

May 28, 2019

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 gages in Mason and Tazewell Counties since August 1992 and a network of groundwater observation wells since 1994. The purpose of the rain gage 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 25, project year 2017 (PY2017), which covers the time period from September 1, 2016 through December 31, 2017. For the precipitation data, PY2107 covers September 1, 2016 to August 31, 2017, for comparing past data.

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 were 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 gage network (Figure 1) was established in late August 1992 with approximately 5 miles between gages. 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.

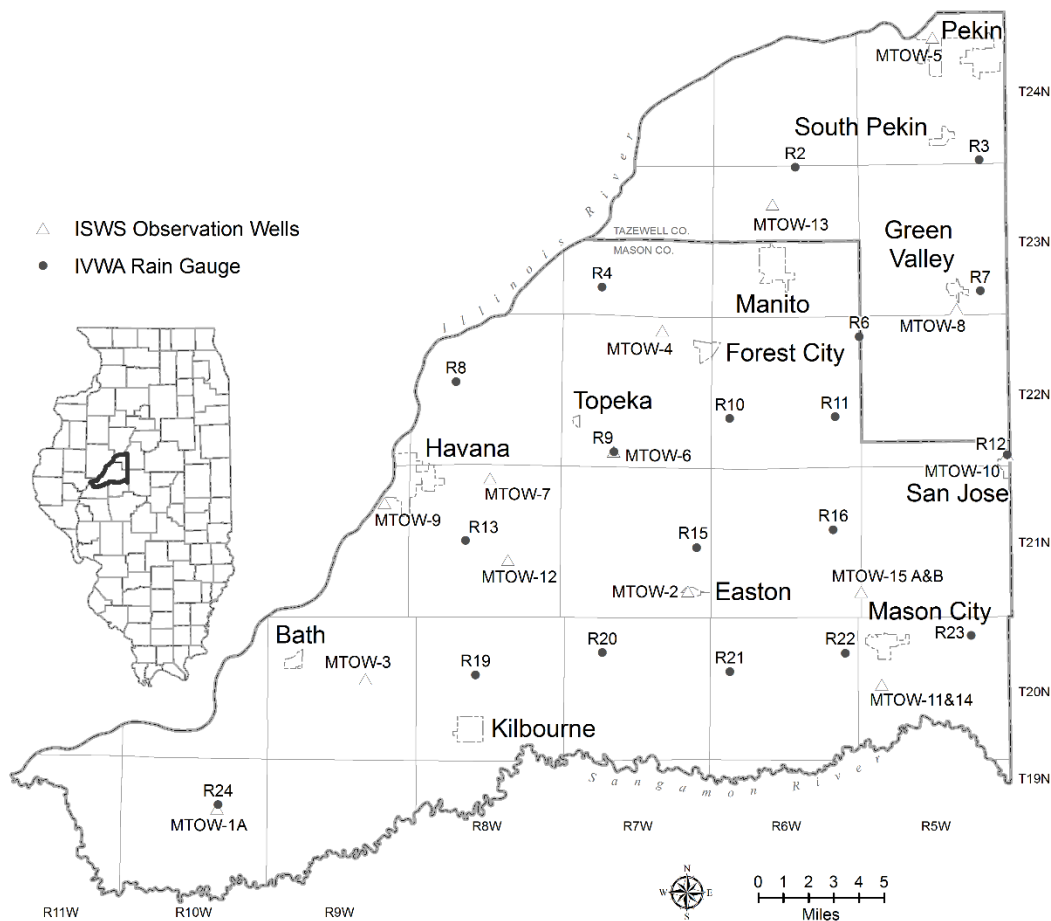


Figure 1. Configuration of the 16-Site Observation Well and 20-Site Rain Gage Networks.

On November 1, 2016, Illinois Climate Network installed a rain gage closer to the long-term ISWS observation well near Snicarte to replace gage #18 near Kilbourne. On November 29, 2016, data collection for site #18 moved from the Kilbourne site to the Snicarte location. The new location of gage #18 is shown in Figure 2. Gage #24 will need to be moved to restore the approximate five-mile spacing between sites.

Data reduction activities during Year 25 of network operation are similar to those performed during the previous 24 years. Each month, hourly rainfall amounts are totaled from 15-minute digital data and are placed into an array of values for the 20 gages. This data array is used to check for spatial and temporal consistency between gages, and to divide the data into storm periods. If the digital data are missing, the hourly amounts are estimated based on an interpolation of values from the nearest surrounding gages.

Groundwater levels for each well for the period of record (September 1, 2016 - December 31, 2017) 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 closely approximate groundwater levels in those regions of the study area. Each hydrograph also contains the daily precipitation for the nearest rain gage, or average of several nearby gages.

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 PY2017 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 24-year (1993-2016) network average precipitation record.

In this report, the annual precipitation total is summed and presented as project year (September–August) and as calendar year (January – December) for comparison with previous reports. Future annual precipitation totals will be summed and presented only by calendar year.

Precipitation Analysis

The Imperial Valley network precipitation was 31.88 inches in project year 2017 (PY2017) (September 2016 – August 2017) which was less than the previous 24-year annual average of 35.15 inches. Figures 2 and 3 show the distribution of total annual precipitation in project year 2017 (PY2017) and calendar year 2017 (CY2017). Table 1 provides the monthly and annual precipitation totals for each rain gage, September 2016 - December 2017. Gages #18 and #8 collected the most precipitation in PY2017, 36.51 and 36.21 inches, respectively.

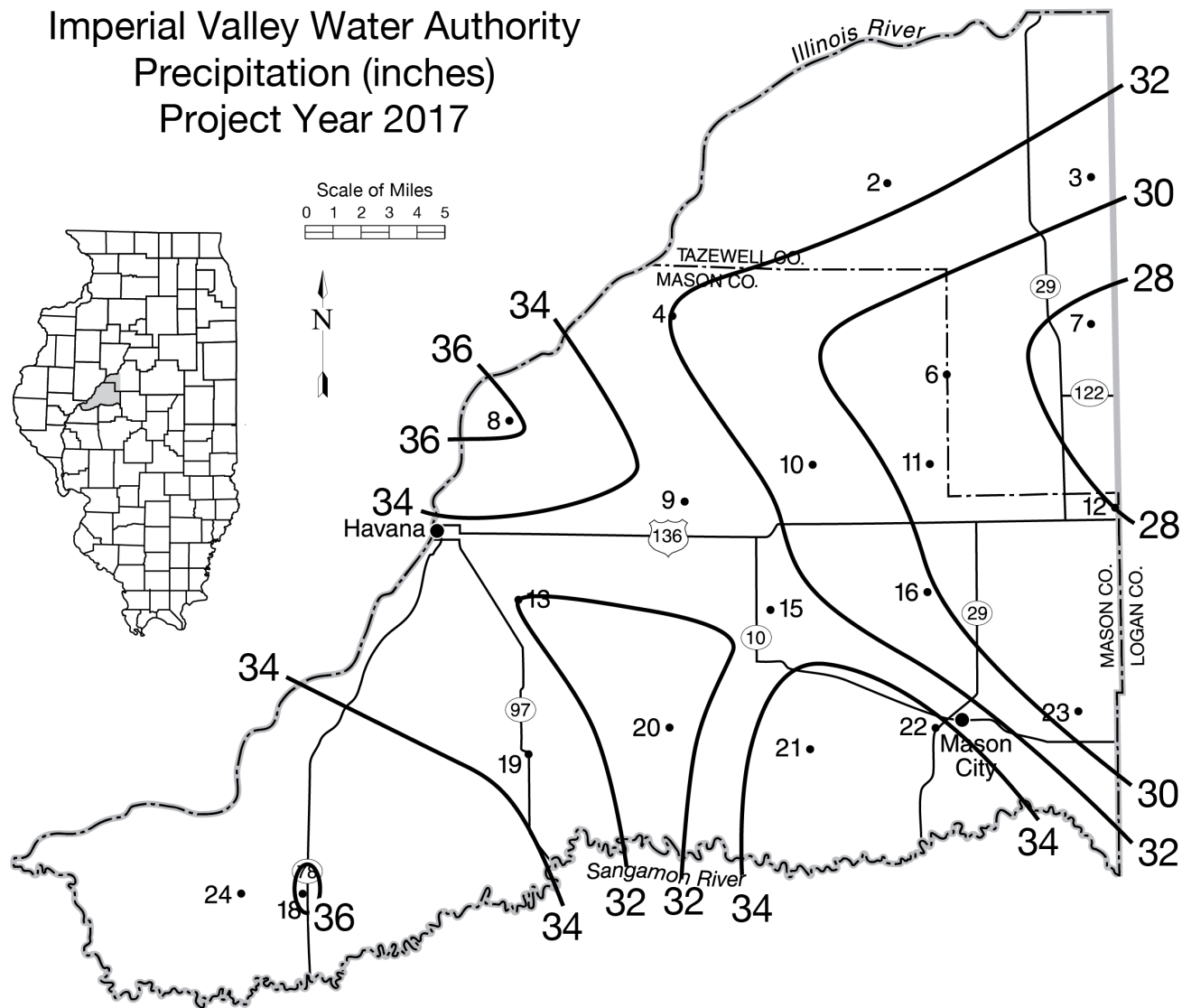
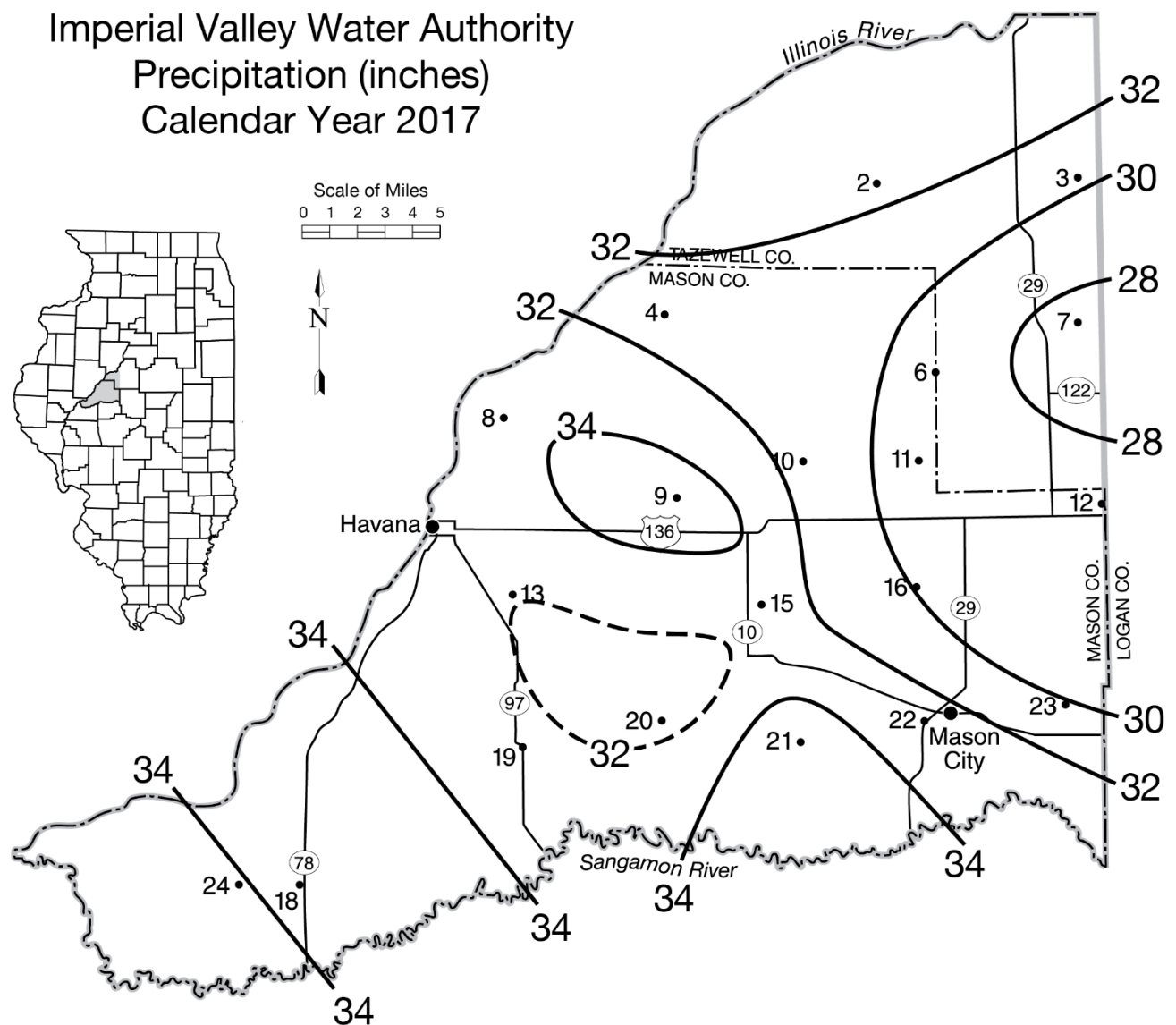


Figure 2. Total Precipitation (inches) for September 2016 - August 2017 (PY 2017).

The lowest precipitation occurred in the east-central region of the network, at gages #7 and #12. During PY2017, annual gage totals varied 8.97 inches, from 27.54 inches at site #7 to 36.51 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.

For the calendar period, January-December 2017 (CY2017), gages in the western and southern portion of the network recorded the greatest precipitation, at gages #18 and #21. The lowest precipitation occurred in the central region of the network, at gage #20. Annual (CY) gage totals varied 9.13 inches.

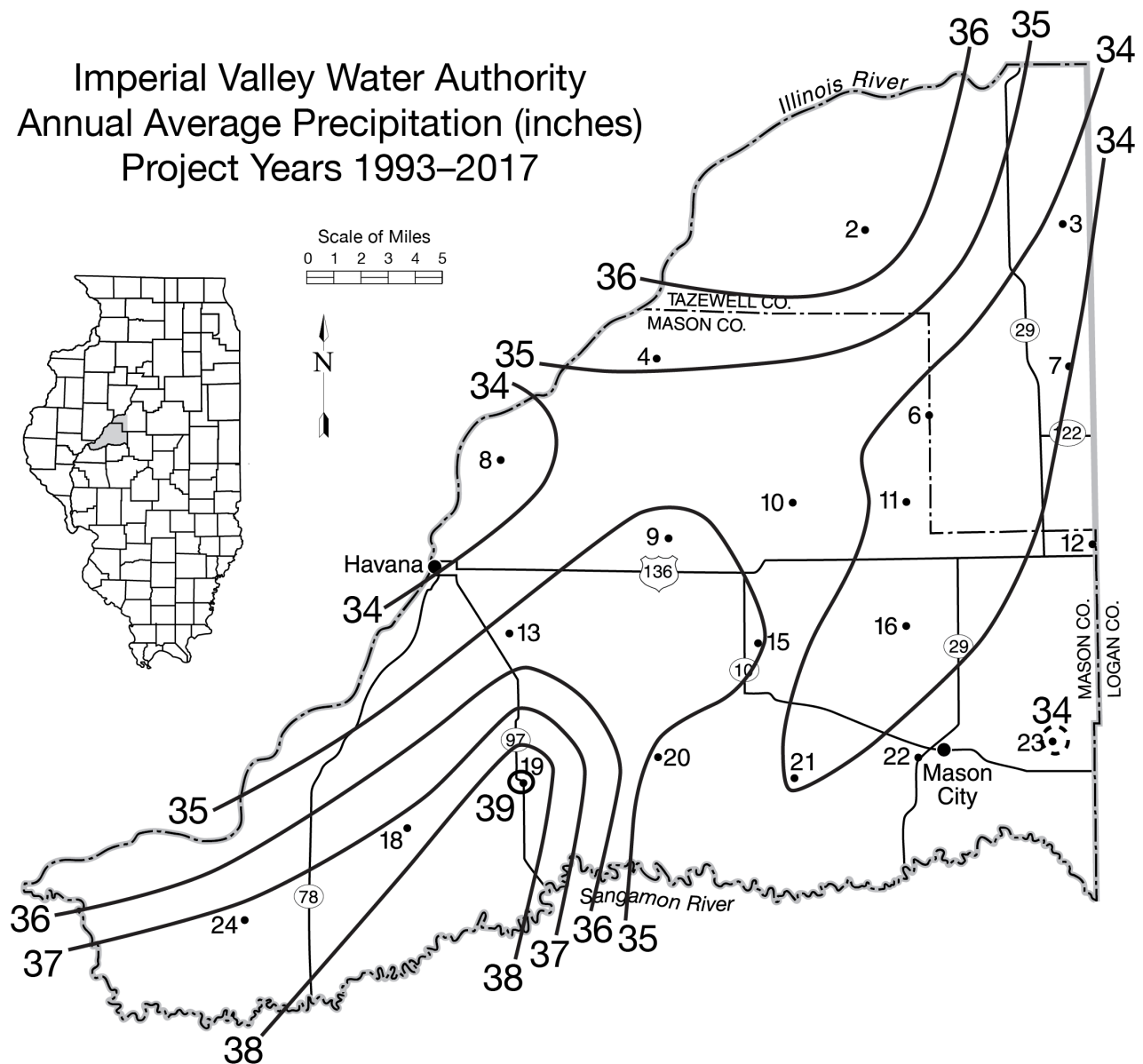


**Figure 3. Total Precipitation (inches) for January 2017 - December 2017.
Calendar Year 2017 (CY2017)**

**Table 1. Monthly Precipitation Amounts (inches), September 2016-December 2017
Project and Calendar Year Annual Totals**

<i>Station</i>	<i>Month 2016</i>				<i>Month 2017</i>								<i>PY 2017</i>	<i>Month 2017</i>				<i>CY 2017</i>
	<i>Sep</i>	<i>Oct</i>	<i>Nov</i>	<i>Dec</i>	<i>Jan</i>	<i>Feb</i>	<i>Mar</i>	<i>Apr</i>	<i>May</i>	<i>Jun</i>	<i>Jul</i>	<i>Aug</i>	<i>Total</i>	<i>Sep</i>	<i>Oct</i>	<i>Nov</i>	<i>Dec</i>	<i>Total</i>
2	3.67	2.55	1.71	1.01	1.30	0.95	3.59	6.87	3.48	1.14	4.14	2.40	32.81	1.52	3.37	2.64	0.96	32.36
3	2.48	1.61	2.07	1.03	0.97	0.73	3.51	6.12	2.75	1.17	6.05	2.09	30.58	1.64	3.32	2.48	0.58	31.41
4	4.06	2.74	2.02	0.94	1.13	0.75	2.63	6.45	4.12	0.62	4.49	1.99	31.94	1.34	4.86	2.47	0.59	31.44
6	3.50	1.43	1.95	0.99	0.99	1.08	2.79	6.23	2.54	0.53	4.23	1.93	28.19	1.57	3.37	2.63	0.51	28.40
7	3.37	1.98	1.71	1.19	0.75	0.76	3.01	5.29	2.45	0.41	4.54	2.07	27.53	0.95	3.27	2.66	0.50	26.66
8	4.29	2.80	1.55	1.07	0.90	0.87	2.97	5.34	3.91	1.74	7.98	2.79	36.21	1.19	3.23	2.24	0.53	33.69
9	2.84	1.38	1.81	1.10	1.40	0.81	2.96	6.57	3.84	0.81	6.92	3.04	33.48	1.04	4.13	2.82	0.66	35.00
10	2.69	1.29	1.90	1.03	0.92	0.50	3.24	6.31	3.28	0.51	6.63	2.96	31.26	0.77	3.29	2.94	0.54	31.89
11	2.31	1.33	1.94	1.21	0.87	0.77	3.03	6.76	2.68	0.91	4.70	2.92	29.43	1.03	2.98	2.79	0.48	29.92
12	2.77	1.06	1.97	1.05	1.13	0.58	3.03	5.46	2.86	0.52	3.95	3.88	28.26	0.53	3.42	2.94	0.54	28.84
13	3.32	1.50	2.01	1.06	1.13	1.05	2.33	6.03	3.89	0.56	5.38	3.70	31.96	0.99	3.46	2.82	0.68	32.02
15	3.63	0.95	1.76	1.20	0.97	1.05	3.52	6.81	3.20	0.90	5.72	2.95	32.66	0.78	3.77	2.82	0.45	32.94
16	3.69	1.25	1.51	1.00	0.81	0.82	2.93	5.36	3.19	0.67	5.39	3.43	30.05	0.88	3.33	2.43	0.60	29.84
18	4.85	1.25	1.63	0.94	0.92	0.95	3.43	7.65	5.68	1.04	5.37	2.80	36.51	0.44	4.79	2.31	0.41	35.79
19	4.48	0.70	1.50	1.14	0.87	1.19	3.25	7.43	4.26	0.39	5.65	2.77	33.63	0.97	3.53	2.35	0.50	33.16
20	4.78	0.56	1.33	1.16	0.82	0.76	3.01	6.16	3.06	0.34	5.34	3.16	30.48	0.69	3.99	2.45	0.49	30.27
21	4.35	1.07	2.26	1.09	0.81	1.26	2.97	7.83	3.29	0.55	6.46	4.02	35.96	0.70	3.37	2.82	0.53	34.61
22	3.89	1.26	2.54	1.21	0.85	1.04	2.72	6.21	2.82	0.77	6.52	4.52	34.35	1.30	3.75	2.44	0.43	33.37
23	3.14	1.08	1.79	1.09	0.93	0.93	2.94	5.49	2.27	0.38	5.51	3.64	29.19	1.24	3.53	2.57	0.65	30.08
24	4.97	1.00	1.29	1.19	0.78	1.09	2.66	6.77	5.47	0.85	5.02	2.08	33.17	0.70	4.67	2.38	0.65	33.12
Average	3.65	1.44	1.81	1.09	0.96	0.90	3.03	6.36	3.45	0.74	5.50	2.96	31.88	1.01	3.67	2.60	0.56	31.74

The distribution of the 25-year annual gage averages across the network is shown in Figure 4. The 25-year annual average for the network is 33.67 inches of precipitation. Gages #13, #18, #19, and #24, in the southwestern third of the network and gage #2 on the northwestern edge of the network received more than average precipitation over the last 25 years. The remaining gages (#3, #6, #7, #9, #10, #11, #12, #15, #16, #20, #21, #22, and #23), those located in the southeastern third of the network, received less than the 25-yr average precipitation. The southeastern region has a 25-yr average of 34.36 inches, compared to the northwestern region with 36.28 inches of precipitation. A pattern of contours trending parallel along the river is apparent. The 25-year average annual precipitation was highest along a line from gages #24 to #19 to #9 to #2, roughly parallel to the Illinois River.



**Figure 4. Network Average Annual Precipitation (inches) for
September 1992 – August 2017**

Figure 5 shows a bar graph of the monthly network averages from Sept. 2016-Dec. 2017, with the 24-yr historical monthly network averages and the 1981-2010 (30 yrs.) Havana, IL monthly averages. During PY2017, the heaviest precipitation occurred during April and July. The precipitation totals for these two months account for 37% of the total project year annual rainfall. In April 2017, the network average precipitation was over 185% of the 24-year monthly network average. September 2016, April 2017, and July 2017 each received over an inch more precipitation than the historical average, while six other months received significantly less precipitation than the historical average. Combined, the months of December 2016, January and February 2017 created a 2.66 inch precipitation deficit compared to the 24-year average, attaining 53%, 51%, and 54% of the historical average, respectively. June 2017 precipitation was extremely low, at 0.74 inches, only 17% of the 24-yr historical average of 4.41 inches.

During the last 4 months of 2017, September and December had well-below average precipitation, with October having slightly-above average precipitation. These last four months of 2017 combined had a 2.47-inch deficit compared with the 24-yr historical network average.

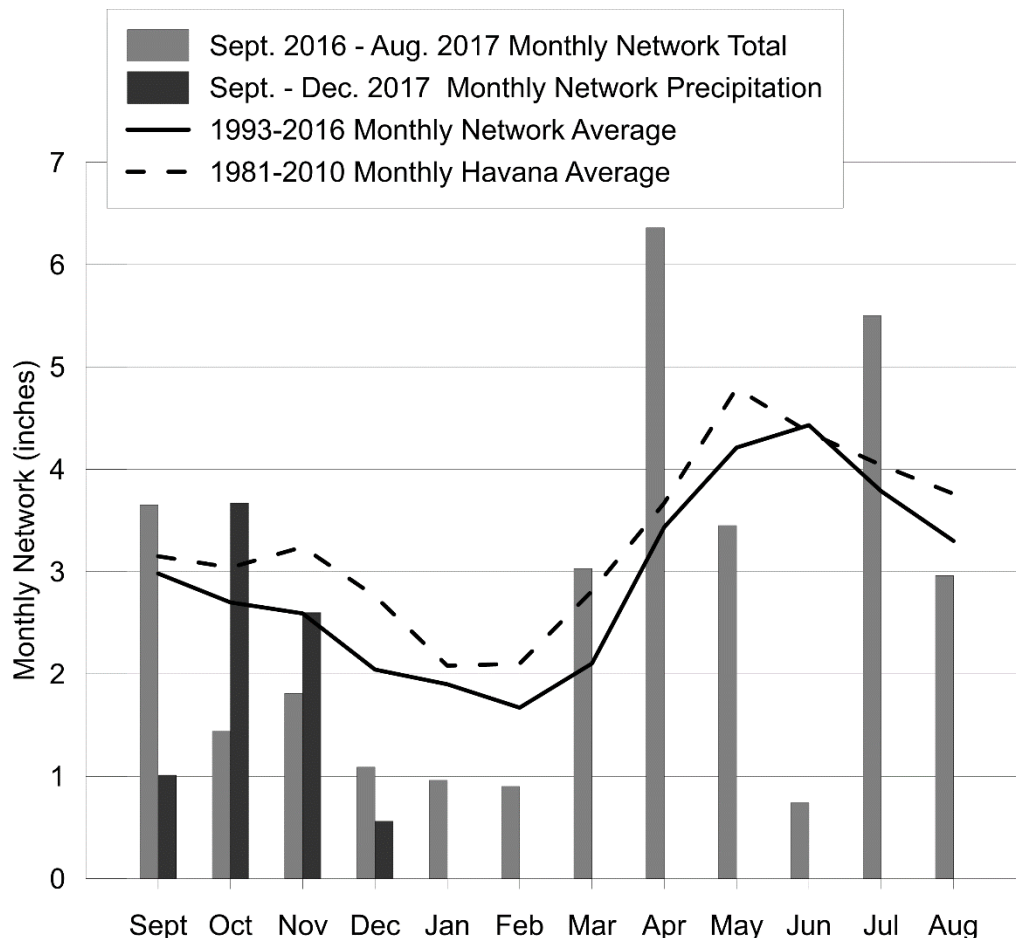


Figure 5. Monthly Comparison with 24-Year IVWA Network Average and 1981-2010 (30 Year Average) at Havana, IL Gage.

The following is a description of how to interpret box-whisker plots, a method of displaying, comparing, and summarizing data. Box-whisker plots are a visual display of the quartiles and upper and lower extremes of the data, in this case, monthly precipitation. Figure 6 is an example box-whisker plot that shows the maximum, median, minimum, and 1st and 3rd quartiles of monthly precipitation totals from 1992-2016 for the month of May, spatially-averaged over all gages in the Imperial Valley. 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 $\frac{1}{4}$ of the numbers are below. ($24 \times \frac{1}{4} = 6$ are below)
- **3rd quartile (Q3)** is the value where $\frac{3}{4}$ of the numbers are below. ($24 \times \frac{3}{4} = 18$ are below)
- In this report, the upper and lower caps present the minimum and maximum values.

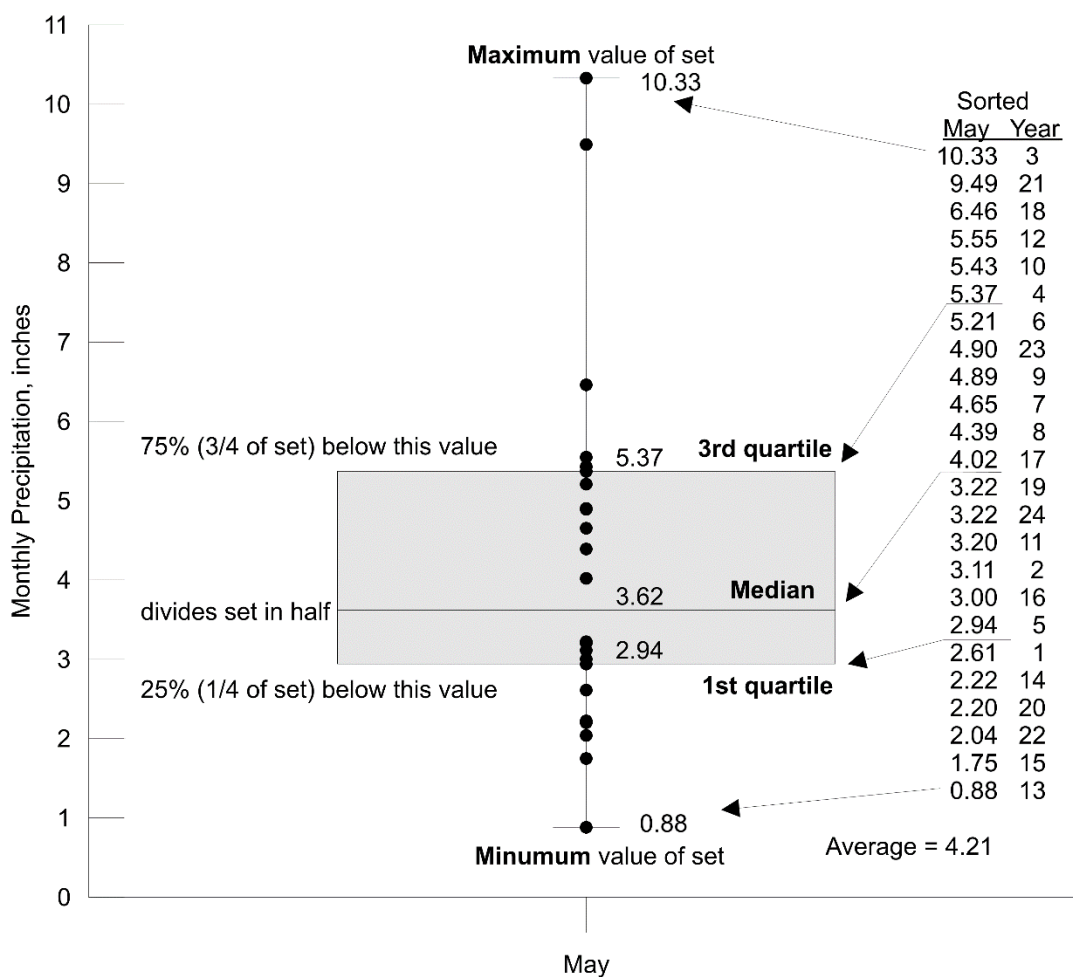


Figure 6. Features of an Example Box-Whisker Plot and Quartiles Using May Data for the Imperial Valley (1992-2016)

This method of displaying the data provides a way of comparing and summarizing the monthly precipitation data. The gray box (range of values between the 1st and 3rd quartiles) represents the middle 50 percent of occurrences, i.e. for this example, 12 of 24 project years, rainfall during the month of May was between 2.94 and 5.37 inches.

Monthly network variability including minimum, maximum, medians and quartiles of the 25-yr monthly precipitation data are shown in Figure 7. Monthly precipitation during the 2017 growing season was a story of extremes. The monthly network precipitation for April 2017 was the highest and for June 2017 the lowest in the last 25 years.

From the beginning of the project year, September 2017 had monthly network precipitation above the 3rd quartile (>75% of occurrences). Then from October 2016-February 2017, monthly precipitation was near or below the 1st quartile for 5 consecutive months. March and April were wet with well-above average precipitation (4th quartile). May had near normal precipitation, then June 2017 received the least amount of rain for any June in the last 25 years. In July, precipitation was well-above normal (4th quartile).

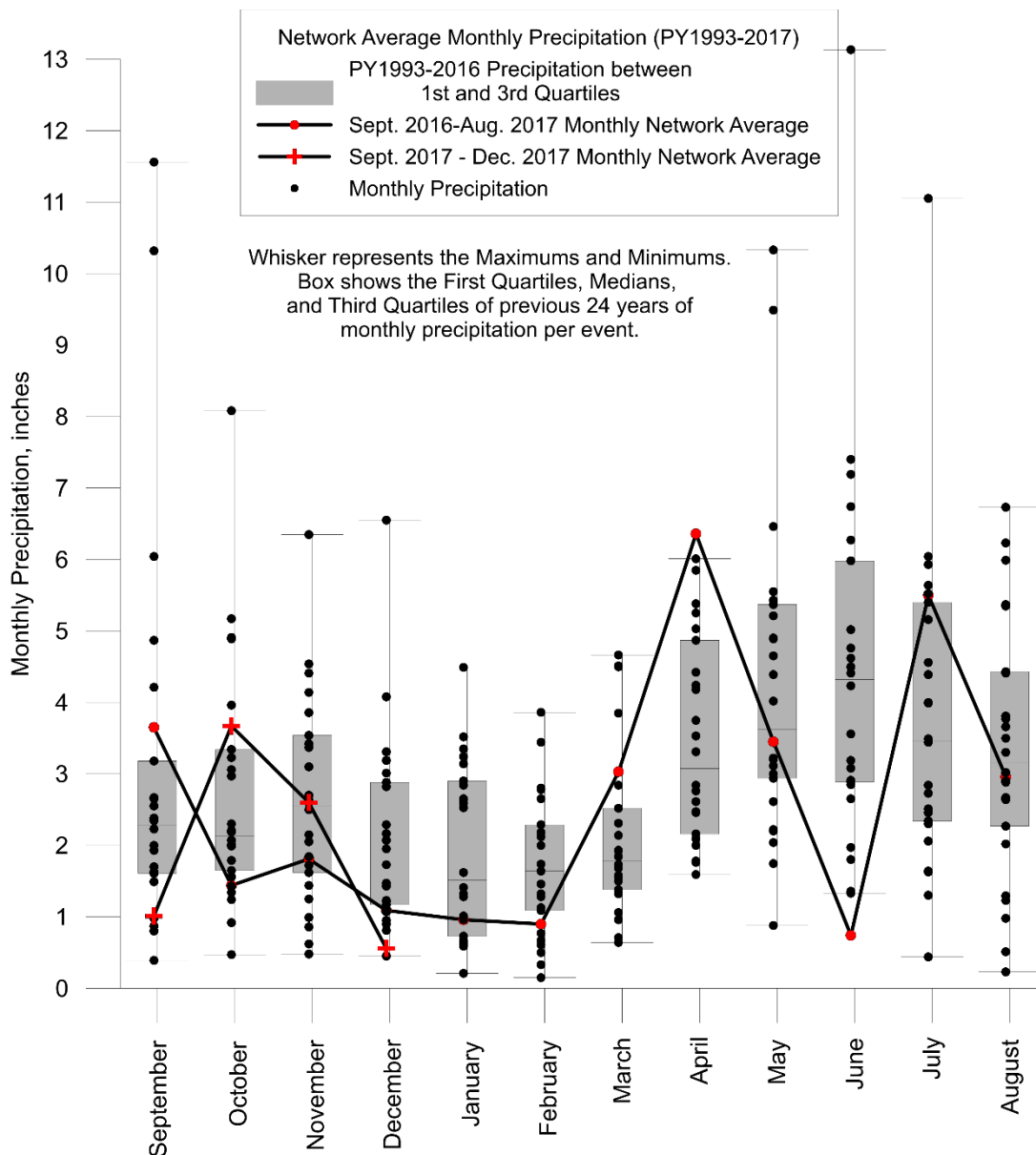


Figure 7. 24-year Monthly Average Precipitation Distribution with

PY2017 Monthly Network Averages

August 2017 precipitation was slightly lower than the 24-yr median. September and December 2017 were dry, well-below average (Q1), while October and November were well-above average and average, respectively.

Figure 8 presents the monthly precipitation in 8-year increments to compare the current year's average monthly precipitation with other years and periods. During these last 16 months, September 2016 – December 2017, Imperial Valley had more variable monthly precipitation than usual. Six of the last 16 months had very low rainfall, (1st quartile range or < 25% occurrence) compared with the last 8 year period (2001-2008). June 2017 had the least amount of rain for that month on record. Decembers 2016 and 2017 precipitation totals were low for this 8-year period but closer to the December median for the period PYs 1993-2000. March and April 2017 monthly precipitation totals were in the 4th quartile (>75% occurrence) and April also had the most rain for that month since data collection began in 1992. Months with the largest interquartile range (longest box) have had the greatest variability of monthly precipitation. The variability of precipitation during April and August from 2009-2017 is greater than in the previous 16-yr period (1992-2008).

Monthly network precipitation maps for September 2016 through December 2017 are shown in Figures 9-16.

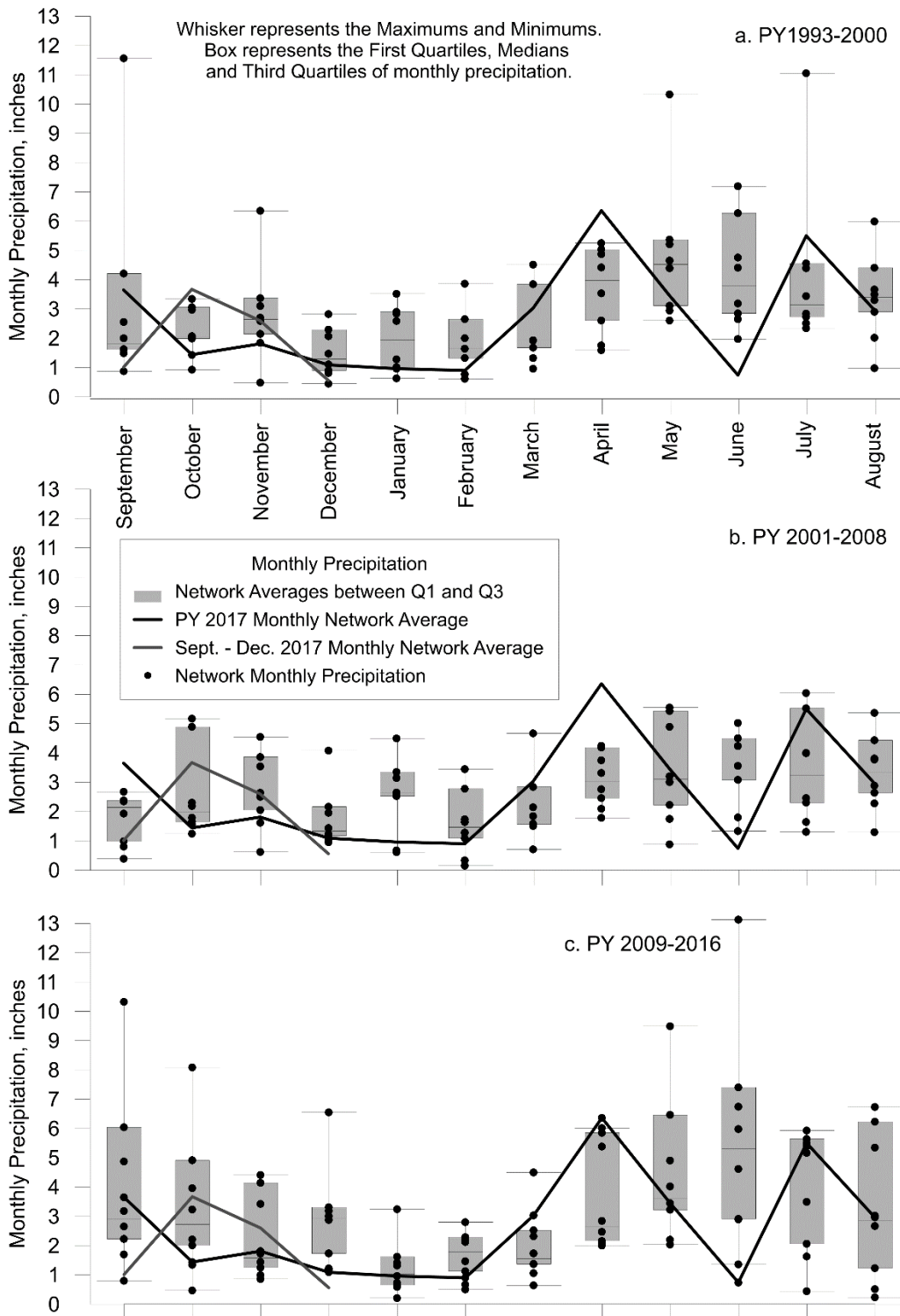


Figure 8. Monthly Box-Whisker Plots of 8 Year Time Spans.
a. PY 1993-2000, b. PY 2001-2008 and c. PY 2009-2017

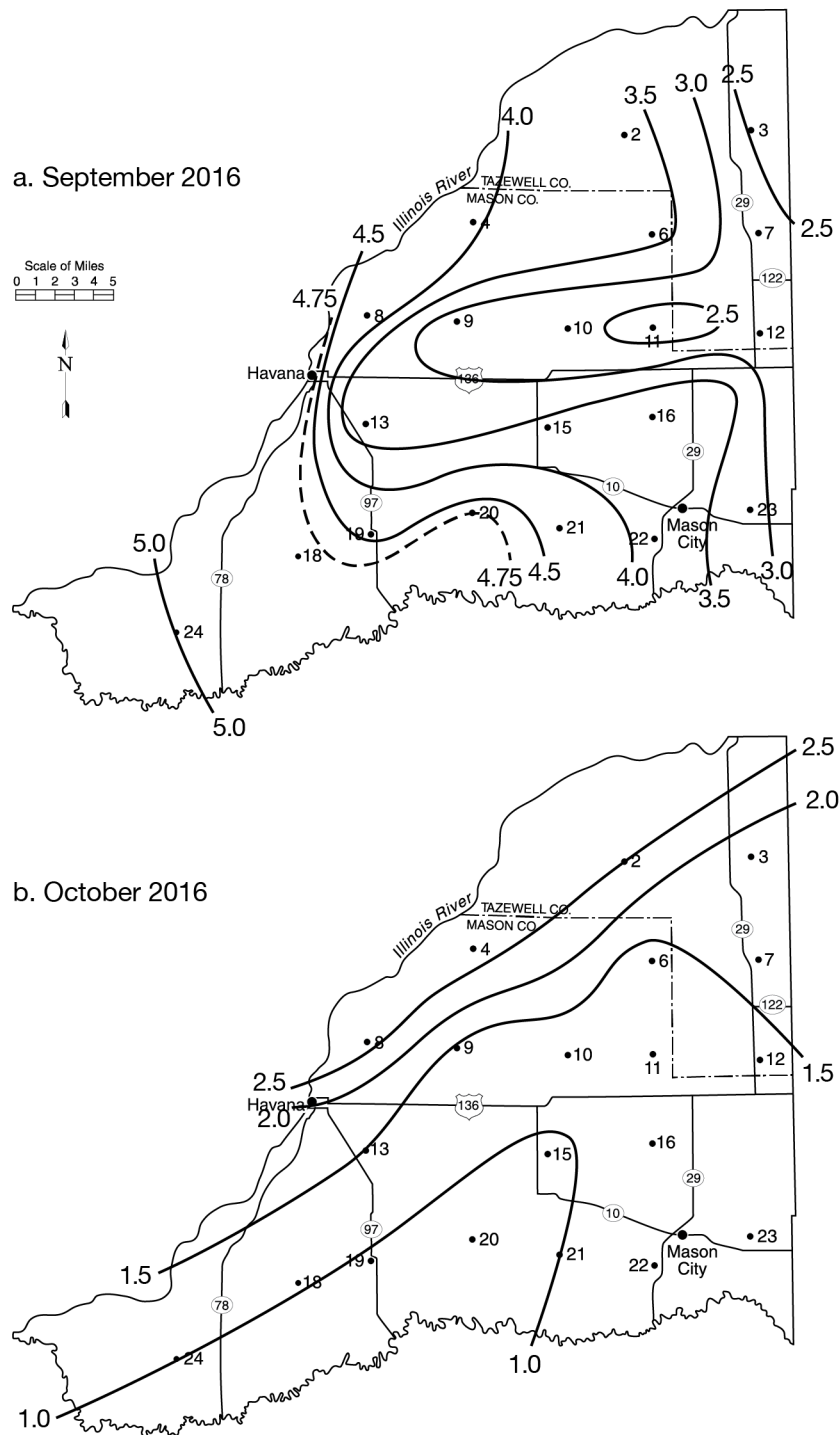


Figure 9. Precipitation (inches) for September 2016 and October 2016

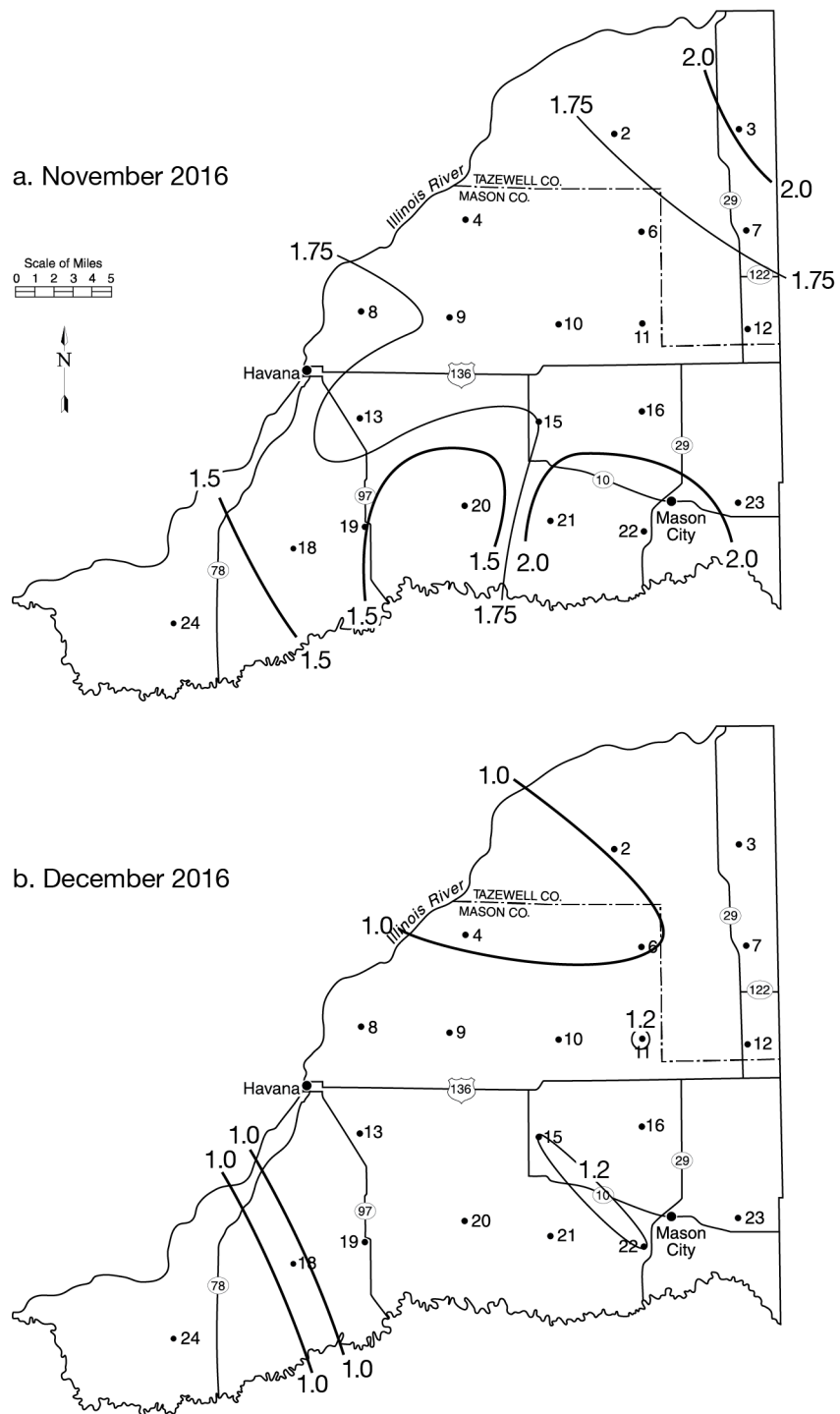


Figure 10. Precipitation (inches) for November 2016 and December 2016

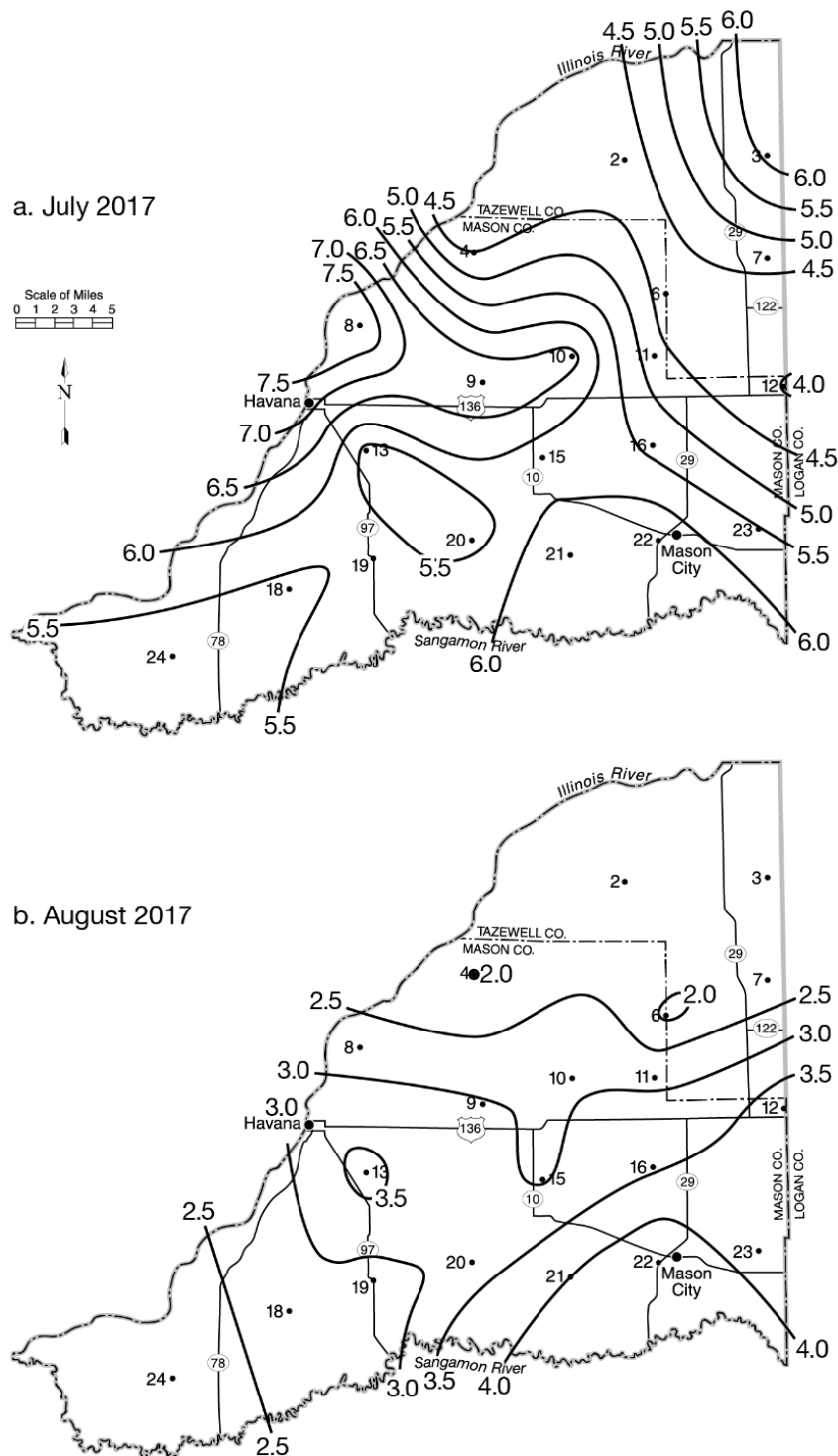


Figure 14. Precipitation (inches) for July 2017 and August 2017

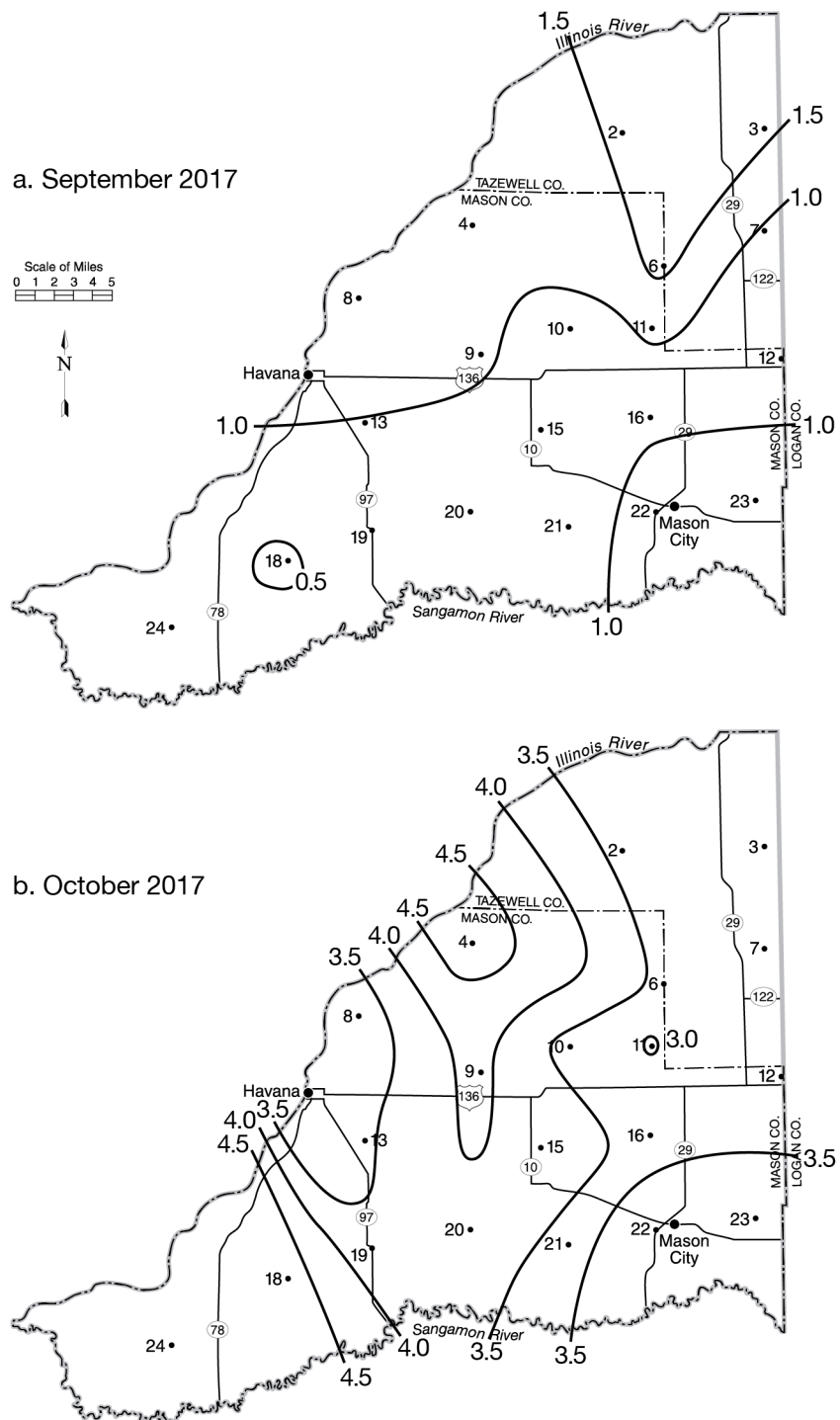


Figure 15. Precipitation (inches) for September 2017 and October 2017

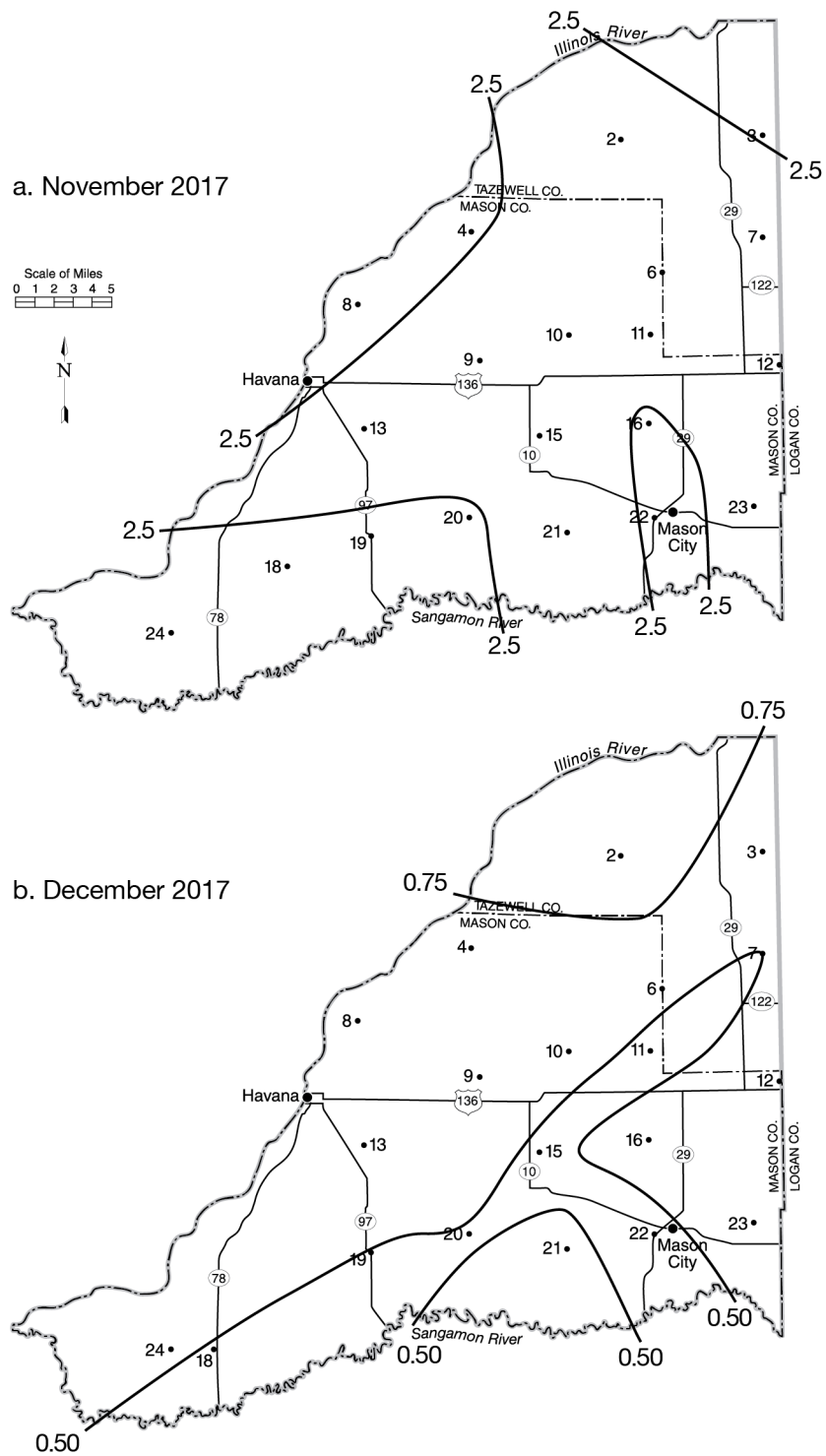


Figure 16. Precipitation (inches) for November 2017 and December 2017

The mean monthly, seasonal, and annual number of network storms (precipitation events) were determined for September 2016 through December 2017 and the 25-yr averages of each (Table 2). A network storm period is defined as a precipitation event separated from preceding and succeeding events at all network stations by at least three hours. The historic average for inches per event over the last 25 years is 0.31 inches per event. Project year 2017 had 0.26 inches per event.

Table 2. Comparison of Total Precipitation (inches), Number of Precipitation Events, and Average Precipitation per Event for Each Month and Season, 1993-2016 and 2016-2017

<i>Period</i>	<i>1993-(2016* or 2017) 25-yr average</i>			<i>September 2016 - December 2017</i>		
	<i>Precipitation</i>	<i>Events</i>	<i>Inches/event</i>	<i>Precipitation</i>	<i>Events</i>	<i>Inches/event</i>
September 2016	3.01*	7.4*	0.40*	3.65	10	0.37
October 2016	2.65*	8.5*	0.32*	1.44	6	0.24
November 2016	2.56*	8.4*	0.33*	1.81	6	0.30
December 2016	2.00*	9.5*	0.24*	1.09	10	0.11
January 2017	1.86	9.4	0.23	0.96	12	0.08
February 2017	1.64	8.2	0.22	0.90	11	0.08
March 2017	2.14	8.5	0.25	3.03	8	0.38
April 2017	3.55	11.2	0.33	6.36	11	0.58
May 2017	4.18	13.1	0.32	3.45	12	0.29
June 2017	4.28	12.0	0.35	0.74	12	0.06
July 2017	3.85	10.7	0.38	5.50	12	0.46
August 2017	3.29	11.6	0.29	2.96	14	0.21
September 2017	2.93	7.3	0.40	1.01	3	0.34
October 2017	2.69	8.6	0.32	3.67	10	0.37
November 2017	2.56	8.6	0.34	2.60	8	0.33
December 2017	1.95	9.5	0.24	0.56	10	0.06
Fall 2016	7.33*	26.5*	0.28*	4.34	22	0.20
Winter 2017	5.64	26.0	0.23	4.89	31	0.16
Spring 2017	12.02	36.4	0.33	10.55	35	0.30
Summer 2017	10.07	29.5	0.34	9.47	29	0.33
Fall 2017	7.20	26.5	0.27	6.83	28	0.24
Project Annual	35.15	118.5	0.31	31.88	124	0.26
Calendar Annual	35.05	118.8	0.31	31.74	123	0.27

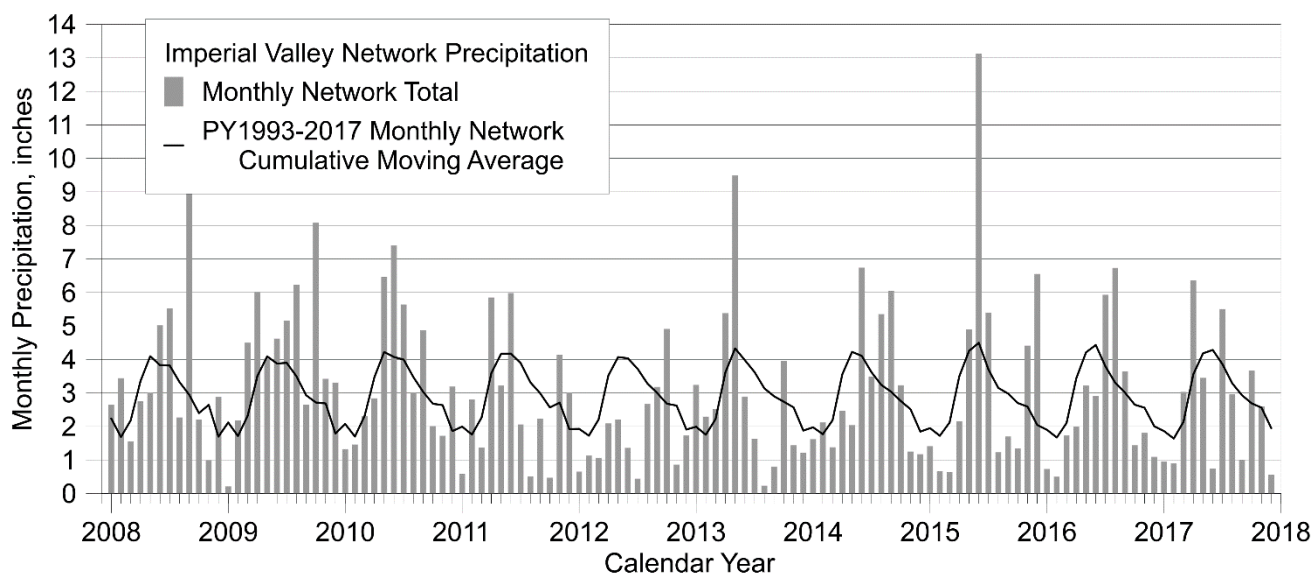
Note: Fall (October – December), Winter (January – March), Spring (April – June), and Summer (July – August)

The Imperial Valley Water Authority precipitation network has a 25-year average of 118.8 storm events per year. During PY2017 (year 25), there were 124 precipitation events, and for September-December 2017, there were 31 events. Seasonally, the 2017 autumn and spring had fewer events than 25-yr average, whereas winter and summer had more. August 2017 had the most

precipitation events in a month (14 events) during PY2017, 2.4 events more than the 25-yr average. September 2017 had only 3 events, less than half of the 25-yr average.

The winter of 2017 had many more events than the 25-yr average yet only 87% of the 25-yr average precipitation. Precipitation in fall 2016 and spring of 2017 were also below average, 59% and 87% of the 25-yr average. Annually, the number of events was 4% more than the historical average (~ 4 events) yet received 90% of the 25-yr average precipitation.

Figure 17 compares the network average monthly precipitation for January 2008 through December 2017 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 September 2016 is the average precipitation of Septembers 1992-2015. The change in the shape of the cumulative moving average shows how each month's precipitation affects the monthly precipitation average over time.



**Figure 17. Network Average Monthly Precipitation (inches),
January 2008 - December 2017**

For the period 2011 through 2017, the total precipitation is about 11.26 inches below the monthly cumulative moving average, indicating a period of drier weather than the previous 18-year average. PY2017 network average was 3.11 inches drier (8.9%) than the 25-year network average.

Figure 18 compares the 25-year seasonal average and variations with the PY 2017 seasonal totals. Autumn was slightly drier than the 25-year average autumn, winter was the 3rd driest winter, spring was the 5th wettest spring, and summer was slightly below the 25 year average. Winter 2017 received much less rain than the 25-yr seasonal average, 2.95 inches or only 87% average. All seasons received slightly less rain than the long-term averages.

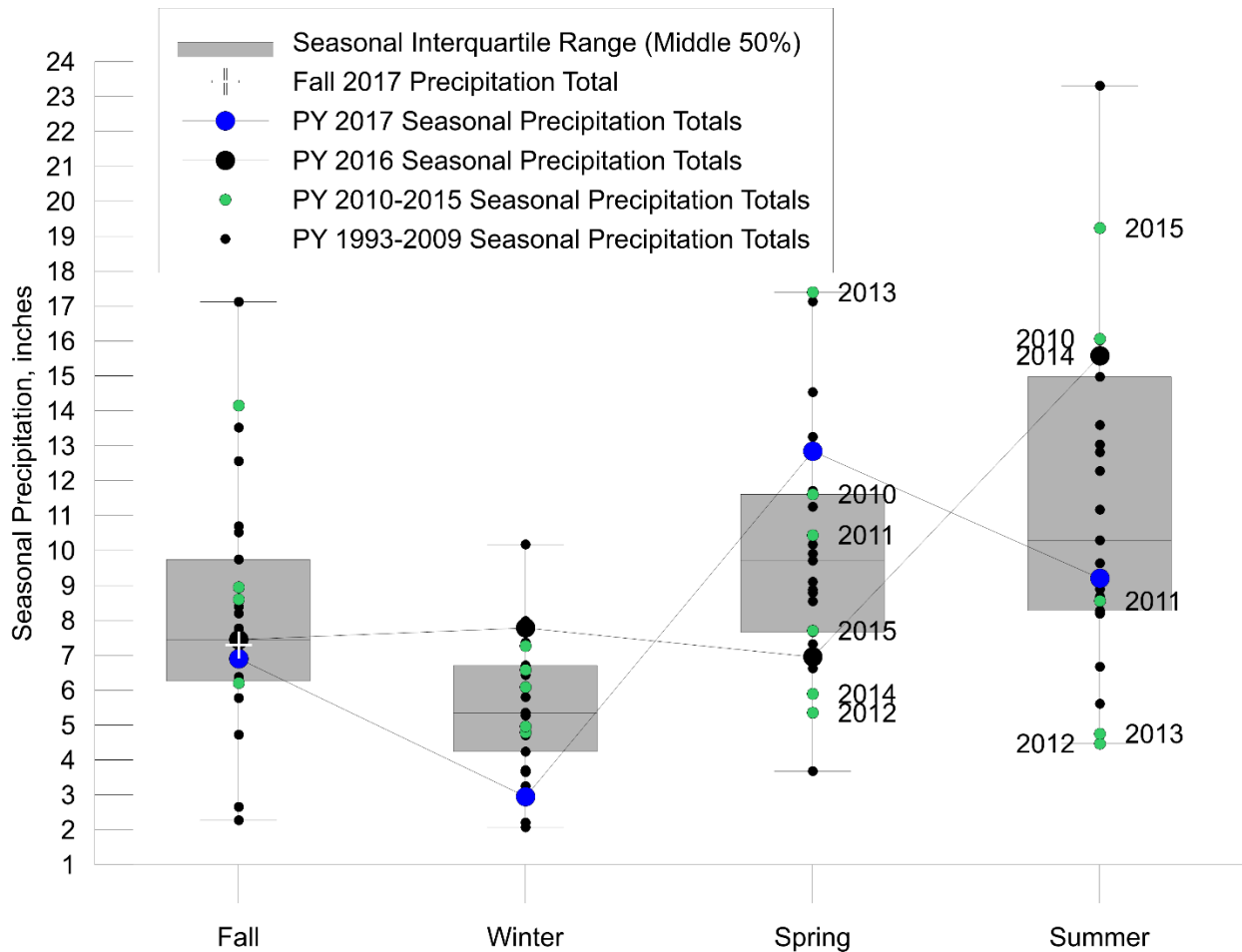


Figure 18. Seasonal Network Average Precipitation with Seasonal Totals for each Project Year. Box Plots Show the Interquartile Range (middle 50% of values), median (horizontal line within the box), Minimum, and Maximum Values.

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 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. Data from the new observation wells continue to 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 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 occur 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 19 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 20. 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 instance 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.

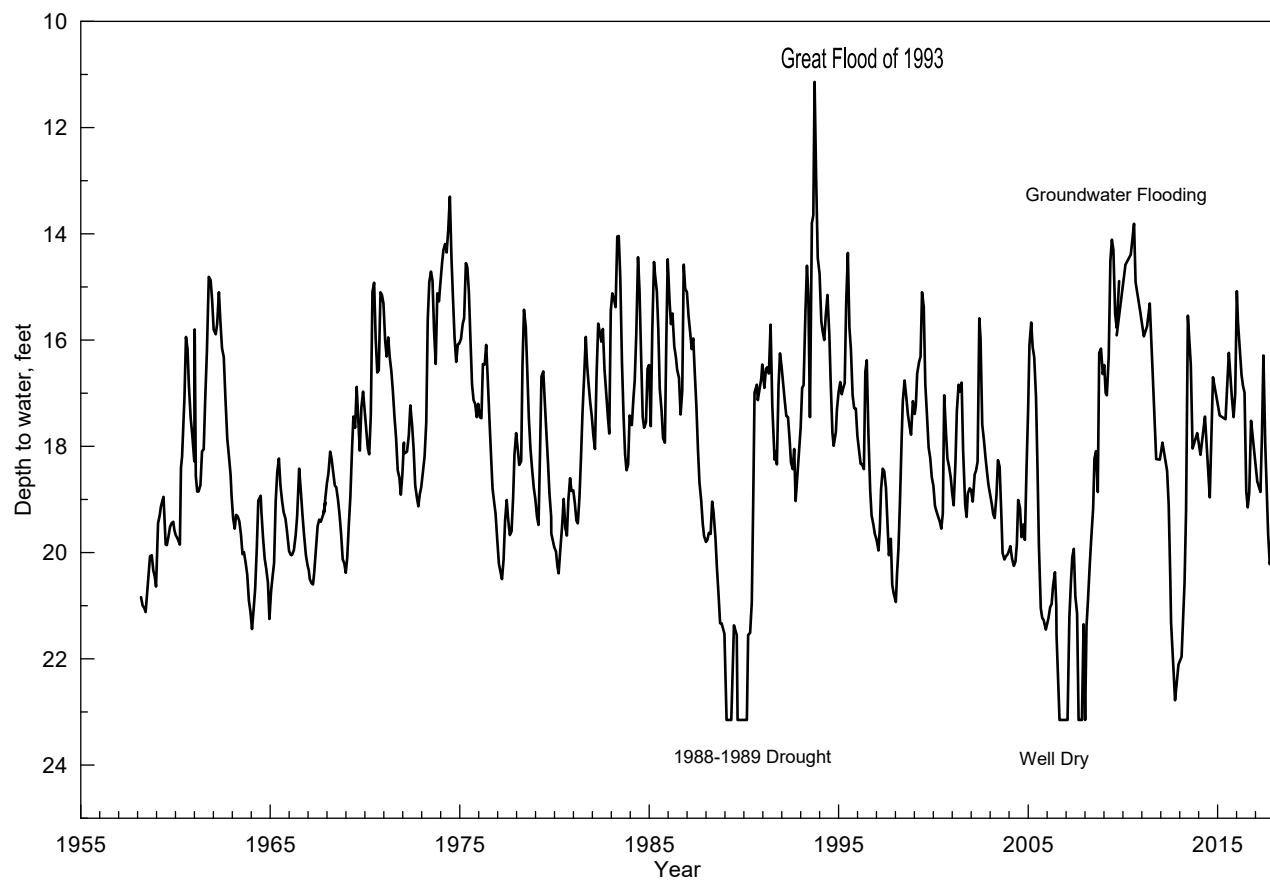


Figure 19. Groundwater Levels at the Snicarte Well, 1958-2017.

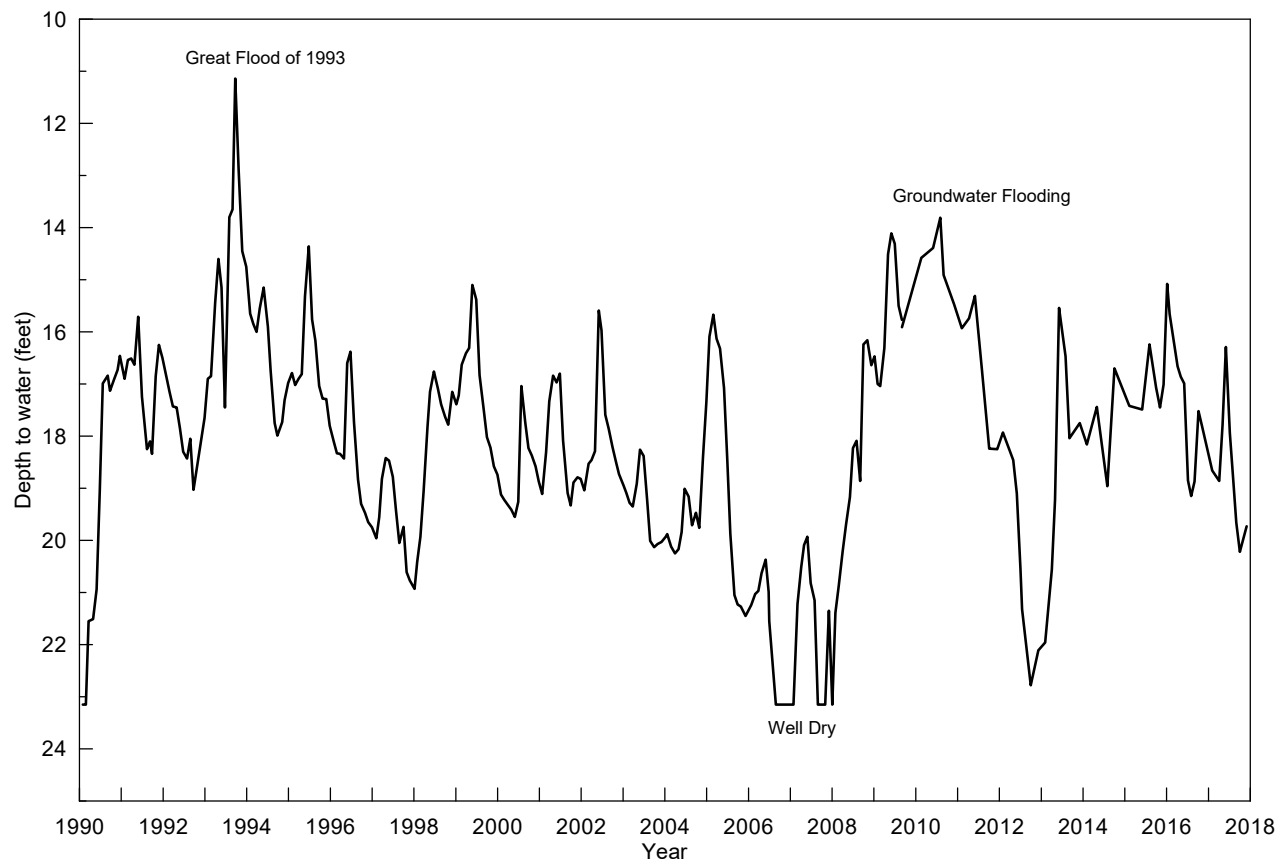


Figure 20. Groundwater Levels at the Snicarte Well, 1990-2017.

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 20 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 21, 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 PY2017, from September 1, 2016 to December 31, 2017, and contain all groundwater elevation or depth to water from land surface data and daily precipitation totals for nearby rain gages.

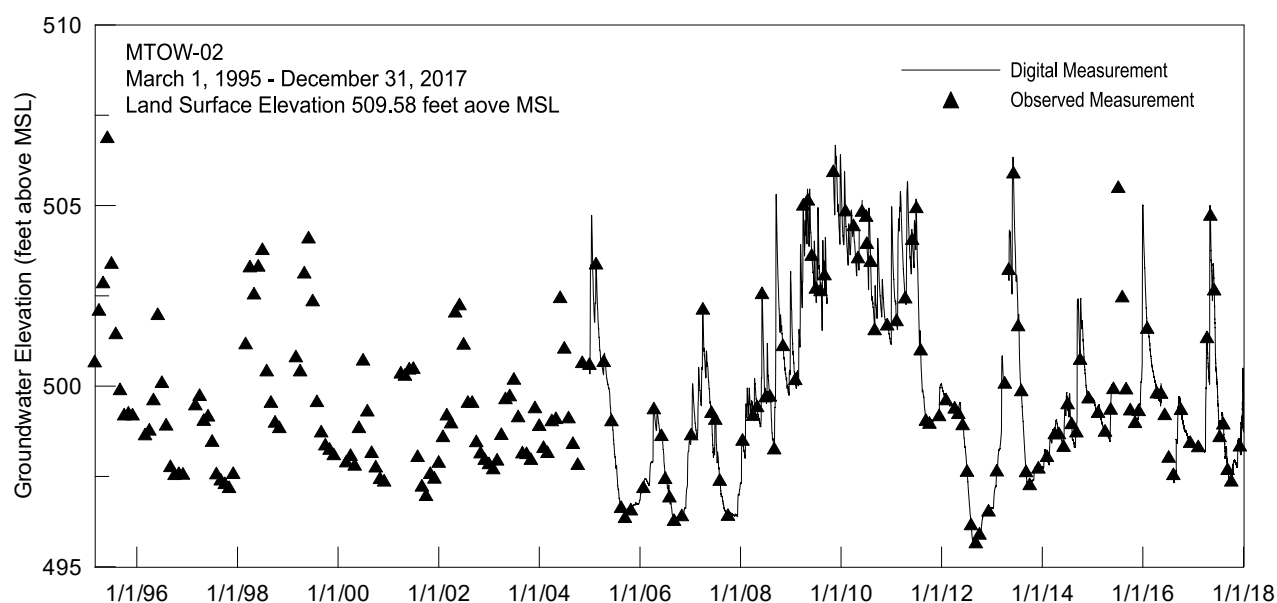


Figure 21. Groundwater Elevations at the Easton Well, MTOW-02, September 1, 1995-December 31, 2017.

Figure 21 shows the entire period of record for MTOW-02, located within the village limits of Easton, IL. The lowest water levels on record occur on 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.

In Figures 22 and 23, 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 event in late April 2016 (around 4.5 inches over 5 days) and the 3-4 weeks following that event.

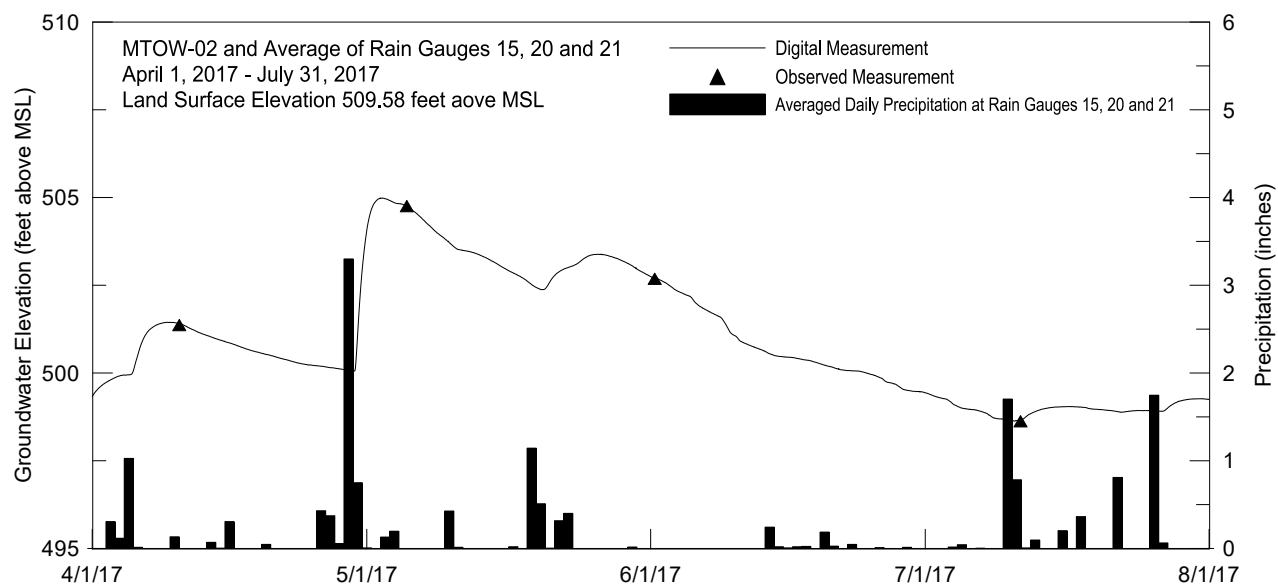


Figure 22. Groundwater Elevations at the Easton Well, MTOW-02, April 1, 2017 - July 31, 2017

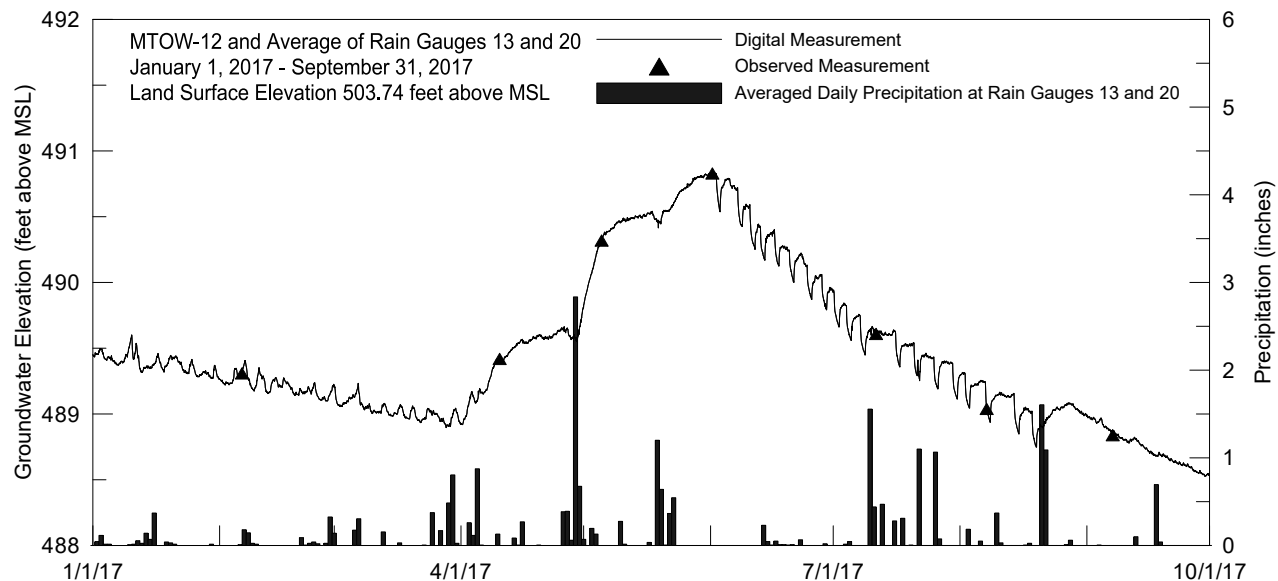


Figure 23. Groundwater Elevations and Precipitation at the Hahn Farm Well, MTOW-12, January 1, 2017-Septemebr 31, 2017

Figure 24 and 25 are hydrographs showing groundwater elevation and precipitation data during the summer of 2017. Figure 24 is the hydrograph of MTOW-11, which is the shallow observation well located south of Mason City, IL. Figure 25 shows the hydrograph for MTOW-14, the deep well located next to MTOW-11. The hydrographs start June 1, 2017 and go to the end of

the project year that ended December 31, 2017 and illustrate the effects of abundant precipitation and irrigation pumpage on groundwater levels in the two wells. Both wells show very little recharge due to abundant precipitation. MTOW-14 (Deep Well), does however show drawdown due to irrigation pumping and MTOW-11 (Shallow Well) shows none.

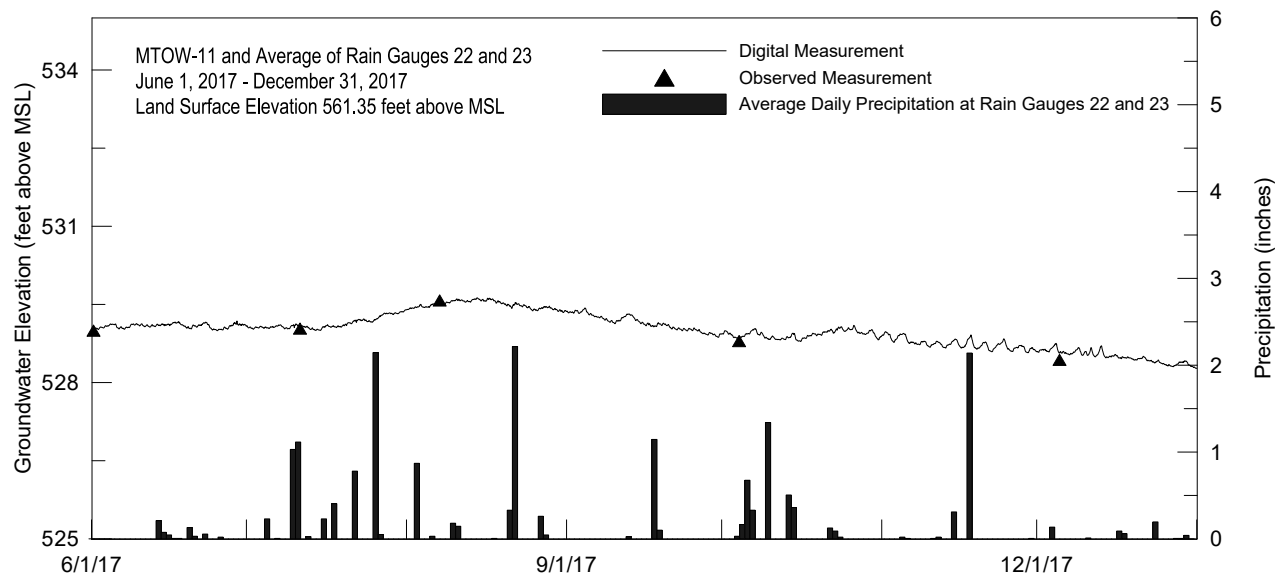


Figure 24. Groundwater Elevations and Precipitation at the Mason city Shallow Well, MTOW-11, June 1, 2017-December 31, 2017.

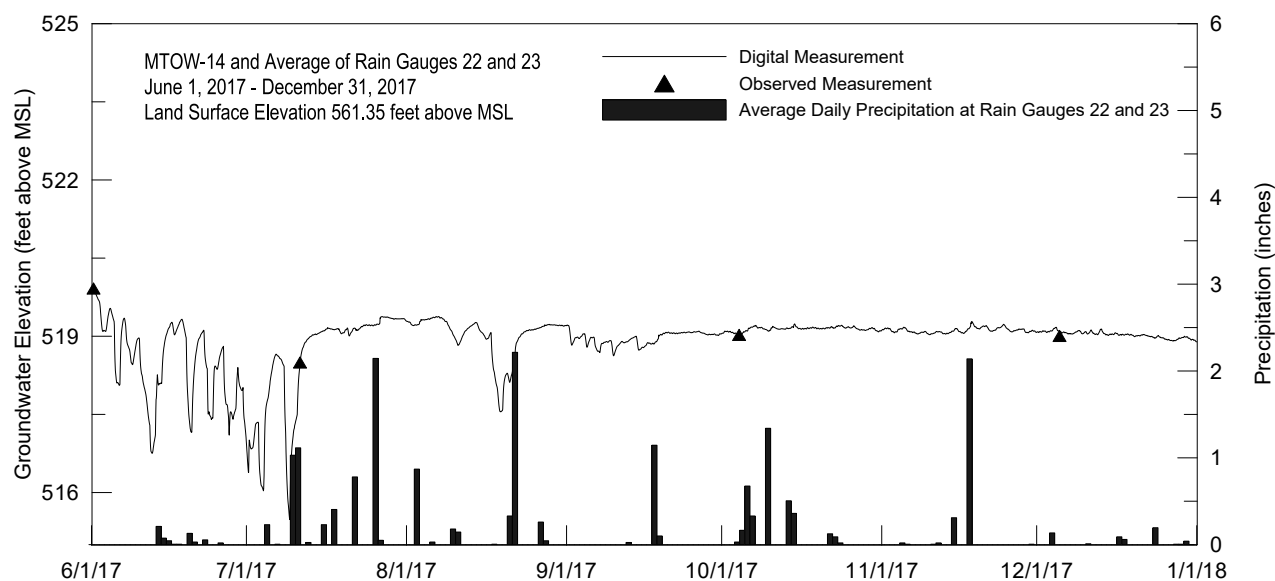


Figure 25. Groundwater Elevations and Precipitation at the Mason City Deep Well, MTOW-14, June 1, 2017-December 31, 2017.

Having continuous water level data allows us to better understand how rainfall affects recharge. At MTOW-14 (Mason City Deep Well), the effect of precipitation in pumpage amounts and aquifer water levels are evident. The lower than average amount of precipitation during June shows increased pumpage in Figure 25. Each “downward spike” on the hydrograph is a pumping event from a nearby irrigation pivot. July and August show a different scenario, precipitation increased and the number of pumpage events decreased.

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 to 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.

The total irrigation pumpage in 2017 was approximately 61.5 billion gallons (bg), which is the fourth highest irrigation amount for the observation period. The number of irrigation systems is now at 2237. 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 26 shows the location of irrigation systems in the IVWA area in 2014.

For Year 25, the lower than normal precipitation during the spring and late summer affected irrigation practices. Irrigation in July, tied for fifth most for period of record, was estimated at 22.0 billion gallons (bg), 7.3 bg more than the long term average. August and September’s irrigation totals were also above average at 17.3 bg and 14.2 bg. The historic average for those two months is 16.8 bg and 9.3 bg.

In recent discussions with the IVWA, it has been discovered the irrigation monthly pumpage figures may be reported incorrectly, and off a month. The monthly figures reported may be for the previous month, once a final determination has been made a correction in practice and reporting will be made. The total annual pumpage data are not affected by this issue.

The monthly and seasonal estimates of irrigation withdrawals are shown in Table 3. The rank from highest to lowest irrigation amounts are shown in the right hand column in Table 3. Year 25 was near the top, ranking fourth overall with 62.5 bg pumped for the year. Typically, irrigation withdrawals are greatest in July and August, with September and June withdrawals

being much lower as compared with July and August. 2017 pumpage followed with historical trends.

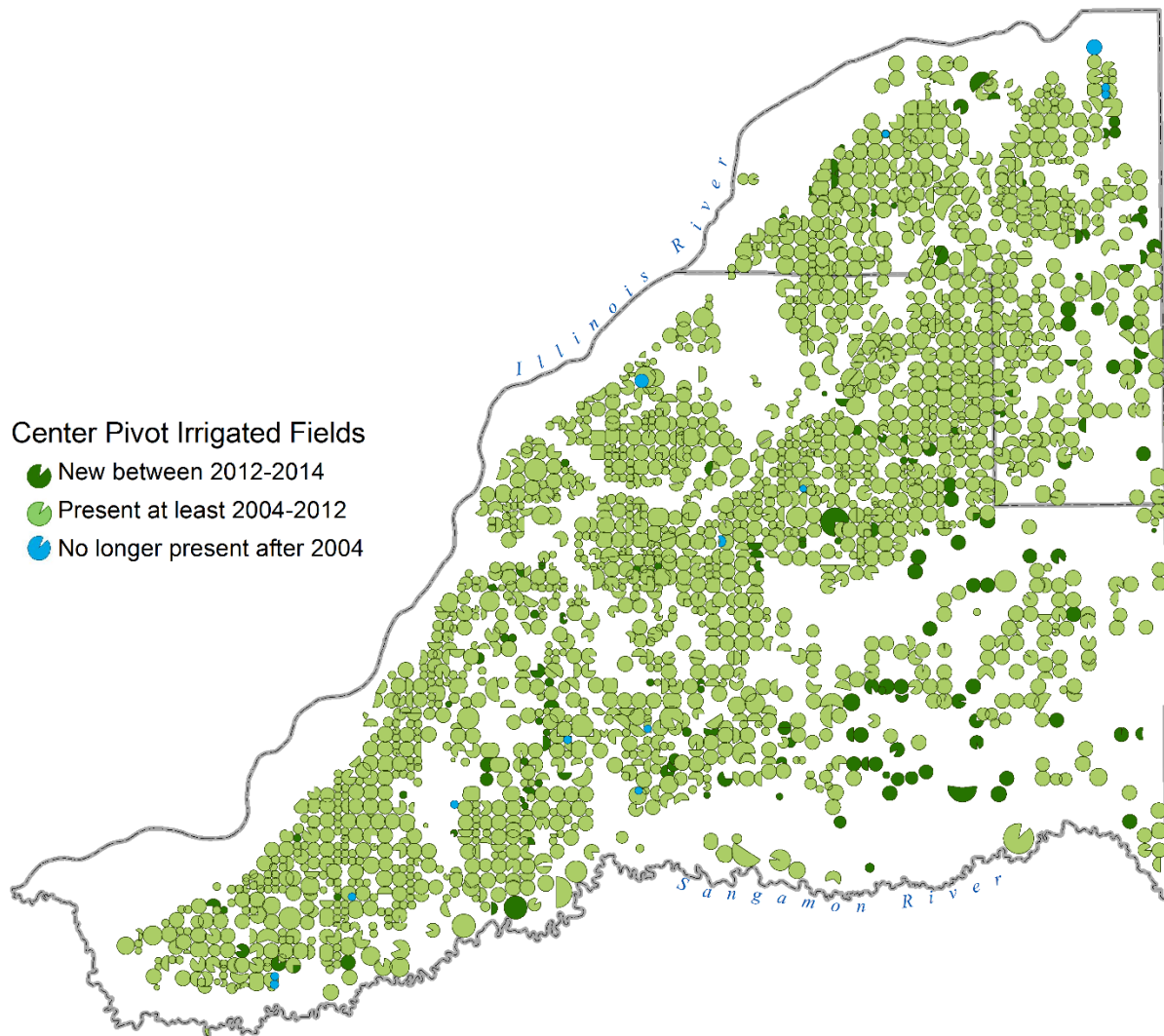


Figure 26. Location of Irrigation Systems within the IVWA (2014).

The estimated monthly irrigation pumpage is displayed graphically in Figure 27 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**

<i>Year</i>	<i>May</i>	<i>June</i>	<i>July</i>	<i>August</i>	<i>September</i>	<i>October</i>	<i>Total #</i>	<i>Systems</i>	<i>BG/system</i>	<i>Rank</i>
1995		2.6	14	10	11		38			16
1996		2.0	20	18	12		52			6
1997		2.6	19	14	2.0		38			16
1998		2.1	7.8	13	6.9		30	1622	.018	20
1999		2.8	18	12	6.0		39	1771	.022	15
2000		6.4	6.0	12	5.6		30	1799	.017	20
2001		4.4	21	17	5.0		47	1818	.026	9
2002		3.4	24	16	3.7		47	1839	.026	9
2003		4.1	16	15	10		46	1867	.025	11
2004		5.3	12	19	5.7		42	1889	.022	13
2005		15	29	23	4.8		72	1909	.038	2
2006		7.2	22	16	5.2		50	1940	.026	8
2007		16	17	19	4.9		57	1971	.029	5
2008		1.2	10	14.5	7.1		33	2014	.016	18
2009		1.6	9.3	12.1	2.9		26	2054	.013	23
2010		1.8	2.4	11.7	10.6		27	2077	.013	22
2011		0.7	2.5	24.7	19.6	5.0	52	2100	.025	6
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	14
2015	0.1	1.6	2.2	9.8	17.0	0.9	31	2197	.014	19
2016	0.1	2.8	23.4	10.9	6.6	1.4	45	2223	.020	12
2017	0.1	1.7	22.0	17.3	14.2	6.2	61.5	2237	.027	4
Average	0.1	4.5	14.7	16.8	9.3	4.3	46.5		.023	

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.

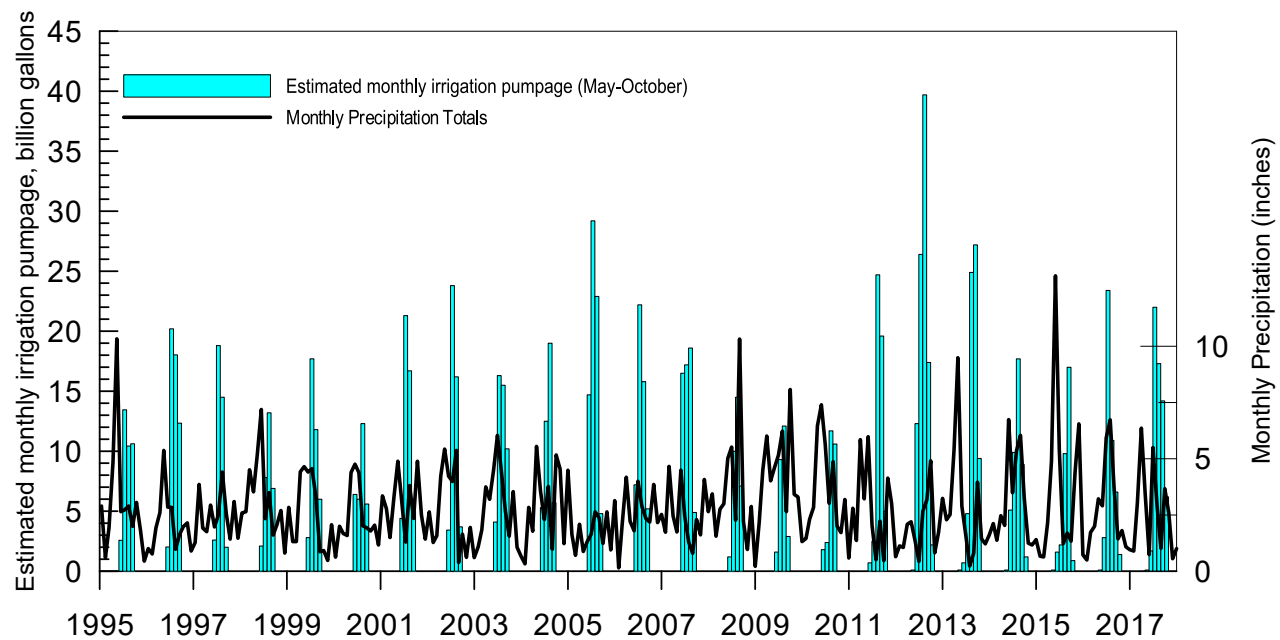


Figure 27. Estimated Irrigation Pumpage and Average Monthly Precipitation, IVWA.

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

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

*Irrigation ranks are from highest total pumpage to lowest for comparison with precipitation.

(Irrigation rankings in previous reports 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 - 2017 25-yr average 35.15 (24-year IVWA network average)

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

Summary

During PY2017 of the rain gage network operation (September 2016-August 2017), the network received an average of 31.88 inches of precipitation, 3.27 inches below the previous 24-year network average precipitation of 35.15 inches, and 6.50 inches below the 30-year average for the study area, 38.38 inches. PY2017 was the 10th driest year since the deployment of the precipitation network. Fall 2017 was below average, winter was also below average, spring was 3+ inches above average, and summer was 2+ inches drier than the network average.

The data collected over the last 25 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. We hope to provide some of these results to the IVWA in the coming years as we continue to develop our understanding the groundwater resources of the area.

The ISWS is grateful to the IVWA for their continued support of the rain gage 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

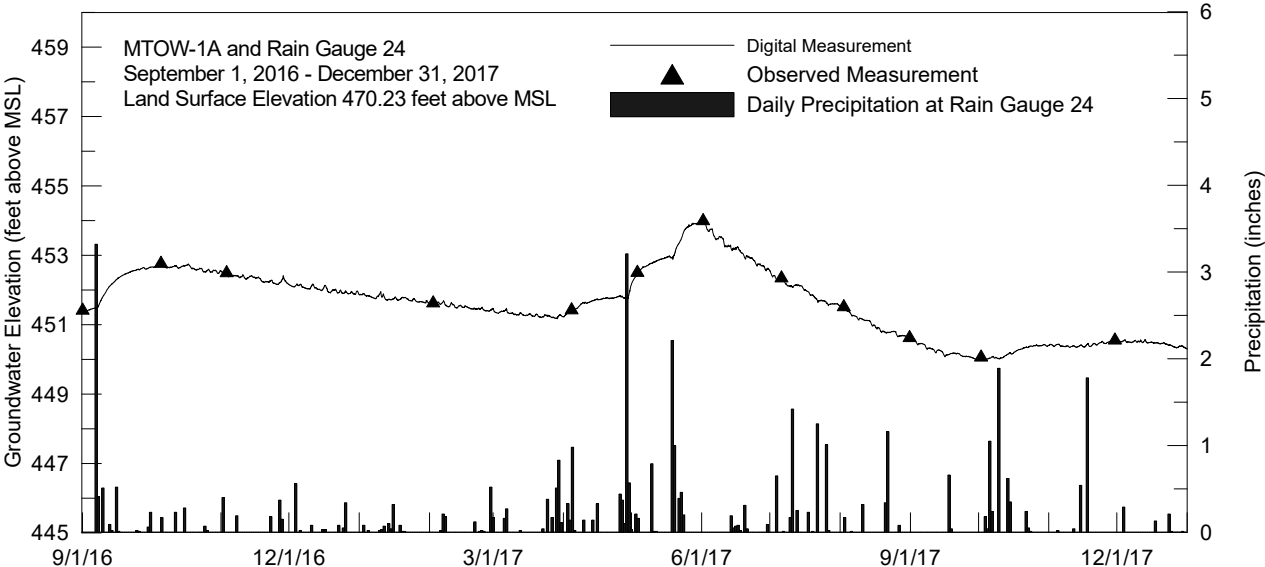


Figure A-1. Year 25 Groundwater Elevation and Precipitation for MTOW-01A

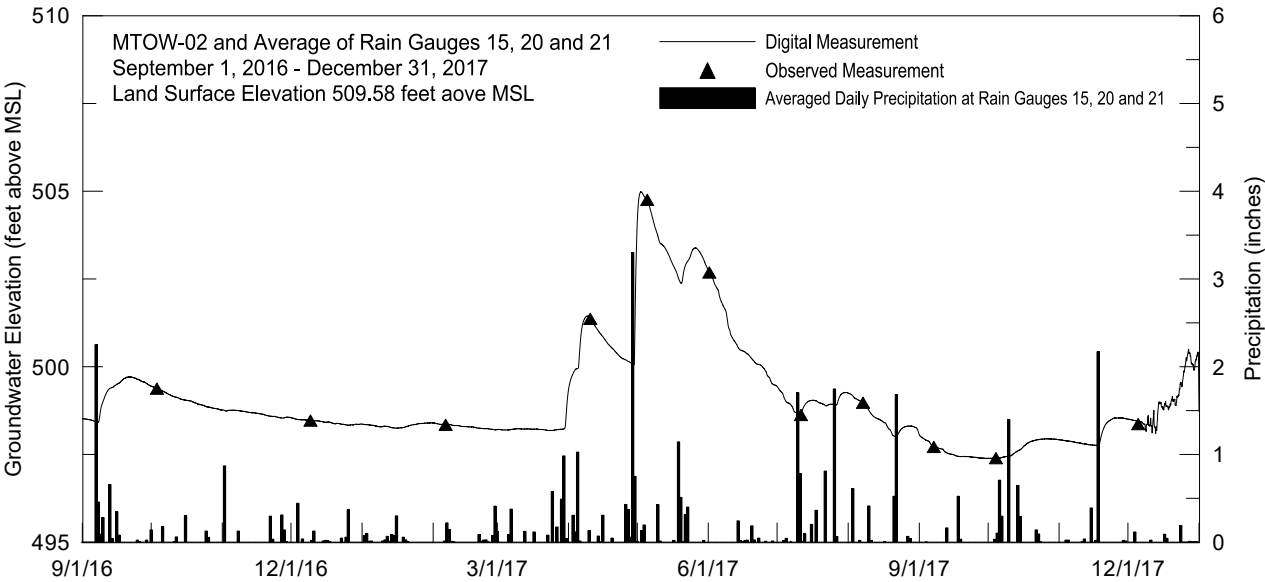


Figure A-2. Year 25 Groundwater Elevation and Precipitation for MTOW-02

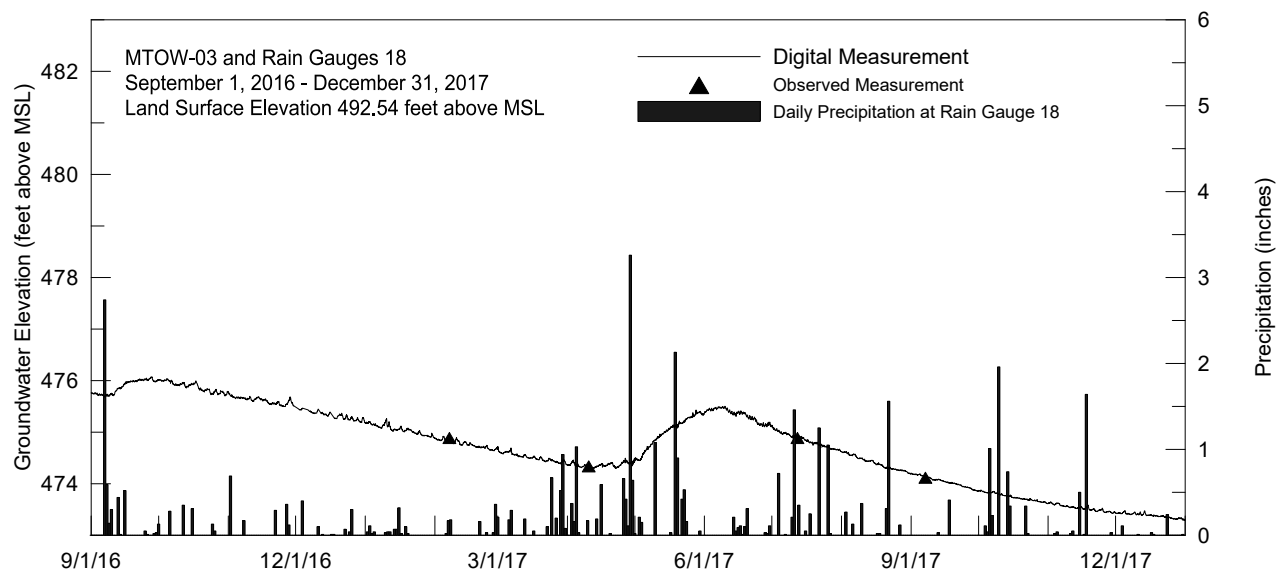


Figure A-3. Year 25 Groundwater Elevation and Precipitation for MTOW-03

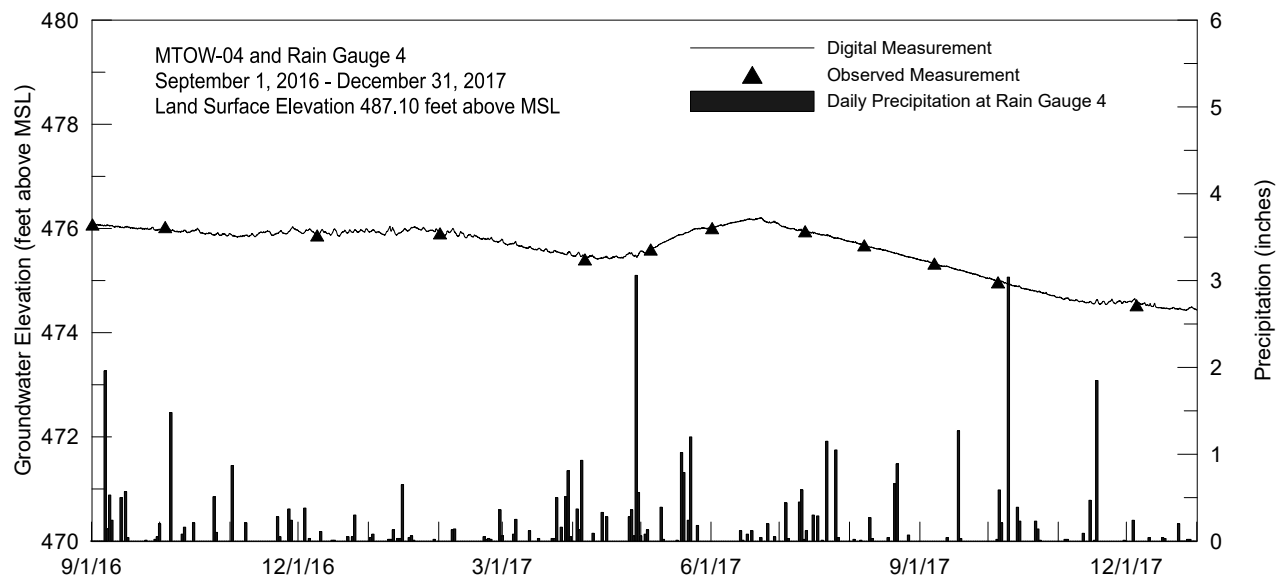


Figure A-4. Year 25 Groundwater Elevation and Precipitation for MTOW-04

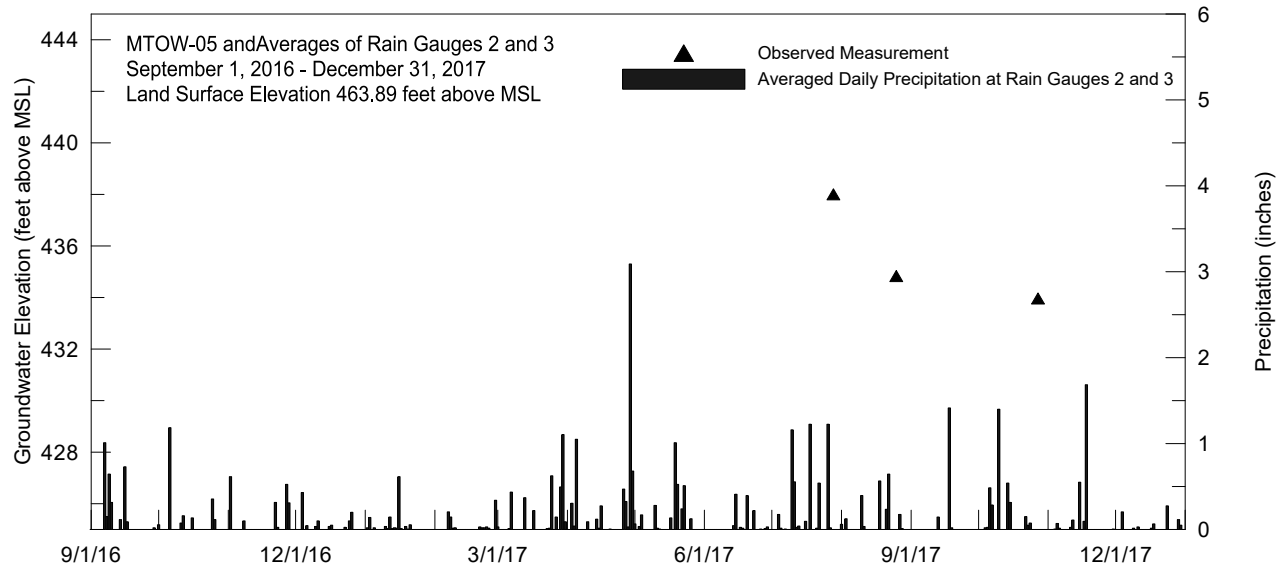


Figure A-5. Year 25 Groundwater Elevation and Precipitation for MTOW-05 (not continuous recorder)

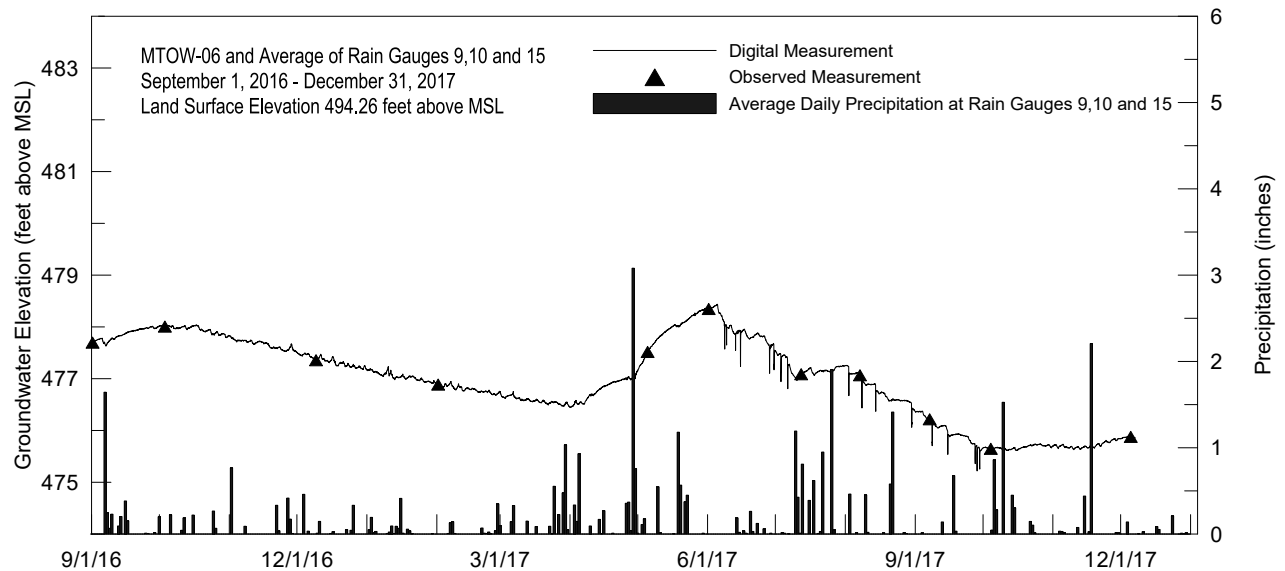


Figure A-6. Year 25 Groundwater Elevation and Precipitation for MTOW-06

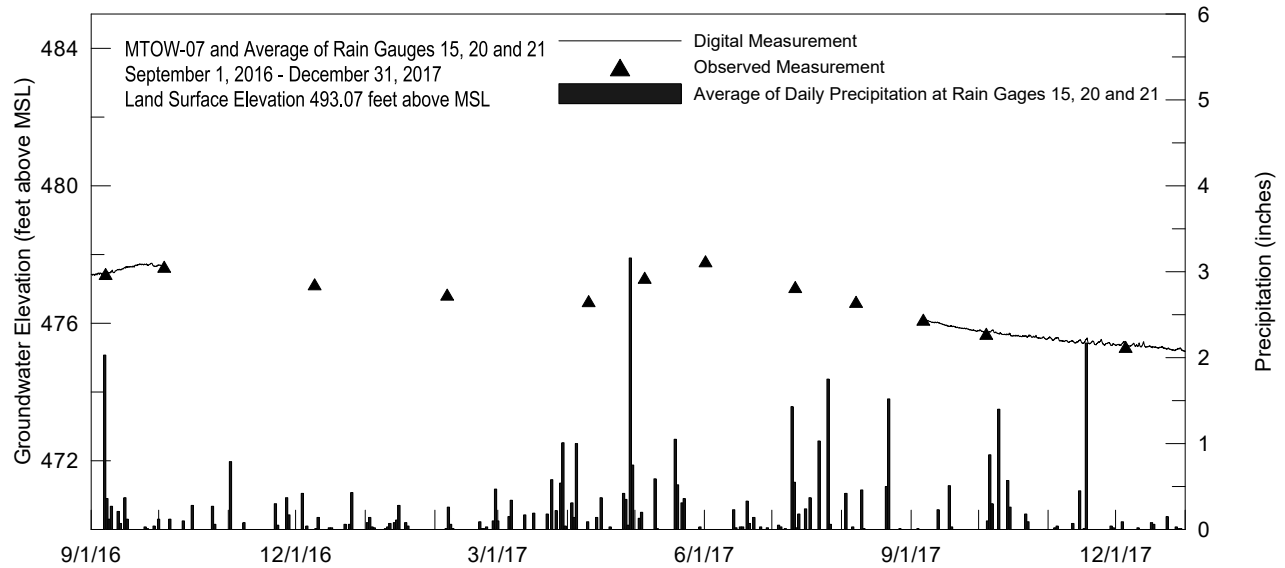


Figure A-7. Year 25 Groundwater Elevation and Precipitation for MTOW-07

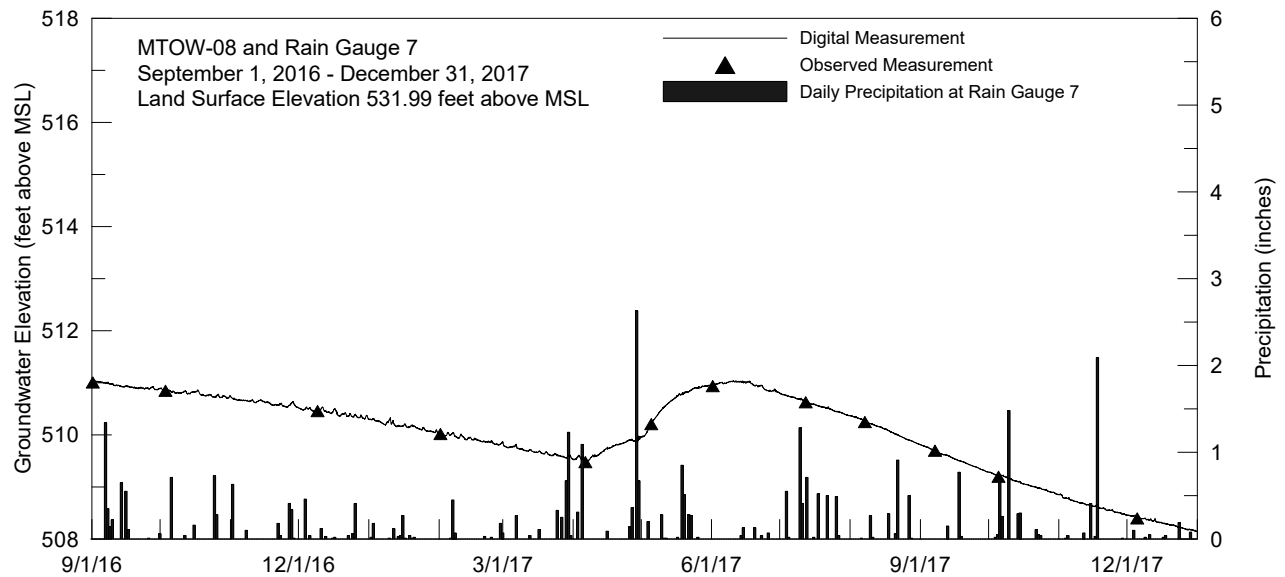


Figure A-8. Year 25 Groundwater Elevation and Precipitation for MTOW-08

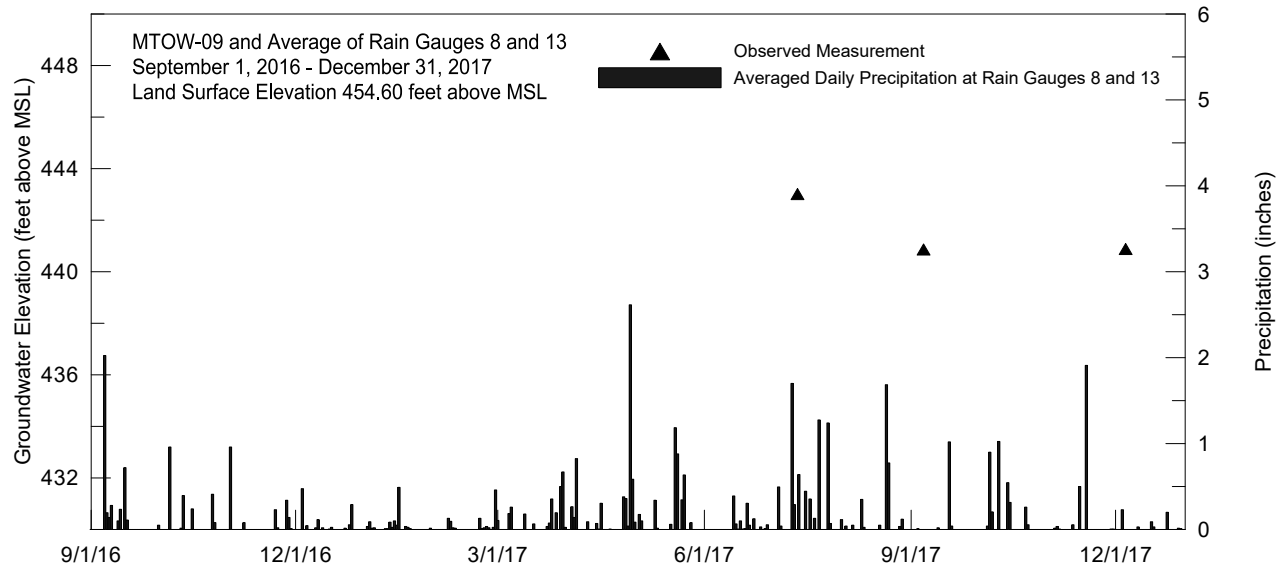


Figure A-9. Year 25 Groundwater Elevation and Precipitation for MTOW-09 (not continuous recorder)

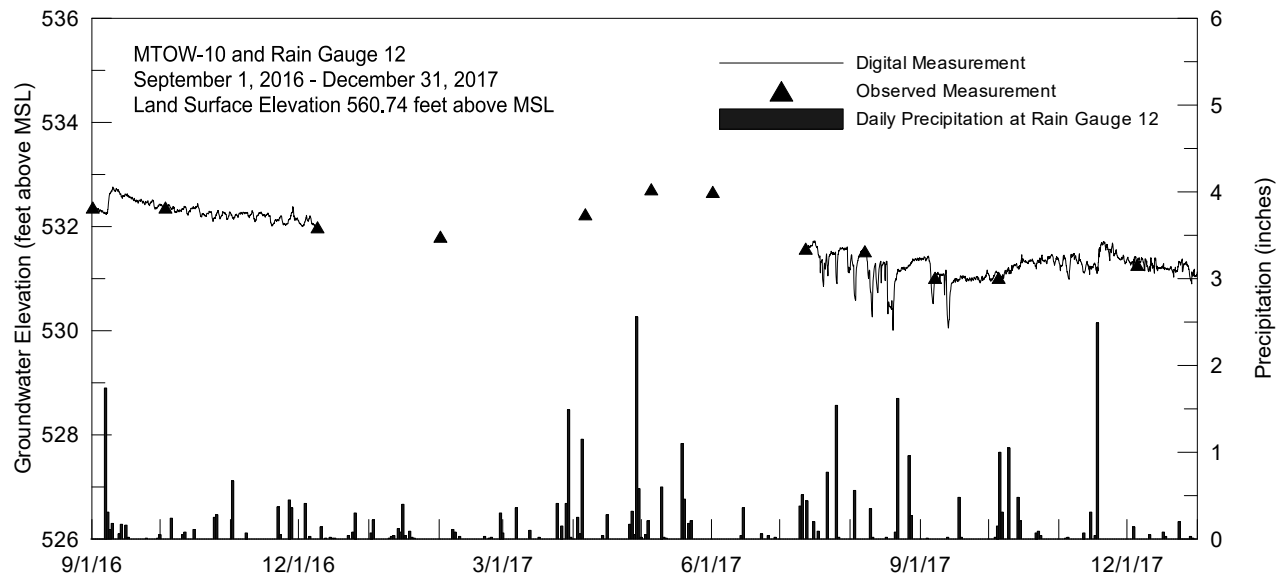


Figure A-10. Year 25 Groundwater Elevation and Precipitation for MTOW-10

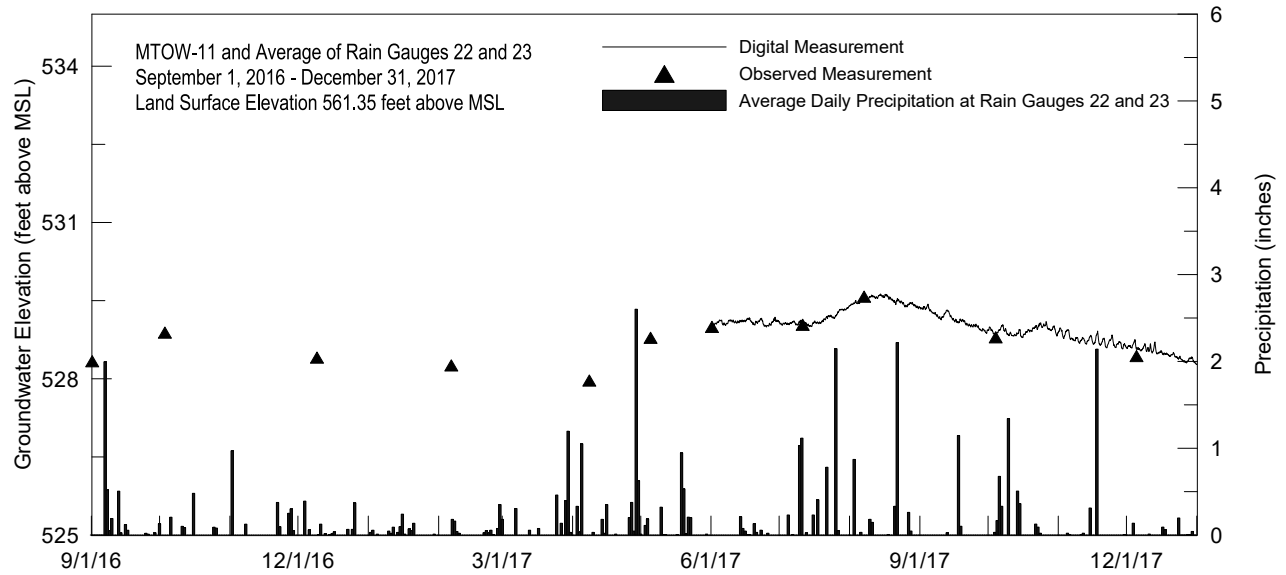


Figure A-11. Year 25 Groundwater Elevation and Precipitation for MTOW-11

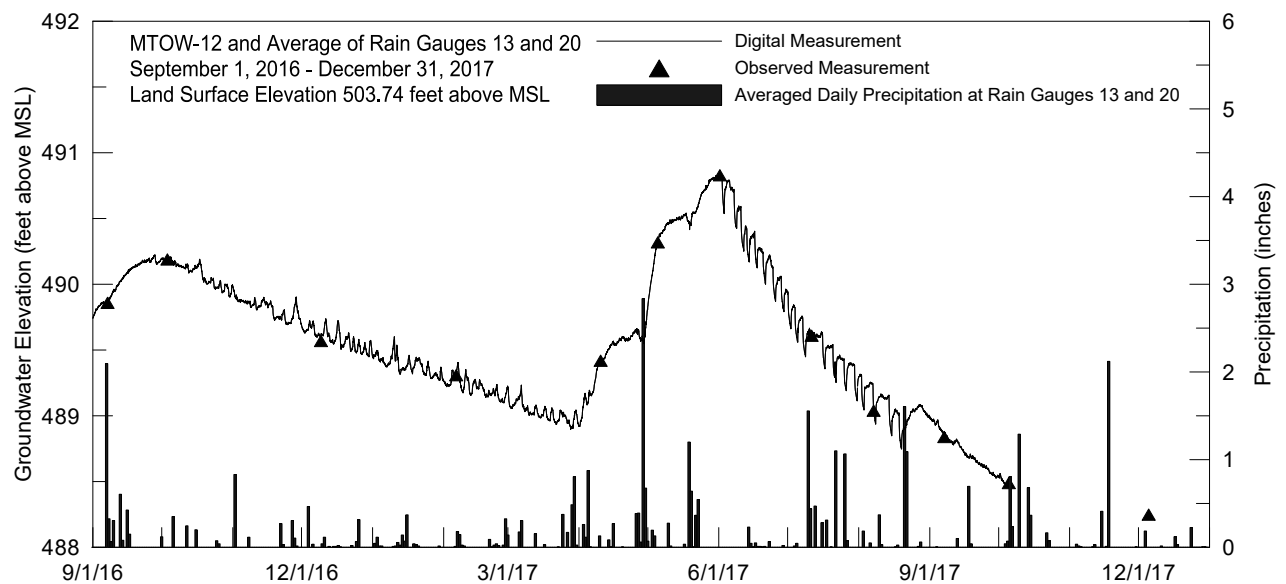


Figure A-12. Year 25 Groundwater Elevation and Precipitation for MTOW-12

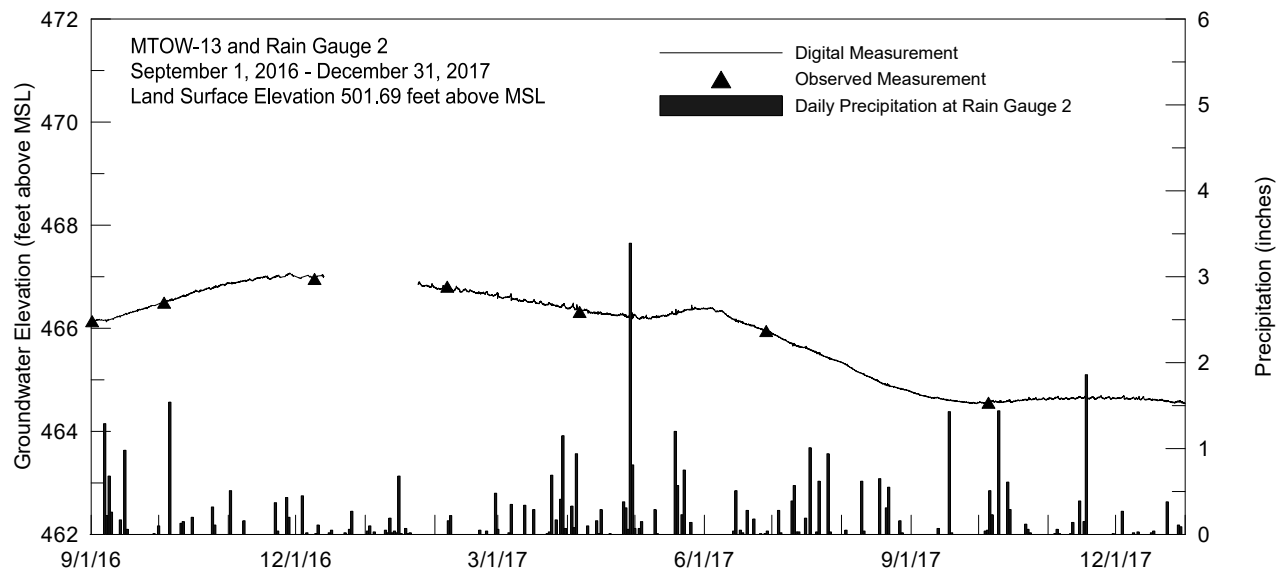


Figure A-13. Year 25 Groundwater Elevation and Precipitation for MTOW-13

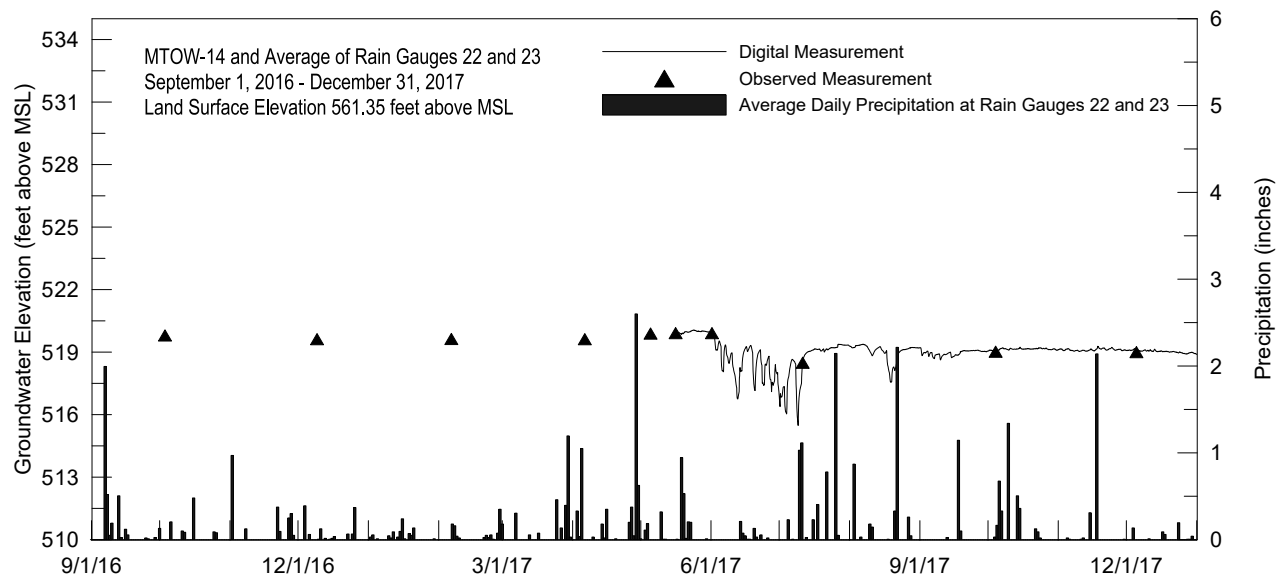


Figure A-14. Year 25 Groundwater Elevation and Precipitation for MTOW-14

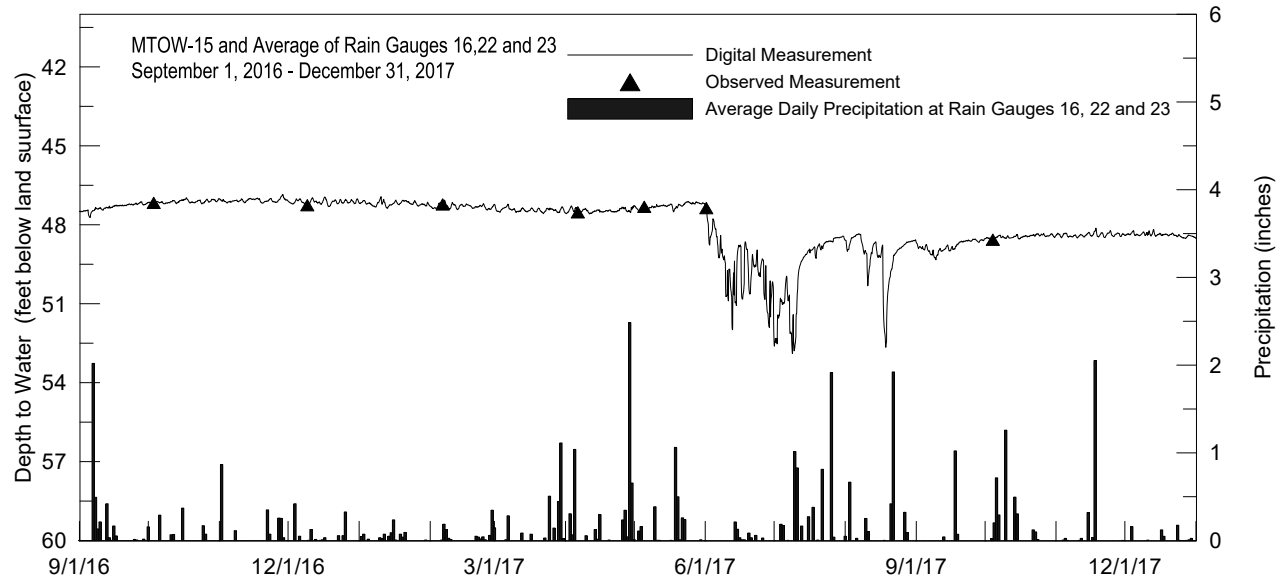


Figure A-15. Year 25 Groundwater Elevation and Precipitation for MTOW-15

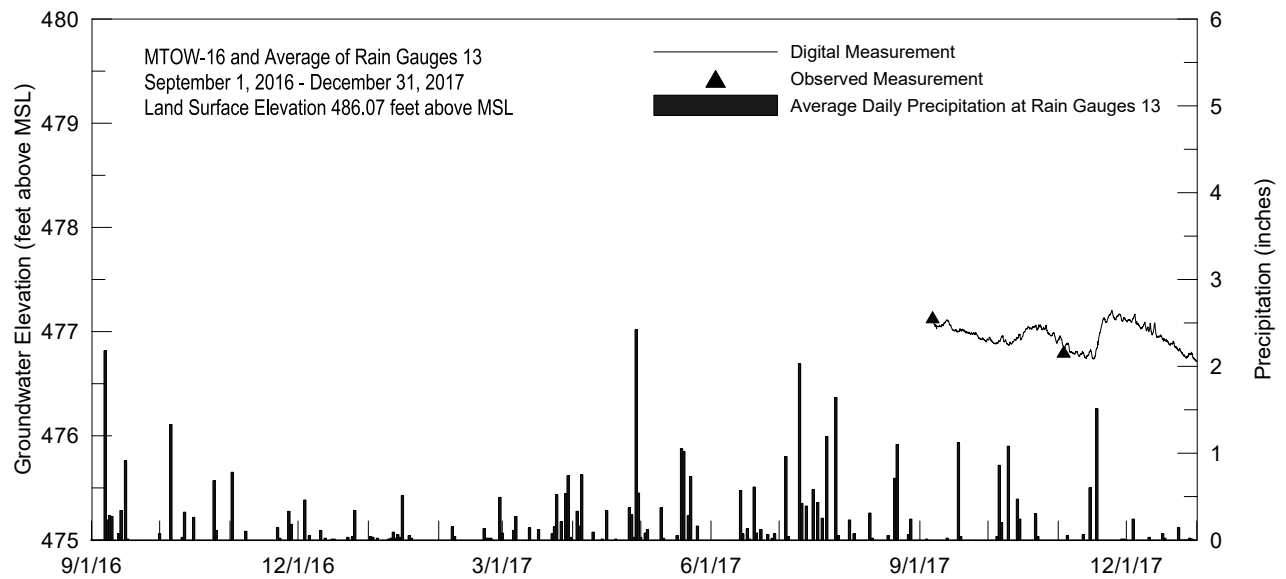


Figure A-16. Year 25 Groundwater Elevation and Precipitation for MTOW-16

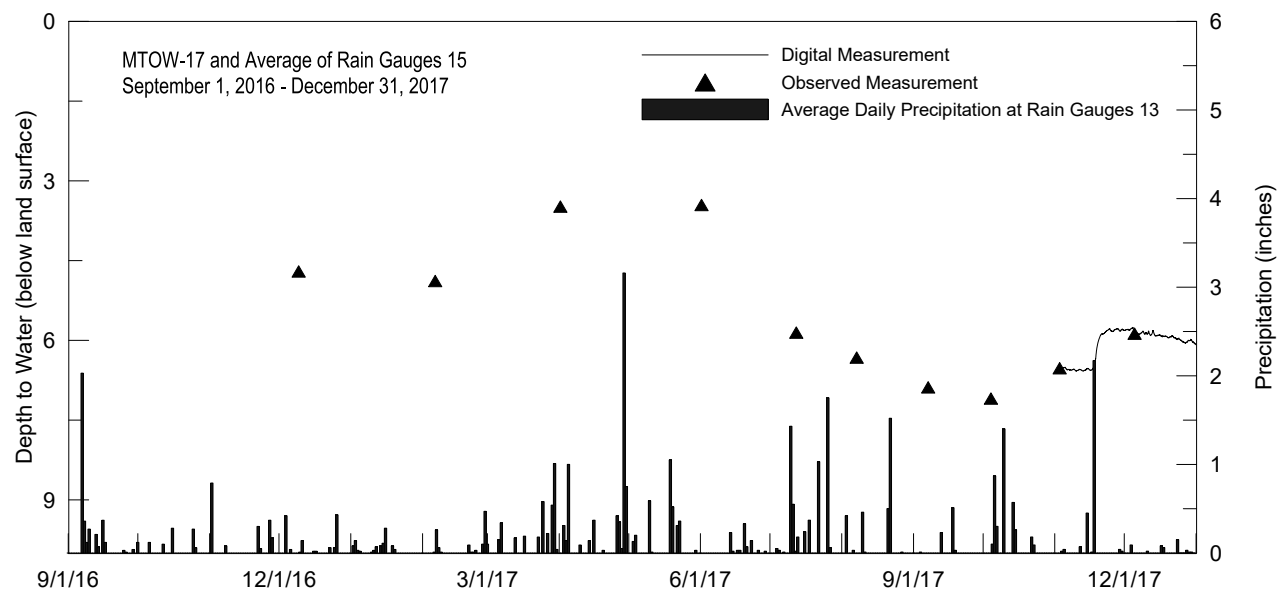


Figure A-17. Year 25 Groundwater Elevation and Precipitation for MTOW-17