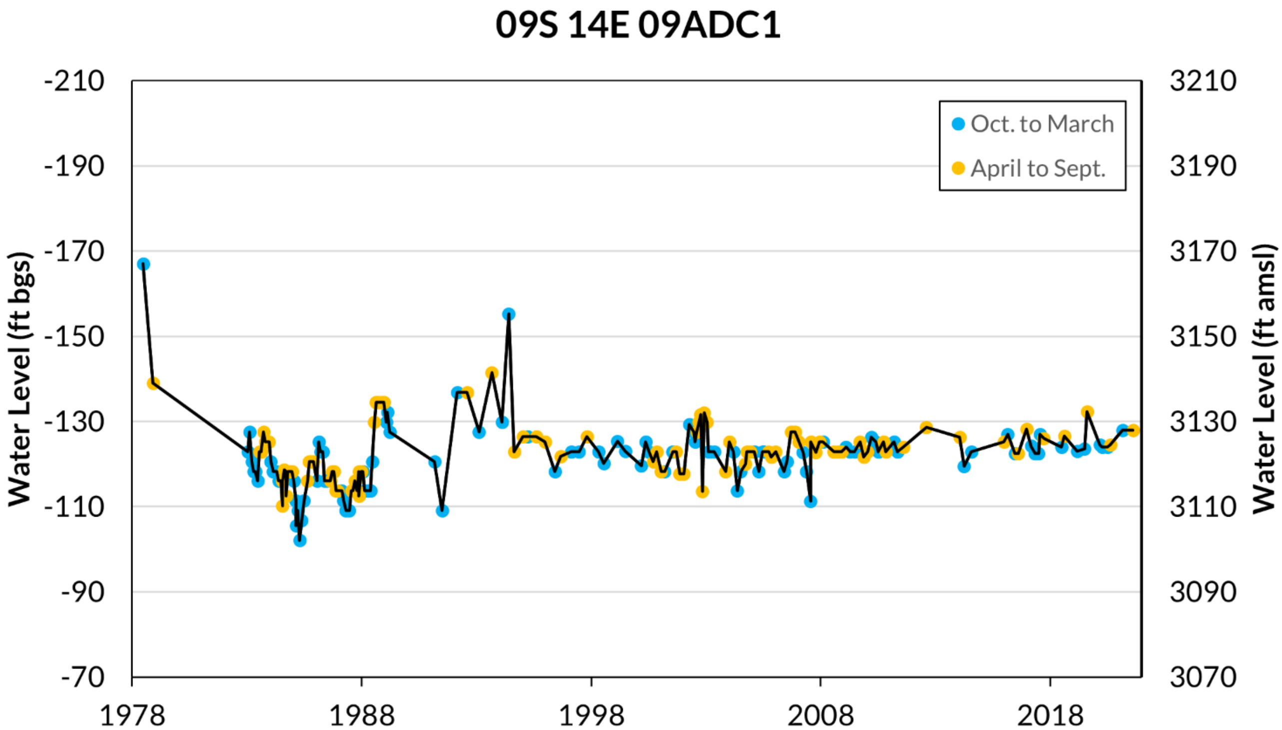


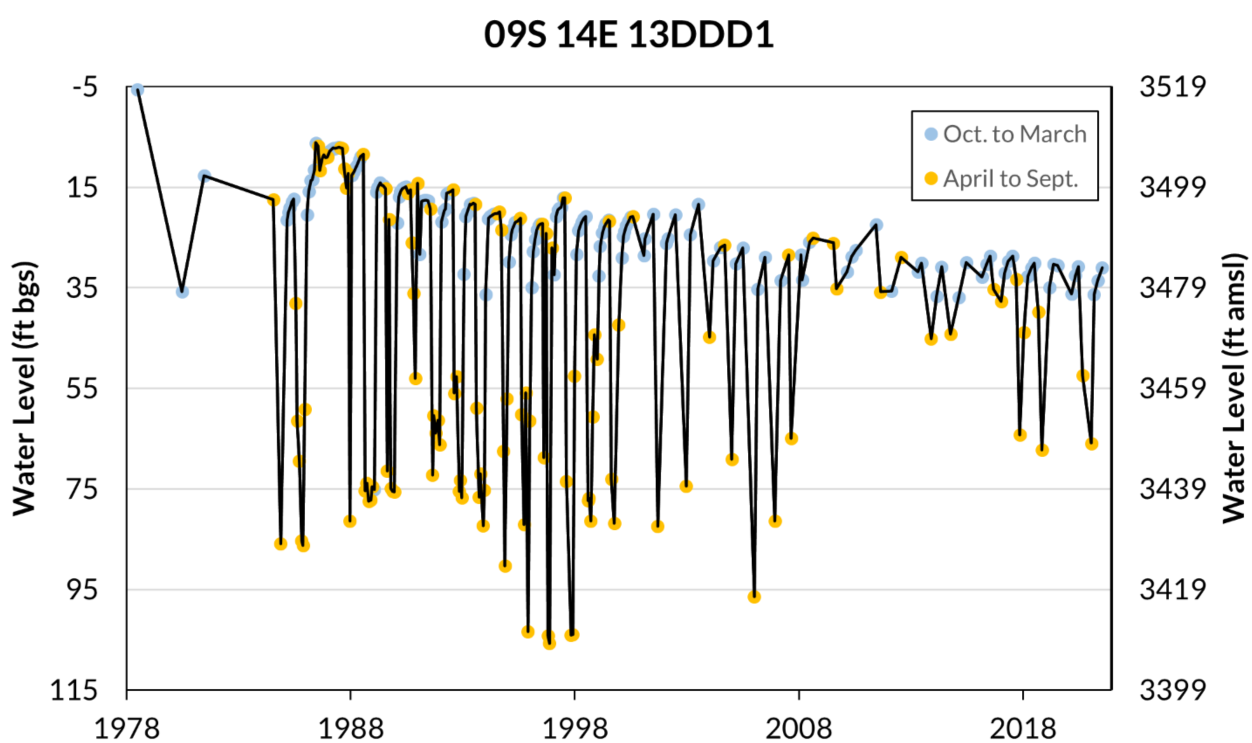
08S 14E 33CCA1

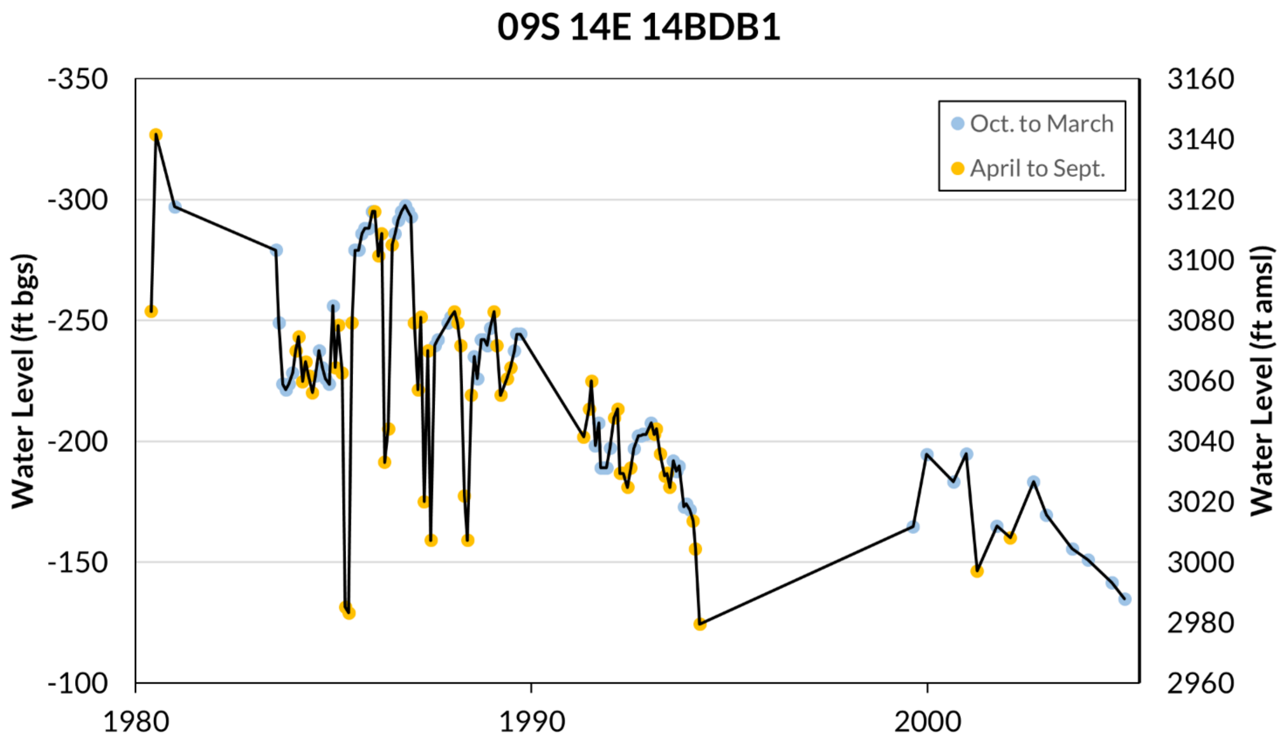


09S 14E 04BBD1




09S 14E 09ADC1
Oct. to March
April to Sept.
Water Level (ft bgs)
Water Level (ft amsl)
-210
-190
-170
-150
-130
-110
-90
-70
3210
3190
3170
3150
3130
3110
3090
3070
1978
1988
1998
2008
2018


09S 14E 13DDD1
Oct. to March
April to Sept.
Water Level (ft bgs)
Water Level (ft amsl)
-5
15
35
55
75
95
115
3519
3499
3479
3459
3439
3419
3399
1978
1988
1998
2008
2018


09S 14E 14BDB1
Oct. to March
April to Sept.
Water Level (ft bgs)
Water Level (ft amsl)
-350
-300
-250
-200
-150
-100
3160
3140
3120
3100
3080
3060
3040
3020
3000
2980
2960
1980
1990
2000