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PRAIRIE RESEARCH INSTITUTE

Illinois State Water Survey
2204 Griffith Drive
Champaign, IL 61820

March 30, 2020

Mr. Jeff Smith, Chairman
Imperial Valley Water Authority
25865 E. County Road 1000 N
Easton, IL 62633

Dear Chairman Smith:

The Illinois State Water Survey (ISWS), under contract to the Imperial Valley Water Authority (IVWA), has operated a network of rain gauges in Mason and Tazewell Counties since August 1992 and a network of groundwater observation wells since 1994. The purpose of the rain gauge and groundwater observation well networks is to collect long-term data to determine the impact of groundwater withdrawals during dry periods and the growing season, and the rate at which the aquifer recharges. This letter serves as the years end report for Year 26, project year 2018 (PY2018), which covers the time period from January 1, 2018 through December 31, 2018.

The groundwater observation well network has previously consisted of thirteen wells, MTOW-01 through MTOW-13. The network was established in 1995-96. Three new observation wells were added to the network during 2014. MTOW-14 is located next to MTOW-11, south of Mason City, and wells MTOW-15 A & B are Northwest of Mason City near Ellsberry Lake. Two additional wells have been added during 2017. Sand Lake (MTOW-16) and Biggs (MTOW-17). MTOW-16 is located southeast of Havana, IL near Sand Lake. Sand Lake is an intermittent lake that only fills with water during times of groundwater flooding in the region. MTOW-17 is a former 24 inch irrigation well located north of Biggs, Illinois. All of the other observation wells within the network are drilled wells between 2 and 6 inches in diameter. With the exception of MTOW-05 and MTOW-09, all wells are equipped with data loggers that electronically log the groundwater level data. Figure 1 shows the location of each well.

In accordance with our agreement, each well, with the exception of MTOW-05 and MTOW-09, is visited by ISWS personnel during the first few days of the month during irrigation season and approximately bi-monthly during the non-irrigated portion of the year.

A 25-site rain gauge network (Figure 1) was established in late August 1992 with approximately 5 miles between gauges. The network was reduced to 20 sites in September 1996 and is currently maintained by ISWS field technician Dana Grabowski. During these visits, data are downloaded, other routine services are performed and major maintenance and repairs are completed as needed.

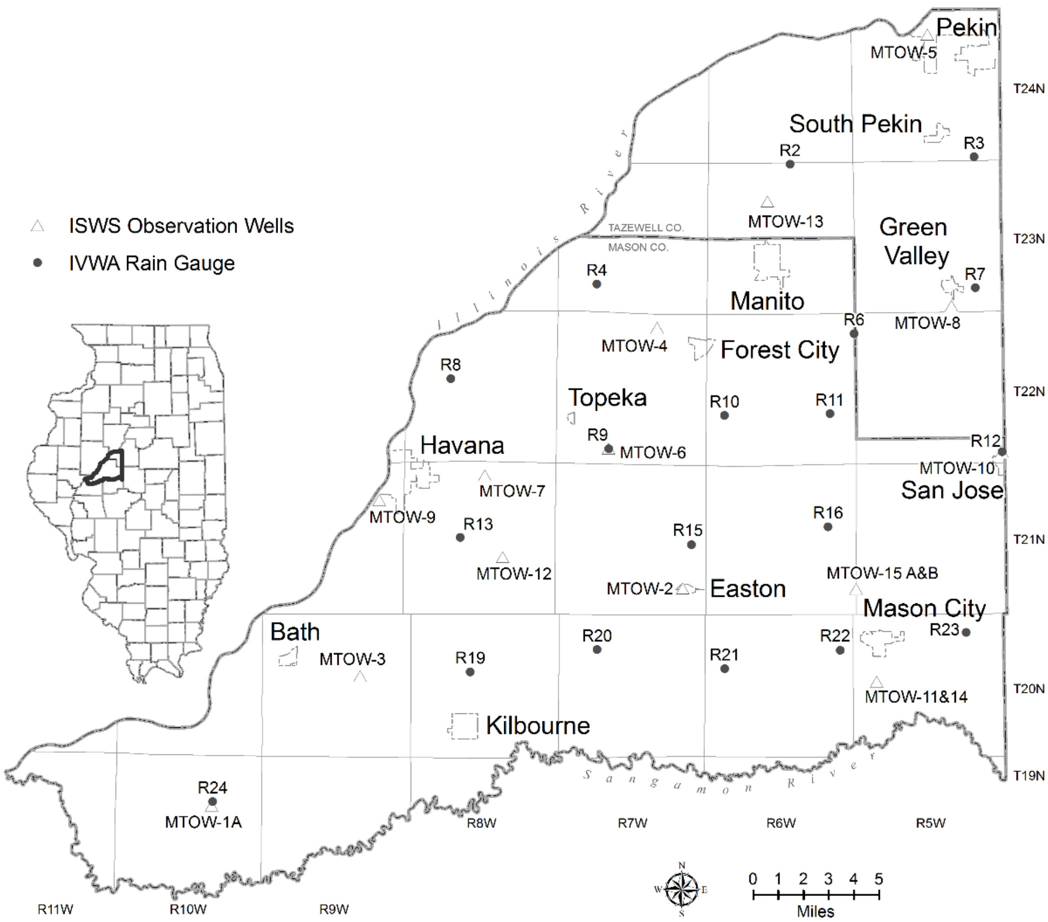

Figure 1. Configuration of the 16-Site Observation Well and 25-Site Rain Gauge Networks.

Precipitation data collection and reduction activities are similar to those of the previous 25 years. To create more even coverage of precipitation data collection across the southwest corner of the network, the gage at site #24 was moved in October 2018 about 6.5 miles at a heading of ~64 degrees to the Sunrise Ag facility. The new location is about 0.6 miles south of the old #18 Kilbourne site. The Water and Atmospheric Resources Monitoring Program (WARM) gage near Snicarte is now gage #24 and the gage at Sunrise Ag is gage #18. This new location for this gage redistributes the gages this section of the network.

Groundwater levels for each well for the period of record (January 1, 2018 - December 31, 2018) are presented in Appendix A. For MTOW-05, and -09, these wells do not have digital recorders and have only been measured periodically since 2005. These two wells have been shown to mimic the stage in the Illinois River. Stage data from the Illinois River can be used, if necessary to recreate groundwater levels in those regions of the study area. Each hydrograph also contains the daily precipitation for the nearest rain gauge, or average of several nearby gauges.

Since 1995, the IVWA has estimated irrigation pumpage from wells in the Imperial Valley based on electric power consumption. Menard Electric Cooperative provides the IVWA with electric power consumption data for the irrigation services they provide during the growing season (June-September). The pumpage estimate assumed that application rates for the irrigation wells with electric pumps in Menard Electric Cooperative also are representative of other utilities and other energy sources. Past estimates were based on the assumption that 33 percent of the irrigation wells were in Menard Electric Cooperative in 1995-1997, 40 percent in 1998-2001.

In 2002, the U.S. Geological Survey (USGS) updated the formula used to calculate pumpage by closely measuring the pumping rate at 77 irrigation systems serviced by Menard Electric. The updated formula provides estimates that are appreciably lower than the previous formula, by approximately 20 percent. Therefore, irrigation withdrawals for the years 1997 to the present were recalculated using the new formula, replacing earlier published estimates (reports through Year 12 use the original formula).

The PY2018 rain gage dataset was used to produce gage and network-wide summaries of total and average precipitation at various time scales including individual storm events, monthly, seasonal, and annual time periods. Monthly and annual time scale summaries are compared with the 26-year (1993-2018) network average precipitation record, unless explicitly noted.

Precipitation Analysis

The Imperial Valley network precipitation was 40.24 inches in PY2018, January – December 2018, which was much more than the previous 25-year annual average of 34.69 inches. Figure 2 shows the distribution of total annual precipitation in PY2018. Table 1 provides the monthly and annual total precipitation for each rain gage and the network monthly and annual average precipitation for January - December 2018.

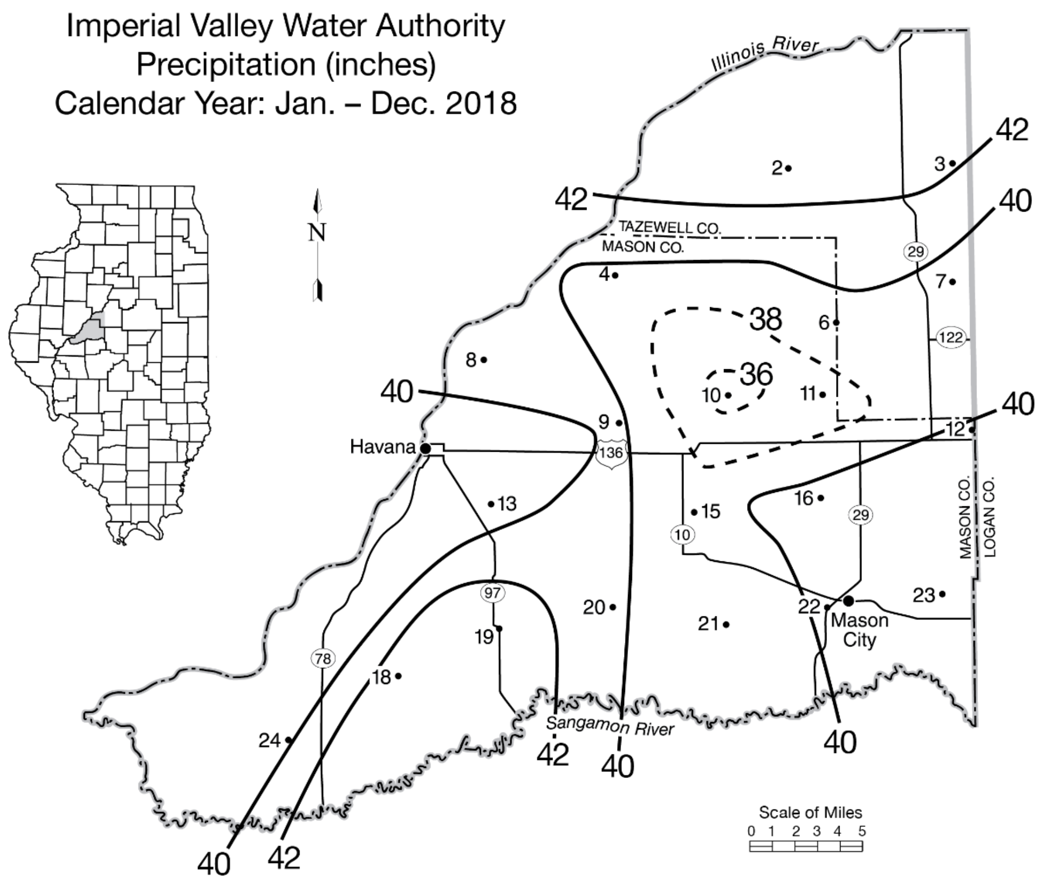

Figure 2. Total Precipitation (inches) for January - December 2018 (PY2018).

The lowest precipitation occurred in the central region of the network, centered on gages #10 and #11. Gages #18 and #2 collected the most precipitation in PY2018, 43.83 and 43.44 inches, respectively. During PY2018, annual gage totals varied 8.52, from 35.31 inches at site #10 to 43.83 inches at site #18. Ten-inch differences between gages in annual precipitation amounts are not unusual during any given year, representing natural variability. If large differences between individual gages are repeated year after year, this would suggest possible differences caused by differences in gage exposure to the wind or by measurement errors. Gages that are overly sheltered or with little or no shelter from the wind (most of the gage sites) can underestimate precipitation under strong wind conditions.

Table 1. Monthly Precipitation Amounts (inches), January-December 2018
Calendar Year Annual Totals

	Month 2018												CY 2018
Station	*Jan*	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*	*Total*
2	1.70	3.33	3.92	2.08	3.60	4.59	2.39	6.44	3.48	5.47	1.95	4.49	43.44
3	1.55	3.24	4.08	1.54	4.36	3.42	3.89	7.19	2.65	5.33	2.23	3.02	42.50
4	1.64	3.38	3.79	1.47	2.60	4.07	1.66	6.77	2.97	5.99	2.29	2.99	39.62
6	1.75	3.29	2.82	2.40	4.43	2.65	2.69	5.63	2.73	5.57	2.28	3.32	39.56
7	1.34	3.55	3.54	2.51	3.81	3.48	3.41	4.59	2.10	5.93	1.71	3.11	39.08
8	1.65	3.27	3.54	1.35	2.49	5.36	2.61	6.82	2.67	6.38	1.96	2.61	40.71
9	1.92	3.34	3.54	1.61	3.59	2.67	4.05	6.92	1.94	4.71	2.48	3.52	40.29
10	1.61	2.94	3.26	1.90	3.68	2.04	2.96	4.73	2.80	4.58	2.02	2.79	35.31
11	1.86	2.76	3.11	2.40	4.68	1.70	3.48	4.79	2.93	4.31	2.19	2.77	36.98
12	1.43	3.01	3.26	2.40	3.25	3.29	4.08	5.80	3.24	5.28	1.92	3.07	40.03
13	1.75	3.05	3.81	1.77	2.99	3.64	2.89	6.52	2.05	4.84	2.11	3.28	38.70
15	1.53	3.03	3.64	2.07	4.72	2.99	4.21	5.82	2.40	4.20	2.23	2.85	39.69
16	1.49	2.70	3.13	2.08	5.77	2.71	3.39	5.00	4.28	4.82	1.80	3.24	40.41
18	2.00	3.42	4.04	1.89	2.58	4.94	4.77	8.34	2.68	4.25	1.78	3.14	43.83
19	1.86	3.40	4.10	2.19	2.57	4.08	3.49	7.07	2.13	3.85	2.32	3.07	40.13
20	1.63	3.11	3.27	1.94	3.13	4.14	4.10	6.21	2.15	4.46	2.32	2.87	39.33
21	1.50	3.37	3.24	2.15	5.89	1.96	3.25	5.02	3.34	5.20	2.35	2.89	40.16
22	1.68	3.44	3.85	2.65	4.79	2.63	2.81	5.09	3.68	6.37	1.89	3.36	42.24
23	1.72	3.37	2.33	2.64	3.34	5.16	2.88	4.73	3.16	5.76	1.79	2.79	39.67
24	1.88	3.27	3.06	1.58	2.34	6.41	4.01	8.50	3.05	3.41	2.42	3.25	43.18
Average	1.67	3.21	3.47	2.03	3.73	3.60	3.35	6.10	2.82	5.04	2.10	3.12	40.24

The monthly network precipitation maps for PY2018 are shown in Figures 3 - 8.

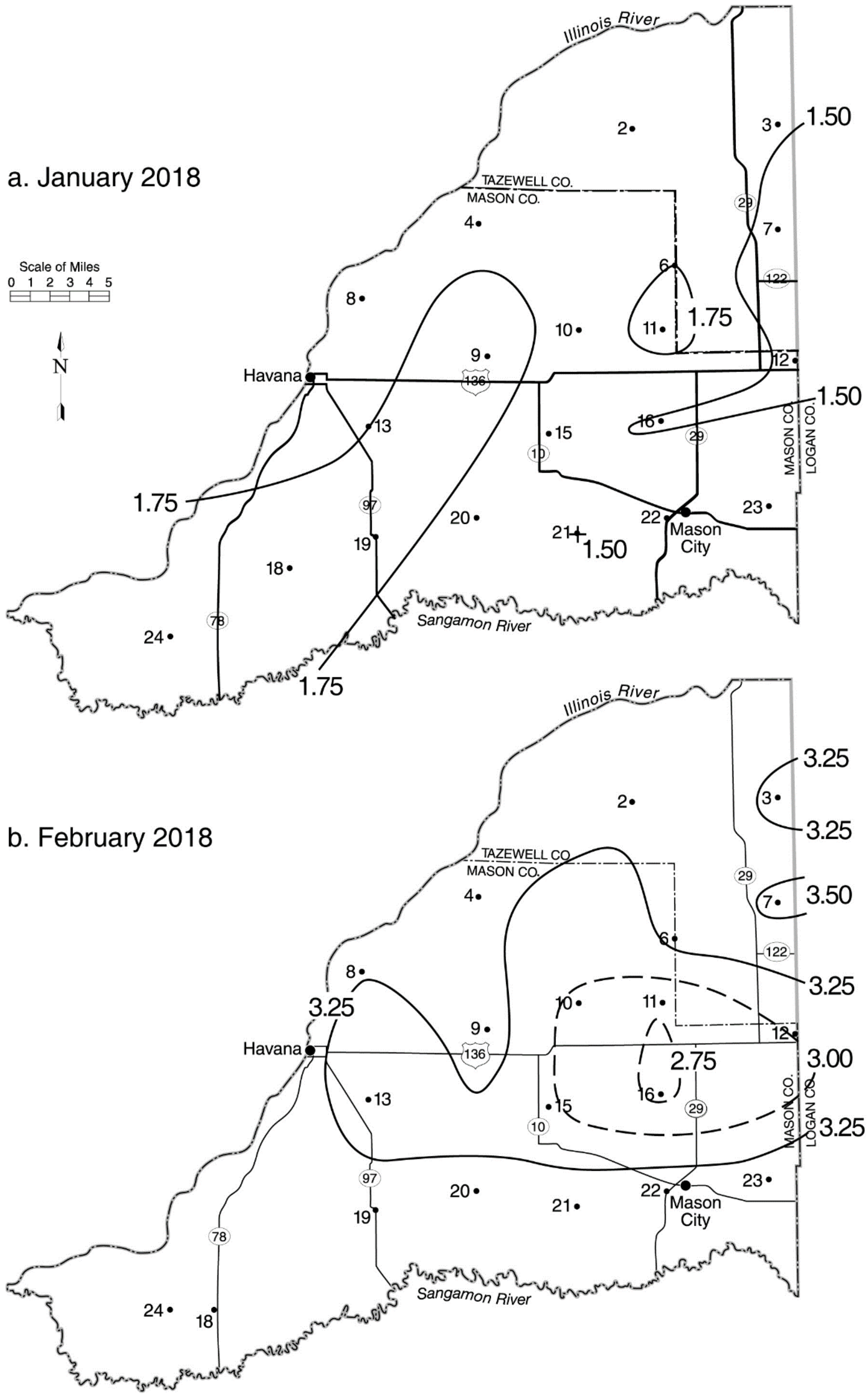

Figure 3. Precipitation (inches) for January 2018 and February 2018

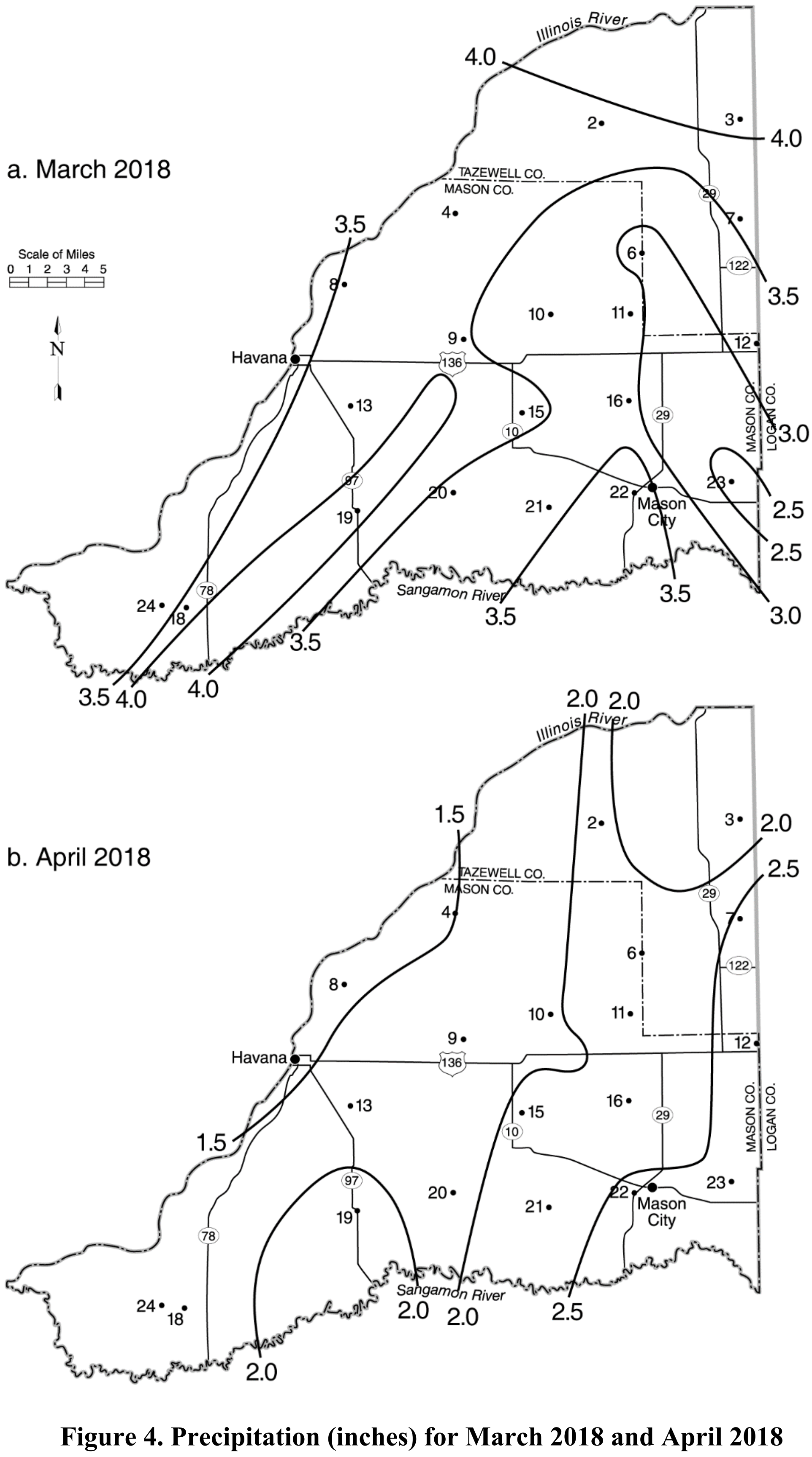

Figure 4. Precipitation (inches) for March 2018 and April 2018

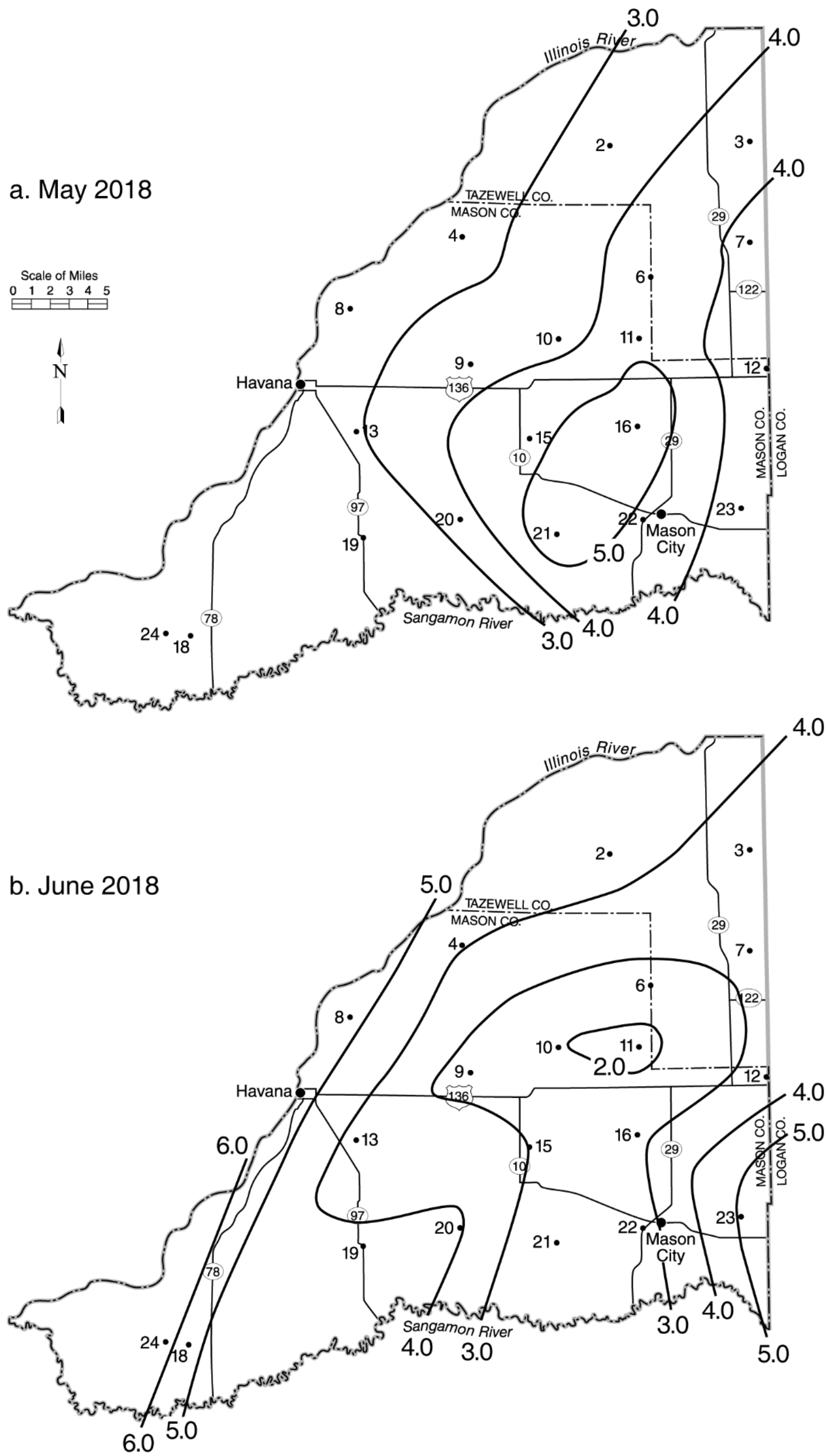

Figure 5. Precipitation (inches) for May 2018 and June 2018

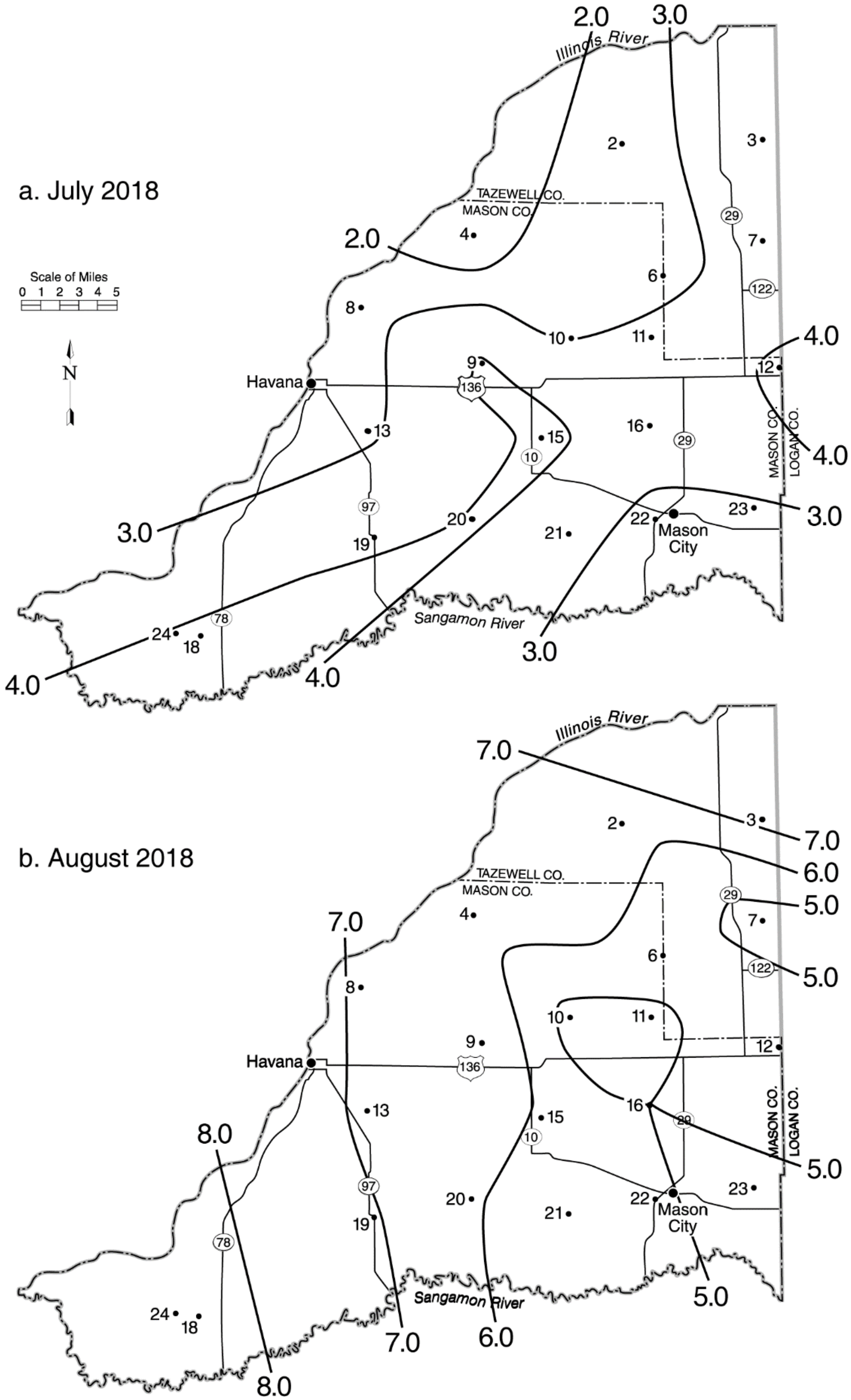

Figure 6. Precipitation (inches) for July 2018 and August 2018

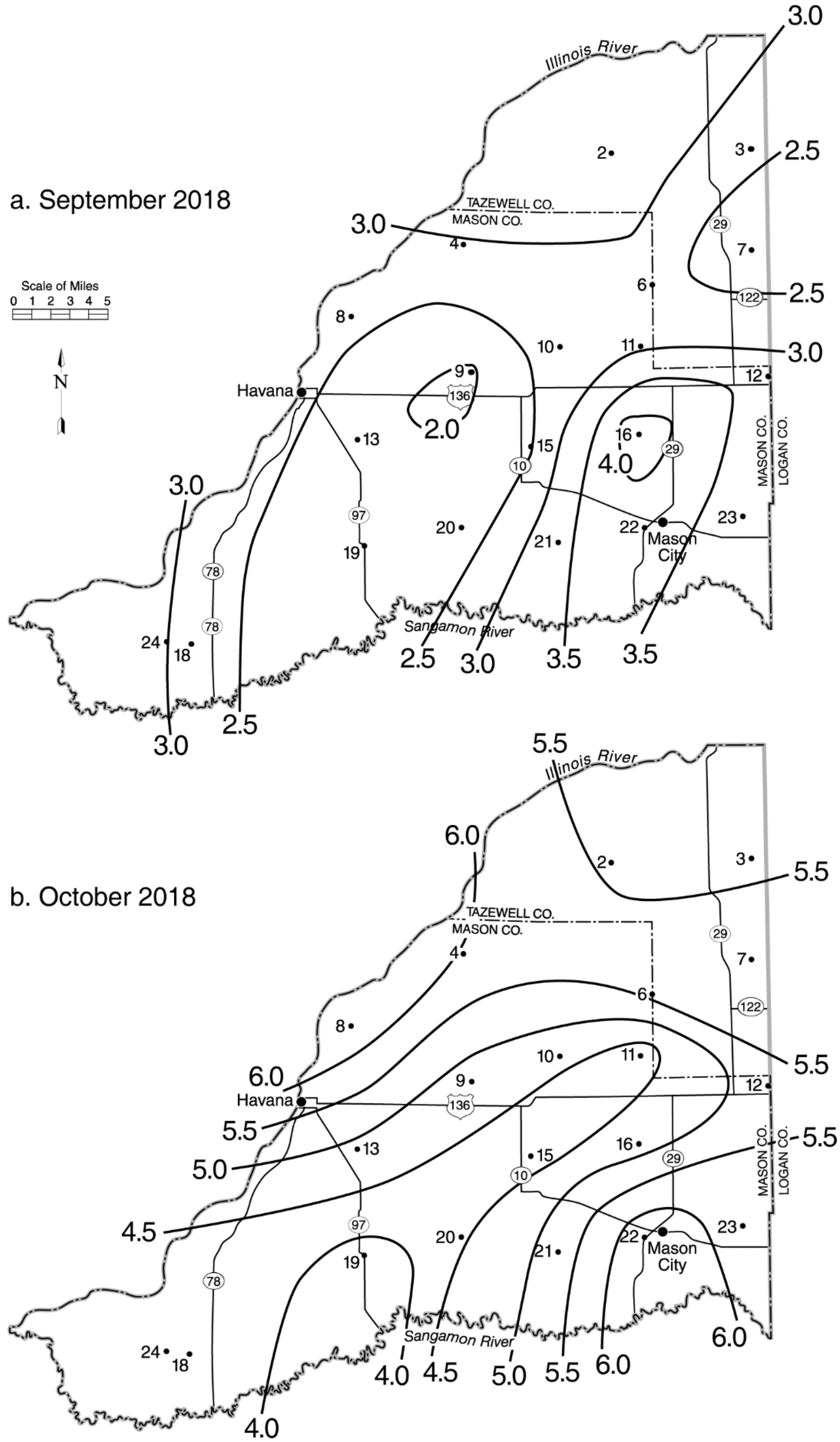

Figure 7. Precipitation (inches) for September 2018 and October 2018

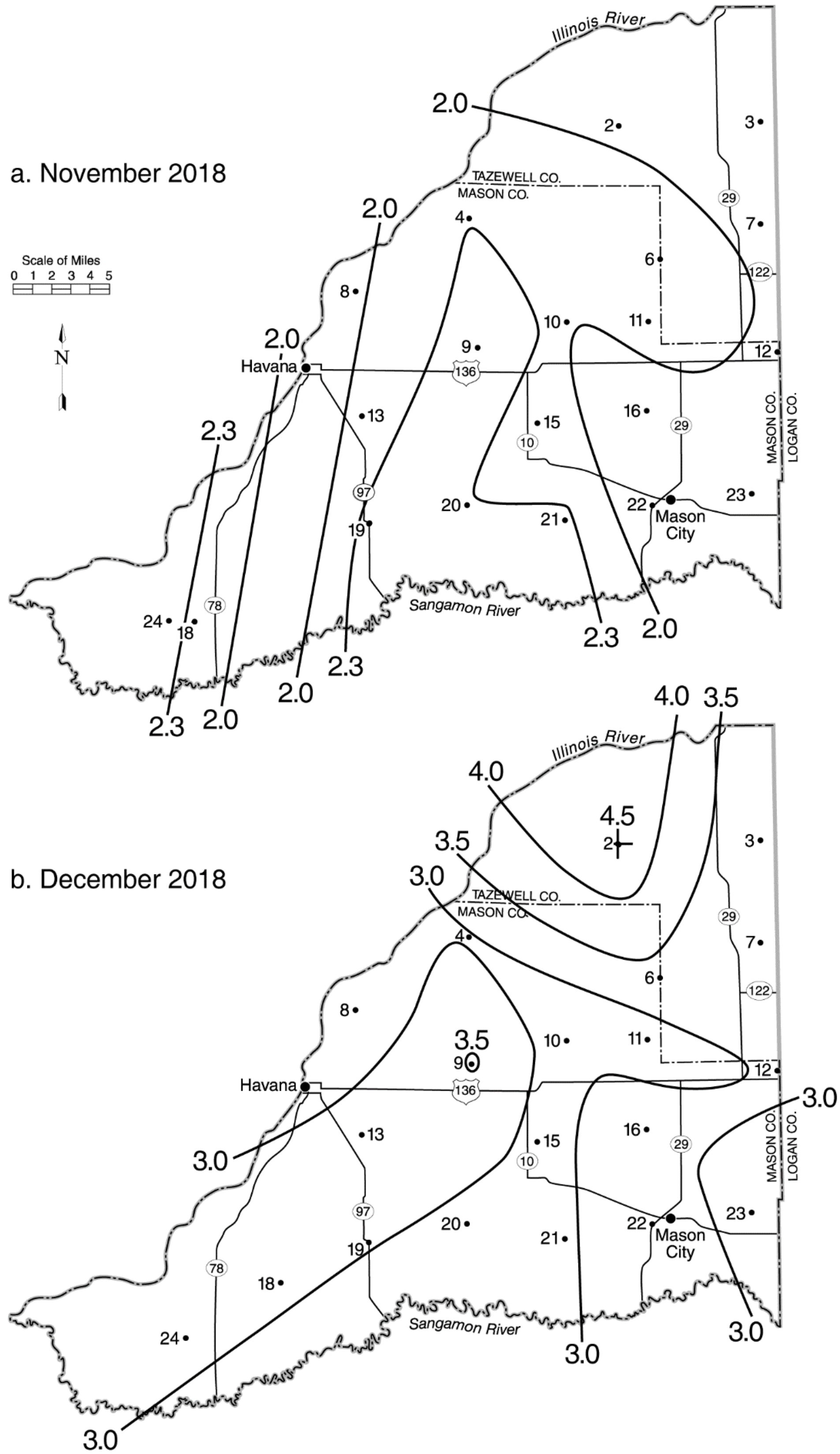

Figure 8. Precipitation (inches) for November 2018 and December 2018

Network Long-term Average Precipitation

Network annual average precipitation is the average of calendar years 1993 - 2018 annual precipitation. Figure 9 provides the contours for the 26-year annual average precipitation. Precipitation contours create a pattern of parallel trending contours to the Illinois River. The 26-year average annual precipitation was highest along a line from Gage #24 to #9 to #2, roughly parallel to the Illinois River.

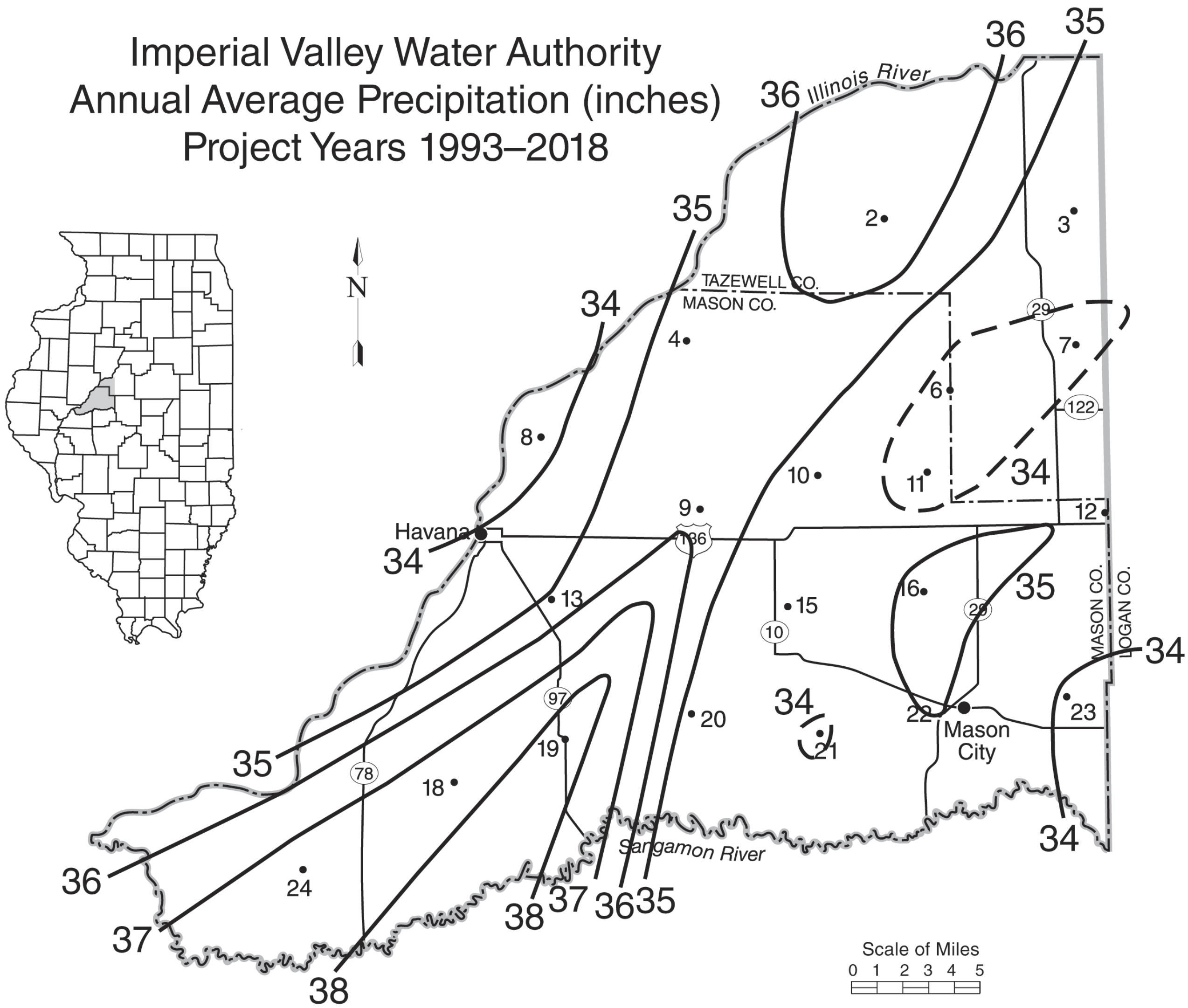

Figure 9. Average Annual Precipitation (inches, calendar year) for January 1993 – December 2018.

The following bar graph, Figure 10, compares the network monthly averages for PY2018 with the 26-yr historical monthly network averages and the 1981-2010 (30 yrs.) Havana, IL monthly averages. During PY2018, the heaviest precipitation occurred during August and October which were both 180% of the 26-yr network monthly average. February's precipitation was 189% or 1.51 inches greater than the historical average. March and December 2018 each received well over an inch more precipitation than the historical average. January, September, and November received slightly less than average precipitation. April received about an inch and a half less than the historical average, while May, June, and July received about 0.5 inch below average precipitation.

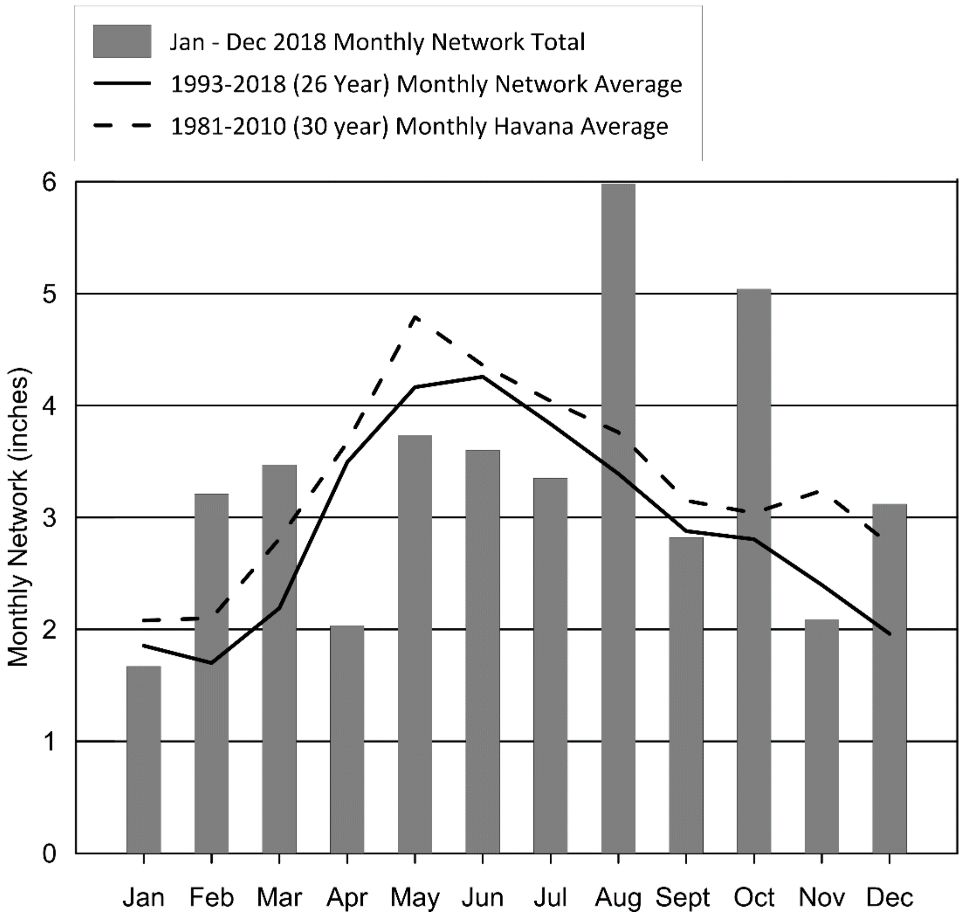

Figure 10. Monthly Comparison with 26-Year IVWA Network Average and 1981-2010 (30 Year Average) at Havana, IL Gage.

Monthly network variability including minimum, maximum, medians, and quartiles of the 26-yr monthly precipitation data are shown in Figure 11. See Appendix B: Explanation of Box-Whisker Plots for an explanation of how to interpret box-whisker plots.

Monthly precipitation during the 2018 growing season was below the 26-yr average. Monthly precipitation for five months (February, March, August, October, and December) was above the 3rd quartile (> 75% of occurrences), and below the 1st quartile (< 25% of occurrences) in April. Months with the larger interquartile range (longest box) indicate greater variability of precipitation during that month. This variability can change over time.

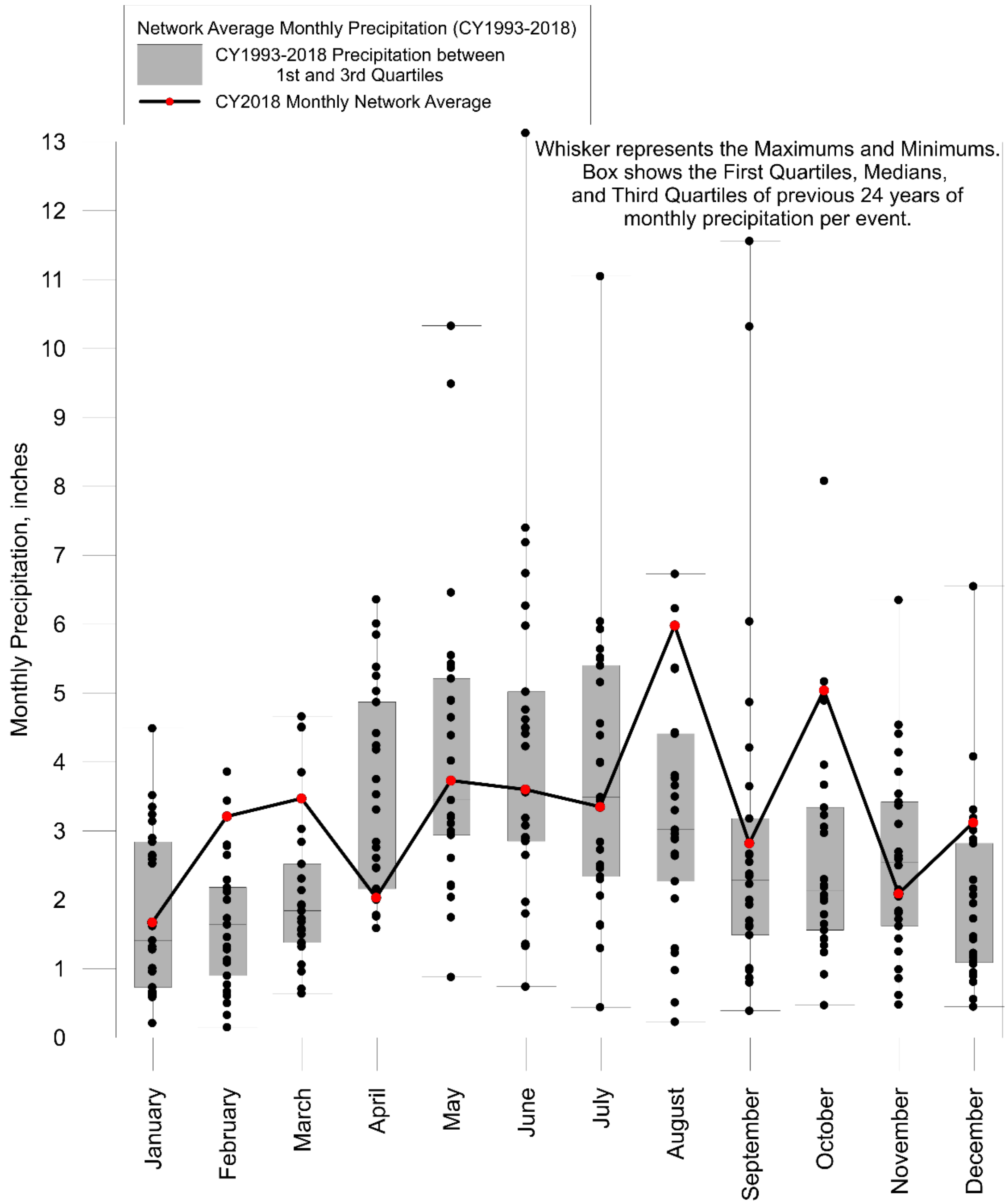

Figure 11. 26-year Monthly Average Precipitation Distribution with PY2018 Monthly Network Averages

In the following analysis, the 26-year period of record is divided into 3 periods, 1993-2001, 2002-2010, and 2011-2018. Figure 12 presents the monthly precipitation variability during these periods in comparison to the current year's average monthly precipitation. In comparing the length of the boxes (variability in total monthly precipitation), the earliest period had the least amount of variability and the last period has had the greatest overall variability. Monthly precipitation variability has increased for all months except for January and May. Monthly variability for August increased the most compared to other months from the first to the third period.

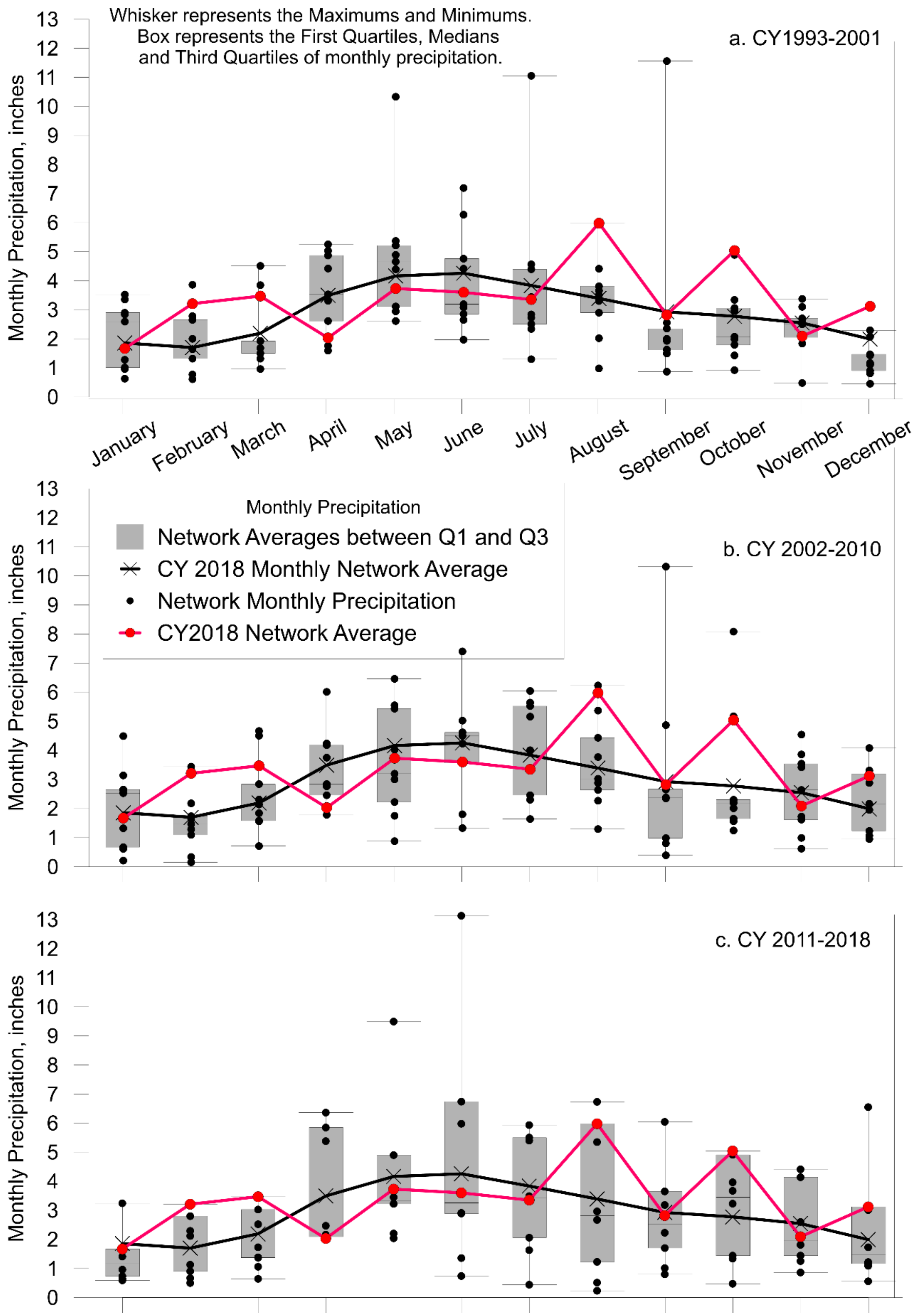

Figure 12. Monthly Box-Whisker Plots of ~9 Year Time Spans. a. CY 1993-2002, b. CY 2003-2010 and c. CY 2011-2018

Mean monthly, seasonal, and annual number of network storms (precipitation events) were determined for January through December 2018 and presented in Table 2. A network storm period is defined as a precipitation event separated from proceeding and succeeding events at all network stations by at least three hours. The historic average for inches per event over the previous 25 years (1993-2017) is 0.30 inches per event. Calendar year 2018 received an average of 0.29 inches per event.

Table 2. Comparison of Total Precipitation (inches), Number of Precipitation Events, and Average Precipitation per Event for Each Month and Season, 1993-2018 and CY 2018

	1993-2018 26-yr average			*January -December 2018*		
Period	*Precipitation*	*Events*	*Inches/event*	*Precipitation*	*Events*	*Inches/event*
January	1.85	9.3	0.23	1.67	8	0.21
February	1.70	8.3	0.22	3.21	13	0.25
March	2.19	8.5	0.26	3.47	10	0.35
April	3.49	11.2	0.33	2.03	11	0.18
May	4.16	13.1	0.32	3.73	13	0.29
June	4.26	12.0	0.35	3.6	11	0.33
July	3.84	10.8	0.37	3.35	13	0.26
August	3.39	11.5	0.30	5.98	10	0.60
September	2.88	7.4	0.39	2.82	12	0.24
October	2.80	8.7	0.33	5.04	11	0.46
November	2.40	8.8	0.33	2.09	18	0.12
December	1.96	9.5	0.24	3.12	8	0.39
Winter 2018	5.74	26.2	0.23	8.35	31	0.27
Spring 2018	11.91	36.3	0.33	9.36	35	0.27
Summer 2018	10.10	29.7	0.34	12.15	35	0.35
Fall 2018	7.16	26.9	0.27	10.25	37	0.28
Calendar Annual	34.92	119.5	0.30	40.11	138	0.29

The Imperial Valley Water Authority precipitation network has a 26-year average of 119.5 storm events per year. During PY2018, there were 138 precipitation events. Seasonally, spring had fewer events than the average of the 26 years, whereas winter, spring, and summer had many more than average. November 2018 had more than twice (18 compared to 8.8) the number of precipitation events in the month than the 26-yr average. February, March, July, September, and October also had more events that the 26-yr average. August 2018 storms averaged twice as many inches per event (0.6 inches) compared to the previous 26-yr average. April and November 2018 had much lower than average (0.33) precipitation inches per event, at 0.18 and 0.12 inch/event, respectively.

Figure 13 compares the network average monthly precipitation for January 2008 through December 2018 and the cumulative moving average of the monthly precipitation. The cumulative moving average is the average of the preceding years. For example, the cumulative moving average compared with January 2018 is the average precipitation of Januarys 1992-2018. The change in the shape of the cumulative moving average shows how each month's precipitation affects the monthly precipitation average over time.

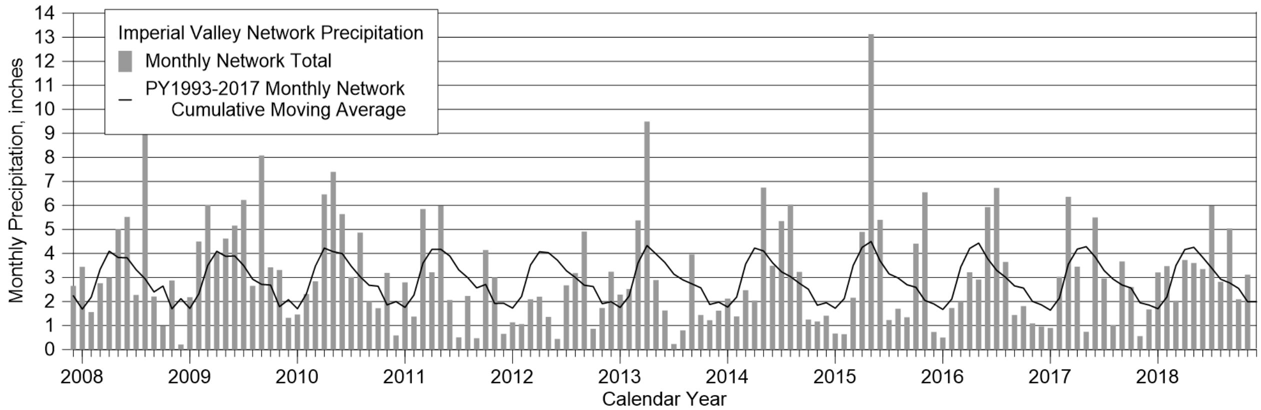

Figure 13. Network Average Monthly Precipitation (inches), January 2008 - December 2018

PY2018 network average of 40.24 was 5.33 inches wetter than the 26-year (1993-2018) network average of 34.91 inches. Precipitation was much greater than average (> 158%) during 5 months of the year and less than 90 percent of average during another 5 months. April 2018 received only 58 percent of the April 26-yr average.

Figure 14 compares the 26-year seasonal medians and variations with the PY2018 seasonal totals. Winter 2018 (January – March) received much more rain than the previous 25-yr seasonal median, and was the fourth wettest winter since this precipitation collection began in fall of 1992. Spring was much drier than the 25-year median, falling below the 2nd quartile (< 25% frequency), and the 7th driest spring in the last 26 years. The summer precipitation total was above the 25-year median and within the range of 50% of occurrences. Fall 2018 was also very wet, receiving much more precipitation than the 25-year median and above the 3rd quartile (>75% frequency) as the fourth wettest fall in the last 26 years.

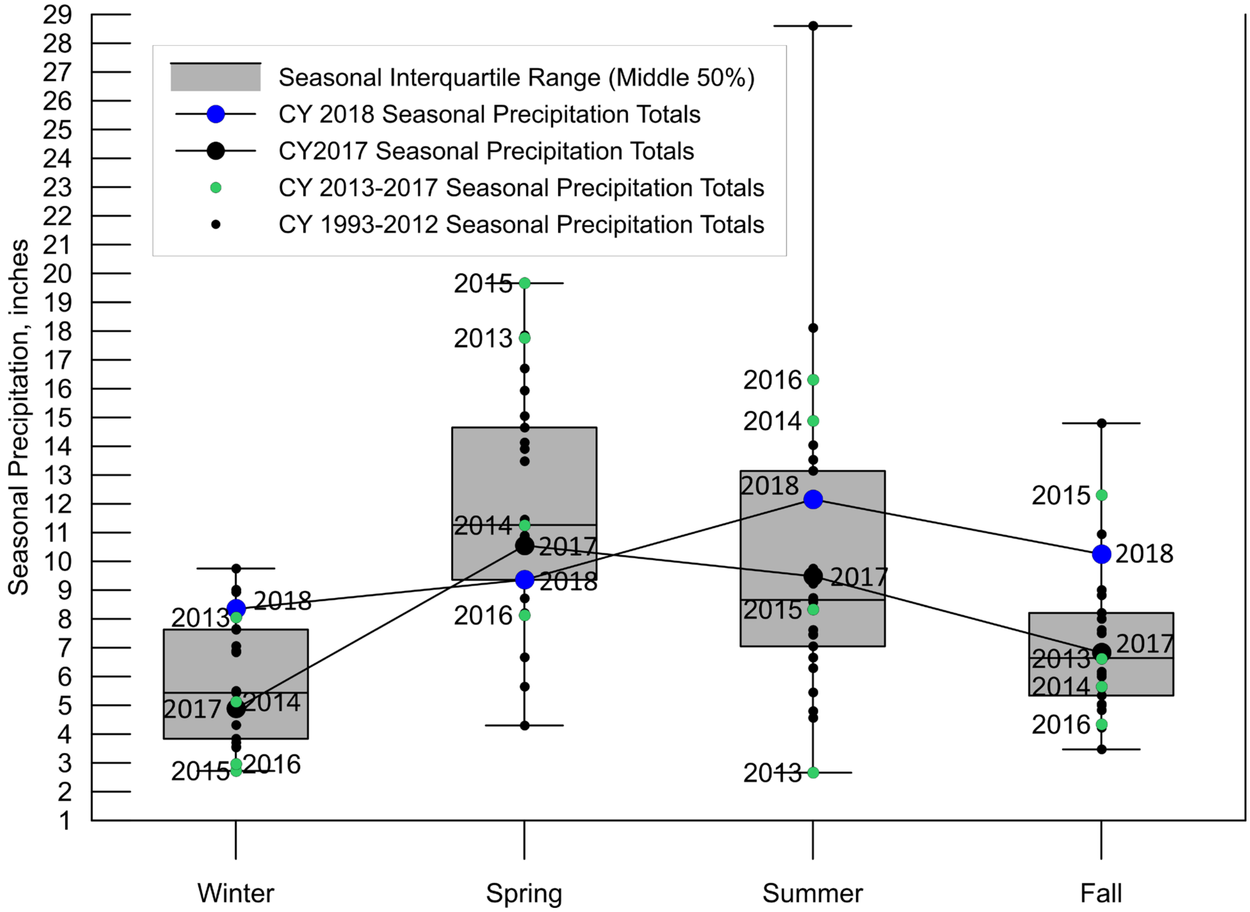

Figure 14. Seasonal Network Average Precipitation with Seasonal Totals for each calendar year. Box Plots Show the Interquartile Range (middle 50% of values, median (horizontal line within the box), Minimum, and Maximum Values.

Groundwater Levels

The IVWA monitoring well network had consisted of thirteen monitoring wells with all but two outfitted with data loggers that record the water level once per hour. As stated earlier, three additional well were drilled during 2014 and two more added during 2017, bringing the total number of observation wells to eighteen. The observation well network has been in existence since 1995 and is used to monitor changes in groundwater levels in the aquifer. The new observation wells add to the understanding of the aquifer. Two wells were installed at Ellsberry Lake as a nest, meaning they are screened at different depths. The third new well added during 2014 was drilled and installed next to the existing well at Mason City to create a second well nest. Having a well nest allows the observance of vertical movement of groundwater from the surface to the deeper sand and gravel units of interest. The two wells added during 2017 will help with aerial distribution of the well network and each well lies within an area that is of particular interest. MTOW-16 is located within Sand Lake, this area has experienced groundwater flooding in the past. MTOW-17, near Biggs, Illinois, is located next to an irrigation pivot near Crane Creek.

In an unconfined system, like the aquifer in the Havana lowlands, water levels typically vary by season. The highest water levels in the aquifer generally occurs during the spring and lowest during early fall. Hydrographs for each well show that water levels in the study area generally fall in late spring through the summer when discharge and withdrawals from the aquifer due to evapotranspiration and irrigation pumpage are at their greatest. Generally, precipitation is not high enough during this time to raise water levels in the aquifer. Most rainfall goes to replenish soil moisture, and make up for irrigation withdrawals. Significant recharge to the aquifer most often occurs during winter and early spring when there is little pumpage, evapotranspiration is low, and soil moisture is more likely high.

The long-term hydrograph at MTOW-01A (Snicarte, 1958 to present) in Figure 15 provides a historical reference for comparison with the shorter records of the other network wells. The ISWS has a record of water levels at this site since 1958. Annual fluctuations from less than a foot to more than 8 feet have been observed. A detailed look at water levels at the Snicarte site since 1990 is shown in Figure 16. During the 1988-1989 drought, the water level fell to 40.5 feet below land surface in the Snicarte well. At the time, it was the only time in its 45-year history that the well had went dry, until it did so again in 2006 and 2007. During the 1993 flood, groundwater levels rose and peaked at approximately 11 feet below land surface in September 1993. The September 1993 water level of 11.14 feet below land surface is the highest water level to date for the Snicarte well.

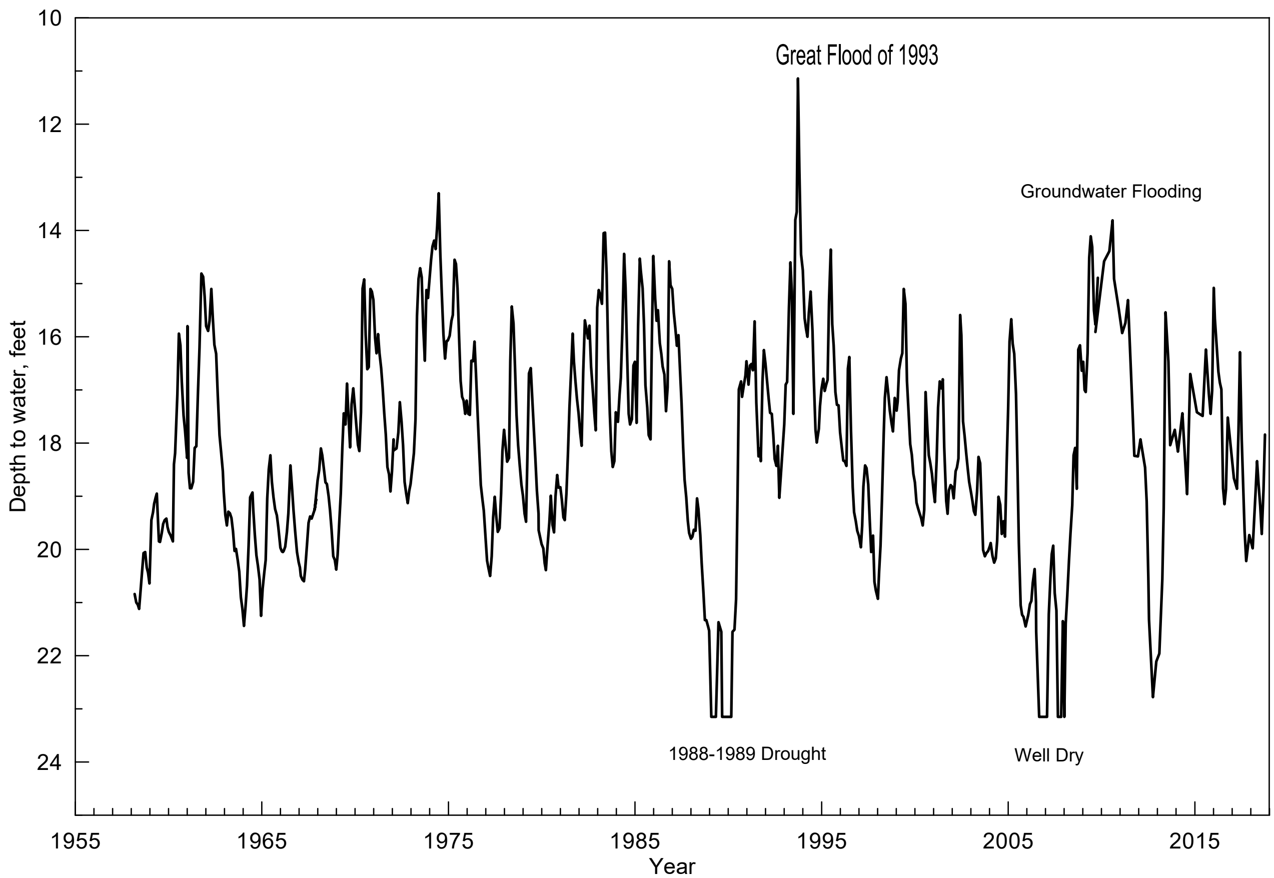

Figure 15. Groundwater Levels at the Snicarte Well, 1958-2018.

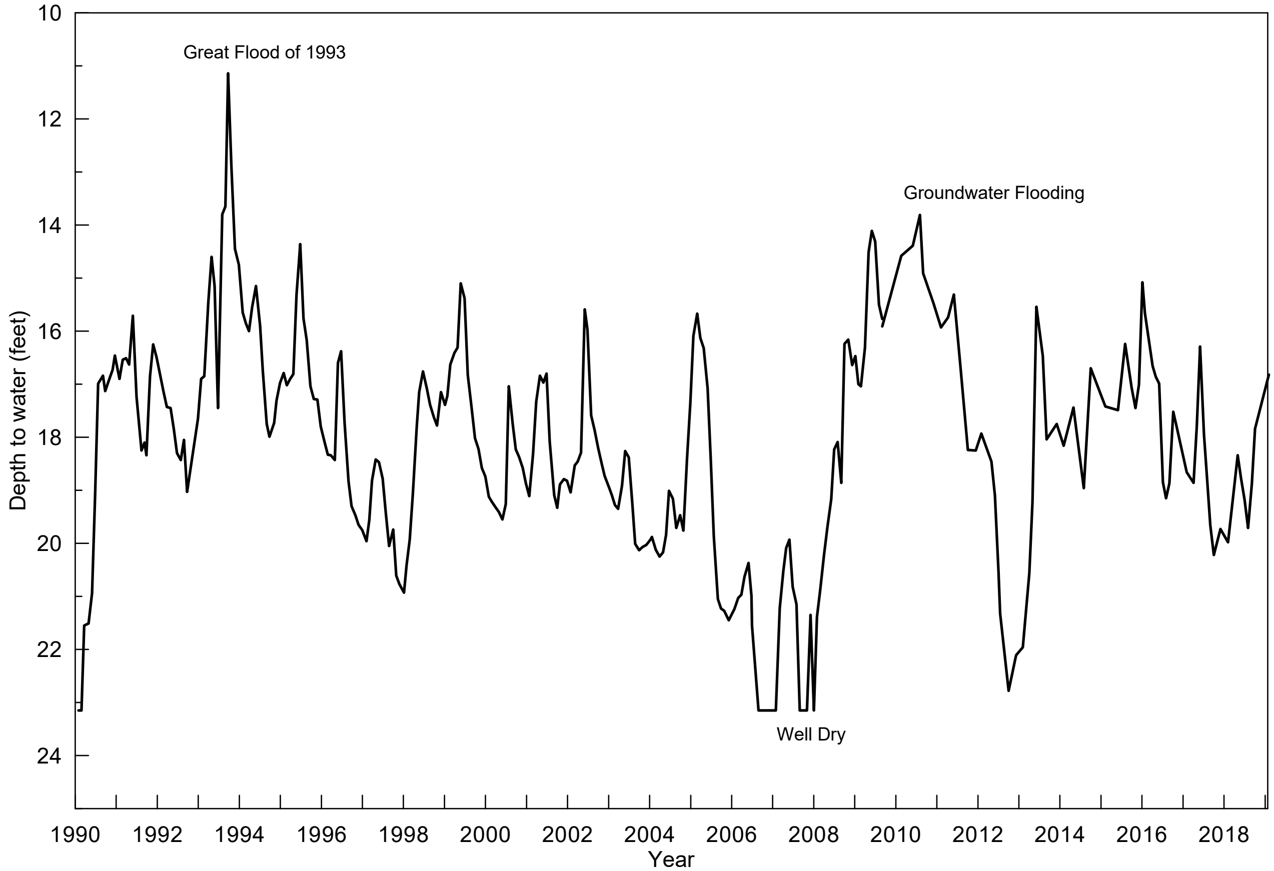

Figure 16. Groundwater Levels at the Snicarte Well, 1990-2018.

The dramatic water level drop in 1988-89 shows how significantly a major drought can impact the aquifer. Though irrigation data is not available for 1988, based on data from the other parts of the state (Cravens, et al., 1989) it is likely that irrigation in 1988 was one of the highest amounts of any year. This is because summer precipitation was so low and summer temperatures were so high in 1988. Similarly, the irrigation amounts in 2005, 2006 and 2007 resulted in dramatic declines in water levels. Conversely, Year 17 (2008-2009), Year 18 (2009-2010) and most of Year 19 (2010-2011) were relatively wet years with low irrigation withdrawals, and water levels rose.

Above average precipitation in Year 17(2008-2009) elevated groundwater levels to the point of near record highs since the observation well network was established in 1995. A second year of higher than average precipitation in Year 18(2009-2010) elevated groundwater levels to record highs in several of the network wells. The above average precipitation continued until June of 2011. Because of the high precipitation totals between 2008 and 2011, the study area experienced widespread Groundwater Flooding. The flooding subsided during the late summer and fall of 2011.

From July 2011 until December 2012, the study area received below average precipitation. Figure 16 above shows groundwater levels declining during the drought of 2012. The groundwater levels came close to approaching the lows seen during the 1988-1989 drought and the exceptionally low groundwater levels of 2006-2008. It is likely that because of a continued increase in the number of irrigation systems in the area, years with below average precipitation will lead to larger drops in aquifer water levels. The drops seen in 2005-2007 and in 2011-2012 suggest it won't take as significant a drought as in 1988 to cause 1988-like water level declines.

The hydrographs created from hourly water level measurements have led to an increased understanding of the relationship between rainfall, irrigation, water levels, and recharge. In Figure 18, data shown consisted of once a month measurements until 2005, when data loggers were installed to record hourly measurements. Appendix A shows the hydrographs for the 18 long-term wells within the observation well network. The hydrographs in Appendix A show water levels in each well for PY2018, from January 1, 2018 to December 31, 2018, and contain all groundwater elevation or depth to water from land surface data and daily precipitation totals for nearby rain gauges.

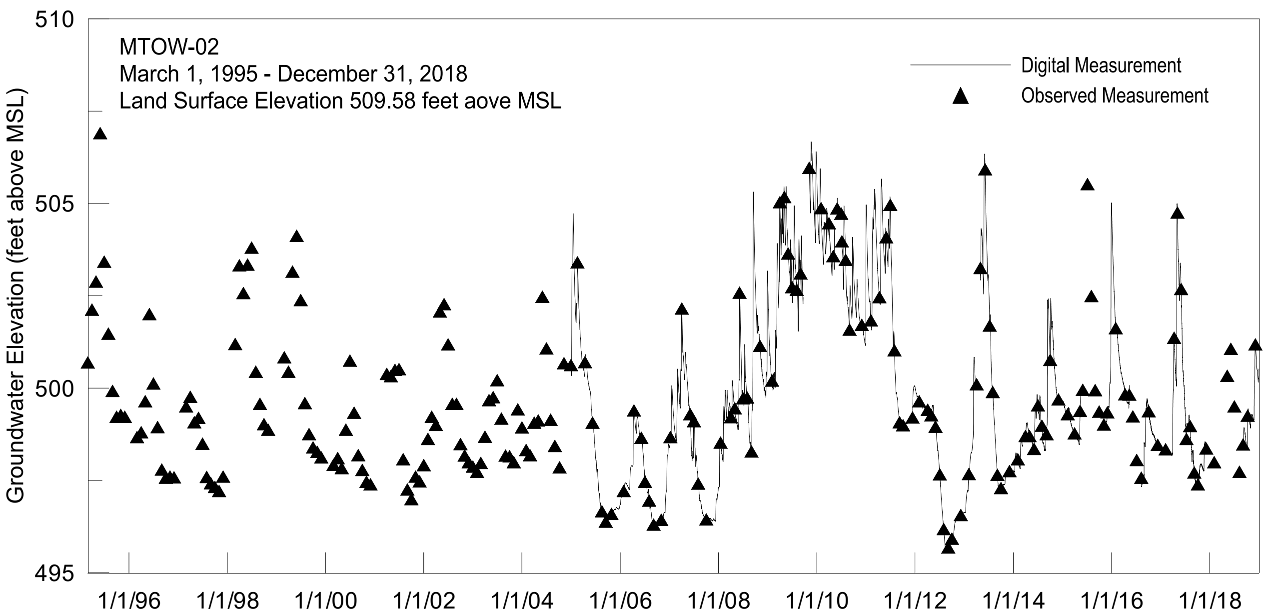

Figure 17. Groundwater Elevations at the Easton Well, MTOW-02, September 1, 1995-December 31, 2018.

Figure 17 shows the entire period of record for MTOW-02, located within the village limits of Easton, IL. The lowest water levels on record occur August 25 and 26, 2012 while one of the highest water levels occur on June 2, 2013. The high and low water levels were 4.24 feet and 14.03 feet below land surface, respectively. The only higher water levels were in June of 1995 and around January 1, 2010. Having such high and low water levels in such a short time period reflects the recharge capabilities of the aquifer, particularly in the Easton region. It also highlights the influence rainfall has on the aquifer when the water table is so shallow and the aquifer is unconfined.

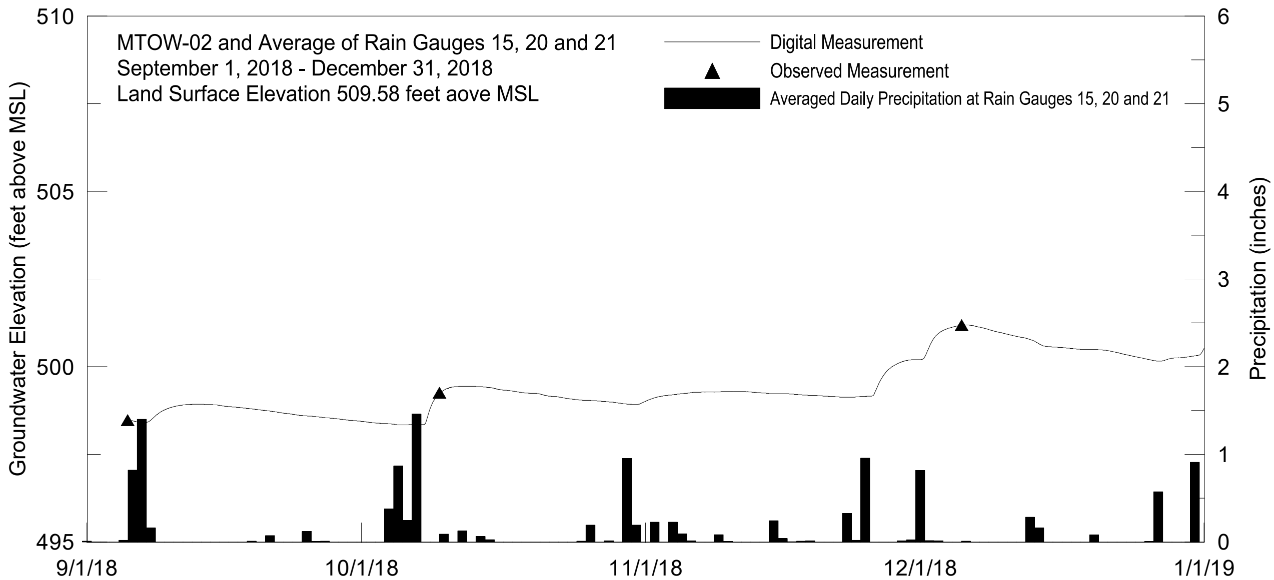

Figure 18. Groundwater Elevations at the Easton Well, MTOW-02, September 1, 2018 - December 31, 2018

In Figure 18, the relationship between rainfall and recharge is observable as groundwater levels rise during periods of heavy precipitation. This is particularly evident after the large rainfall events in early September, October and December (around 3 inches over 5 days) and the 2-3 weeks following that event.

Having continuous water level data allows for a better understanding of how rainfall and pumpage affect recharge and water levels. At MTOW-17 (Figure 19), the bottom of the graph shows rainfall events and how the water levels respond to precipitation, particularly noticeable in April of 2018. Conversely, each “downward spike” on the water level hydrograph is a pumping event from a nearby irrigation pivot. When precipitation is sufficient and frequent, the number of pumpage events decreased and water levels rose.

Figures 20 and 21 are hydrographs showing groundwater elevation and precipitation data during the summer of 2018. Figure 20 is the hydrograph of MTOW-11, which is the shallow observation well located south of Mason City, Il. Figure 21 shows the hydrograph for MTOW-14, the deep well located next to MTOW-11.The hydrographs start June 1, 2018 and go to the end of the project year which ends December 31, 2018. These hydrographs illustrate how location dependent the effects of precipitation and irrigation are on groundwater levels. Both wells show very little recharge even though there is abundant precipitation. MTOW-14 (Deep Well), shows drawdown due to irrigation pumping even when MTOW-11 (Shallow Well) shows none, indicating there is a hydraulic separation between the aquifers here.

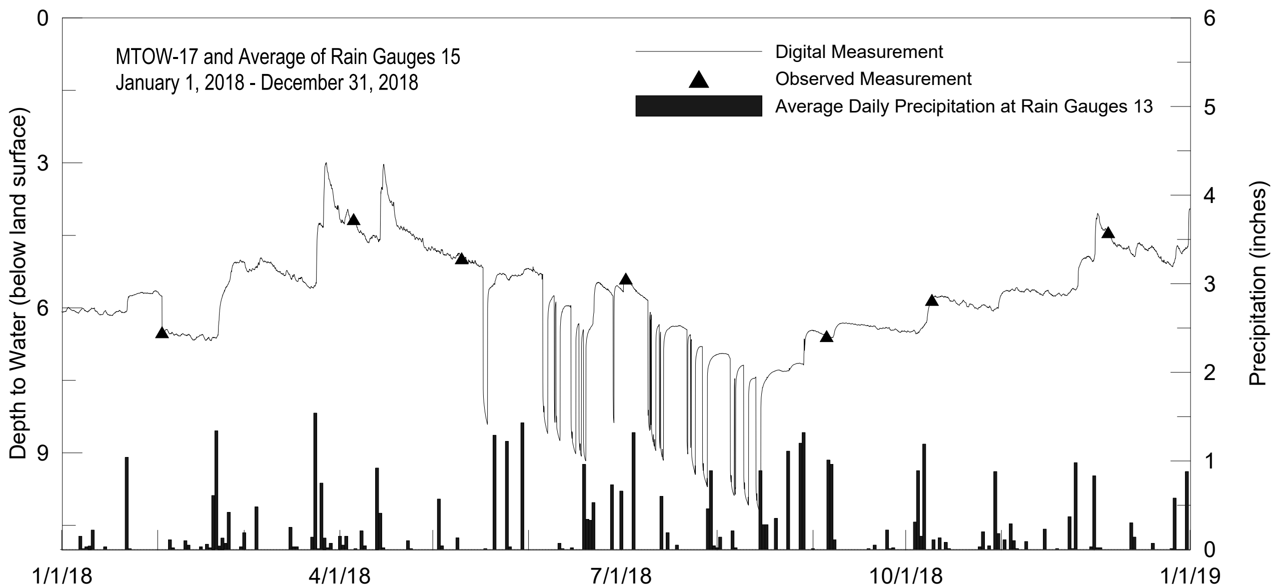

Figure 19. Groundwater Elevations and Precipitation at the Biggs Well, MTOW-17, January 1, 2018-December 31, 2018

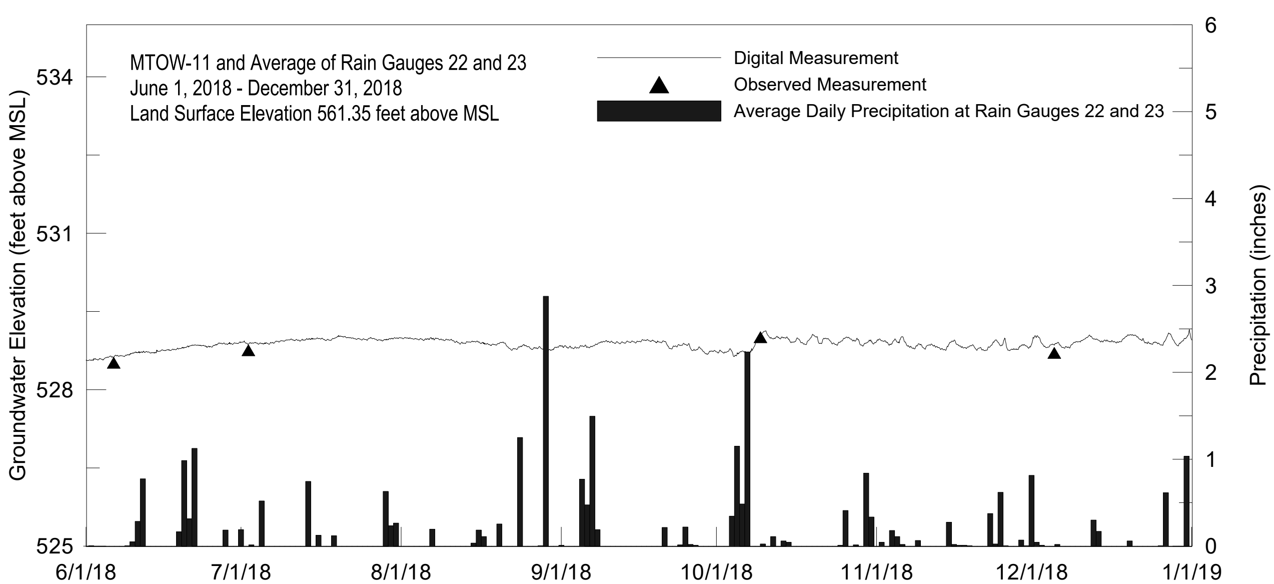

Figure 20. Groundwater Elevations and Precipitation at the Mason city Shallow Well, MTOW-11, June 1, 2018-December 31, 2018.

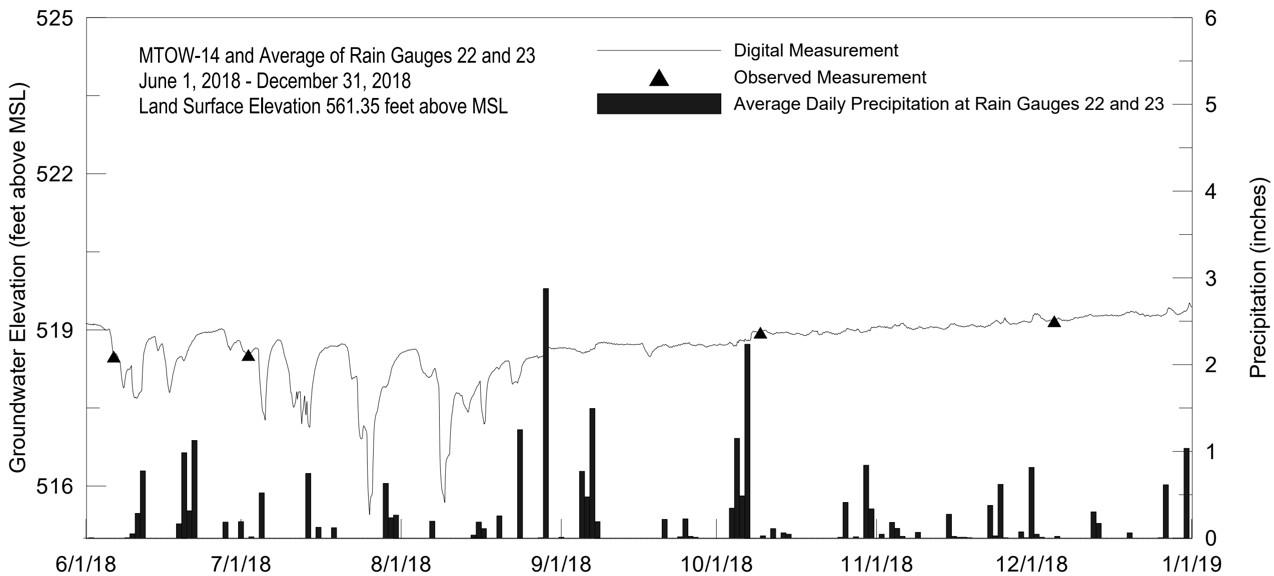

Figure 21. Groundwater Elevations and Precipitation at the Mason City Deep Well, MTOW-14, June 1, 2018-December 31, 2018.

Groundwater levels in the Pekin (MTOW-05) and Havana-IDOT (MTOW-09) wells have been found to fluctuate largely in response to river stage because of their proximity to the Illinois River. Since these two monitoring wells are so strongly influenced by the Illinois River, the wells are not outfitted with pressure transducers and are measured three to four times a year. The hydrographs for these two wells (MTOW-05 and MTOW-09) are located in Appendix A.

Irrigation Water Use

The IVWA has provided the ISWS a monthly estimated total pumpage of irrigation since 1997. These data are calculated by the Imperial Valley by evaluating power consumption at nearly 1100 irrigations systems in the area supplied by the Menard Electric Cooperative. The pumpage is a monthly aggregate of all irrigation which occurs over the water authority area. The water authority area includes Mason County and parts of six townships in Tazewell County as shown in Figure 1 and Figure 22.

The total irrigation pumpage in 2018 was approximately 52.4 billion gallons (bg), which is the sixth highest irrigation amount for the observation period (Table 3). The number of irrigation systems is now at 2252. During 2014, the ISWS developed a statewide map of irrigation based on USDA aerial photography. Based on those data, it was determined the number of irrigation systems in the IVWA was lower than the IVWA was estimating. The IVWA uses new well construction reports to determine the number of irrigation systems each year, which doesn't necessarily account for wells installed to replace existing wells. This likely led to the over-counting of irrigation systems by the IVWA. Figure 22 shows the location of irrigation systems in the IVWA area in 2014, based on ISWS mapping efforts.

Lower than normal precipitation and warmer weather in the Spring and early Summer affected irrigation practices in 2018. Early planting led to the most irrigation ever in May (6.5 bg) and June (16 bg), and higher than average irrigation in July (19.3 bg, which is 4.4 bg more than the long-term average). It also led to August, September, and October having the least amount of irrigation of any year since the data collection started in 1995 (Table 3).

The monthly and seasonal estimates of irrigation withdrawals from 1995 to 2018 are shown in Table 3. The rank from highest to lowest irrigation amounts are shown in the right-hand column. Year 26 was near the top, ranking sixth overall with 52.4 bg pumped for the year. Typically, irrigation withdrawals are greatest in July and August, with September and June withdrawals being lower. 2018 was an unusual year because of early planting and dry weather in the early part of the growing season.

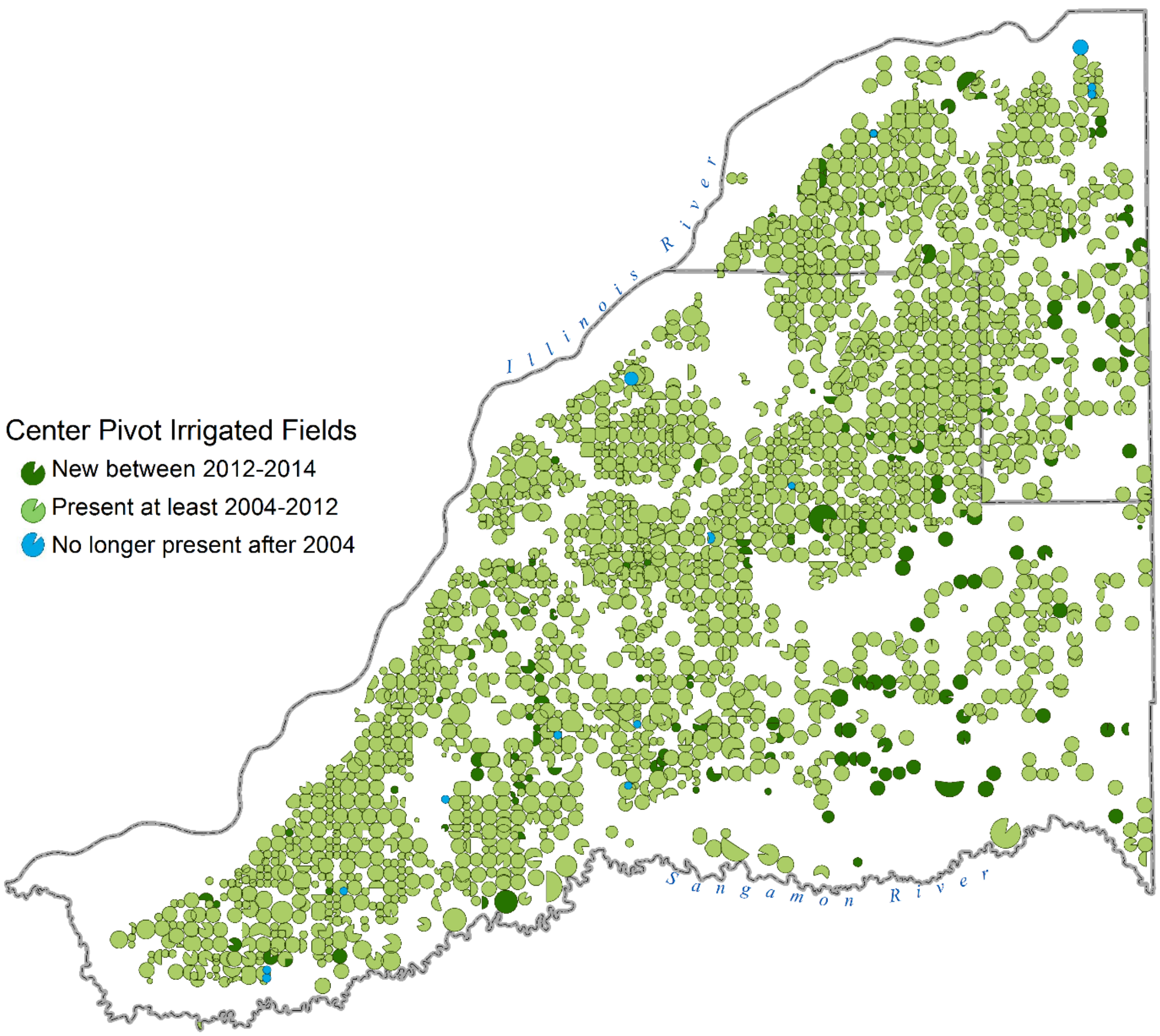

Figure 22. Location of Irrigation Systems within the IVWA (2014).

The estimated monthly irrigation pumpage is displayed graphically in Figure 23 along with average monthly network precipitation. These pumpage values show a tendency for lower irrigation amounts during times of increasing precipitation and vice versa, but also show that irrigation is dependent on the timing of precipitation. Table 4 provides a comparison of rainfall and irrigation parameters showing their overall relationship. The irrigation rank is from least pumpage to most so that ranks between precipitation and pumpage are comparable. This ranking makes it clear, that the timing and amount of rainfall received during the irrigation season (rather than total annual precipitation) is the primary factor affecting the amount of irrigation pumpage. The 1999-2000 project year is a great example. Even though annual precipitation was over 12 inches below normal, the 2000 growing season had the 3rd lowest total irrigation pumpage for the 22 years of record.

Table 3. Estimated Monthly Irrigation Withdrawals (billion gallons), Number of Irrigation Systems, Withdrawal per System and Withdrawal Rank

Year	*May*	*June*	*July*	*August*	*September*	*October*	*Total #*	*Systems*	*BG/system*	*Rank*
1995		2.6	14	10	11		38			17
1996		2.0	20	18	12		52			7
1997		2.6	19	14	2.0		38			17
1998		2.1	7.8	13	6.9		30	1622	.018	21
1999		2.8	18	12	6.0		39	1771	.022	16
2000		6.4	6.0	12	5.6		30	1799	.017	21
2001		4.4	21	17	5.0		47	1818	.026	10
2002		3.4	24	16	3.7		47	1839	.026	10
2003		4.1	16	15	10		46	1867	.025	12
2004		5.3	12	19	5.7		42	1889	.022	14
2005		15	29	23	4.8		72	1909	.038	2
2006		7.2	22	16	5.2		50	1940	.026	9
2007		16	17	19	4.9		57	1971	.029	5
2008		1.2	10	14.5	7.1		33	2014	.016	19
2009		1.6	9.3	12.1	2.9		26	2054	.013	24
2010		1.8	2.4	11.7	10.6		27	2077	.013	23
2011		0.7	2.5	24.7	19.6	5.0	52	2100	.025	7
2012	0.1	12.3	26.4	39.7	17.4	2.2	98	2160	.045	1
2013	0.1	0.7	4.8	25.0	27.2	9.4	67	2293	.029	3
2014	0.1	4.7	9.2	16.3	8.2	1.1	40	2169*	.018	15
2015	0.1	1.6	2.2	9.8	17.0	0.9	31	2197	.014	20
2016	0.1	2.8	23.4	10.9	6.6	1.4	45	2223	.020	13
2017	0.1	1.7	22.0	17.3	14.2	6.2	61.5	2237	.027	4
2018	6.5	16.0	19.3	8.7	1.6	0.3	52.4	2252	.023	6
Average	1.0	5.0	14.9	16.4	9.0	3.3	46.7			

Note: Total annual withdrawal may differ from sum of monthly withdrawals due to rounding error.
*Total number of system was updated during June 2014 by ISWS using aerial photography.

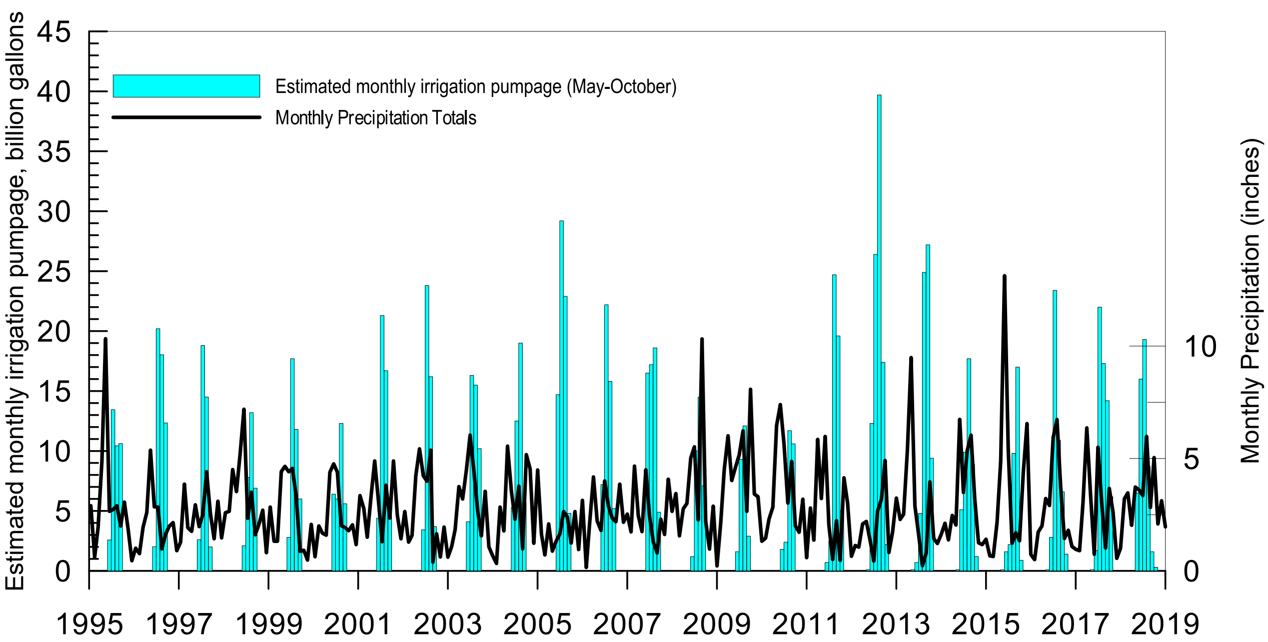

Figure 23. Estimated Irrigation Pumpage and Average Monthly Precipitation, IVWA.

Table 4. Average Annual Precipitation, Annual Precipitation Surplus, and Ranked Annual Precipitation and Irrigation, Imperial Valley Network

Sept-Aug Project Year	*Network average precipitation (in.)*	*Annual surplus (in.)*	*Rank Precip.*	*Rank Irrigation**
1992 - 1993	55.55	+17.17	1	-
1993 - 1994	40.21	+1.83	5	-
1994 - 1995	39.42	+1.04	9	17
1995 - 1996	25.70	-12.68	25	7
1996 - 1997	27.31	-11.07	23	17
1997 - 1998	40.06	+1.68	7	21
1998 - 1999	34.02	-4.36	14	16
1999 - 2000	25.81	-12.57	24	21
2000 - 2001	30.97	-7.41	17	10
2001 - 2002	39.91	+1.53	8	10
2002 - 2003	30.06	-8.32	18	12
2003 - 2004	29.64	-8.74	19	14
2004 - 2005	27.34	-11.04	22	2
2005 - 2006	27.74	-10.64	21	9
2006 - 2007	31.94	-6.44	16	5
2007 - 2008	35.02	-3.36	12	19
2008 - 2009	49.34	+10.96	2	24
2009 - 2010	47.91	+9.53	3	23
2010 - 2011	34.17	-4.21	13	7
2011 - 2012	21.44	-16.94	26	1
2012 - 2013	38.35	-0.03	10	3
2013 - 2014	32.63	-5.75	15	15
2014 - 2015	41.23	2.85	4	20
2015 – 2016	37.75	-0.63	11	13
2016 – 2017	31.88	-6.50	17	4
2017 – 2018	40.11	1.73	6	6

***Irrigation ranks are from highest total pumpage to lowest for comparison with precipitation. (Irrigation rankings in reports through YR24 were from lowest to highest pumpage)**

1981 - 2010 30-yr average 39.80 (Havana)
1981 - 2010 30-yr average 36.98 (Mason City)
1981 - 2010 30-yr average 38.38 (average of Mason City and Havana used to determine surplus)
1993 - 2018 26-yr average 34.92 (25-year IVWA network average)

Note: Site 16 was excluded from network average computations from 1996-1997 through 2001-2002.

Summary

During PY2018 of the rain gauge network operation (January 2018-Decemebr 2018), the network received an average of 40.11 inches of precipitation, 5.19 inches above the previous 25-year network average precipitation of 34.92 inches, and 1.73 inches above the 30-year average for the study area, 38.38 inches. PY2018 was the 6th wettest year since the deployment of the precipitation network. Spring was dry in 2018, over 2.5 inches below the long-term average, but

Winter, Summer, and Fall were all wetter than normal, resulting in such a high annual value. As we have seen in the past, the seasonality of rainfall is a significant factor in irrigation pumpage.

The data collected over the last 26 years as part of this project have been invaluable to the ISWS in developing a better understanding of the groundwater system in the Havana Lowlands, as well as the Mahomet Aquifer as a whole. What amazes many people who have looked at the data for the Havana Lowlands Region is the fact that water levels are basically unchanged from the 1960's even though there are now over 2000 irrigation systems in the region and in the early 1960's, there were less than 100.

ISWS scientists are using these data in new ways. Recently developed methods for evaluating water level information using MODFLOW are leading to a better approach to understanding how irrigation, rainfall, river stage, and groundwater levels all affect each other.

The ISWS is grateful to the IVWA for their continued support of the rain gauge and observation well networks. Please contact Kevin Rennels, Steve Wilson or Erin Bauer, if you have any questions or comments.

Sincerely,

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Appendix A. Hydrographs, Imperial Valley Observation Well Network

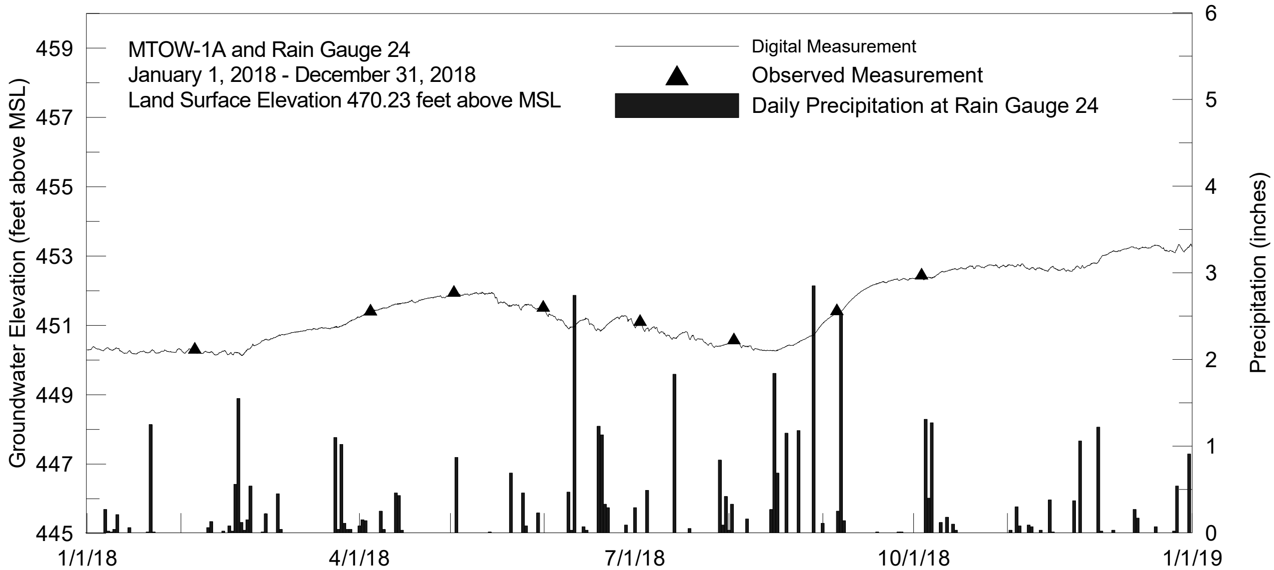

Figure A-1. Year 26 Groundwater Elevation and Precipitation for MTOW-01A

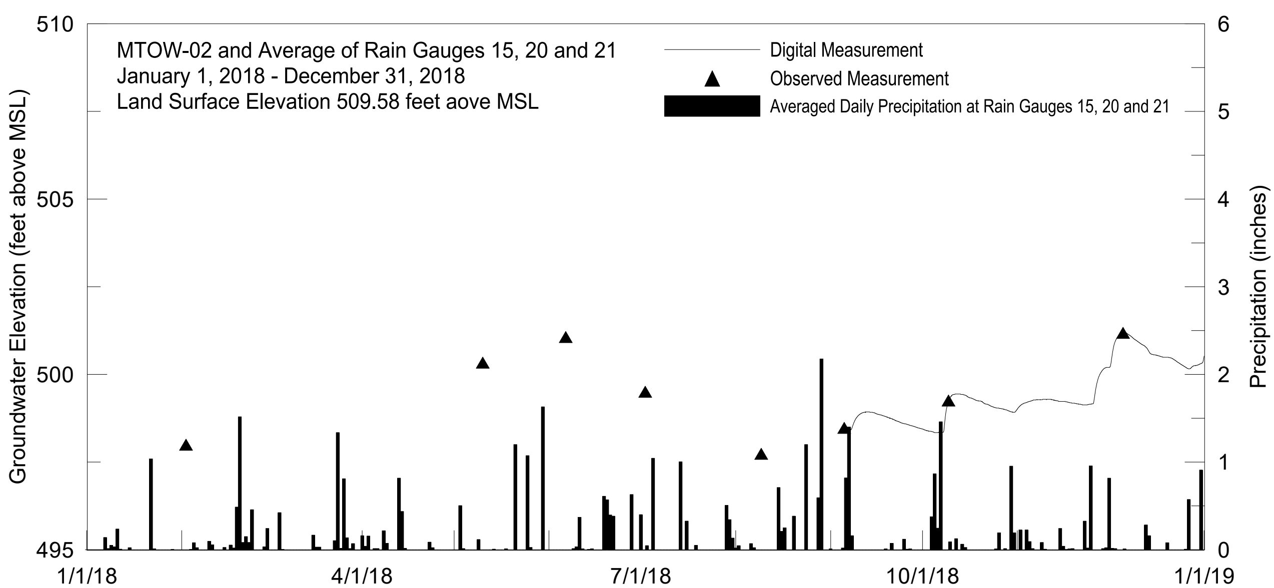

Figure A-2. Year 26 Groundwater Elevation and Precipitation for MTOW-02

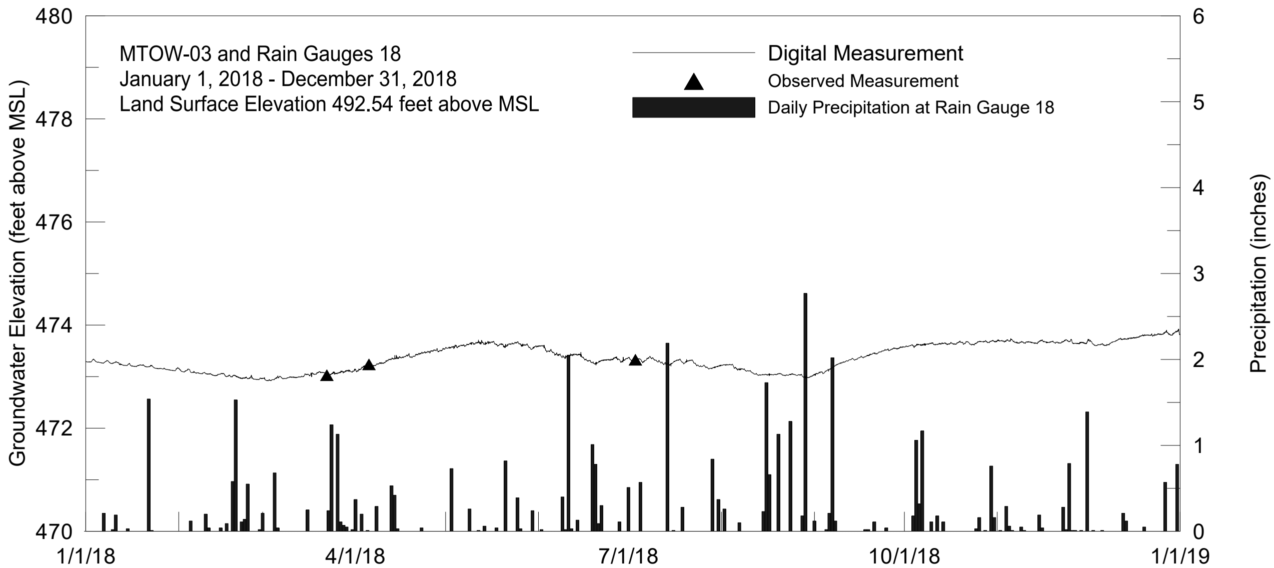

Figure A-3. Year 26 Groundwater Elevation and Precipitation for MTOW-03

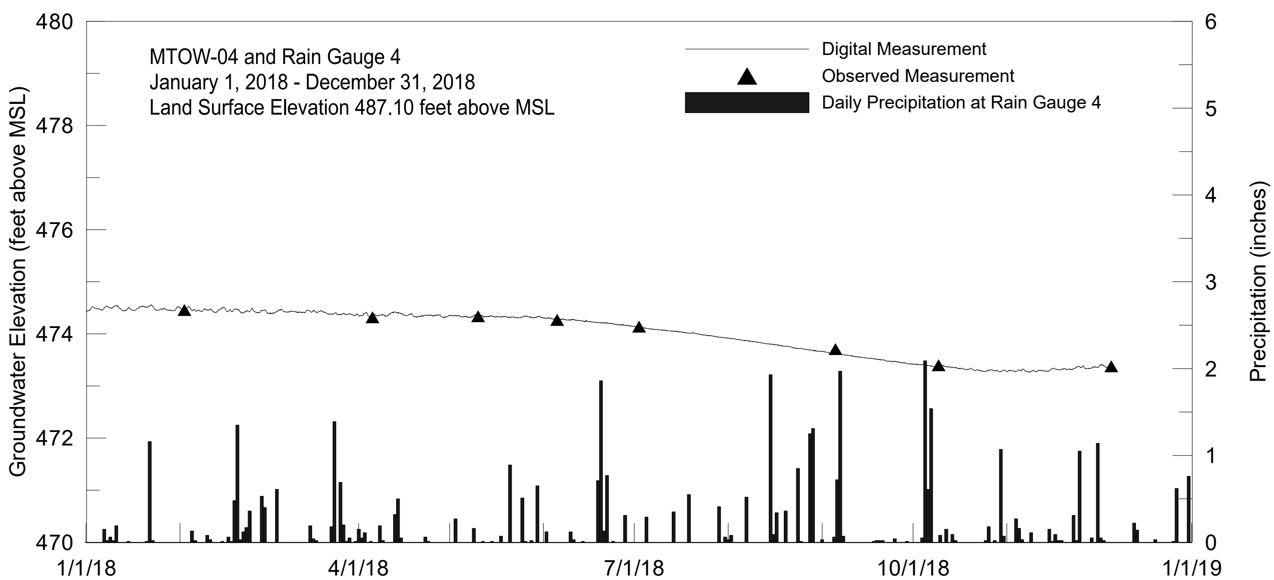

Figure A-4. Year 26 Groundwater Elevation and Precipitation for MTOW-04

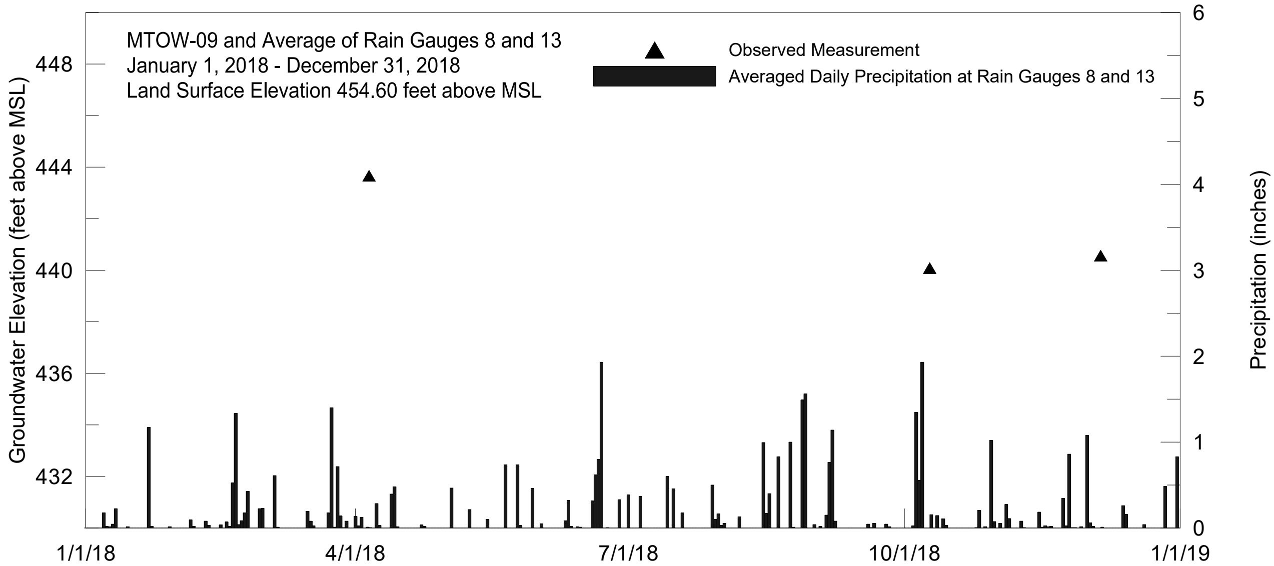

Figure A-5. Year 26 Groundwater Elevation and Precipitation for MTOW-05 (not continuous recorder)

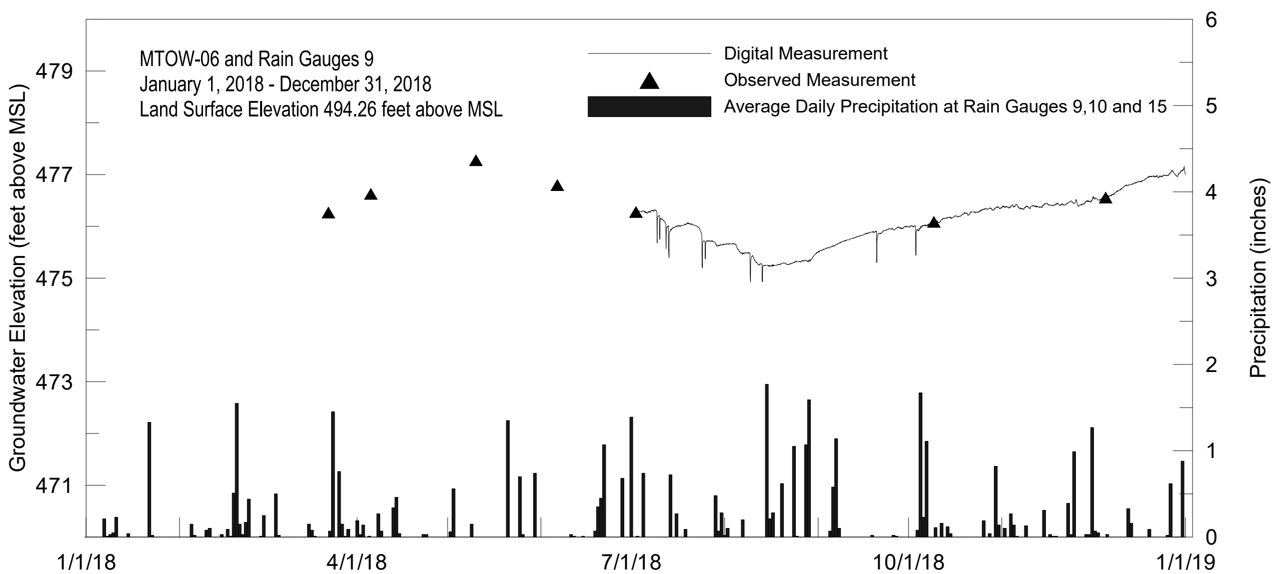

Figure A-6. Year 26 Groundwater Elevation and Precipitation for MTOW-06

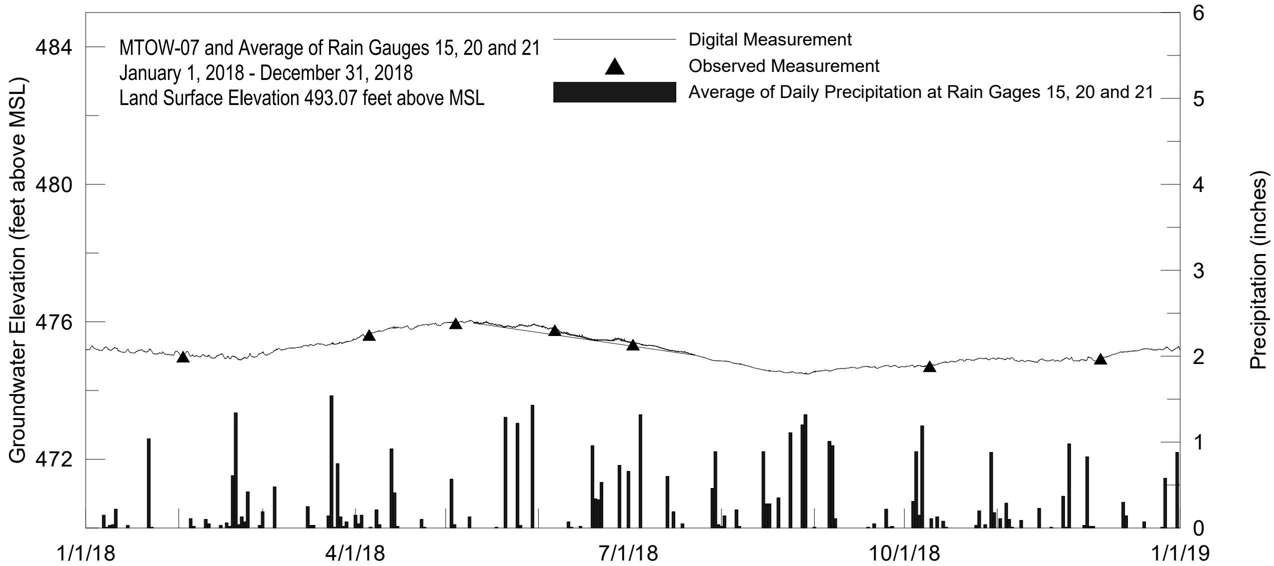

Figure A-7. Year 26 Groundwater Elevation and Precipitation for MTOW-07

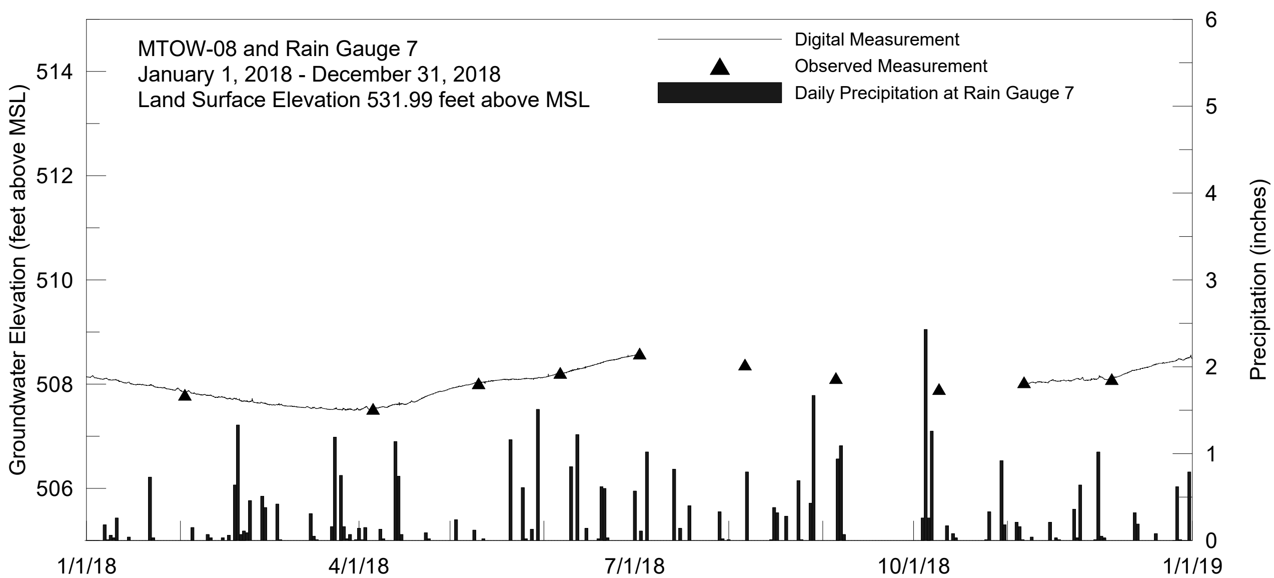

Figure A-8. Year 26 Groundwater Elevation and Precipitation for MTOW-08

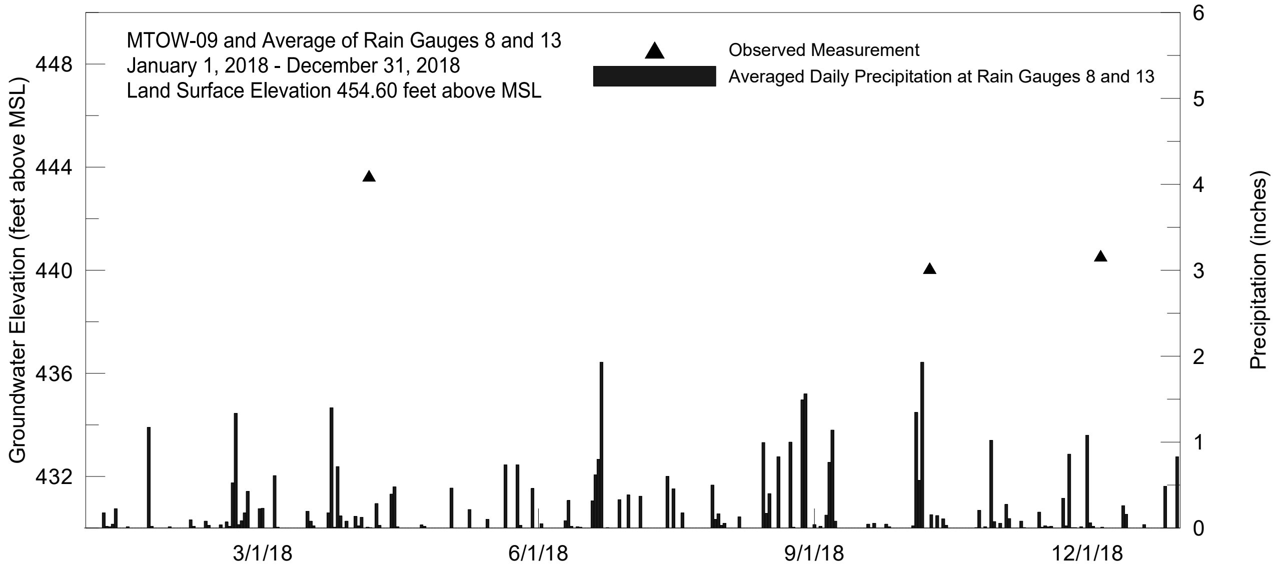

Figure A-9. Year 26 Groundwater Elevation and Precipitation for MTOW-09 (not continuous recorder)

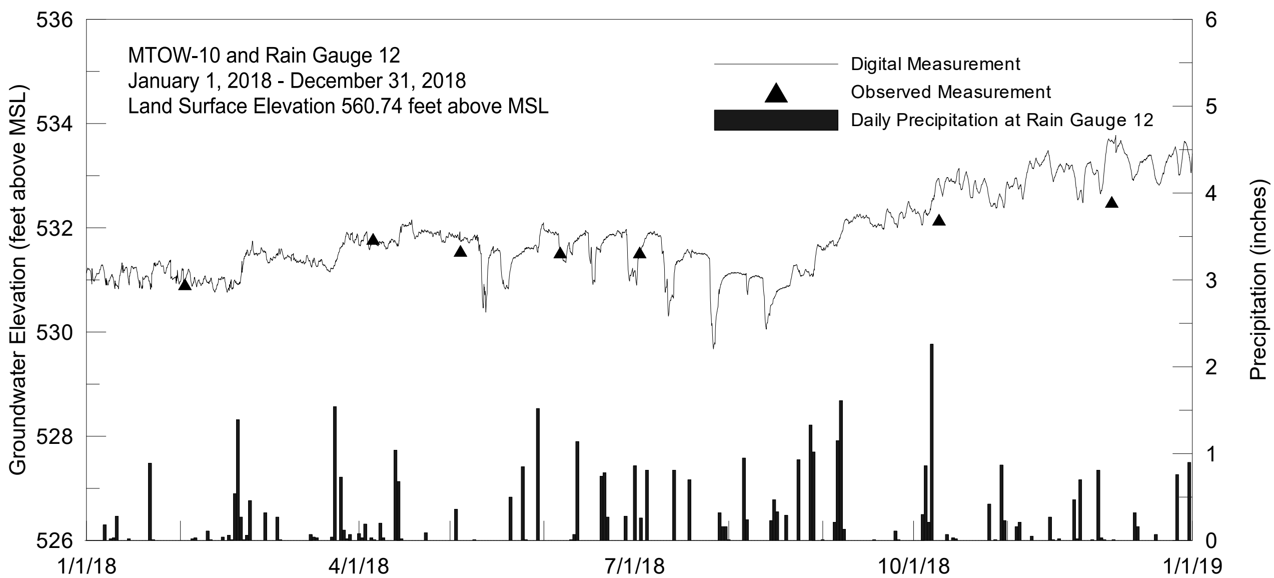

Figure A-10. Year 26 Groundwater Elevation and Precipitation for MTOW-10

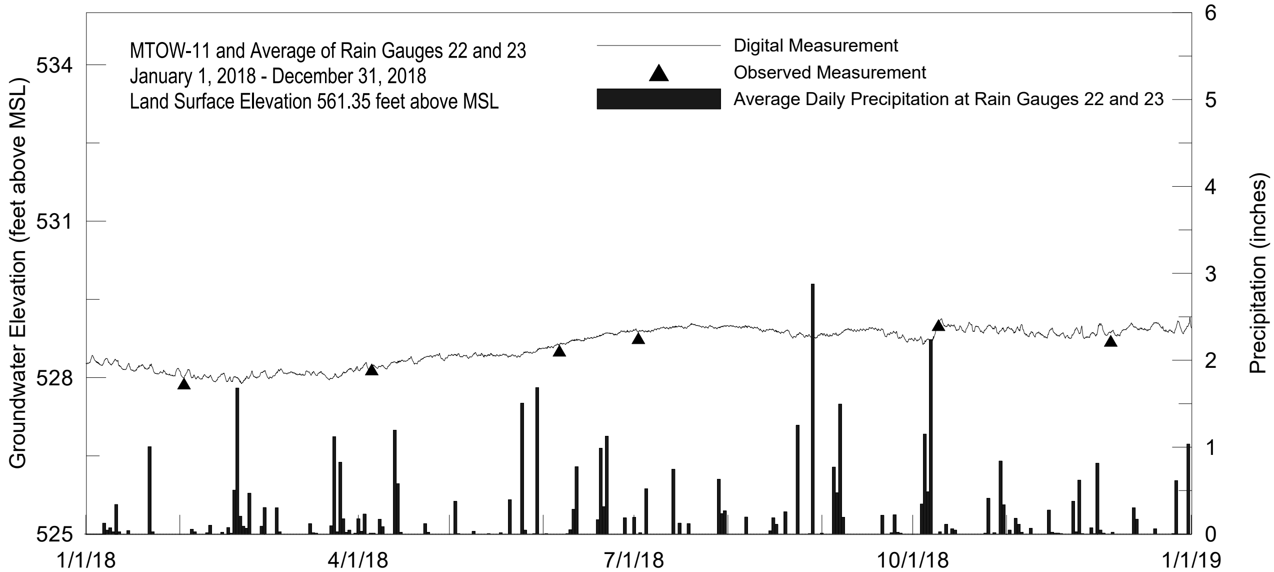

Figure A-11. Year 26 Groundwater Elevation and Precipitation for MTOW-11

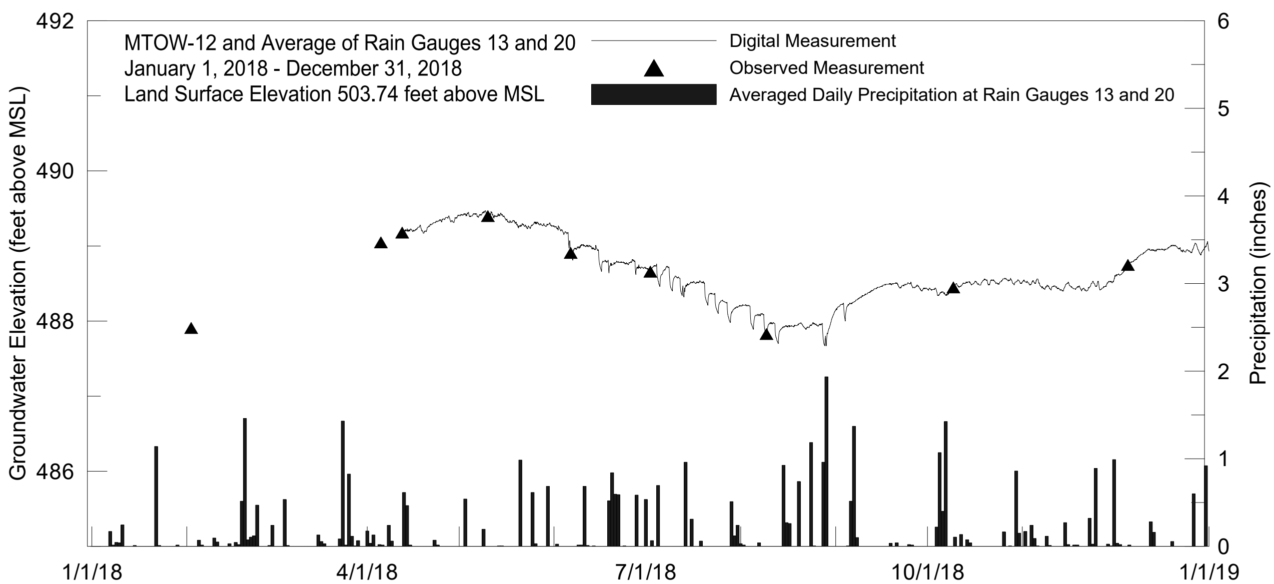

Figure A-12. Year 26 Groundwater Elevation and Precipitation for MTOW-12

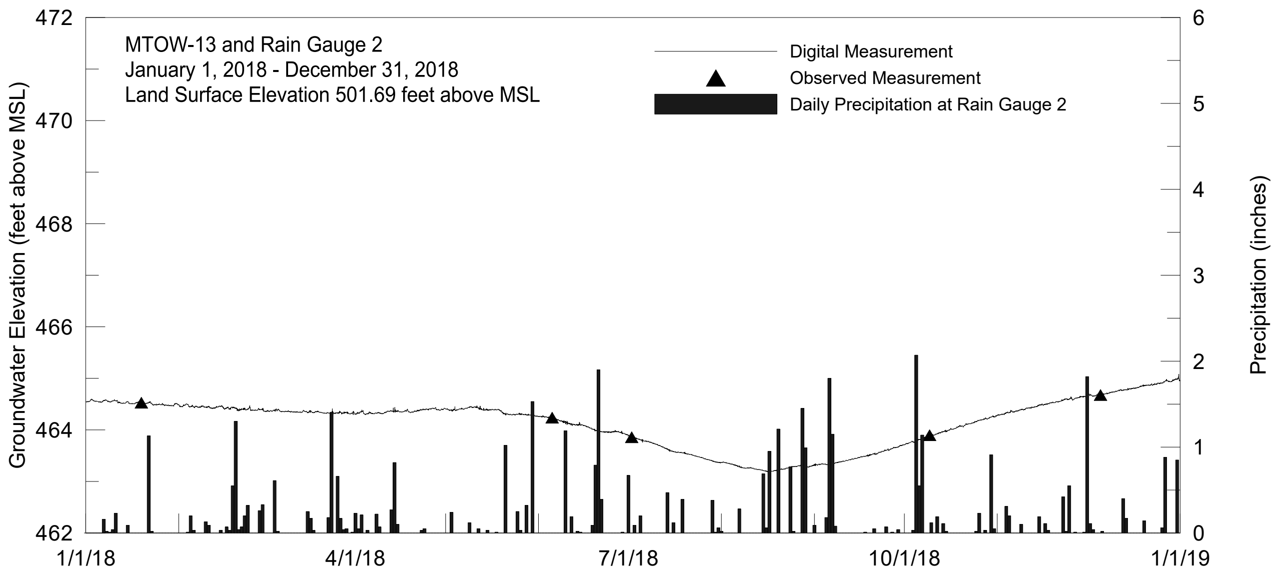

Figure A-13. Year 26 Groundwater Elevation and Precipitation for MTOW-13

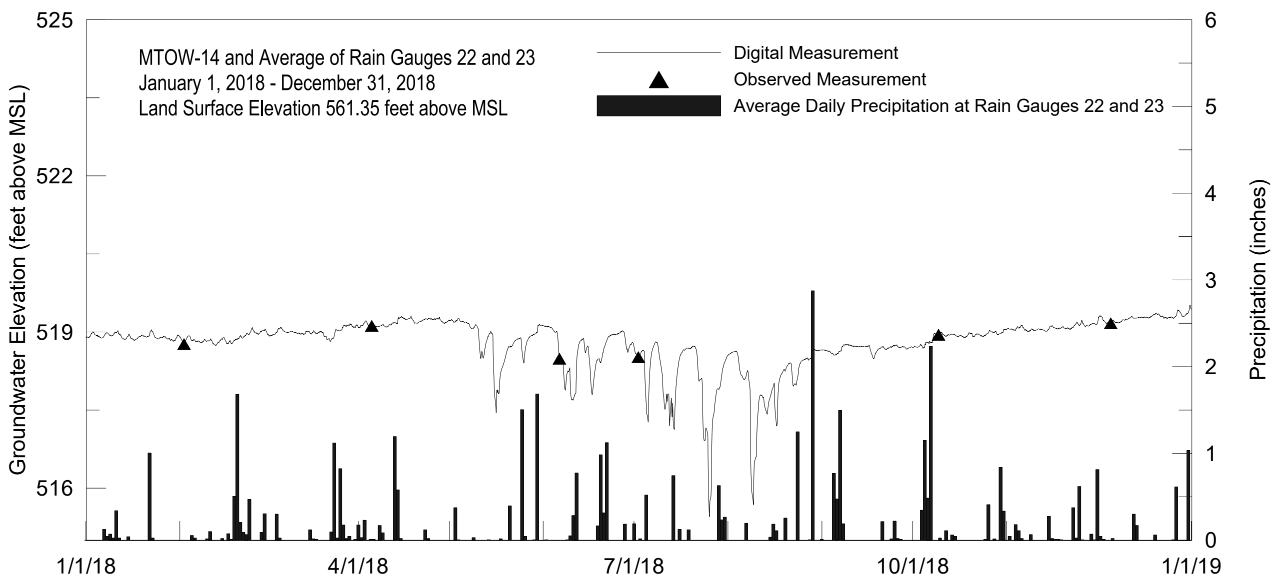

Figure A-14. Year 26 Groundwater Elevation and Precipitation for MTOW-14

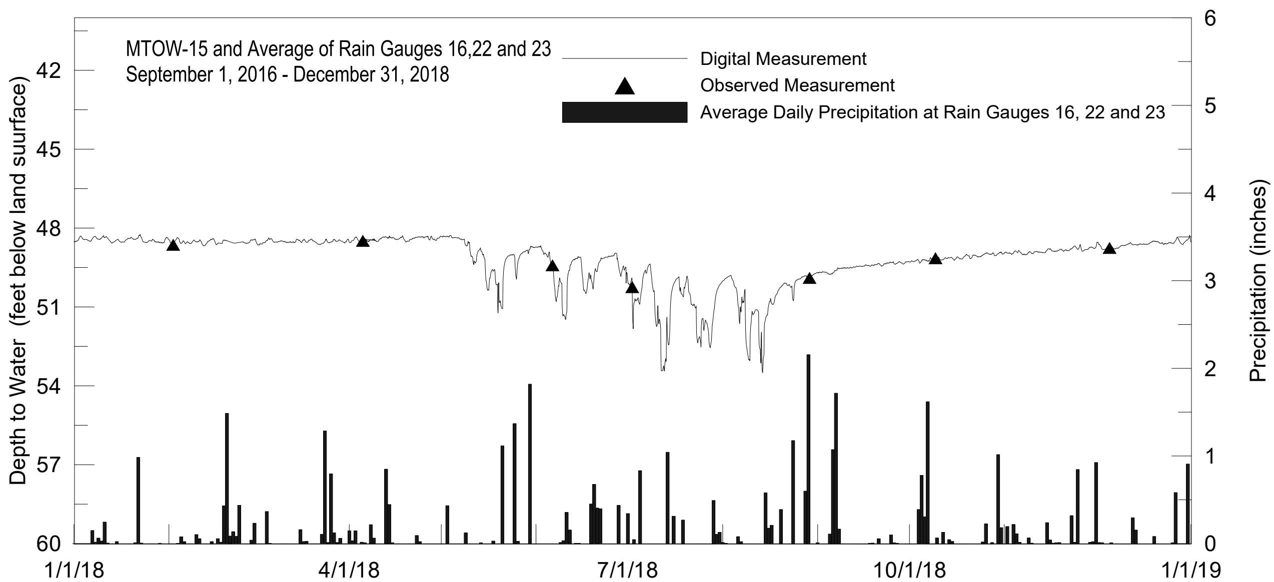

Figure A-15. Year 26 Groundwater Elevation and Precipitation for MTOW-15

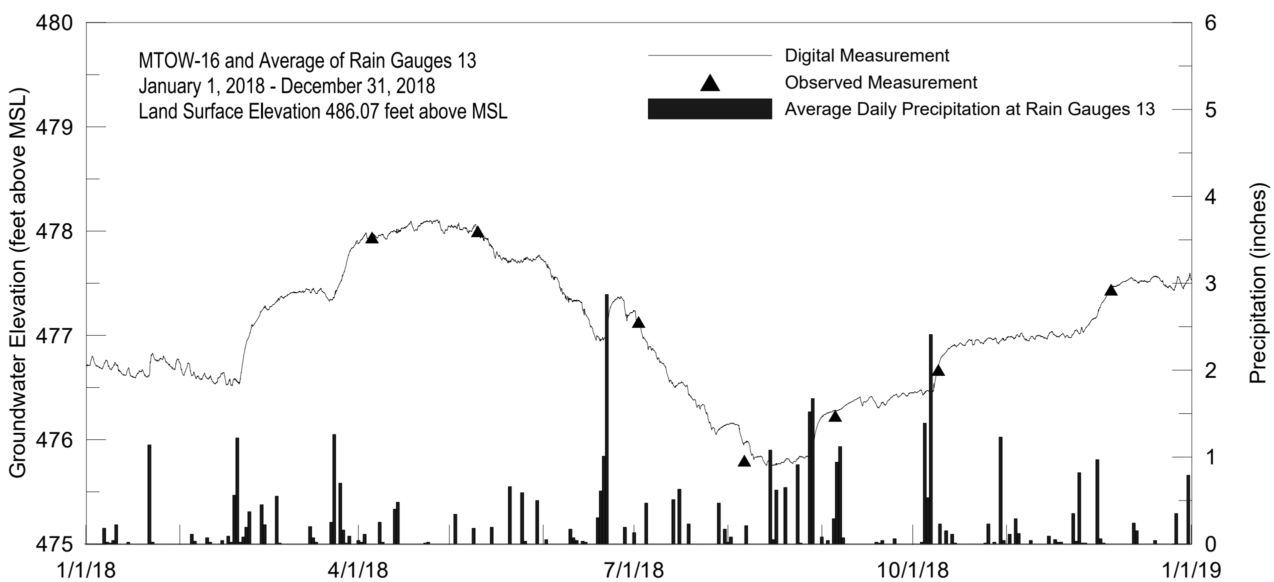

Figure A-16. Year 26 Groundwater Elevation and Precipitation for MTOW-16

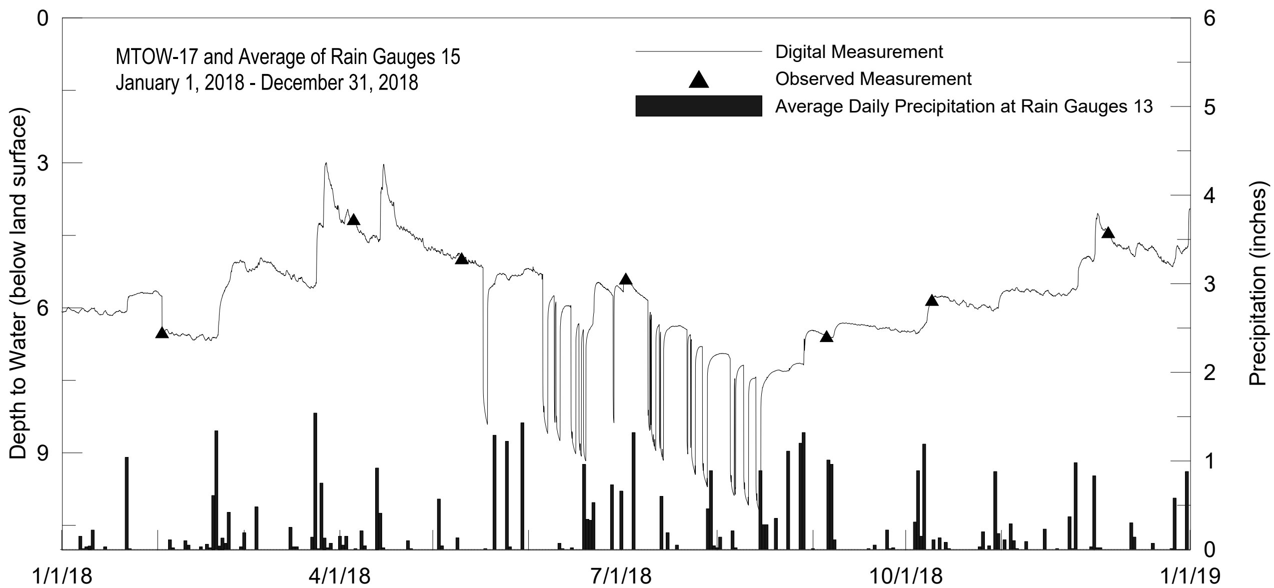

Figure A-17. Year 26 Groundwater Elevation and Precipitation for MTOW-17

Appendix B. Explanation of Box-Whisker Plots

Box-whisker plots are a visual display of the quartiles and upper and lower extremes of the data, in this case, monthly precipitation. Using the monthly precipitation totals for 26 Januarys from 1993-2018 for the Imperial Valley, the box-whisker plot in Figure B1 shows the maximum, median, minimum, and 1st and 3rd quartiles of each month. The May data are sorted from large to small to clearly display the median, 1st and 3rd quartiles in a list view. This presentation divides the data into quarters, not by value but by place order of the sorted set.

The **median** divides the set in half. It is the value where half the set values are above and half the numbers are below. (24 divided by 2 = 12). This is also called the **2nd quartile**.

- **1st quartile (Q1)** is the value where ¼ of the numbers are below. (24 x ¼ = 6 are below)
- **3rd quartile (Q3)** is the value where ¾ of the numbers are below. (24 x ¾ = 18 are below)
- In this report, the upper and lower caps present the minimum and maximum values.

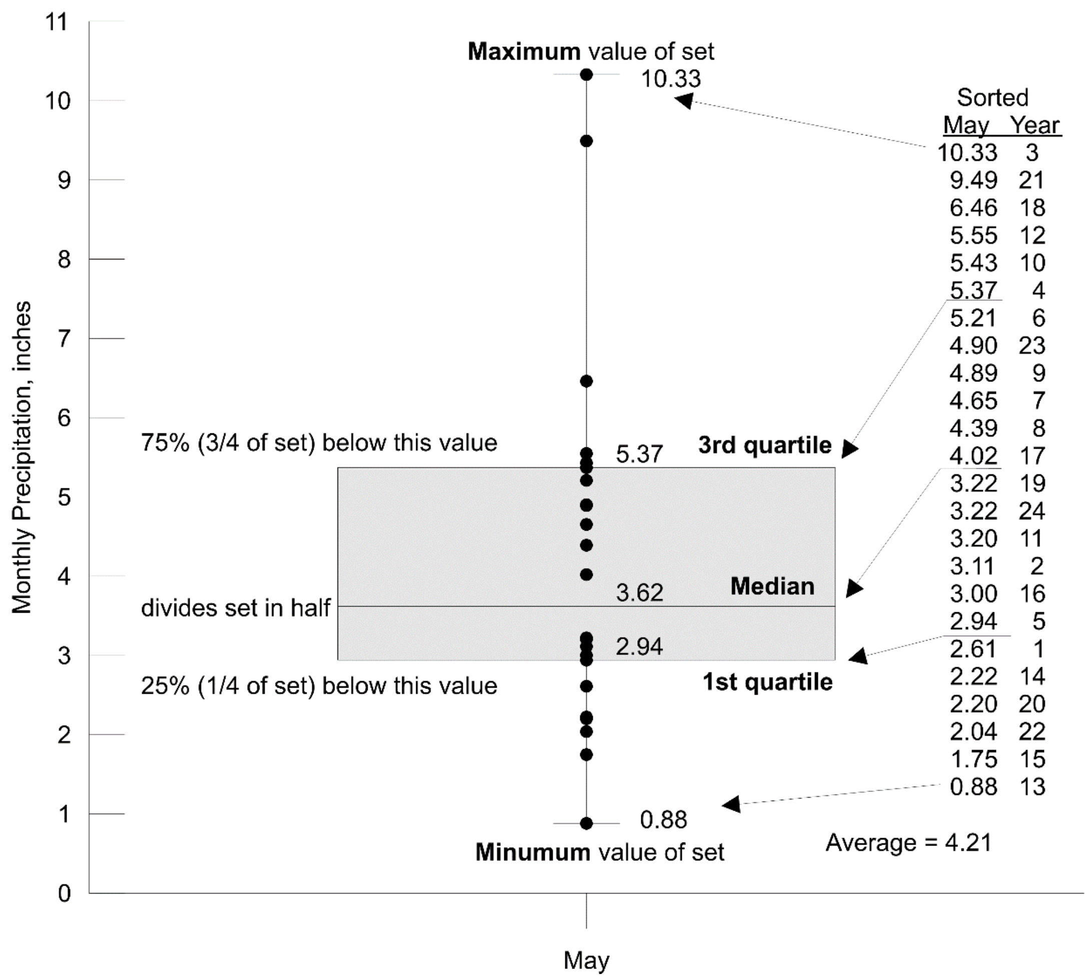

Figure B1. Features of an Example Box-Whisker Plot and Quartiles Using May Data for the Imperial Valley