Blue Hole Cienega Nature Preserve, Santa Rosa, New Mexico
Groundwater Monitoring Project Final Report FY 2016-2017

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Contents

Introduction and Site History

The town of Santa Rosa and the Blue Hole Cienega Nature Preserve are located in east-central New Mexico within the Pecos River watershed (~4 million hectares/12.3 million acres in size) at an elevation of about 1,400 meters (~4,600 feet). Santa Rosa is situated inside a 10-kilometer (6-mile) diameter sink, making this one of the most unusual physiographic features of any city in the state (Kelley 1972) (Figure 1). A sink, or sinkhole is best described as a topographic depression formed when underlying limestone and/or gypsum bedrock is dissolved by groundwater. The climate is typical of Eastern New Mexico, with most annual precipitation coming in the form of summer rains and thunderstorms, while there is considerably less precipitation in the winter. The area averages about 14 inches of precipitation annually. Average temperatures range from 32° Celsius (90° Fahrenheit) in the summer to below freezing in the winters. In this area, sinks are caused by the infiltration of water into joints and cracks in soluble rocks such as salt, gypsum and limestone. As these solutions take place underground, the process eventually leads to land subsidence (Sweeting 1972), as evidenced by some 190 sinks present in the basin, with 16 having a perennial water supply (Kelley 1972). The groundwater of certain parts of these sinks migrates to the surface as seeps that cause most of the soils to be saturated near the surface and/or root zone (Sivinski and Bleakly 2004). The local term for such an ecosystem - cienega, can best be described as an alkaline, freshwater, wet meadow with permanently saturated soils in an arid landscape.

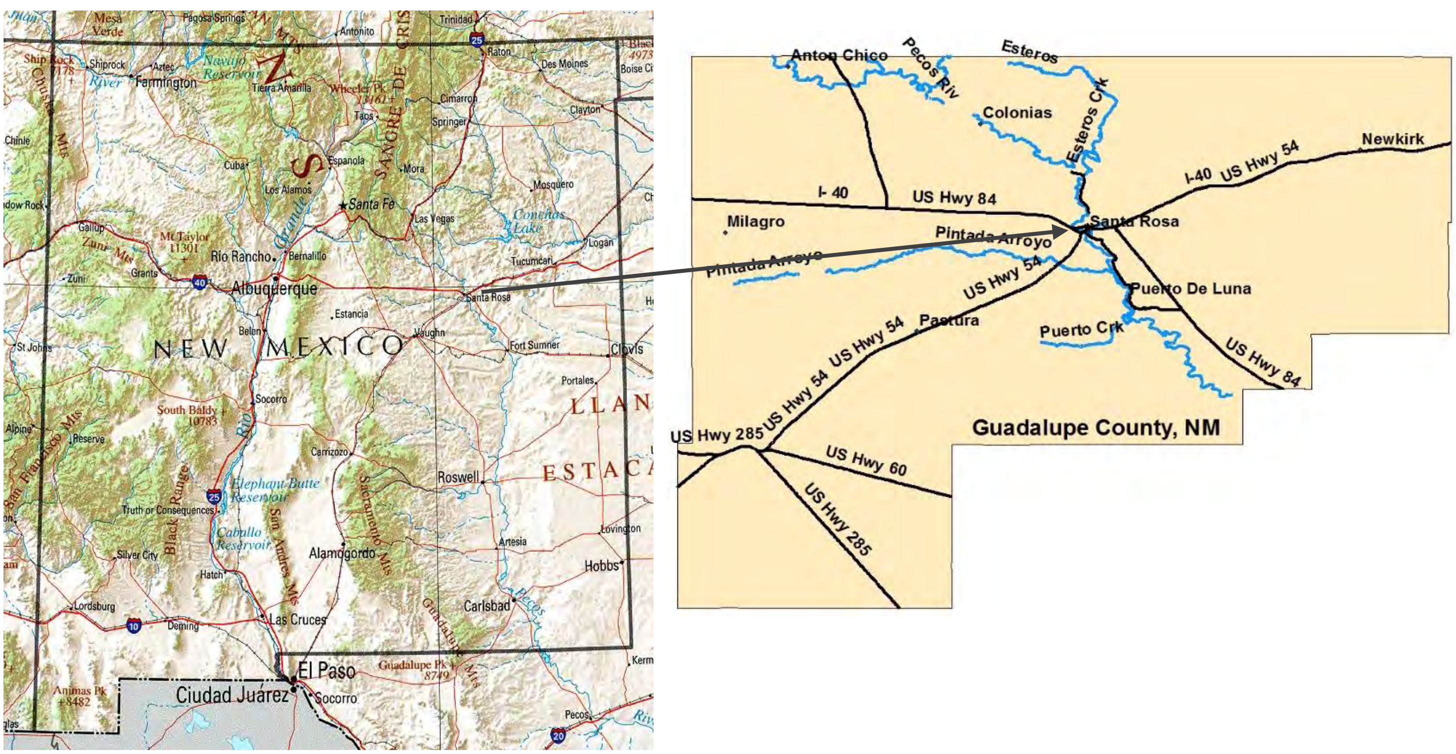

Figure 1. Santa Rosa Location Map

The location of the groundwater monitoring project, the Blue Hole Cienega Nature Preserve (BHCNP), is situated less than two kilometers southeast of the town center of Santa Rosa, New Mexico, located in Guadalupe County. This location is set on 116 acres of native wetland just south of Blue Hole Spring Park, known for its bell-shaped, approximate 30 meter-deep (100 ft), clear sinkhole, and famous for its regional scuba diving. The runoff from the Blue Hole spring flows across the northwest portion of the cienega into El Rito Creek, and ultimately into the Pecos River (Figure 2).

Figure 2

The Blue Hole Cienega (original name) was purchased by the New Mexico Energy, Minerals and Natural Resources Department in the summer of 2005 to protect and manage the cienega in perpetuity for its unique values and particularly to maintain habitat for the Pecos sunflower *(Helianthus paradoxus)* and other rare wetland plants (Figure 3). The BHCNP supports one of the few remaining natural stands of Pecos Sunflower in the entire state of New Mexico (five sites) and west Texas (two sites). These types of habitats have been reduced and/or eliminated by excessive groundwater withdrawals, agricultural activities, and overgrazing by sheep and cattle (USFWS 2005). Due to this overgrazing, a well-documented cycle of arroyo cutting began compromising and ultimately destroying southwestern cienegas (Hendrickson and Minckley 1984).

The sunflower was first noted in 1947 near Fort Stockton, Texas and the 1851 Woodhouse specimen from New Mexico (USFWS 2005). In December of 1980, the Pecos Sunflower was proposed as a candidate for listing as an endangered species under the Federal Endangered Species Act (ESA). The species is now listed as threatened under the ESA, and endangered under the New Mexico Endangered Plant Species Act. In September of 2005, the United States Fish and Wildlife Service's (USFWS) "Pecos Sunflower Recovery Plan," was published with the ultimate goal being to maintain sustainable populations of the plant in its native range and remove the sunflower from the Federal list of endangered species. Wright's marsh thistle (*Cirsium wrightii)* is another rare plant found on the BHCNP and is currently considered a "candidate species" for listing by the federal government and is listed as endangered in the State of New Mexico because of diminished habitat of its historical range since it was discovered in 1851 (Sivinski and Bleakly 2004)(Figure 3).

Helianthus paradoxus
(Pecos sunflower)

Cirsium wrightii **(Wright's marsh thistle)**

Figure 3

Because the Pecos Sunflower thrives and is dependent upon water-saturated soil conditions, any adverse changes to the hydrology of the cienega could result in the rapid degradation of this ecosystem, which would affect not only the sunflower, but other wetland plants and wildlife unique to the cienega habitat. The purpose of the long-term groundwater monitoring project is to provide quantifiable groundwater fluctuation data over time which should assist in better understanding cienega functioning and provide important information with respect to the conditions needed by the Pecos Sunflower and other native wetland vegetation to best succeed. Currently, the main threat to this habitat is the recent encroachment of exotic vegetation species such as *Elaeagnus angustifolia* (Russian olive) and to a lesser extent, *Tamarix* (salt cedar).

General Site and Regional Characteristics

Soils

The dominant soil type that covers approximately ninety percent of the BHCNP is referred to as Bluhol loam and is classified as a hydric soil with 0-2% slopes. The soils are somewhat poorly drained. From 0-10 centimeters in depth, the soils have a pH value of 6.6-8.4 standard units (SU) and are composed of about 5-10% calcium carbonate and about 5-10% calcium sulfate (gypsum). From 10-150 centimeters in depth, the soils have a pH value of 6.6-7.8 SU and are composed of approximately 15-40% calcium carbonate and 30-60% calcium sulfate (NRCS Soil Data 2005).

Physical properties of the soils from 0-10 centimeters in depth are composed of approximately 35-50% sand, 35-50% silt and 10-20% clay, and about 2-5% organic matter. From 10-150 centimeters in depth, approximately the same percentages are found. The site is classified as a wet meadow and characteristic rangeland vegetation includes approximately 40% Alkali sacaton, and 10% each of inland saltgrass, other perennial forbs and grasses.

Vegetation

According to a vegetation study performed in 2004 by Robert Sivinski of the New Mexico Forestry Division (who was instrumental in the land acquisition), and Robert Bleakly of Bleakly Botanical and Biological in Albuquerque, there are 81 plant species found on the BHCNP, of which 18 are non-native species. Of this total, 36 are considered rare (few individual plants and/or infrequent patches); 26 are found occasionally (no continuous distribution, yet encountered in suitable habitats) and 19 considered common (encountered often and nearly continuous in suitable habitats).

The vegetation survey by Sivinski and Bleakly (2004), also determined that the wetlands at Blue Hole Cienega are characterized by four types of habitats and their respective dominant vegetation:

Habitat	Dominant Vegetation
1) Riparian edges along El Rito and Blue Hole Creek	*Baccharis salicina* (great plains seepwillow) *Apocynum cannabinum* (Indian hemp)
2) Wet cienega with fine-sand and alkaline soils that are saturated at/near surface most of the year	*Distichlis spicata* (Indian saltgrass) *Juncus arcticus var. balticus* (Baltic rush)
3) Subirrigated cienega composed of alkaline soils that	*Sporobolus airoides* (alkali sacatan)

are wet on surface during winter and spring and mostly dry on the surface by mid-summer	*Isocoma pluriflora* (southern jimmyweed) *Suaeda calceoliformis* (low seepweed)
4) Tall-grass prairie-deep, sandy, alkaline soils that are moist on surface and subirrigated by groundwater	*Sorghastrum nutans* (Indian grass)

Geology

During Permian time of the Fort Sumner Sheet, which includes portions of Torrance, Lincoln, De Baca, Quay, and Guadalupe counties, there were massive periods of deposition of calcium sulfate, or gypsum. These processes began in the Yeso formation (0-425 meters thick) and continued through time in the San Andres formation (0-215 meters thick), Grayburg and Queen formations (0-120 meters thick), and the Seven Rivers formation (0-90 meters thick); the former two formations being part of the Leonardian series, and the latter two formations being part of the Artesian group in the Guadalupian series (Kelly 1972b).

Subsurface solution phenomenon of soluble rocks such as salts, limestone and gypsum beneath the Santa Rosa Sandstone "cover" eventually led to the collapse of the Santa Rosa basin and smaller sinkholes within the six-mile diameter sinkhole of the town of Santa Rosa itself (Kelly 1972b). According to Sweeting (1972), figures for dissolved salt concentrations in the waters of the Rio Pecos provide ample evidence of the solubility of gypsum and limestone. Total Dissolved Solids (TDS) values for Rio Pecos water above Santa Rosa were 131 parts per million (ppm) - consisting mostly of calcium, sodium, chloride and sulfate. Below Santa Rosa, the values spike to 1,642 ppm, indicating the start of increasing solution of gypsum beds. As readings were taken further south towards Roswell and Carlsbad, the values rise to 3,444 ppm, while at Malaga Bend just above the Texas state line, TDS rose to over 5,000 ppm. There is no mention in Sweeting's (1972) paper as to when this data was collected, but it was pre-1972, the year of her publication. These values are consistent with water quality testing performed by the author at regular intervals since 2005 at the Blue Hole, the Blue Hole Creek, El Rito, and several different seeps and springs found on the BHCNP and in the region.

Hydrology

The groundwater aquifer in the Santa Rosa area is recharged by precipitation descending upon outcrops of permeable rocks and by streams and storm runoff flowing over outcrops of permeable rocks. Recharge water moves downward through permeable rocks to the saturation zone and towards areas of discharge. Water in the Santa Rosa Sandstone formation (located in the general vicinity of the town of Santa Rosa as well as the BHCNP) generally moves eastward (Dinwiddie and Clebsch 1973). As was mentioned in the Geology section above, Permian limestone and gypsum have been removed by subsurface solution and have resulted in a karst topography, or an area in which land subsidence has produced fissures, sinkholes, underground streams, and caverns.

The variations in chemical quality of both groundwater and surface water in the area are closely related to the subsurface geology of the region, with higher amounts of chloride and gypsum found in the Santa Rosa area and the BHCNP. The town of Santa Rosa taps into the San Andreas limestone approximately 16 km (10 miles) north of town for its municipal water supply, likely due to the chemical composition of waters in the town limits.

Groundwater Monitoring Project History and Methodology

On October 6, 2009, Lori Walton (New Mexico Department of Transportation Biologist), Bob Sivinski (NM Forestry Botanist), and Christian LeJeune (Principal Investigator/Hydrologist of Wetwater Environmental Services), proposed ten locations for the installation of shallow groundwater monitoring wells on the BHCNP. Groundwater monitoring was one of several components required by the USFWS as part of wetland mitigation activities. Lori Walton generated a Biological Assessment which was submitted to the USFWS on May 12, 2010, and findings were that the installation of the monitoring wells "may affect, but is not likely to adversely affect (with implementation of preventative practices)" the *Helianthus paradoxus* or *Cirsium wrightii* populations on the cienega. The Section 7 consultation (Consultation #22420-2010-I-0057) was concluded and approved on June 14, 2010 by the USFWS.

Groundwater well installation field assistance was provided by HDR, Inc., middle and high school students from the Santa Rosa Consolidated School District (SRCSD), and Wetwater Environmental Services. Funding for all supplies, equipment, and data loggers were provided by the New Mexico Department of Transportation. The original thinking when the first set of groundwater wells was installed in 2010 was to refer to a typical southwest arid hydrograph in order to determine the optimal time of year to install groundwater wells. Most rivers in the region are generally at their lowest flows in late-summer through early-fall (generally September through November) because of natural low-flows and irrigation withdrawals being at their highest demand.

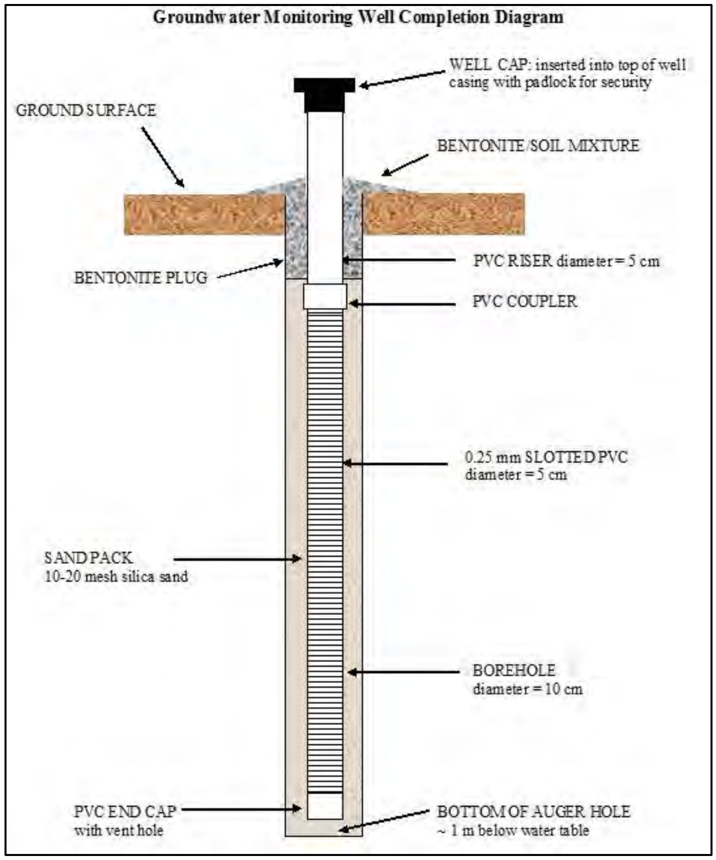

Figure 4

Therefore, the water table is at its lowest point of the year, allowing for a well to be drilled deeper before encountering the water table. The past several years have produced more precipitation in September than historical data trends, hence one has to ensure not to install a well after a known rain event, for the water table will be temporarily high and may not allow for deeper drilling as desired.

Groundwater well boreholes were made using a 10-centimeter (cm) diameter manual soil auger with bucket attachments to minimize impact to the immediate areas. Once the water table was encountered, it was generally possible to auger to approximately one meter (m) below the water table. Five-centimeter diameter PVC pipe was used for well construction, with 0.25 millimeter screened pipe in the water table, and solid pipe used for the riser. The 5 cm vertical void space surrounding the well was packed with 10-20 mesh silica sand to help prevent fine particles from caking up the screened pipe. Approximately 30 cm of the vertical void space below ground surface was plugged with bentonite to form a seal so that surface water would not infiltrate through the disturbed boring (Figure 4). Total well lengths varied from 220 cm to 455 cm below ground surface based upon field conditions and the time of year they were installed.

Soil was analyzed from each retrieved core at well locations with the average height of cores being 10 cm. Field parameters analyzed and documented were: moisture content, grain size, and soil color using Munsell Color Charts. A typical soil profile encountered at monitoring well locations was composed of varying amounts of organic matter at the surface "O" horizon, and the "A" topsoil horizon. The soil was generally moist in the "B" horizon, to very moist near the water table, and saturated at the water table in the "C" horizon (Figure 5). Soil colors ranged from grayish-brown to yellowish-brown to dark brown. Soil textures were mostly fine sand to silty and clay loams. Redox features encountered in soil were calcium sulfate concretions and iron and manganese mottling and/or specks.

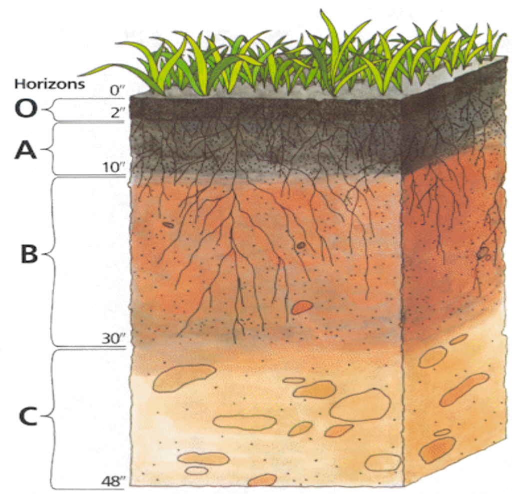

Figure 5. NRCS Soil Profile

Wells are named Blue Hole Cienega 1 (BHC 1), BHC 2, etc... On-the-ground work commenced in summer of July 2010, and wells were installed and instrumented as described below:

- July 2010: BHC 1 and 3 installed
- August 2010: BHC 4, 5, 7, 9 installed
- October 2010: BHC 8 and 10 installed
  (BHC 10 was broken [thus abandoned] attempting to repair it in late 2013- instead of replacing it in the same location, BHC 6 was chosen as an alternative replacement location after consultation with NM Forestry because it was closer in vicinity to the Pecos sunflower and Wright's marsh thistle).
- March 2014: BHC 2 installed (all wells except BHC 6 and 11 were instrumented with pressure transducers and programmed to begin recording data on April 1, 2014)
- May 2014: BHC 6 and 11 installed (BHC 6 replaced BHC 10; BHC 6 and 11 were instrumented with pressure transducers and programmed to begin recording data on May 22, 2014)

All wells are instrumented with Solinst Edge Leveloggers (pressure transducers) as of 2017, along with one barometric data logger co-hung in well BHC 3 for compensation of barometric pressure for all wells. Because of damage to BHC 7 during a prescribed burn on February 1, 2017 (discussed below), the barologger was re-located to BHC 3. Direct data read cables attached to pressure transducers are suspended from specialized Solinst well caps, and data is downloaded using a smartphone from the well head using the Solinst Levelogger App Interface device. In the case of malfunction or uncertainty with the App interface device, a field laptop computer is used to download data and re-program the transducers. Field recording intervals are set at 15-minutes. As of October 27, 2017 (the fifth and final site visit under this contract), there are approximately 42 months of baseline groundwater data for all wells except BHC 6 and 11, which have approximately 40 months of data respectively.

With the July 2016 deployment of an automated data-logging rain gauge, a precipitation dataset has been coupled with groundwater data to better quantify how localized precipitation affects the ground water table.

Site visits to download data from the monitoring wells under this contract were made on the following dates:

- October 30, 2016
- January 12, 2017
- February 7-8, 2017 (Post-Rx burn)
- May 10, 2017
- October 27, 2017

Prescription Burn: February 1, 2017
A prescribed burn conducted on the cienega on February 1, 2017, damaged three groundwater wells: BHC 1, 4, and 7. These wells were out of service starting on February 8, repaired and field tested for accuracy in early May, and were back in service on May 12, 2017.

Figure 6: Post-Rx Burn at BHCNP

The date ranges in Table 1 indicate when a well was down for repair and not recording data, or was not recording data because the well was dry. Depending on the nature of the graphical representations of data in this report, some of the below data may be portrayed or left out.

Well	Date Range	Reason for Lack of Data
BHC 1	2/8/2017 – 5/12/2017	Rx burn repairs
BHC 2	7/4/2016 – 10/10/2016 6/11/2017 – 9/29/2017	Dry well
BHC 4	2/8/2017 – 5/12/2017	Rx burn repairs
BHC 6	6/30/2016 – 12/16/2016 5/28/2017 – 10/27/2017	Dry well
BHC 7	2/8/2017 – 5/12/2017	Rx burn repairs

Table 1

The purpose of the groundwater monitoring project is to provide quantifiable groundwater fluctuation data over time to assist in better understanding hydrological functioning within the cienega and provide important information with respect to the hydrological conditions needed by the Pecos Sunflower and other rare and native wetland vegetation to best succeed. This report is a continuation of work completed in 2016 by the author (LeJeune 2016).

Results

Trend Observations from Over Three Years of Automated Groundwater Data

Since there are now over three years of groundwater data, seasonal fluctuation patterns are becoming apparent, with some minor variations from year to year. From June through September, the water table is very flashy due to monsoonal rain, with the water table at most wells often rising to near ground surface during large rain events (Figure 8). From early-October through late-November, the water table rises to near ground surface and remains so through February and early March. From early-March through late-May, the water table gradually declines, before exhibiting a drastic drop from late-May through June. In an attempt to best hypothesize why the water table behaves as such, several factors below may assist in understanding with further study.

It is known that the cienega is likely recharged by naturally-occurring seeps and springs, as well as the run-off from the Blue Hole itself. According to the Dinwiddie and Clebsch report from 1973, water in the Santa Rosa Sandstone formation (located in the general vicinity of the town of Santa Rosa as well as the BHCNP) generally moves eastward (Dinwiddie and Clebsch 1973). This being accurate, surface water flows in El Rito may be one of the driving forces of groundwater fluctuation since it borders the BHCNP on the western edge. Since precipitation during the colder months does not appear to be a factor in water table levels, it is possible that the water table is affected by larger-scale phenomena such as surface water levels at Santa Rosa Lake State Park and surface water levels in the Pecos River, which are driven by controlled dam releases from Santa Rosa Lake State Park. Another hypothesis is that as the dam at James Wallace Dam continues to degrade and allow more surface water from El Rito to ultimately flow into the Pecos River, this could affect the water table in ways which are not yet understood. According to a conversation with Santa Rosa City Manager, Tim Dodge, work performed by a contractor (author has no information for this project) in El Rito upstream of the BHCNP in approximately 2015, may have altered El Rito channel geomorphology (in combination with severe rain events and flooding), and ultimately affected the water table. Regular draining and refilling of City Park Lake could also be another factor which needs further study.

The most striking patterns for all 10 water wells with respect to the water table, is that it has been dropping substantially over the past three years. Table 2 and Figure 7 below present the mean annual depth to water table values (in table and graphic representation respectively) for each well for the years of 2015, 2016, and 2017. The 2017 dataset ends on October 27, 2017, therefore it has approximately two months short of one full year of data. 2017 data has been included to show that a declining trend in the water table is still evolving.

Well	2015	2016	2017
BHC 1	38	64	102
BHC 2	26	43	49
BHC 3	50	111	140
BHC 4	43	97	151
BHC 5	149	177	191
BHC 6	68	69	81
BHC 7	81	164	265
BHC 8	32	60	81
BHC 9	41	84	106
BHC 11	41	77	100
BARO	879	879	877

Table 2. Depth to Water Table Mean Annual Values for Years 2015 – 2017.

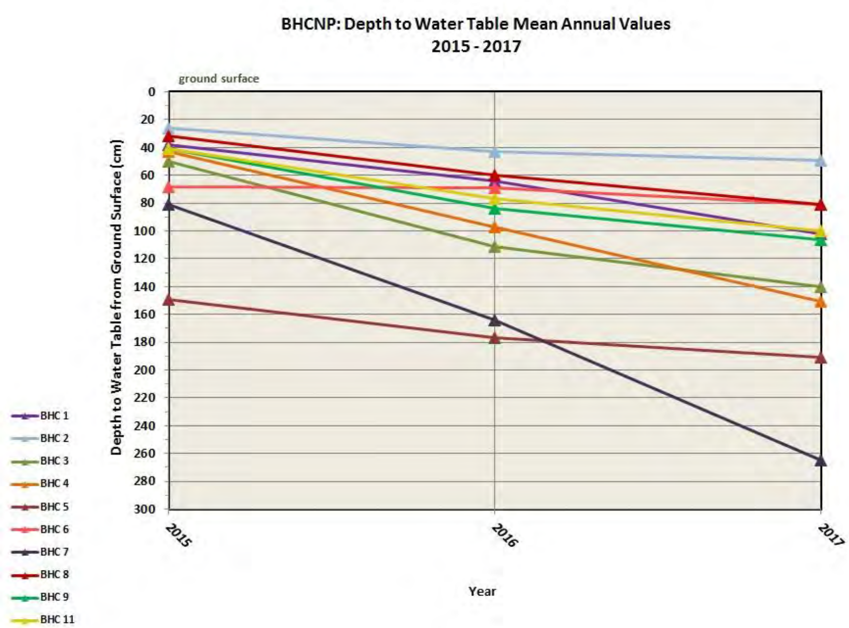

Figure 7

The water table mean values at all wells except for BHC 5 and 6, have dropped either two or three-fold between 2015 and 2017. BHC 5 and 6 still exhibited declining water levels, although to a lesser degree. Though this trend is happening, it does not appear to be affecting the number of flowering Pecos Sunflowers, as discussed below. In fact, sunflower numbers have been increasing and/or stable from 2013 – 2016, and more than doubled in 2017 in the transects associated with wells.

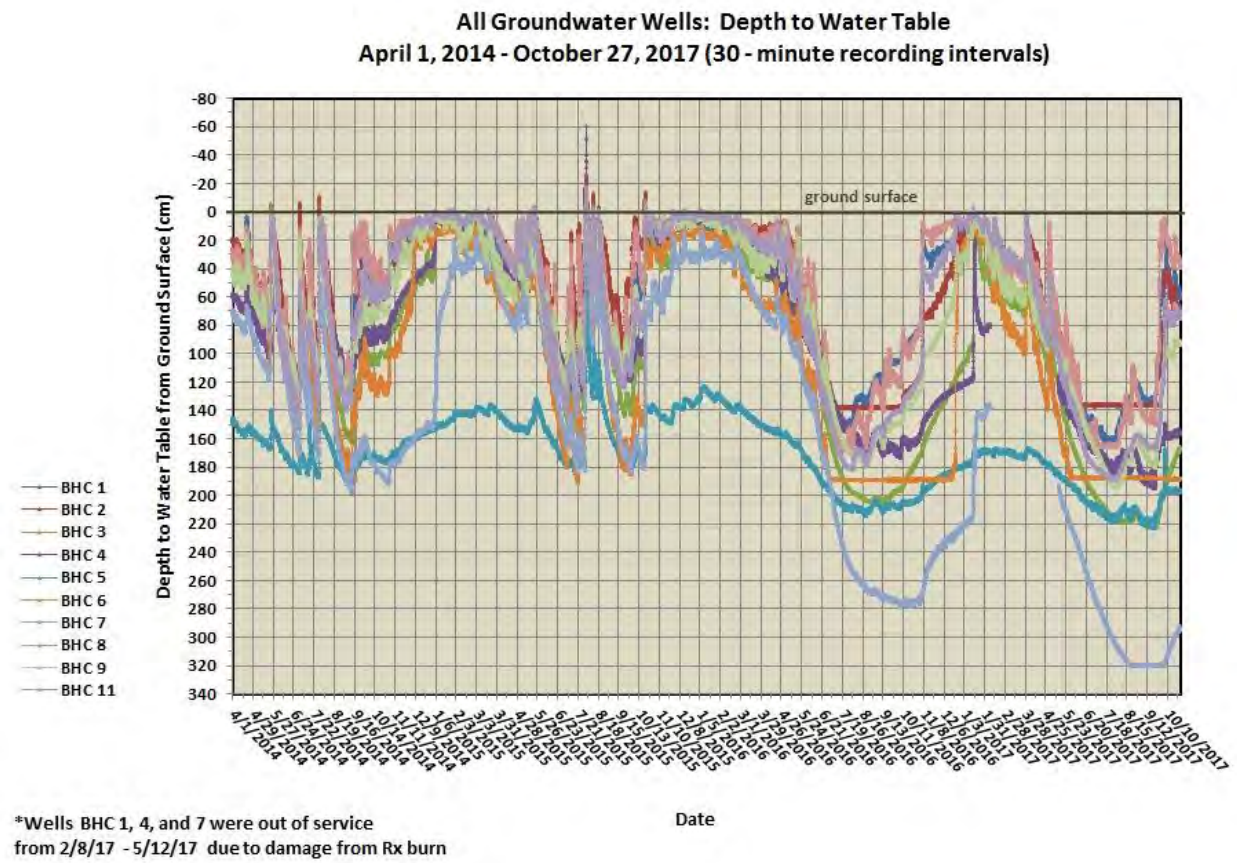

Figure 8

The behavior of the water table is of interest with respect to germination, establishment, and reproduction of the Pecos Sunflower (which germinate and establish in early spring and reproduce in late summer). Data analysis shows that the water table drops approximately one meter across most wells starting in early-August through the end of September and into early-October, with the earlier part of this range occurring during the active growing season for the sunflowers. Though numerous rain events also occur during this timeframe, this pattern can still be observed. Since the reproduction period for the sunflower is coincident with the monsoon season, perhaps an abundant sunflower population is more dependent upon sufficient precipitation and associated surface water availability during this timeframe.

Pecos Sunflower population trend data has been collected in early-October since 2013. The number of plants is counted along eleven 2 m x 30 m transects, of which five have groundwater wells located adjacent to the transect (Table 3).

Transect	Associated Well	#Plants 2013	#Plants 2014	#Plants 2015	#Plants 2016	#Plants 2017
2	BHC 1	198	1213	1276	1731	1072
8	BHC 1	2	0	0	0	164
9	BHC 2	306	28	0	0	14
10	BHC 2	486	712	726	400	1508
3	BHC 3	0	65	0	14	153
11	BHC 6	41	17	2	1	10
7	BHC 7	9	125	21	74	2225
	TOTAL	**1042**	**2160**	**2025**	**2220**	**5146**

Table 3

Visual observations made by the author over the years confirms that there are dense concentrations associated with groundwater wells BHC 1 and 2, and meager concentrations at BHC 3 and 6. The area around BHC 7 has experienced the greatest fluctuation in terms of plant count, and has had an observed abundance of sunflowers in most of the years preceding 2013. *Helianthus paradoxus* is an annual plant with shallow roots. Populations contract and expand depending on resource availability from year to year. Soil salinity concentrations, water availability, wind, wildlife, and precipitation play a large part in germination and establishment, reproduction, and seed dispersal. Fire or other disturbances likely affect where the sunflower may occur in its habitat and annual fluctuations in population numbers. It is theorized that the sunflowers best germinate in high water table conditions, but does not like to have its roots in the saturated zone or in standing water for extended periods of time. Sunflowers germinate in March, after the danger of major frost subsides, when the water table is high. They are well established by the time it recedes by the end of May. They remain in a stagnant state until the monsoons come in and provide enough surface moisture to allow for maximum growth and flowering. In addition, it is thought that the salinity in the soil is diluted when there is plenty of surface moisture, allowing plants to germinate and establish from March to May, then to continue their growth after the monsoons provide sufficient water to dilute salt concentrations, allowing for maximum growth and flowering.

As can be observed in Figure 8 above, the water table across all wells during most of the year is variable, except for BHC 5, which has the lowest consistent water table of all wells during the year. From January – May, the water table is up to approximately 80 cm from ground surface, and from October through December, the water table is up to approximately 40 cm from ground surface. During June – September, the water table is more erratic due to flashy precipitation events during the monsoon season, which generally starts in early July. Although germination and establishment of sunflowers occurs in early spring, the majority of active growth occurs with the onset of the monsoons, leading to flowering in early September.

One approach to correlate sunflower transect and groundwater data is to compare the mean water table depth over the entire year at each well with the number of sunflower individuals found at those transects with wells associated with them (Table 2). In addition, a comparison of groundwater levels from March – May of each year from 2015 – 2017 during the timeframe in which may be most critical for correlations of groundwater and sunflower populations is also provided in Table 4. Summary statistics for each well are included for reference in Tables 5 & 6.

Both 2015 and 2016 have complete groundwater data sets, and 2017 has data through late-October.

One trend observed in 2015 and 2016, was that sunflowers may be more prevalent at locations with higher water tables. However, data from 2017 does not really follow any trend. The water table at all wells was substantially lower in 2017 compared to the two previous years and the sunflower thrived. Perhaps soil moisture should be incorporated into monitoring data; it may provide important information to better understand what drives the Pecos Sunflower.

Well	2015	2016	2017
BHC 1	38	64	102
BHC 2	26	43	49
BHC 3	50	111	140
BHC 4	43	97	151
BHC 5	149	177	191
BHC 6	68	69	81
BHC 7	81	164	265
BHC 8	32	60	81
BHC 9	41	84	106
BHC 11	41	77	100

Table 2. Depth to Water Table Mean **Annual** Values for Years 2015 - 2017

Well	2015	2016	2017
BHC 1	23	36	108
BHC 2	16	19	55
BHC 3	29	47	91
BHC 4	25	45	133
BHC 5	145	155	177
BHC 6	50	70	110
BHC 7	50	76	210
BHC 8	16	21	58
BHC 9	32	37	76
BHC 11	19	33	67

Table 4. Depth to Water Table Mean Values from **March – May** for Years 2015 – 2017.

During March – May, mean water table values are substantially lower across all three years, with a few exceptions. The mean water table values at wells 1, 2, and 6 are slightly higher (translating into a lower water table) in 2017 than compared to the previous two years. This can likely be attributed to wells 2 and 6 going dry during various timeframes mentioned above. BHC 1 only had data from May 12 – 31st, providing a skewed mean. Since the period from March – May is a critical time for germination of the sunflower, the fact that the water table is higher during this time may be the driving force into the ultimate success of sunflower numbers for any given year, since precipitation does not appear to be a factor since most rainfall occurs during the summers.

2015

Well	*Mean*	Standard Deviation	Range	Minimum	Maximum	# Plants 2015
BHC 1	***38***	35	135	-14	121	1276
BHC 2	***26***	28	153	-27	126	726
BHC 3	***50***	47	174	-18	156	0
BHC 4	***43***	42	194	-60	133	-
BHC 5	***149***	19	185	2	187	-
BHC 6	***68***	57	182	8	191	2
BHC 7	***81***	51	188	-3	184	21
BHC 8	***32***	37	133	0	133	-
BHC 9	***41***	37	130	-3	127	-
BHC 11	***41***	44	162	-18	144	-

2016

Well	*Mean*	Standard Deviation	Range	Minimum	Maximum	# Plants 2016
BHC 1	***64***	49	153	-1	152	1731
BHC 2	***43***	41	134	1	135	400
BHC 3	***111***	72	205	0	205	14
BHC 4	***97***	61	173	1	174	-
BHC 5	***177***	29	91	123	214	-
BHC 6	***69***	49	177	10	187	1
BHC 7	***164***	96	266	13	279	74
BHC 8	***60***	58	166	3	169	-
BHC 9	***84***	59	180	-1	179	-
BHC 11	***77***	64	184	-1	182	-

2017

Well	*Mean*	Standard Deviation	Range	Minimum	Maximum	# Plants 2017
BHC 1	***102***	53	259	-1	258	1236
BHC 2	***49***	35	137	-2	135	1522
BHC 3	***140***	70	224	0	224	153
BHC 4	***151***	35	190	5	195	-
BHC 5	***191***	18	57	167	223	-
BHC 6	***81***	50	180	7	188	10
BHC 7	***265***	58	185	135	321	2225
BHC 8	***81***	59	165	2	167	-
BHC 9	***106***	60	197	-1	195	-
BHC 11	***100***	66	192	-3	189	-

Table 5: **Annual** Summary Statistics from January 1 – December 31, Years 2015 – 2017. Bad data runs during dry periods were deleted and not included in above statistics. Depth measurements are in centimeters.

2015

Well	Mean	Standard Deviation	Range	Minimum	Maximum	#Plants 2015
BHC 1	***23***	14	61	-6	55	1276
BHC 2	***16***	9	43	-4	40	726
BHC 3	***29***	17	63	-5	58	0
BHC 4	***25***	19	63	-4	59	-
BHC 5	***145***	6	24	132	156	-
BHC 6	***50***	20	64	12	77	2
BHC 7	***50***	20	80	4	85	21
BHC 8	***16***	12	51	0	51	-
BHC 9	***32***	18	70	-3	67	-
BHC 11	***19***	15	63	-6	57	-

2016

Well	Mean	Standard Deviation	Range	Minimum	Maximum	#Plants 2016
BHC 1	***36***	17	79	6	85	1731
BHC 2	***19***	14	66	4	71	400
BHC 3	***47***	14	67	23	90	14
BHC 4	***45***	19	87	6	93	-
BHC 5	***155***	9	39	137	177	-
BHC 6	***70***	17	90	36	126	1
BHC 7	***76***	22	100	30	130	74
BHC 8	***21***	15	73	5	79	-
BHC 9	***37***	16	80	3	83	-
BHC 11	***33***	20	85	6	92	-

2017

Well	Mean	Standard Deviation	Range	Minimum	Maximum	#Plants 2017
*BHC 1	***108***	7	31	90	121	1236
BHC 2	***55***	29	114	3	117	1522
BHC 3	***91***	34	143	20	164	153
*BHC 4	***133***	7	30	115	146	-
BHC 5	***177***	8	27	167	194	-
BHC 6	***110***	37	173	15	188	10
*BHC 7	***210***	9	32	193	225	2225
BHC 8	***58***	28	118	4	122	-
BHC 9	***76***	26	126	1	126	-
BHC 11	***67***	35	138	0	138	-

Table 6: Summary Statistics from **March 1 – May 31**, Years 2015 – 2017. *No data recorded until May 12th because wells were down for repairs. Depth measurements are in centimeters.

Groundwater and Precipitation

As of October 12, 2017, there were approximately 15 months of precipitation data to couple with groundwater data as presented in Figure 9. There were 119 total days during this period in which rainfall was recorded in varying amounts from 0.3 cm (0.1 in) – 4.0 cm (1.6 in). The total precipitation recorded over this time was 60.4 cm (23.8 in). Most precipitation occurs during July through September. In 2016 and 2017, the monsoon season did not commence until late-July or early-August. Appendix B portrays graphs coupling precipitation and groundwater data for the four largest rain events during the period of record.

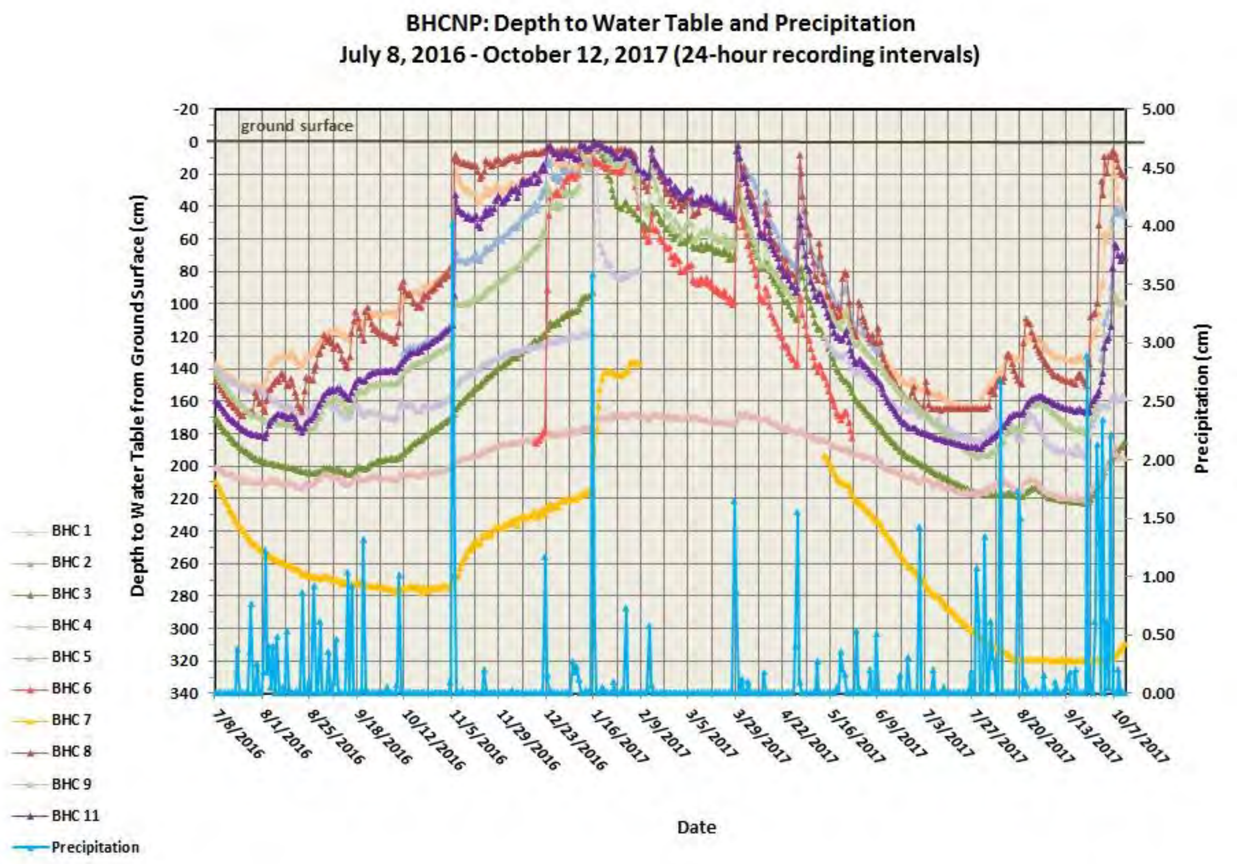

Figure 9

Discussion

Many points have been highlighted and discussed in past reports as to why the water table on the BHCNP behaves as patterns are starting to indicate. Some of these could be contributing to an overall decline in water table levels in the larger wetland complex expanding well beyond the BHCNP.

- Fluctuations in surface water run-off from recreational usage of the Blue Hole which flows through the northwest portion of the BHCNP, and ultimately El Rito.
- Occasional dredging of the Blue Hole by the United States Army Corps of Engineers
- The compromised James Wallace Dam just southwest of BHCNP. El Rito flows into this small reservoir and continues to flow past the waste water treatment plant, and into the Pecos River approximately 400 meters south.
- Dam releases and water levels of Santa Rosa Lake at the State Park have downstream effects that may interact with the shallow water table complex and El Rito.
- Unknown status of groundwater well located approximately 150 meters south of the Blue Hole transition stream. If this well is still active and pumping water, it could have an impact on localized water table levels.
- Surface water diversion head gate along Blue Hole transition stream. At one point, this diversion was channeled through a culvert which was placed underneath El Rito, but this was destroyed by several high flow events in summer 2013 and to the author's knowledge, has yet to be repaired. It is very likely that these events may have altered the hydro-geomorphology of El Rito, thus potentially altering hydrological functioning and adjacent groundwater levels.
- Past efforts to divert and channel water on the cienega as evidenced on the aerial photo map in Figure 2 and observing the diagonal and other lines that look out of place. Since the general region much larger than the BHCNP itself is considered the same wetland complex, any past and current activities or projects associated with the wetland complex such as construction (roads, convention center, back-filling of old fish hatchery, ball park development, residence), irrigation diversions, upstream work on El Rito, etc…may certainly affect the hydrologic functioning on the cienega.
- Beaver dams have been observed by the author intermittently along the transition stream from the Blue Hole near the diversion headgate. These dams diverted some of the main channel flow to the north and south of the stream, often leaving sheet flow and several inches of water in approaching the main channel from either direction. In approximately 2014, a neighboring land owner told the author they had finally fixed the beaver dams by removing them, but they do come back, often along El Rito as well. These dams may also have impacted the water table in ways which are difficult to quantify, for there exists no data on precisely when and where the dams were, or their frequency.

More obvious and quantifiable events have happened in the past year such as the prescribed burn, the completion of a residence on the eastern slope of the BHCNP, the monsoon season starting approximately one month late the past two years, manipulation of El Rito upstream of the BHCNP from another project (~2 years ago, but may still have effects), and intermittent beaver dams along El Rito west of the cienega. It is only hypothesized that these actions and events may contributing factors to groundwater table declines. Wells BHC 2 and 6 first became dry in early July 2016 and registered groundwater again in early-October and mid-December respectively. In 2017, BHC 2 and 6 first became dry in early-June, and as of October 27, 2017, only BHC 2 has registered groundwater again in late-September, while BHC 6 remained dry. The drying of these two wells corresponds with the overall decline in the water table observed by this research.

Groundwater is very responsive to precipitation events. It was observed that wells with higher pre-rain event water tables responded with greater magnitude, while those wells with lower pre-rain event water tables responded with less magnitude and often had more lag time to response than shallower wells.

Recommendations for Future Research and Work

The installation of a surface water gauge which can withstand the flashy waters of El Rito would help quantify the interaction between ground and surface water, at least on the western edge of the BHCNP in the general locations of wells BHC 4 and 5. As mentioned previously, the groundwater wells need to be professionally surveyed so that groundwater fluctuations can be observed with respect to the elevation of the water table. Gradient and flow path estimations can also be derived with elevation data.

Additional recommendations are as follows:

- Document and measure likely recharge sources of the BHCNP such as the Blue Hole, the Blue Hole transition stream, and El Rito.
- Installation of automated-logging soil moisture probes to monitor fluctuations in surface soil moisture would complement the other data sets and provide insight into optimum soil moisture needs of the sunflower.
- Monitor fluctuations and trends in sunflower germination and establishment during high water table months (March – May) to correlate with water table levels and complement existing fall monitoring and reproduction success.

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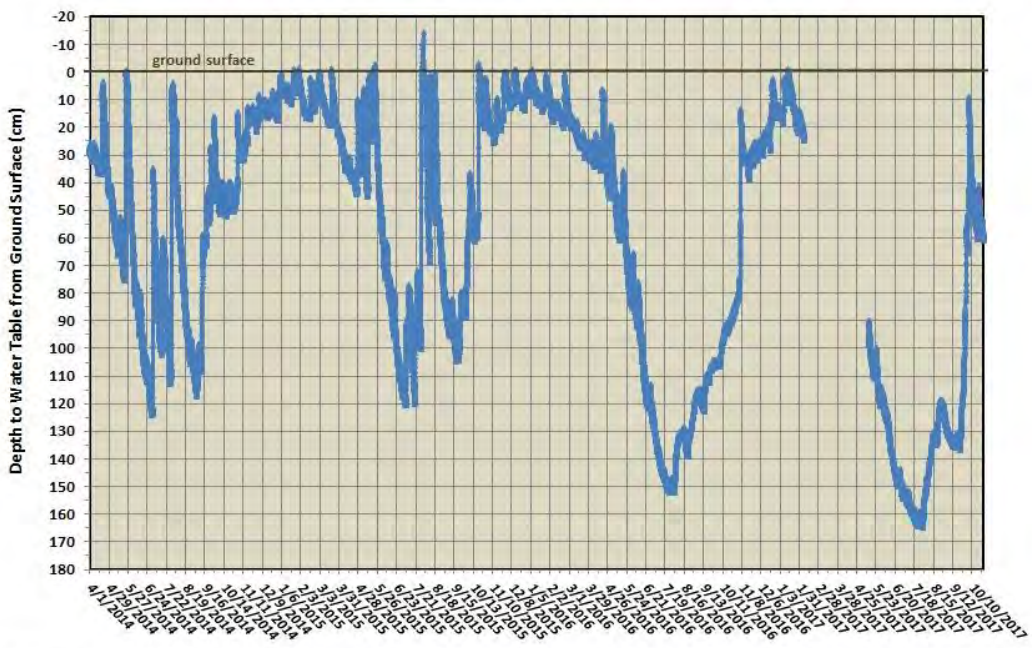
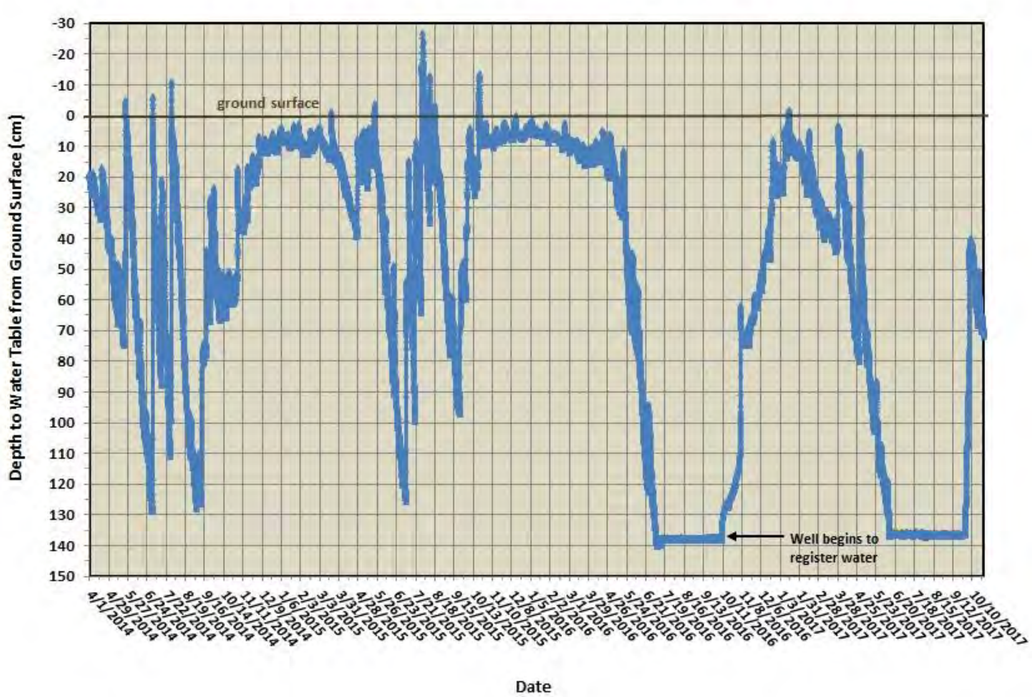
Appendix A: Depth to Water Table Individual Graphs

BHC 1: Depth to Water Table
April 1, 2014 - October 27, 2017 (30 - minute recording intervals)

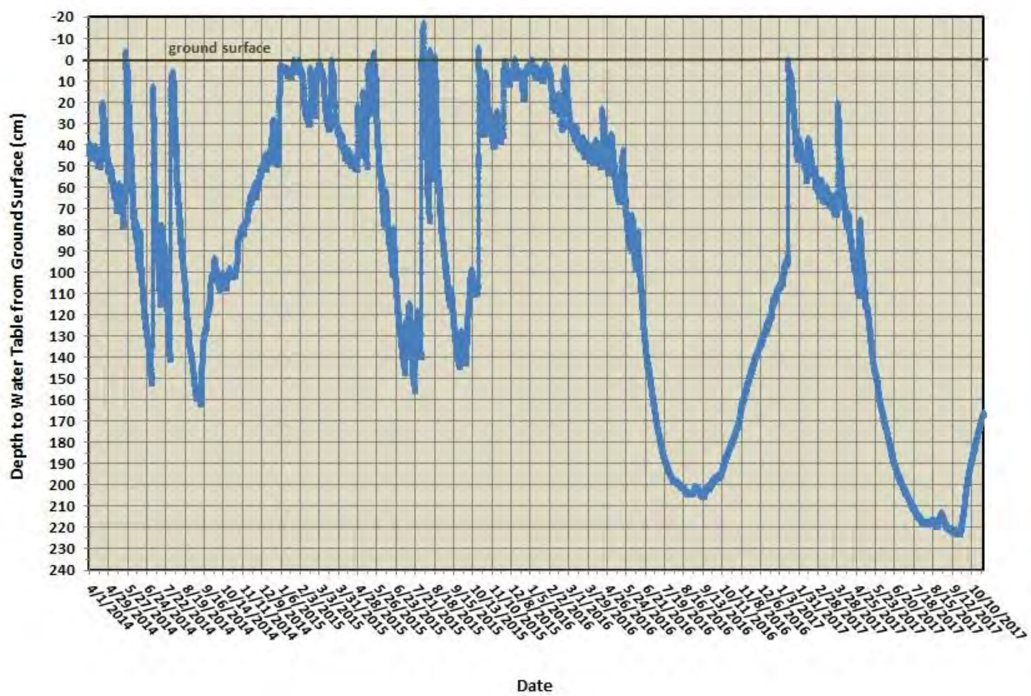


*BHC 1 was out of service from 2/8/17 - 5/12/17 due to damage from Rx burn

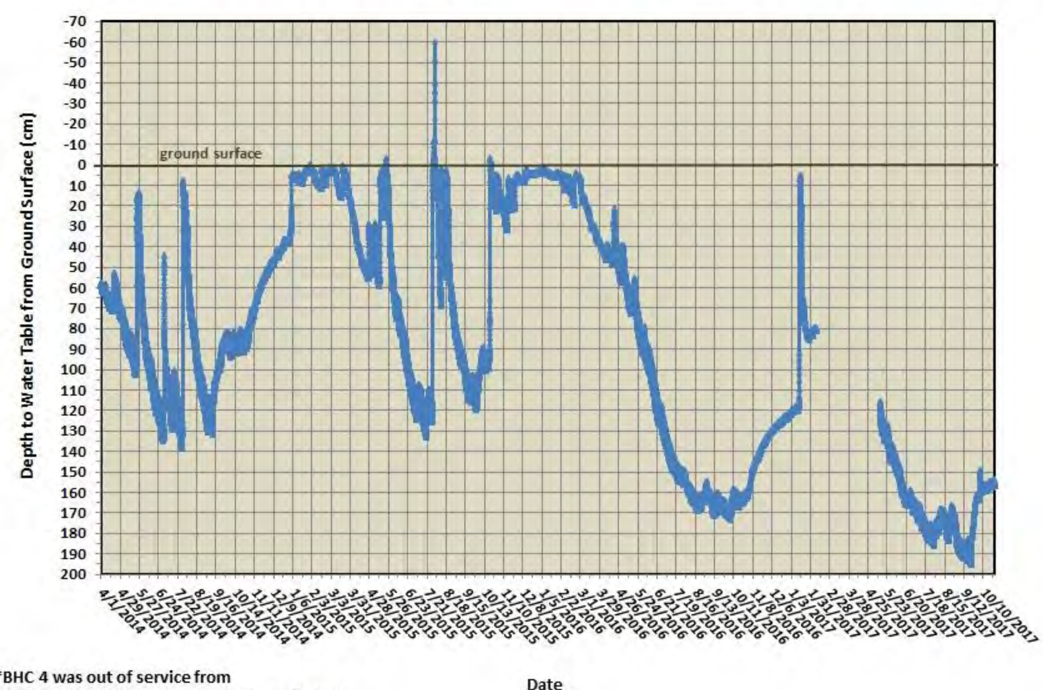
BHC 2: Depth to Water Table
April 1, 2014 - October 27, 2017 (30 - minute recording intervals)



BHC 3: Depth to Water Table
April 1, 2014 - October 27, 2017 (30 - minute recording intervals)

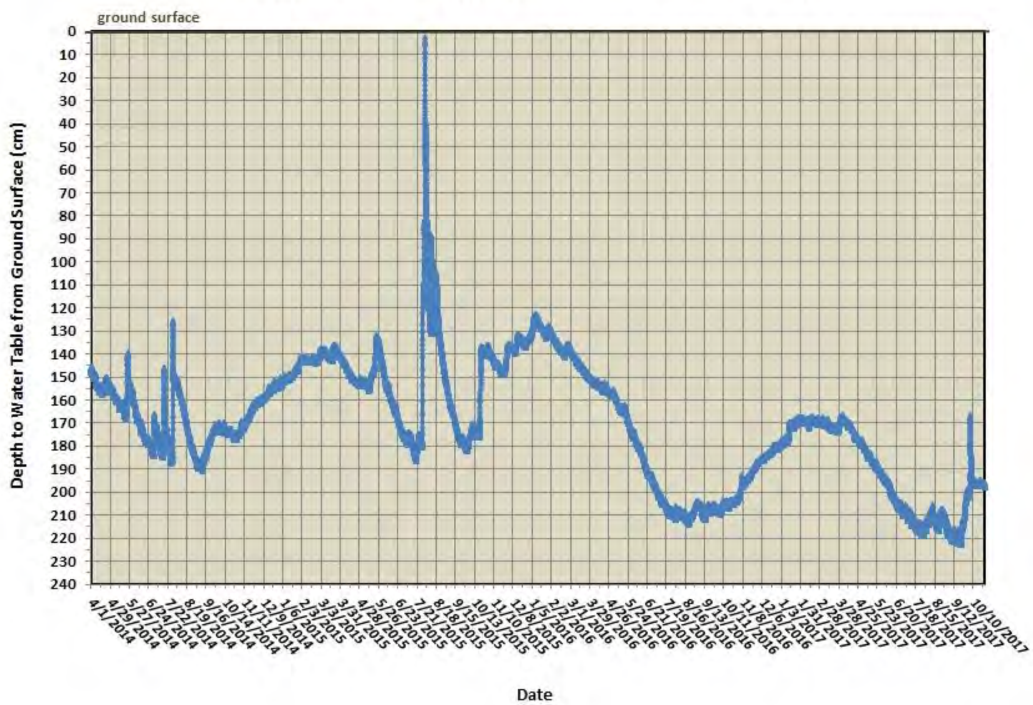


BHC 4: Depth to Water Table
April 1, 2014 - October 27, 2017 (30 - minute recording intervals)

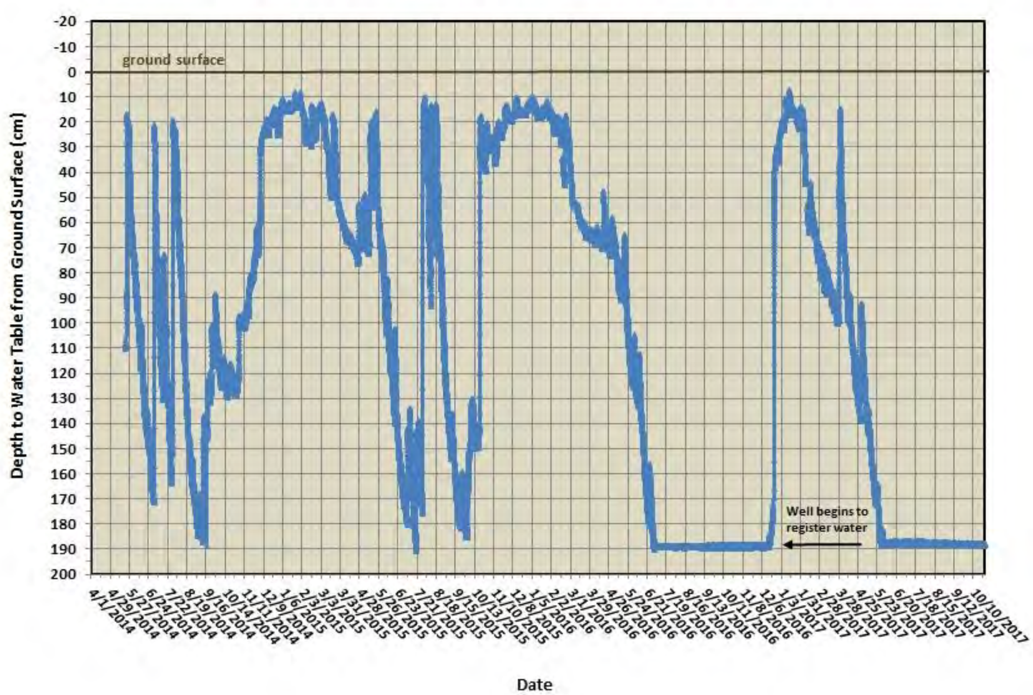


*BHC 4 was out of service from 2/8/17 - 5/12/17 due to damage from Rx burn

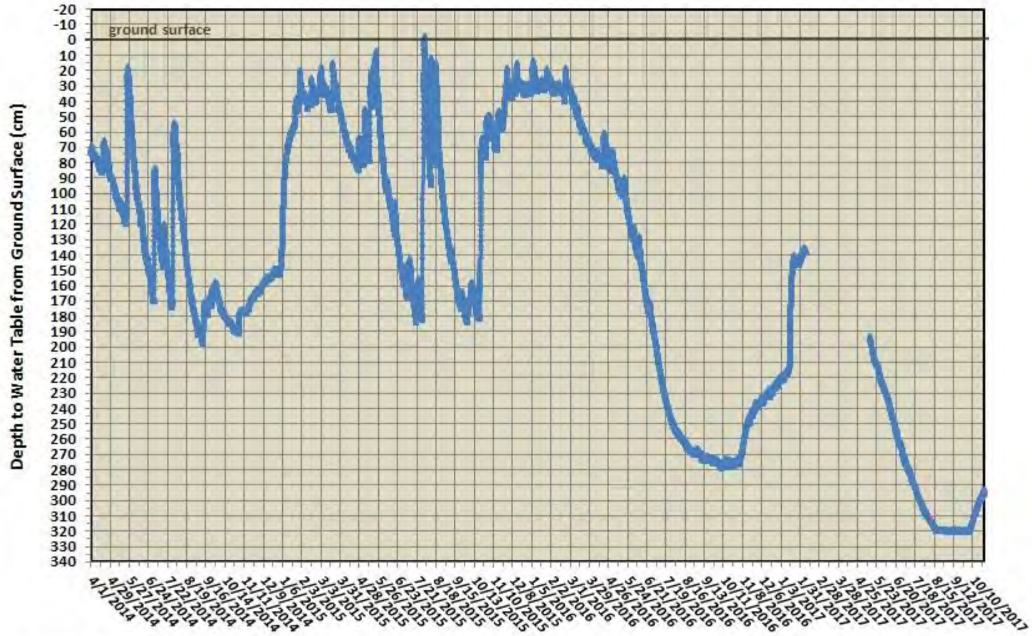
BHC 5: Depth to Water Table
April 1, 2014 - October 27, 2017 (30 - minute recording intervals)



BHC 6: Depth to Water Table
May 22, 2014 - October 27, 2017 (30 - minute recording intervals)

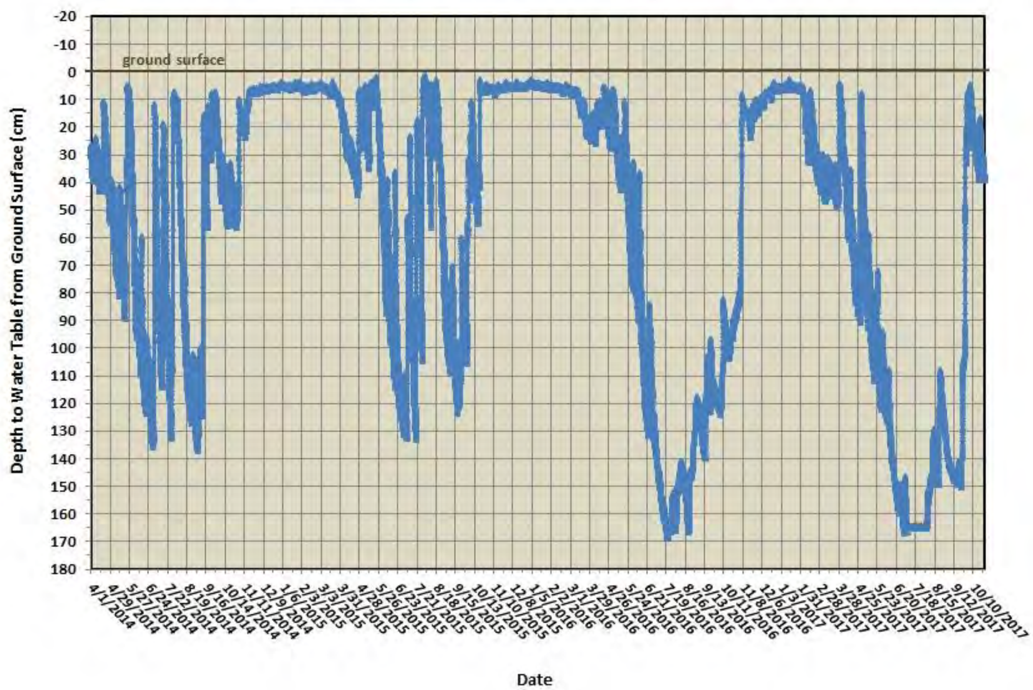


BHC 7: Depth to Water Table
April 1, 2014 - October 27, 2017 (30 - minute recording intervals)

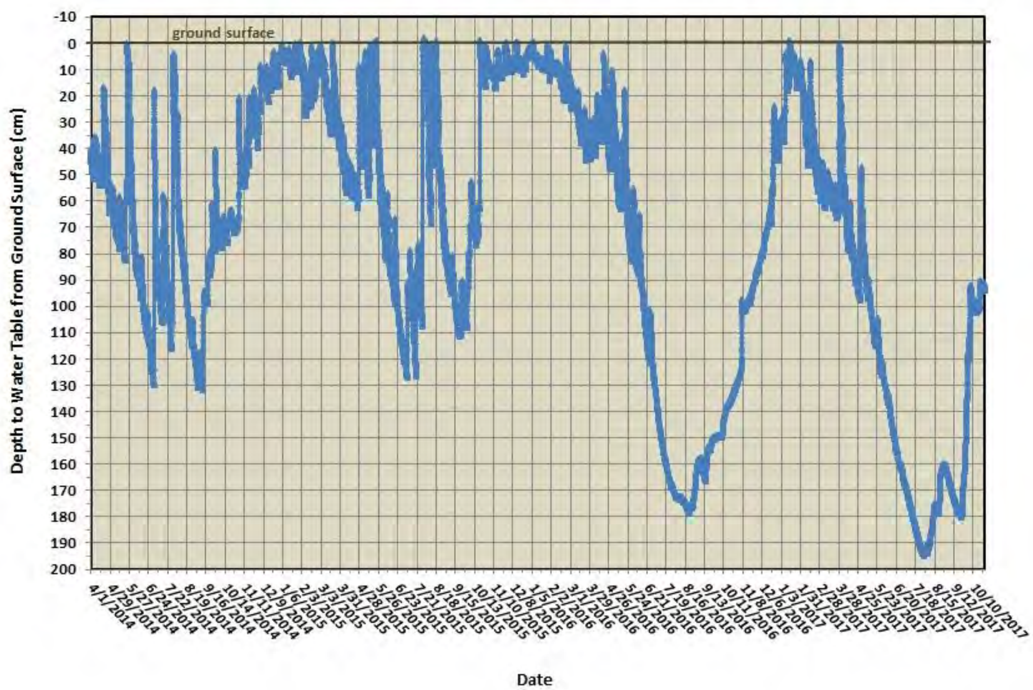


*BHC 7 was out of service from
2/8/17 - 5/12/17 due to damage from Rx burn

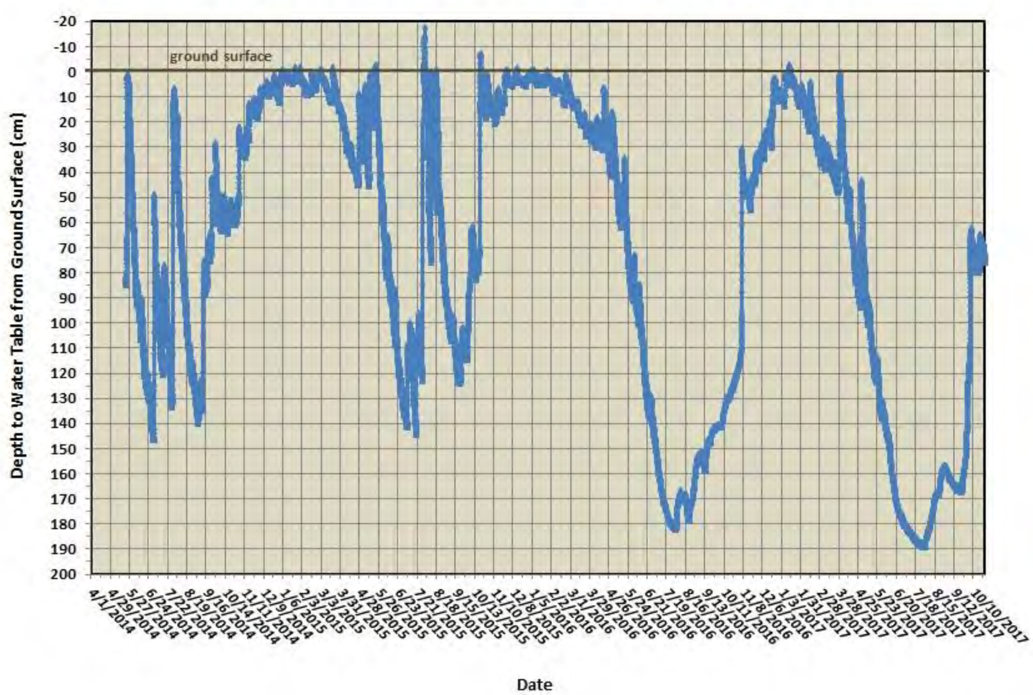
BHC 8: Depth to Water Table
April 1, 2014 - October 27, 2017 (30 - minute recording intervals)



BHC 9: Depth to Water Table
April 1, 2014 - October 27, 2017 (30 - minute recording intervals)



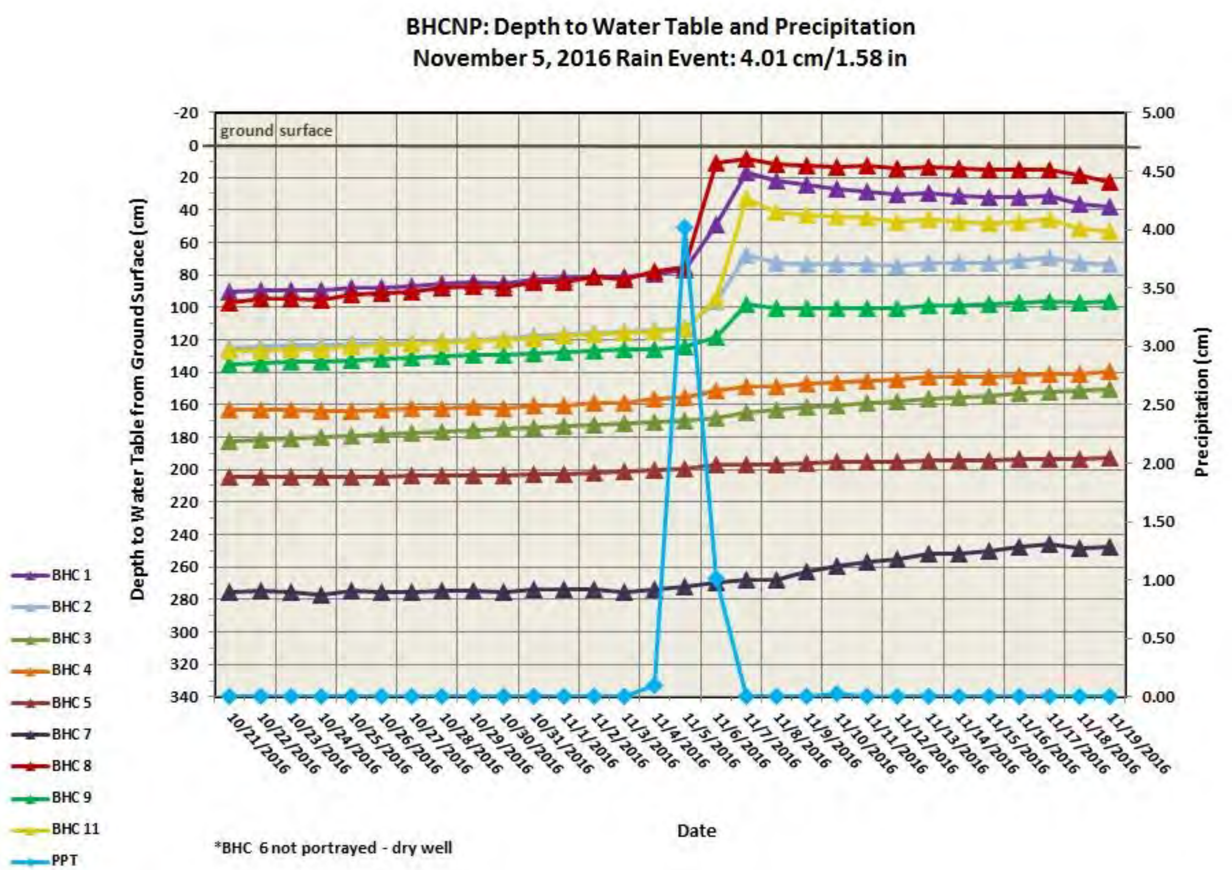
BHC 11: Depth to Water Table
May 22, 2014 - October 27, 2017 (30 - minute recording intervals)



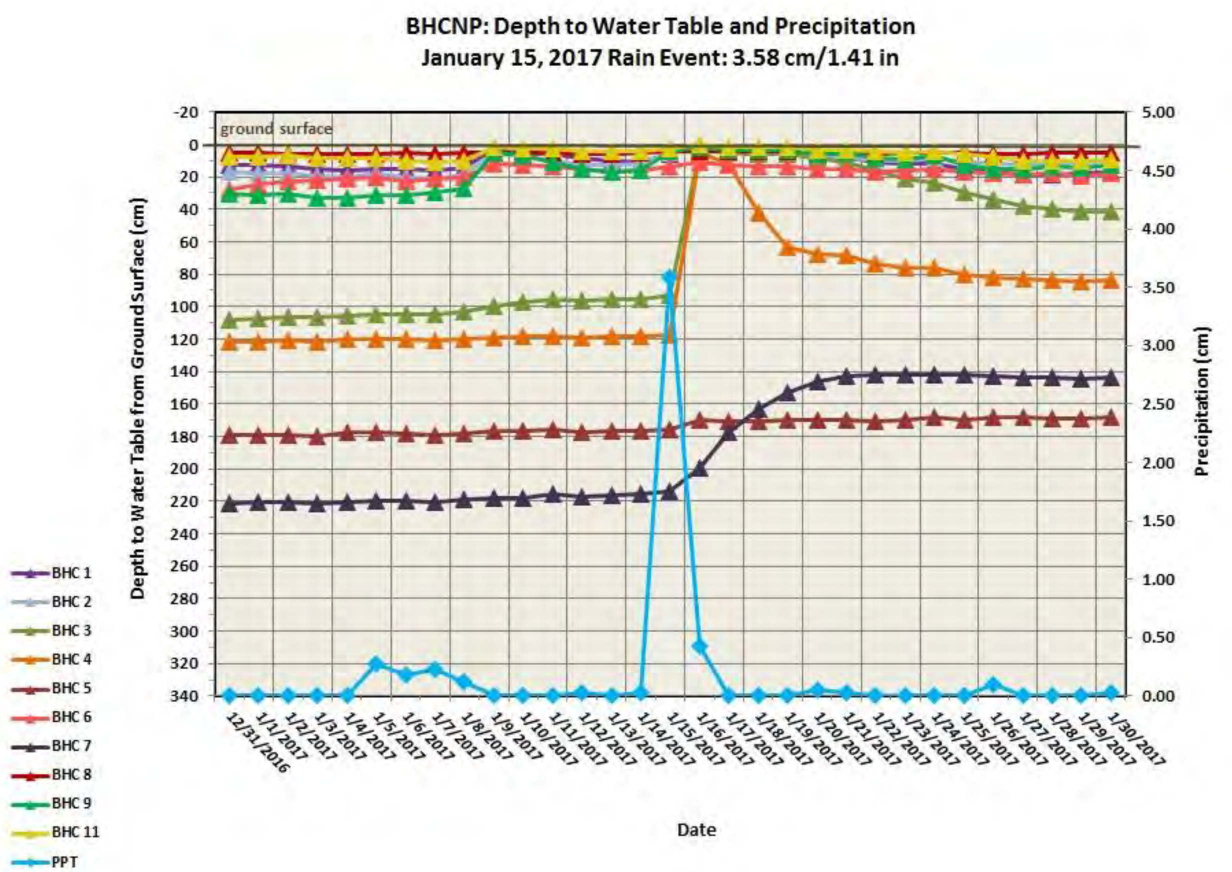
Appendix B: Depth to Groundwater and Precipitation Graphs

Date	Amount (cm)	Amount (in)
11/05/2016	4.01	1.58
01/15/2017	3.58	1.41
08/10/2017	2.67	1.05
09/23/2017	2.90	1.14

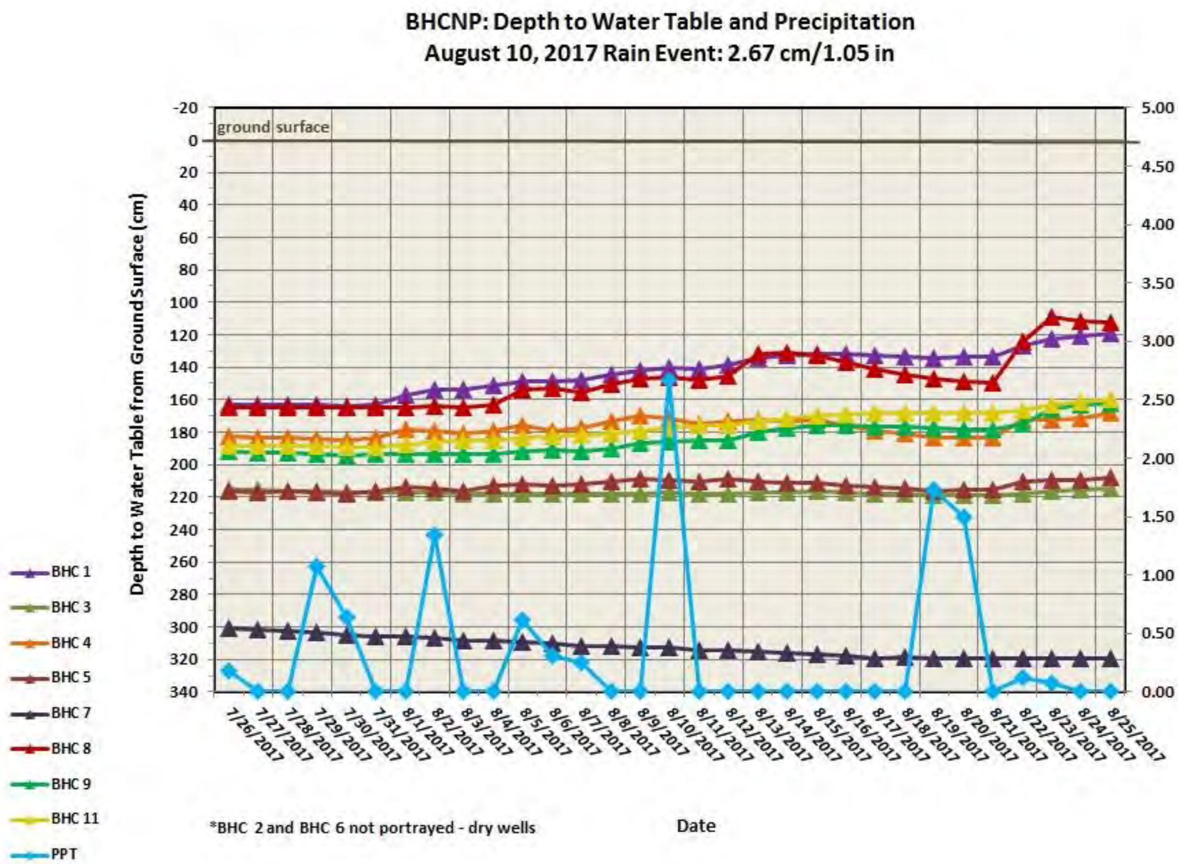
Four Largest Rain Events Since Rain Gauge Deployment



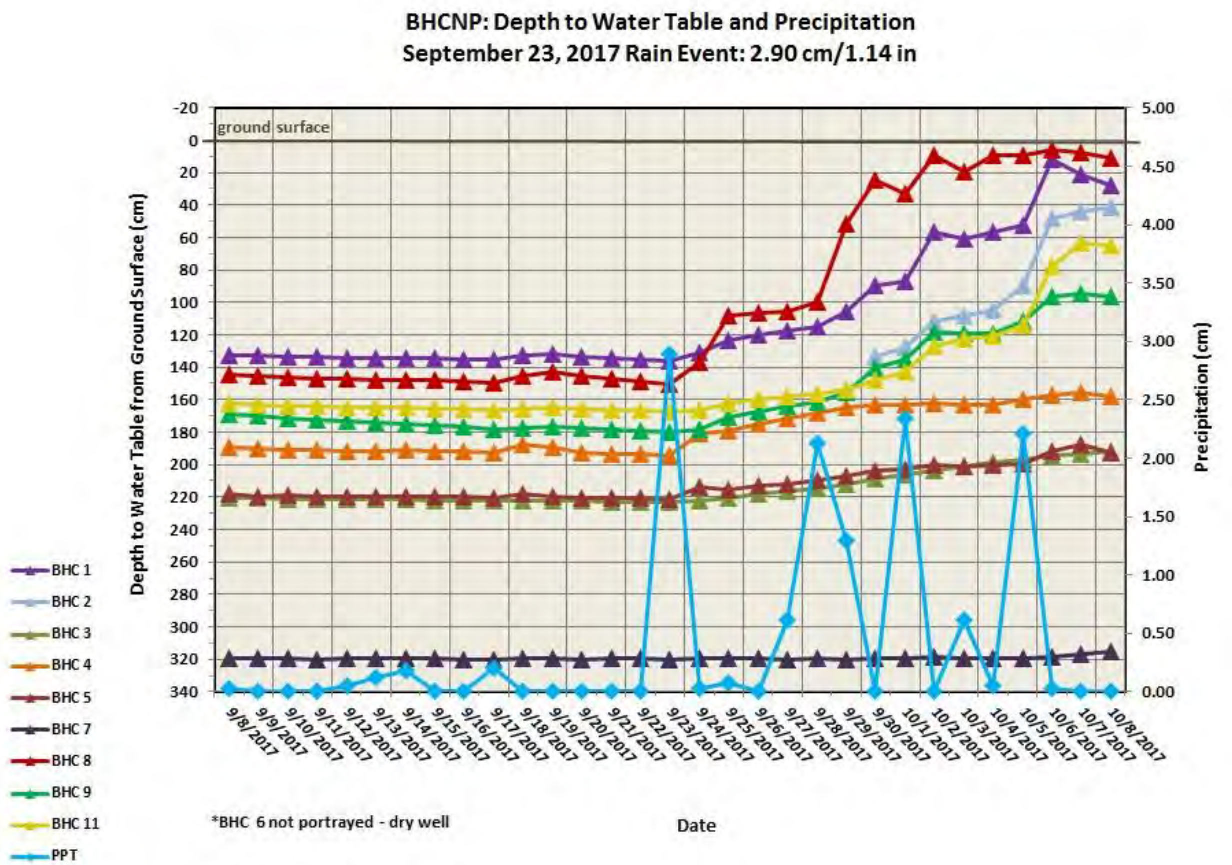
The precipitation event on November 5, 2016 produced 4.01 cm of rain, and is the only of the four portrayed in which there is no precipitation recorded before the event (other than a negligible amount the day before the event). It is also the only event in which there is no precipitation recorded after the event, other than the 1.02 cm the very next day as the storm was winding down. The graph is very easy to look at and interpret, for each well has a very distinctive level, even if only by a few centimeters between each other such as BHC 1 & 8, and BHC 2 & 11 before the event. After the event, each well level becomes even more distinctive. The water table at all wells was slowly on the rise before the event due to this observed trend over the past several years in the colder months. The wells with an existing higher water table before the event (BHC 1, 2, 8, 9, 11) responded more rapidly and exhibited a sharper rise towards ground surface due to the event. The remaining wells (BHC 3, 4, 5), responded with lesser magnitude. This general occurrence would be expected, for it takes longer for surface water to infiltrate in the lower strata of the soil profile of the lower water table wells. BHC 7 exhibited a slight deviation from the other deep wells, in that the water table rose nearly two-fold in comparison to the other three wells. The rain event did appear to cause a rise in the water table which stabilized at higher values approximately three days after the event - the apparent seasonal water table rise may also account for the higher ending values.



The precipitation event on January 15, 2017 resulted in 3.58 cm of rain. The water table at the shallower wells (BHC 1, 2, 6, 8, 9, 11) was within 40 cm of ground surface due to seasonal trends. The rain event spiked the water table to within 20 cm or less of ground surface at all wells except BHC 5 and 7. BHC 7 rose from 220 cm to 140 cm below ground surface (BGS) with more of a lag effect to its peak value than other wells. BHC 5 had a minimal response to the rain event. All wells ended with substantially higher water table values during the two-week period after the event. It is likely that since the water table was at its highest point of the year, that the water table would take longer to stabilize to near pre-rain event values.



The precipitation event on August 10, 2017 resulted in 2.67 cm of rain. The water table is at a lower level because of the season. There are several smaller rain events before and after the main event portrayed. Both BHC 2 and 6 are dry during this period. The shallower wells responded with a sharper rise in the water table than the deeper wells. BHC 7 continued a downward trend during the 2017 monsoon season, which did not get going until the end of July. Most monsoon precipitation occurred in August, September, and October. This is the second year in a row in which the monsoon season has come approximately one month later then the historic start in early July.



The precipitation event on September 23, 2017 resulted in 2.90 cm of rain. Water table values were similar to the August 10, 2017 event before the rain commenced. This was the only event of the four discussed in which there were several substantial events after the main event, which appeared to keep the water table on the rise. With the exception of the deeper wells: BHC 3, 4, 5, and 7, all wells ended with water table values substantially higher than before the rain event, likely due in large part to the three similar rain events which followed the larger one. BHC 2 began to register groundwater again on September 30, 2017 as the water table rose.