ILLINOIS

PRAIRIE RESEARCH INSTITUTE

Illinois State Water Survey
2204 Griffith Drive
Champaign, IL 61820

April 13th, 2022

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 are 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 year-end report for Year 29, project/calendar year 2021 (CY2021), which covers the period from January 1, 2021 through December 31, 2021.

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. Each gage records precipitation every 15-minutes year-round. The network gages are currently managed, maintained, analyzed, and reported monthly by ISWS researcher, Erin Bauer. The gages are visited regularly; precipitation data are retrieved, and routine maintenance and repairs are completed.

The groundwater observation well network was established in 1995-96 and consists of eighteen wells, MTOW-01 through MTOW-18. MTOW-15 A & B, located northwest of Mason City near Ellsberry Lake, are nested. MTOW-17 & MTOW-18 are former 24-inch irrigation wells. MTOW-17 is located north of Biggs, Illinois, while MTOW-18 is located south of Biggs, Illinois and is new to the monitoring network for CY2021. All the other observation wells within the network are drilled wells between 2 and 6 inches in diameter. In accordance with our agreement, each well, except for 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. In addition, all wells except for MTOW-05 and MTOW-09 are equipped with data loggers that electronically log the groundwater level data. Figure 1 shows the location of each well.

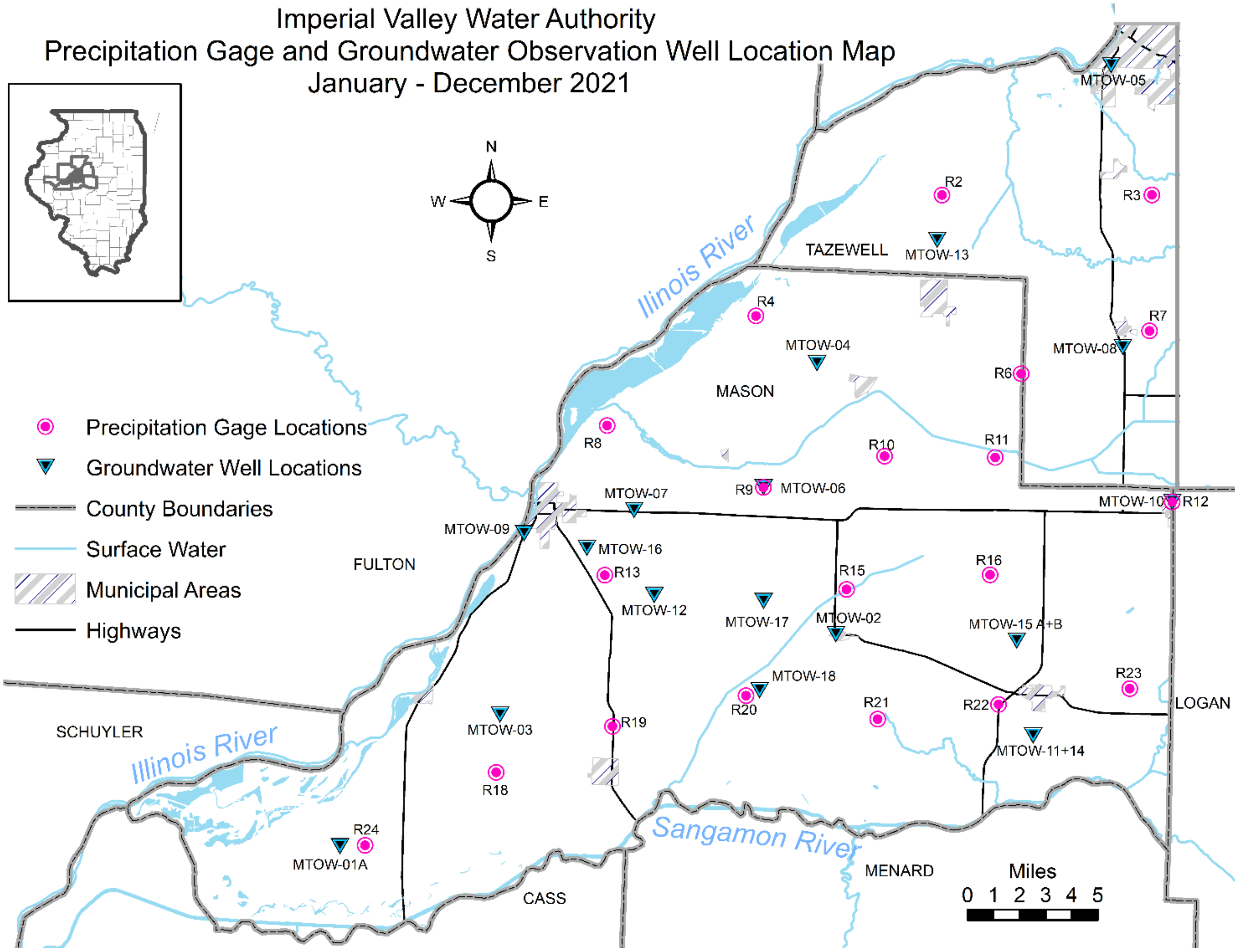


Figure 1. Configuration of the 18-Site Observation Well and 20-Site Rain Gage Networks.

Background

The CY2021 rain gage dataset was used to produce gage and network-wide summaries of total and average precipitation at various time scales including individual precipitation events, monthly, seasonal, and annual time periods. Monthly and annual time scale summaries are compared with the previous 28-year (1993-2020) network average precipitation record, unless explicitly noted to clearly compare the CY2021 record with a long-term average.

Groundwater levels for each well for the period of record (January 1, 2021 - December 31, 2021) 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 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 assumed 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).

In accordance with our agreement, the ISWS also maintains the Imperial Valley Water Authority website (http://imperialvalleywaterauthority.org/). The most frequently updated portion of this site is the data collection tab, which includes annual updates of estimated irrigation, links to real-time groundwater levels, monthly precipitation reports, and archived versions of this letter report dating back to 2004. The site is also used to update important items, such as details of proposed ordinances.

Precipitation Analysis

The Imperial Valley network average precipitation was 41.60 inches in CY2021, January – December 2021, which was more than the long term, 28-year annual average (Jan – Dec. 1993-2020) of 35.00 inches. Figure 2 shows the distribution of total annual precipitation in CY2021. Table 1 provides the monthly and annual total precipitation for each rain gage and the network monthly and annual average precipitation for January - December 2021.

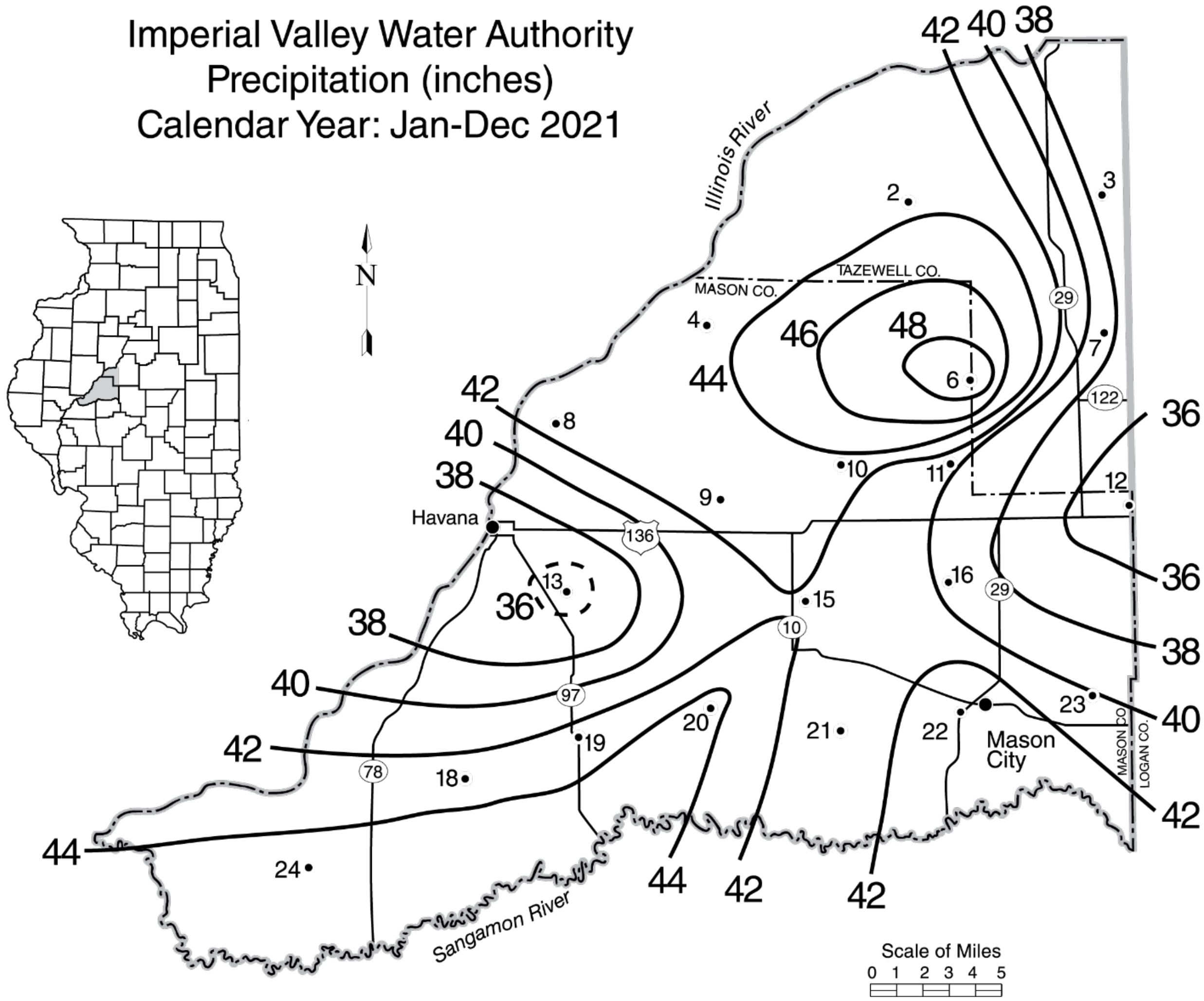


Figure 2. Total Precipitation (inches) for January - December 2021 (CY2021).

The lowest annual precipitation occurred on the eastern edge of the network at gage #12 near San Jose and at gage #13 on the west side of the network. Gage #6 collected the most precipitation in CY2021, 49.45 inches, with nearby gages #2 and #4 collecting 43.44 and 43.2 inches respectively. During CY2021, annual gage totals ranged 15.40 inches. 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.

Gage #6 received the most precipitation of all the gages in January, February, March, then near average or below average precipitation from May through September, and again receiving the most precipitation of all the gages for the months of October, November, and December 2021. The monthly network precipitation maps for CY2021 are shown in Figures 3 through 8.

Table 1. Monthly Precipitation Amounts (inches), January-December 2021 Calendar Year Annual Totals

Station	*Month*												*CY2021*
	Jan	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*	*Total*
2	2.54	1.00	3.84	3.33	6.18	6.79	2.70	5.30	1.37	8.44	0.52	1.44	43.44
3	1.86	0.63	3.20	2.48	5.81	6.24	2.98	3.40	1.03	7.42	0.55	2.11	37.70
4	2.23	0.69	5.09	3.13	5.54	4.52	2.65	7.84	1.12	8.57	0.40	1.42	43.20
6	2.98	2.12	6.65	4.48	5.80	5.35	4.44	4.46	0.97	8.95	0.63	2.63	49.45
7	2.53	0.78	4.65	3.63	5.30	5.89	2.49	3.81	0.90	6.93	0.45	1.42	38.78
8	2.43	1.24	5.02	3.33	4.93	4.82	2.82	7.14	0.80	7.97	0.37	1.61	42.48
9	2.41	1.18	4.76	3.82	4.74	5.72	2.85	6.75	1.05	7.92	0.57	1.88	43.65
10	1.97	0.90	4.92	3.98	5.08	5.43	4.25	5.78	1.03	7.33	0.31	2.01	43.00
11	2.37	1.00	4.72	3.76	4.11	3.82	5.16	4.45	1.00	7.99	0.33	1.54	40.25
12	2.46	0.53	4.04	2.52	4.45	4.48	4.24	2.95	0.84	6.25	0.30	0.99	34.05
13	2.13	0.44	4.77	1.77	4.55	4.75	2.92	4.81	0.83	6.28	0.19	1.02	34.47
15	2.19	0.66	4.65	2.92	5.10	4.57	5.43	6.76	1.09	6.42	0.32	1.61	41.73
16	2.38	1.08	5.03	2.52	4.51	4.10	5.92	5.24	1.15	6.13	0.38	1.21	39.64
18	2.41	0.94	5.02	2.92	5.23	6.13	6.68	4.50	0.84	6.46	0.39	1.86	43.38
19	2.53	1.32	4.57	3.29	5.59	5.94	5.86	4.36	1.04	6.34	0.37	1.87	43.07
20	2.26	0.93	4.74	2.83	6.13	4.20	7.16	6.27	1.09	7.13	0.35	1.41	44.50
21	2.39	1.47	4.42	2.69	5.85	4.15	7.62	3.58	1.10	5.84	0.30	0.71	40.12
22	2.37	1.00	4.46	2.57	6.10	3.92	8.08	5.66	1.25	6.43	0.56	1.52	43.92
23	2.74	1.43	4.32	1.91	5.36	5.29	5.83	5.00	1.07	5.46	0.42	1.43	40.26
24	2.39	1.29	5.16	3.08	5.23	5.17	8.44	4.03	0.67	6.42	0.61	2.35	44.84
Avg	2.38	1.03	4.70	3.05	5.28	5.06	4.93	5.10	1.01	7.03	0.42	1.60	41.60

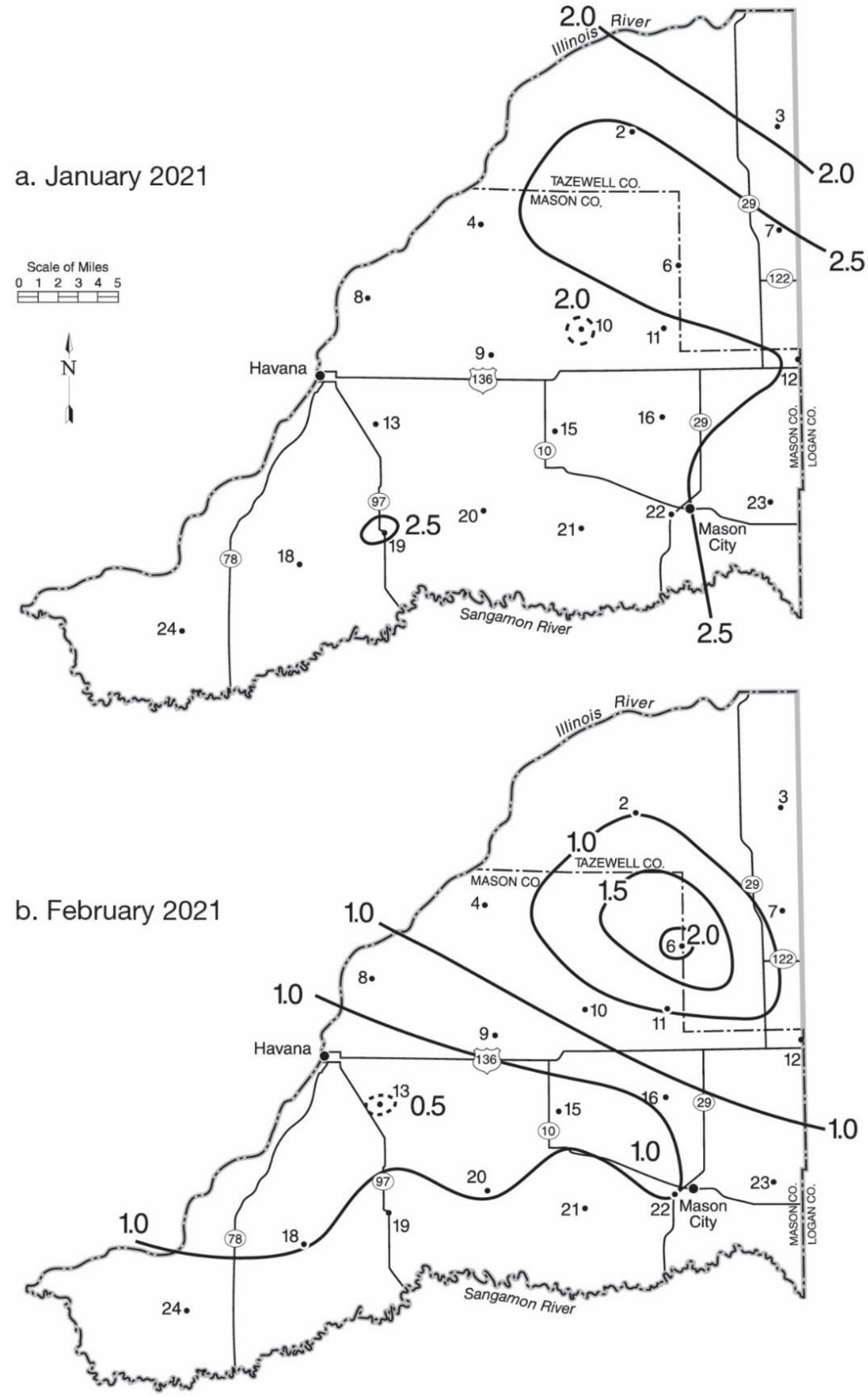


Figure 3. Precipitation (inches) for January 2021 and February 2021

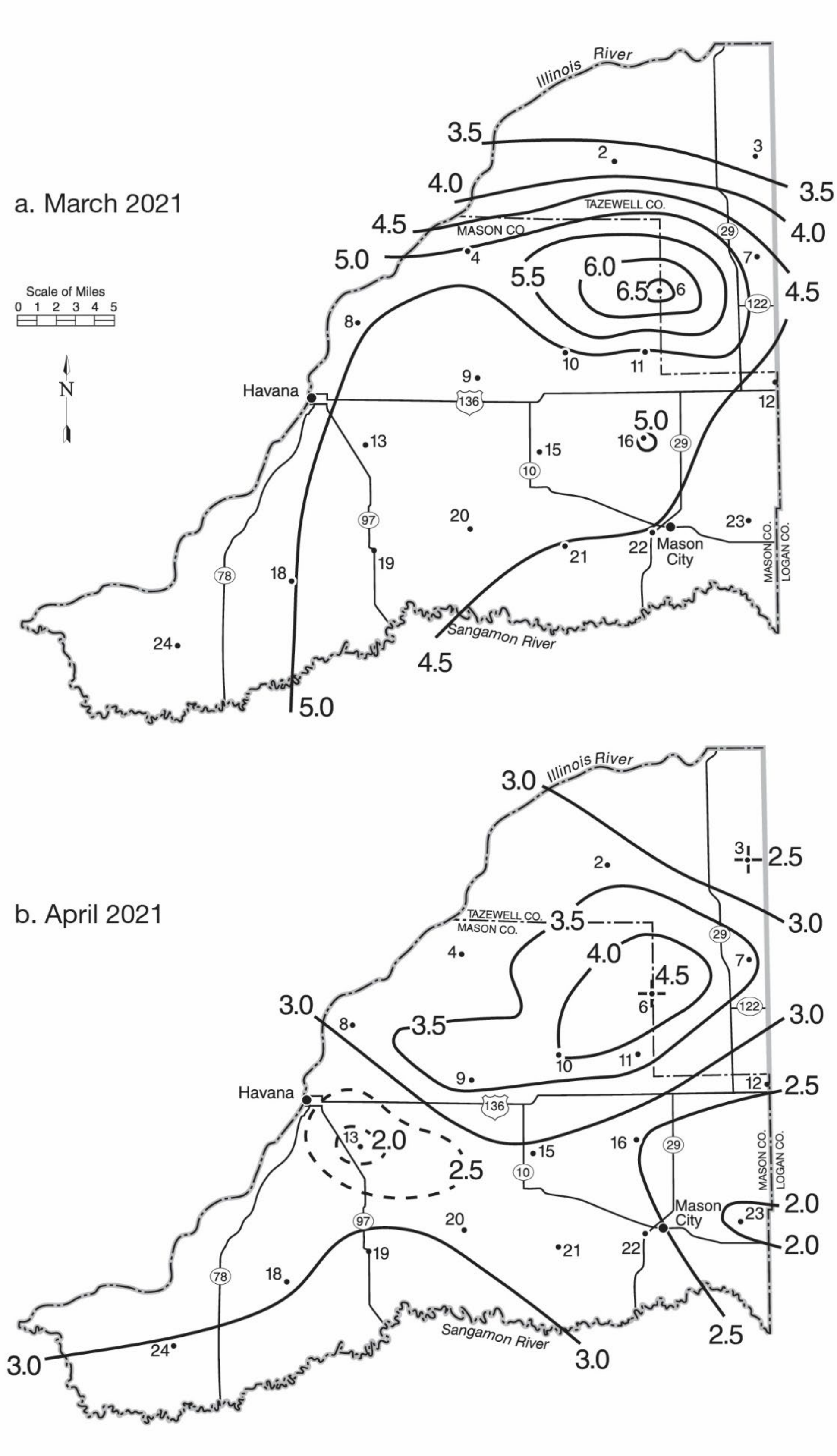


Figure 4. Precipitation (inches) for March 2021 and April 2021

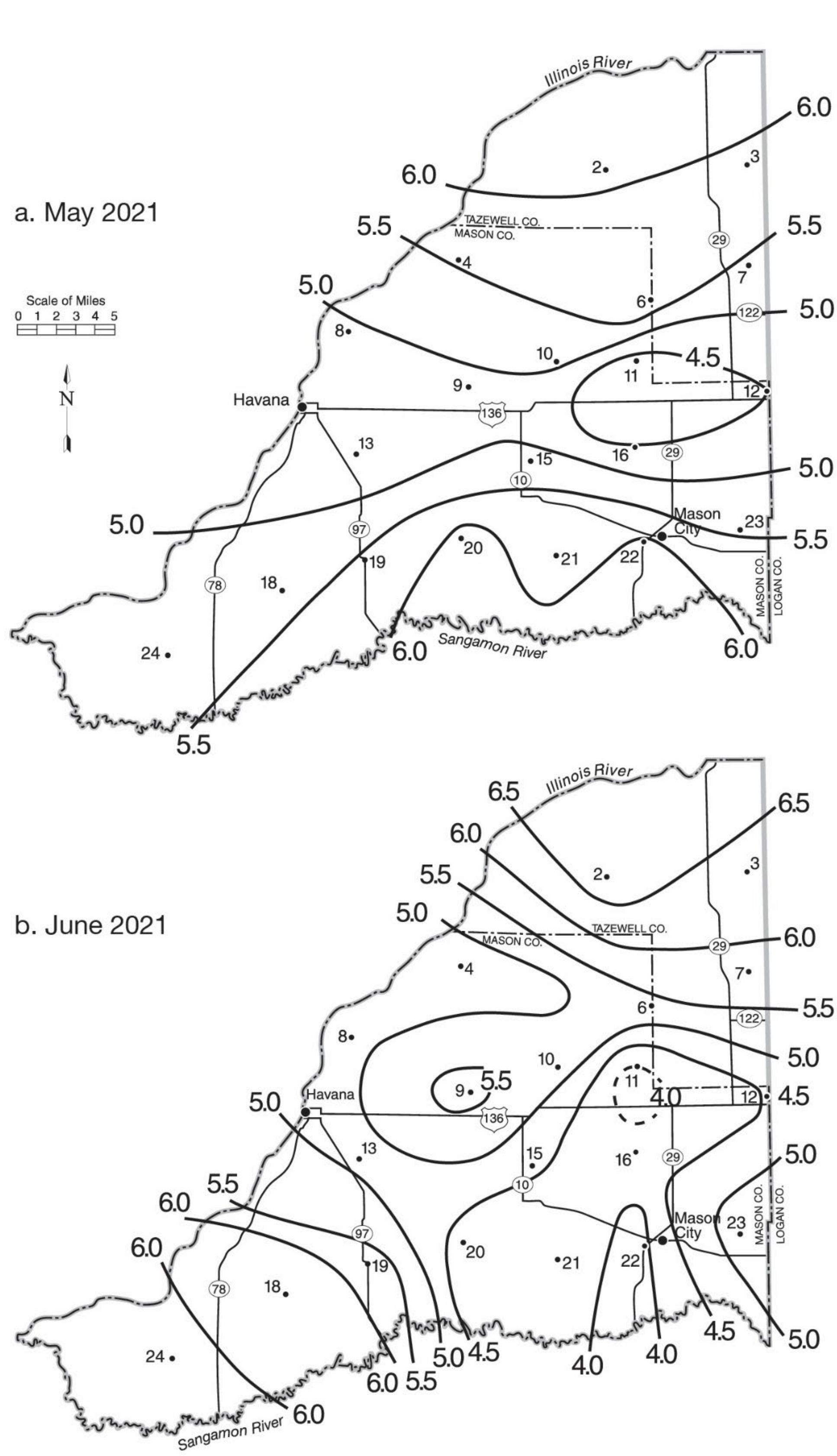


Figure 5. Precipitation (inches) for May 2021 and June 2021

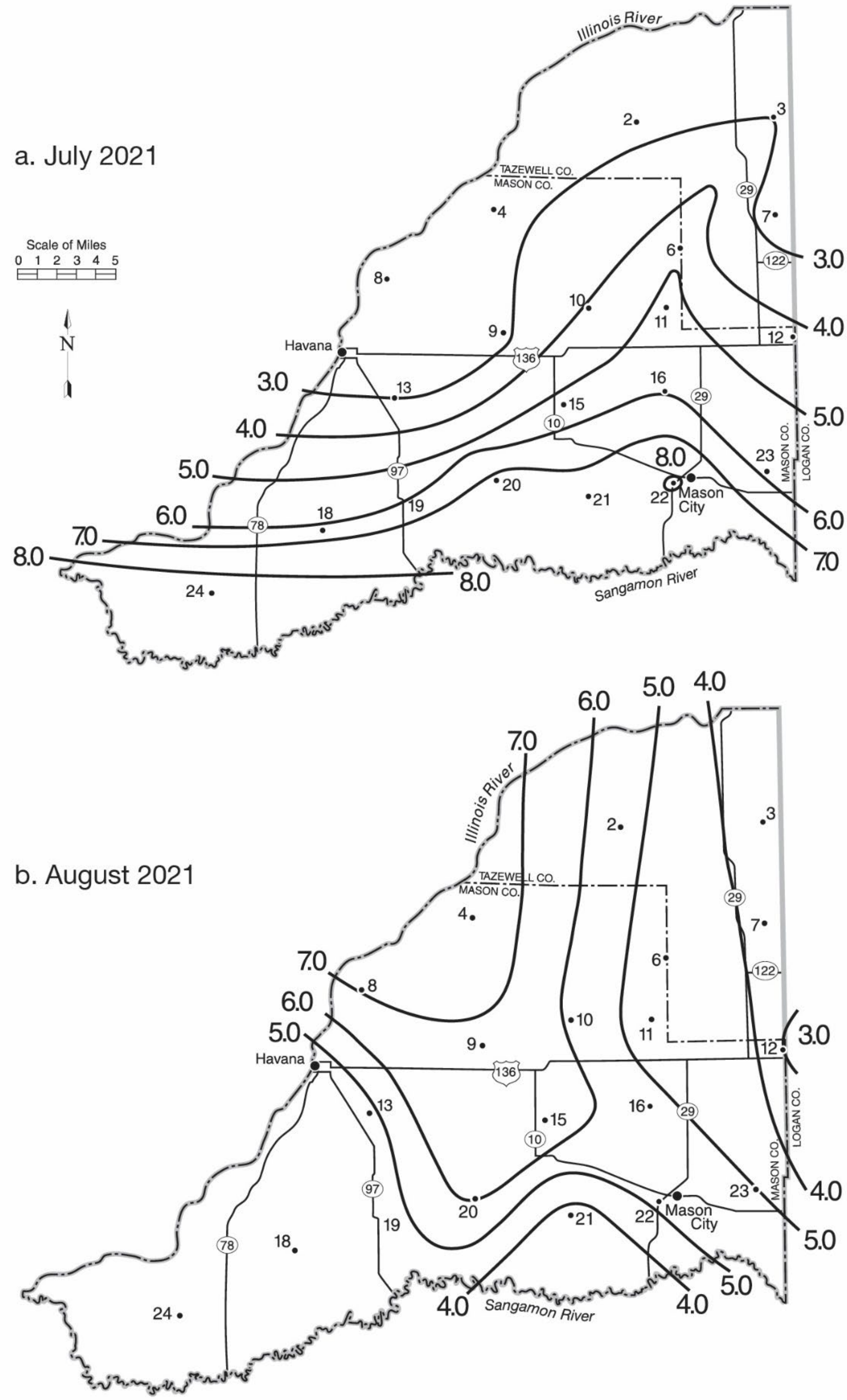


Figure 6. Precipitation (inches) for July 2021 and August 2021

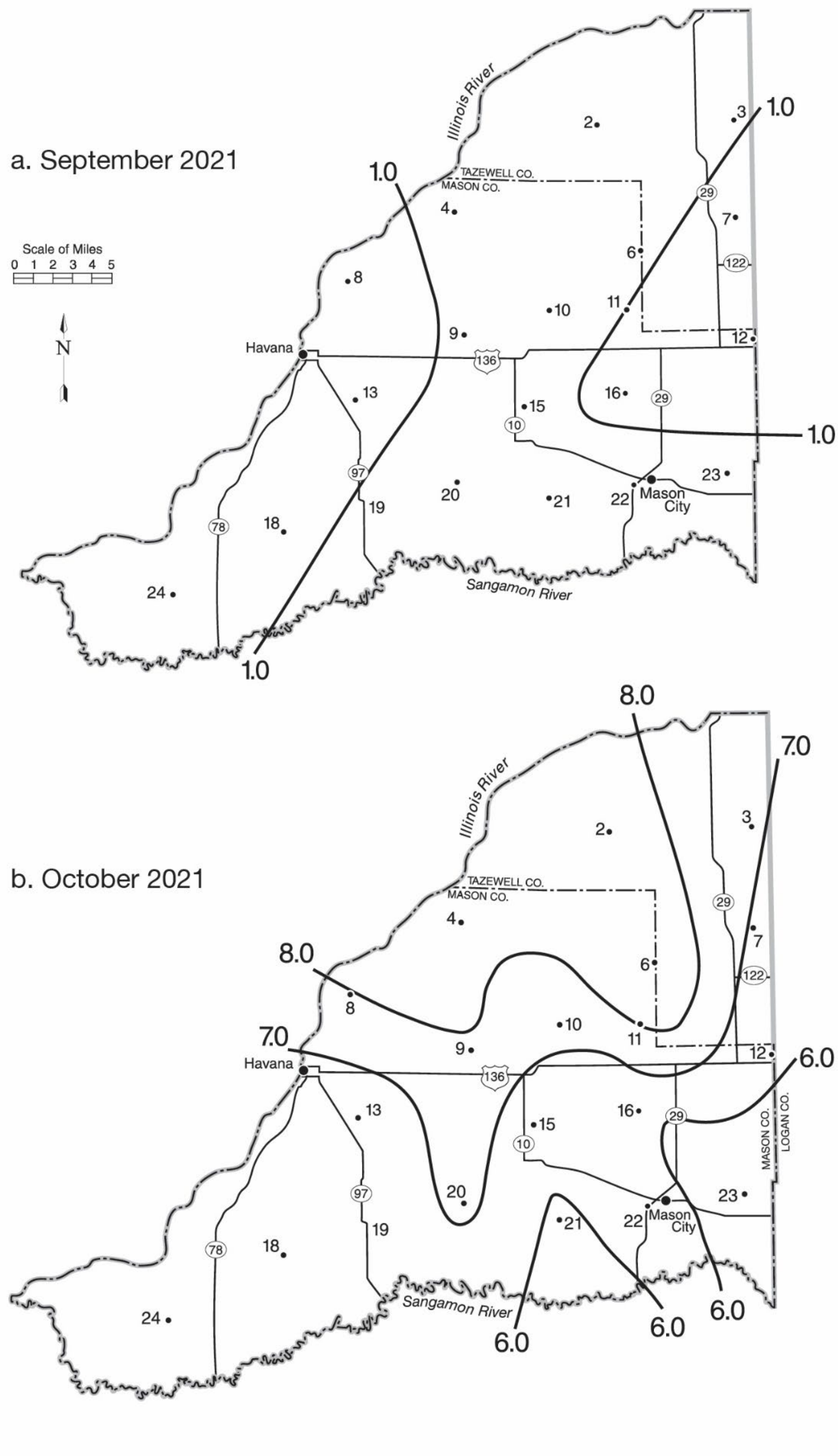


Figure 7. Precipitation (inches) for September 2021 and October 2021

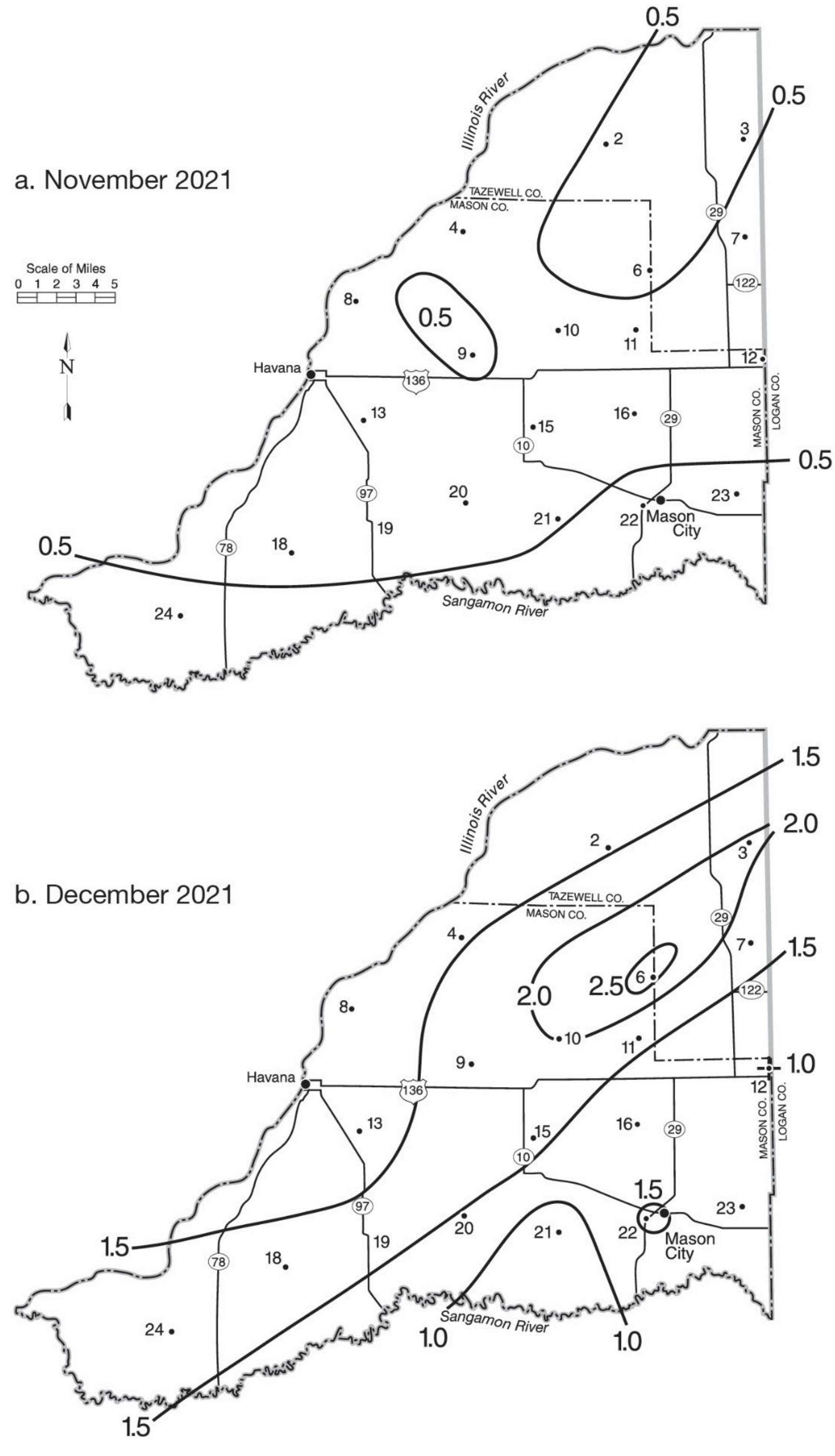


Figure 8. Precipitation (inches) for November 2021 and December 2021

Network Long-term Average Precipitation

Network annual average precipitation is the average of calendar years 1993-2021 annual precipitation. Figure 9 provides the contours for the 29-year annual average precipitation, January 1993 through December 2021. Precipitation contours create a pattern of parallel trending contours to the Illinois River along the southwestern half of Mason County. The 28-year average annual precipitation was highest along a line from Gage #24 to #19 and along the river north of Havana. The eastern side of the network received lower precipitation.

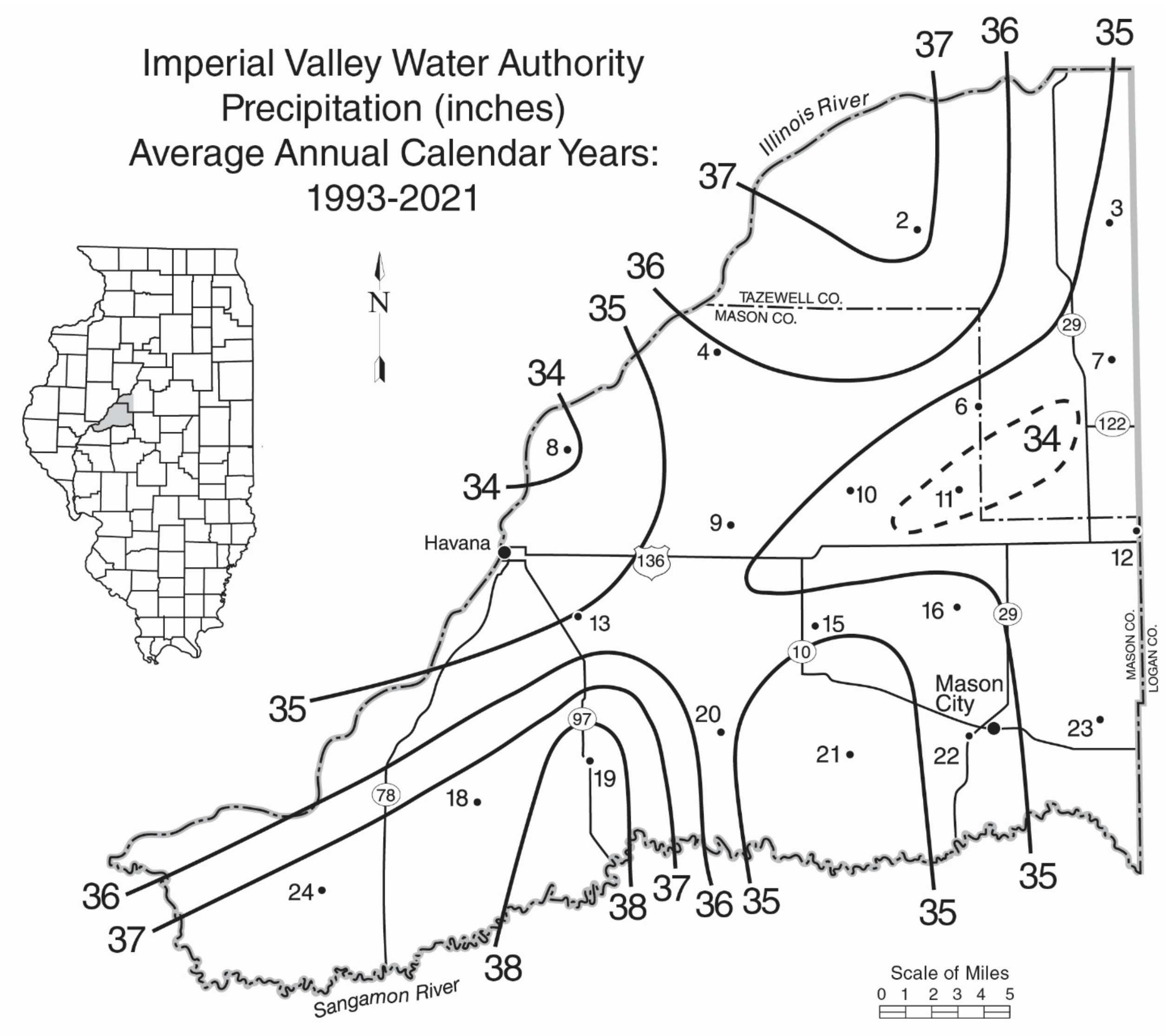


Figure 9. Average Annual Precipitation (inches, calendar year) for January 1993 – December 2021, 29 years.

The following bar graph, Figure 10, compares the network monthly averages for CY2021 with the previous 28-yr historical monthly network averages (1993-2020 not including 2021) and the Havana and Mason City 1991-2020 monthly averages. During CY2021, the heaviest monthly precipitation occurred in October at 7.03 inches which was 253% of the previous 28-yr network monthly average. October 2021 ranks as the second wettest October behind October 2009 (8.08 inches). May through August monthly precipitation totals were close to 5 inches for each month, from 121% to 158% of the 28-year average, 4 months in a row. March precipitation was 4.7

inches and 209% of the 28-year average, making it the wettest March in the last 29 years. In 2021, three months had below average (less than 60% long-term average) precipitation: February (60%), September (34%), and November (18%). In CY2021, there were no months within +/- 15% of the long-term averages. The IVWA network received a network-wide average of 41.60 inches of precipitation in CY2021, (6.60 inches more than the 28-year average of 35.00 inches).

Monthly network variability including minimum, maximum, medians, and quartiles of the previous 28-yr monthly precipitation data are shown in Figure 11, with year-29 plotted for comparison. See *Appendix B: Explanation of Box-Whisker Plots* for an explanation of how to interpret box-whisker plots. The interquartile range represents the 'middle fifty' percent of the values; or in other words, the most probable rainfalls totals for a given month. The interquartile range for each month is shown in Figure 11 as gray boxes. Months with larger interquartile range (gray box) indicates greater variability of precipitation during that month. Monthly precipitation was above the 3rd quartile (> 75 percent of occurrences) in March, August, and October. Months with precipitation below the 1st quartile (< 25 percent of occurrences) occurred in February, September, and November. When the current year's monthly precipitation values are greater or less than the interquartile range (developed over 28 years), this indicates that monthly precipitation has become more variable for that month. Monthly precipitation variability increased for 6 of the 12 months during CY2021.

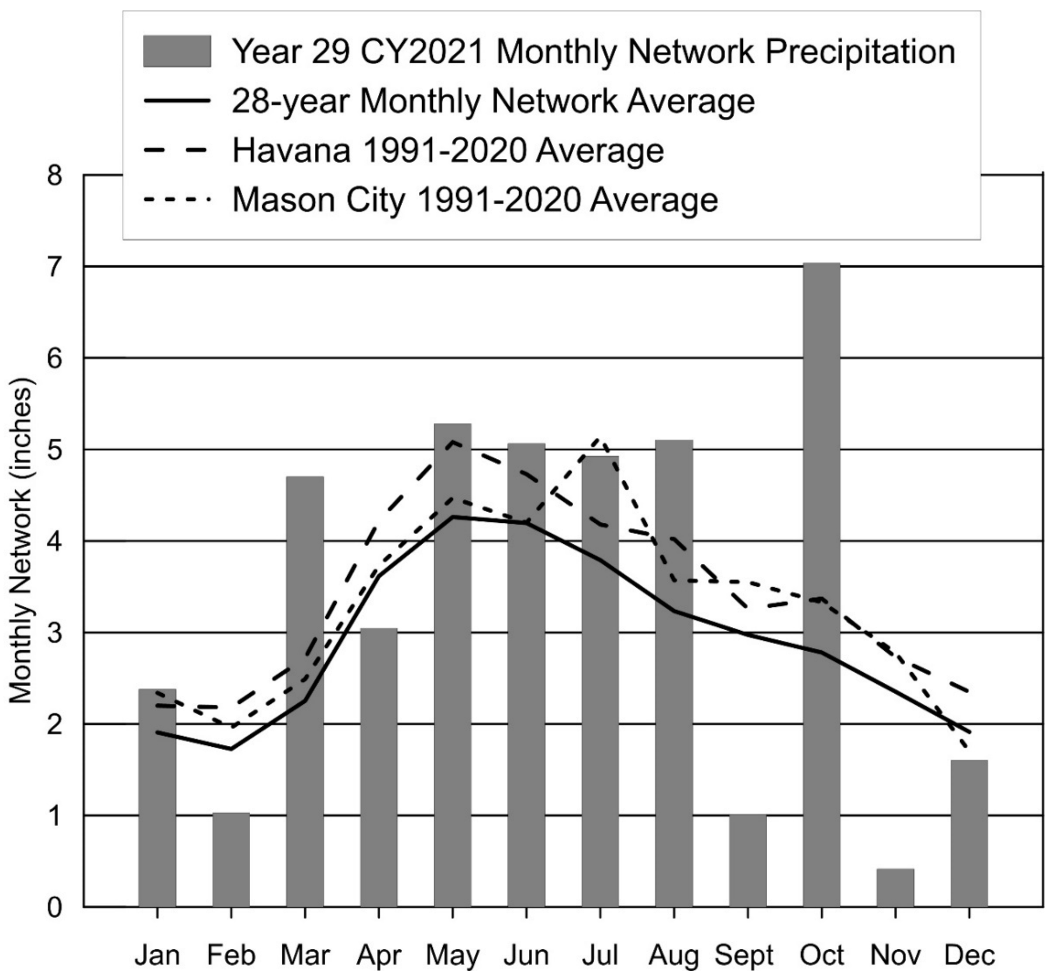


Figure 10. Monthly Comparison with 28-Year IVWA Network Average and 1991-2020 (30-Year Average) at Havana, IL and Mason City, IL Gages.

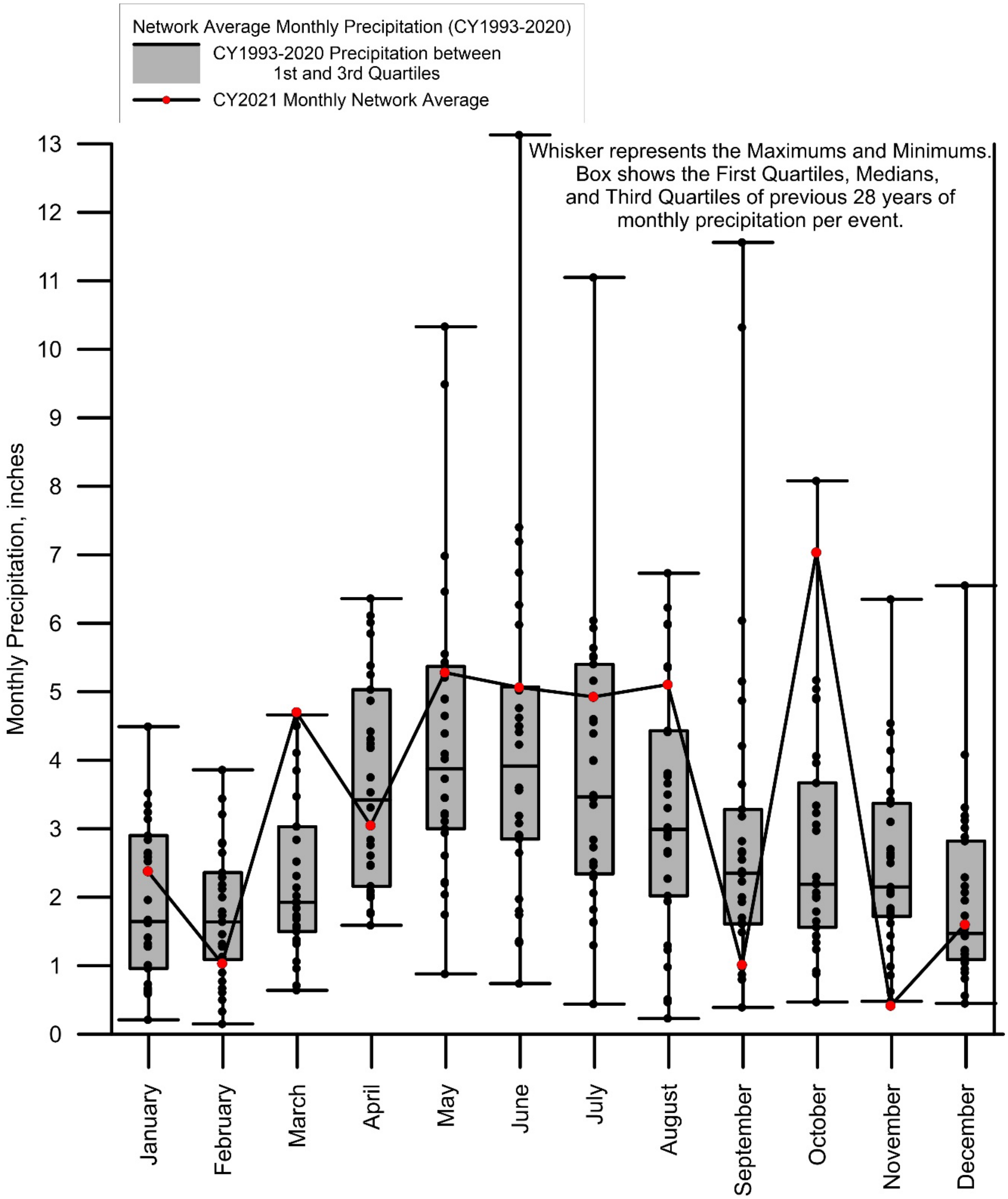


Figure 11. 28-year Monthly Average Precipitation Distribution with CY2021 Monthly Network Averages

In the following analysis, the 29-year period of record is divided into 3 periods, 1993-2001, 2002-2010, and 2011-2021. Figure 12 presents the monthly precipitation variability during these periods (represented by the box and whisker elements) in comparison to the current year's average monthly precipitation (red line). In comparing the length of the boxes (variability in total monthly precipitation for that time span), the earliest period (1993-2001) had the lowest ability, and the last period (2011-2021) has had the greatest overall variability. Monthly precipitation variability has increased for all months except for January and May. Variability of January precipitation decreased by 0.57 inches. Monthly variability for August increased the most compared to other months (3.24 inches since 2001) from the first to the third period.

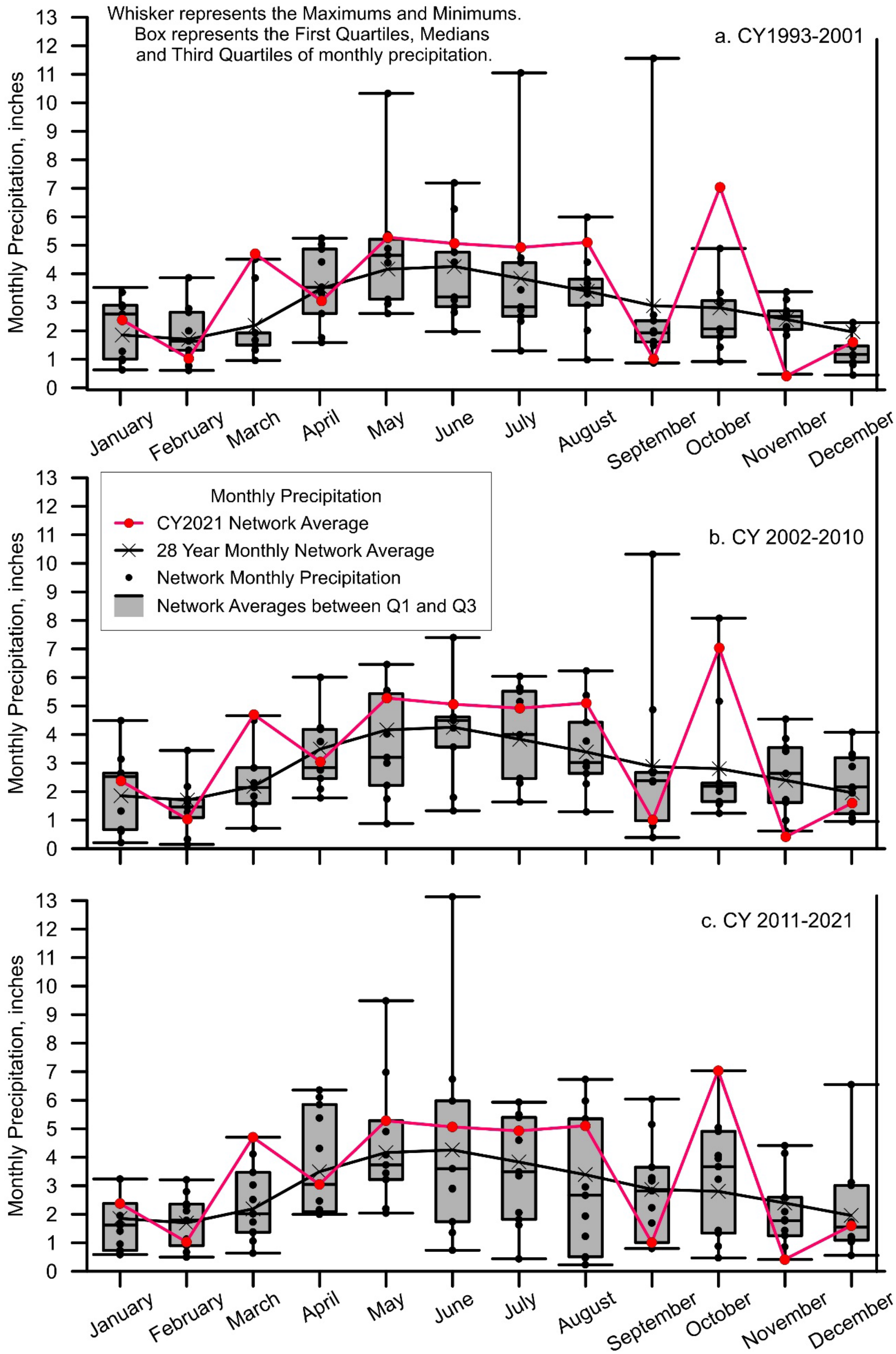


Figure 12. Monthly Box-Whisker Plots of ~9 Year Time Spans. (a) CY 1993-2001 (9 years), (b) CY 2002-2010 (9 years) and (c) CY 2011-2021 (11 years)

Mean monthly, seasonal, and annual number of network precipitation events were determined for January through December 2021 and presented in Table 2 and Figure 13. A network precipitation 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 28 years (1993-2020) is 0.29 inches per event. Calendar year 2021 received an average of 0.30 inches per event.

The Imperial Valley Water Authority precipitation network has an average of 120.6 precipitation events per year during the previous 28-years. Calendar year 2021 had 139 events which is about 15 percent more events than the 28-year average. All seasons had more events than the long-term average with September being the only month with fewer events than the long-term monthly average. March precipitation events had twice the number of inches per event and October had 84% more precipitation per event than the long-term average. May, June, July, and August (averaging ~0.42 inches per event) each had more inches per event than the 28-yr average. February, April, September, and November events saw significantly fewer inches per precipitation event than the 29-year average. February saw almost twice the average precipitation events yet averaged only 0.06 inches per event. November precipitation events produced only 0.04 inches per event in 2021.

Table 2. Comparison of Total Precipitation (inches), Number of Precipitation Events, and Average Precipitation per Event for Each Month and Season, 1993-2020 and CY2021

	1993-2020 28-yr averages			*Year 29 (CY2021)*		
Period	*Precipitation*	*Events*	*Inches/event*	*Precipitation*	*Events*	*Inches/event*
January	1.91	9.2	0.24	2.38	11	0.22
February	1.73	8.5	0.22	1.03	16	0.06
March	2.25	8.7	0.26	4.70	9	0.52
April	3.62	11.6	0.33	3.05	15	0.20
May	4.26	13.6	0.32	5.28	13	0.41
June	4.20	12.3	0.34	5.06	11	0.46
July	3.79	11.0	0.37	4.93	11	0.45
August	3.23	11.3	0.29	5.10	14	0.36
September	2.97	7.7	0.39	1.01	7	0.14
October	2.78	8.7	0.32	7.03	12	0.59
November	2.35	8.7	0.32	0.42	10	0.04
December	1.91	9.1	0.24	1.60	10	0.16
Winter	5.89	26.4	0.23	8.11	36	0.23
Spring	12.07	37.4	0.32	13.39	39	0.34
Summer	10.00	30.0	0.33	11.04	32	0.35
Fall	7.05	26.5	0.27	9.05	32	0.28
Calendar Annual	35.00	120.6	0.29	41.60	139	0.30

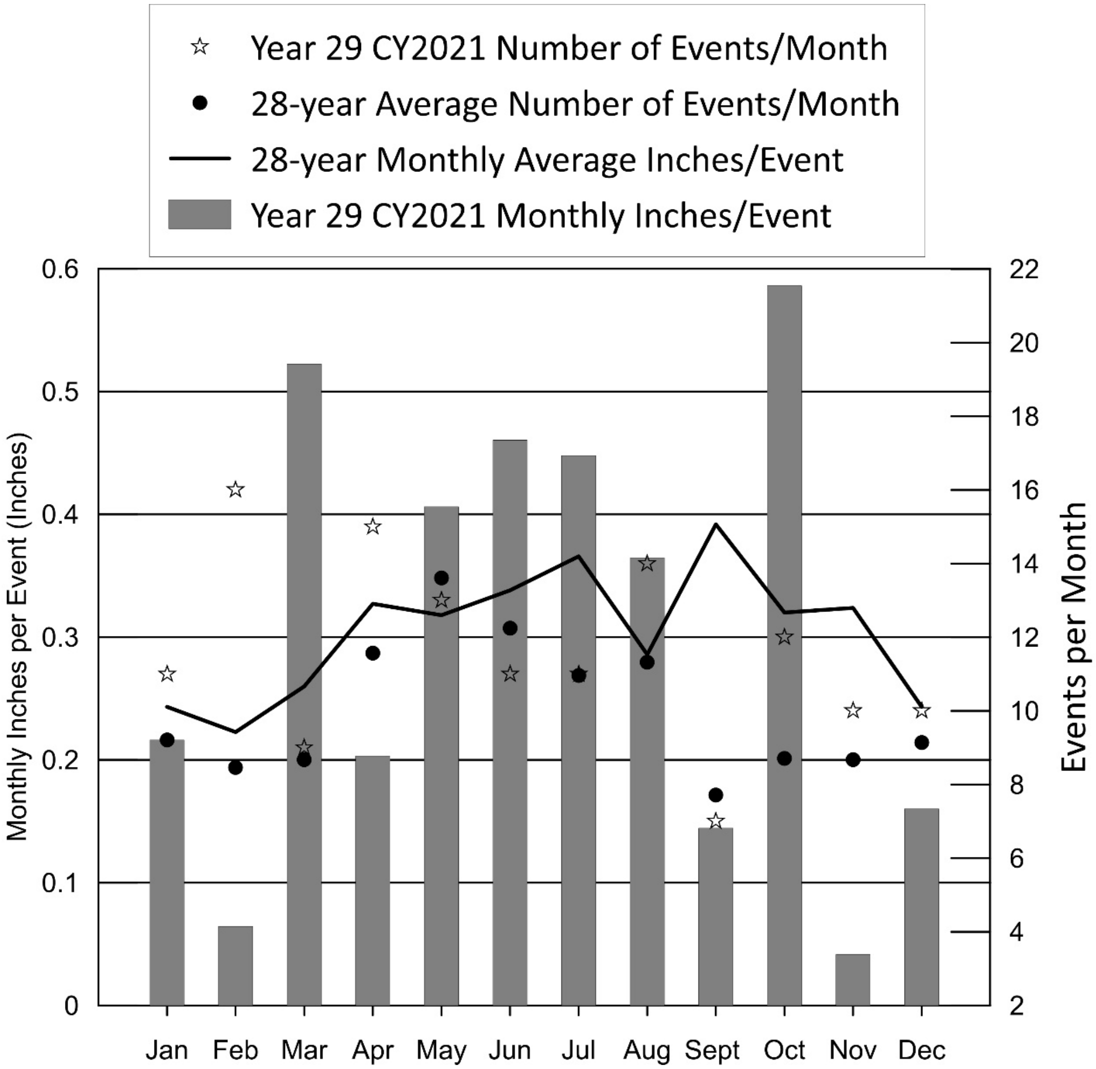
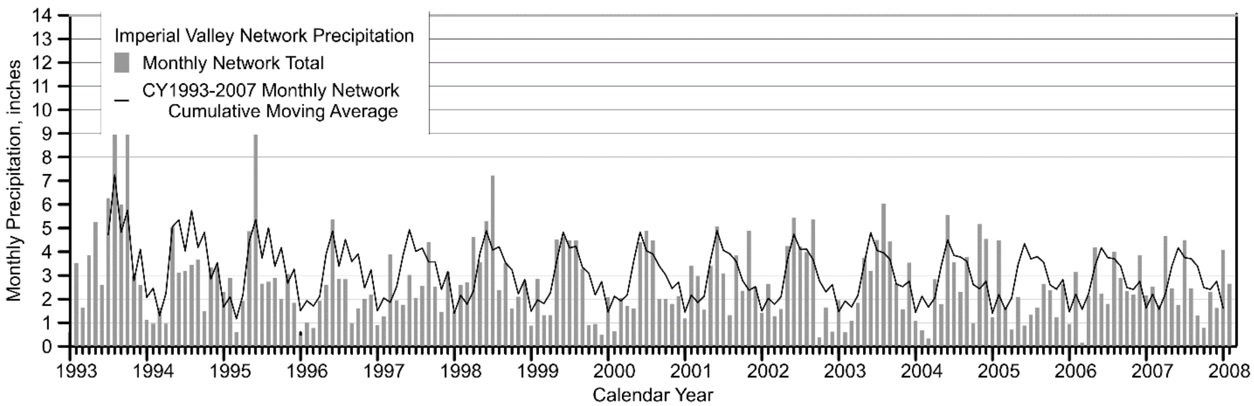


Figure 13. CY 2021 Events per Month and Inches per Month compared to 28-year (1993-2020) Averages

The following two plots in Figure 14 compare the network average monthly precipitation for January 1993 through December 2021 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 2021 is the average precipitation of Januarys 1992-2020. The change in the shape of the cumulative moving average shows how each month's precipitation affects the monthly precipitation average over time.

CY2021 network average of 41.60 was 6.60 inches wetter than the previous 28-year (1993-2020) network average of 35.00 inches. Annual precipitation in 2021 was 119% of the 28-year average. Two months had over 200% the 28-year average: March (209%) and October (253%). Five of the months had between 121% and 158% the 28-year average: for CY2021, January (125%), April (124%), May (121%), June (130%) and July (158%). For three months of 2021, the network average was less than 75 percent of average: February (60%), September (34%), and November (18%).

a.1993 – 2007



b. 2008 – 2021

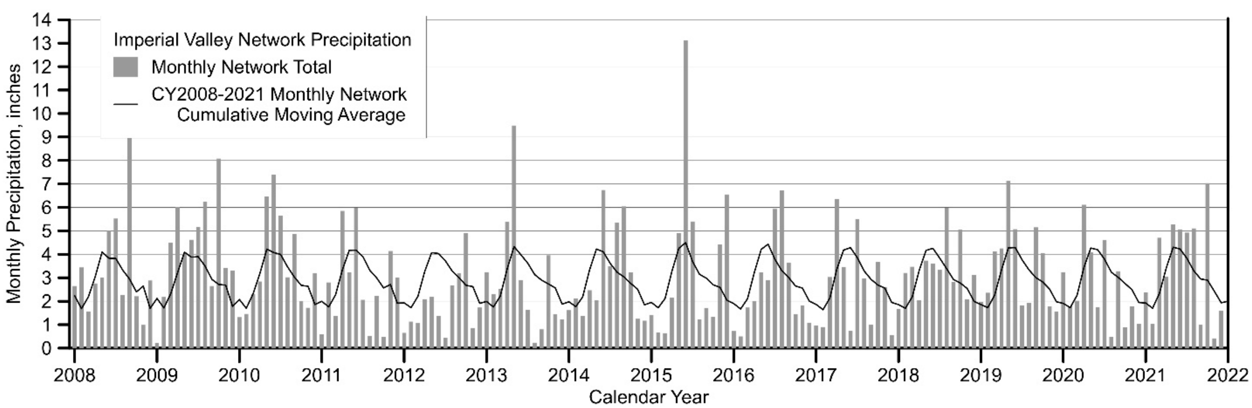


Figure 14. Network Average Monthly Precipitation (inches), a. January 1993 - December 2007, b. January 2008 - December 2021

Figure 15 compares the 29-year seasonal medians and variations with the CY2021 seasonal totals. Winter 2021 (January – March) received more rain than the 28-yr seasonal 75th quartile (more than 75% of the other winters) with over half the winter precipitation arriving in March after an extremely dry February. Spring (April – June) and summer (July – September) seasonal totals were greater than their season long-term median and within the middle 50% for those seasons even though April and September totals were well below average. October 2021 was the second wettest October since 1993 accounting for 7.03 inches (78%) of fall's 9.05 inches of precipitation (October – December). This abnormally high October 2021 precipitation is only slightly less than the entire fall season's long-term average, which contributed to the 2021 fall seasonal being in the top 25% of all fall precipitation totals (despite 2021 being the lowest precipitation for November ever recorded by the IVWA network).

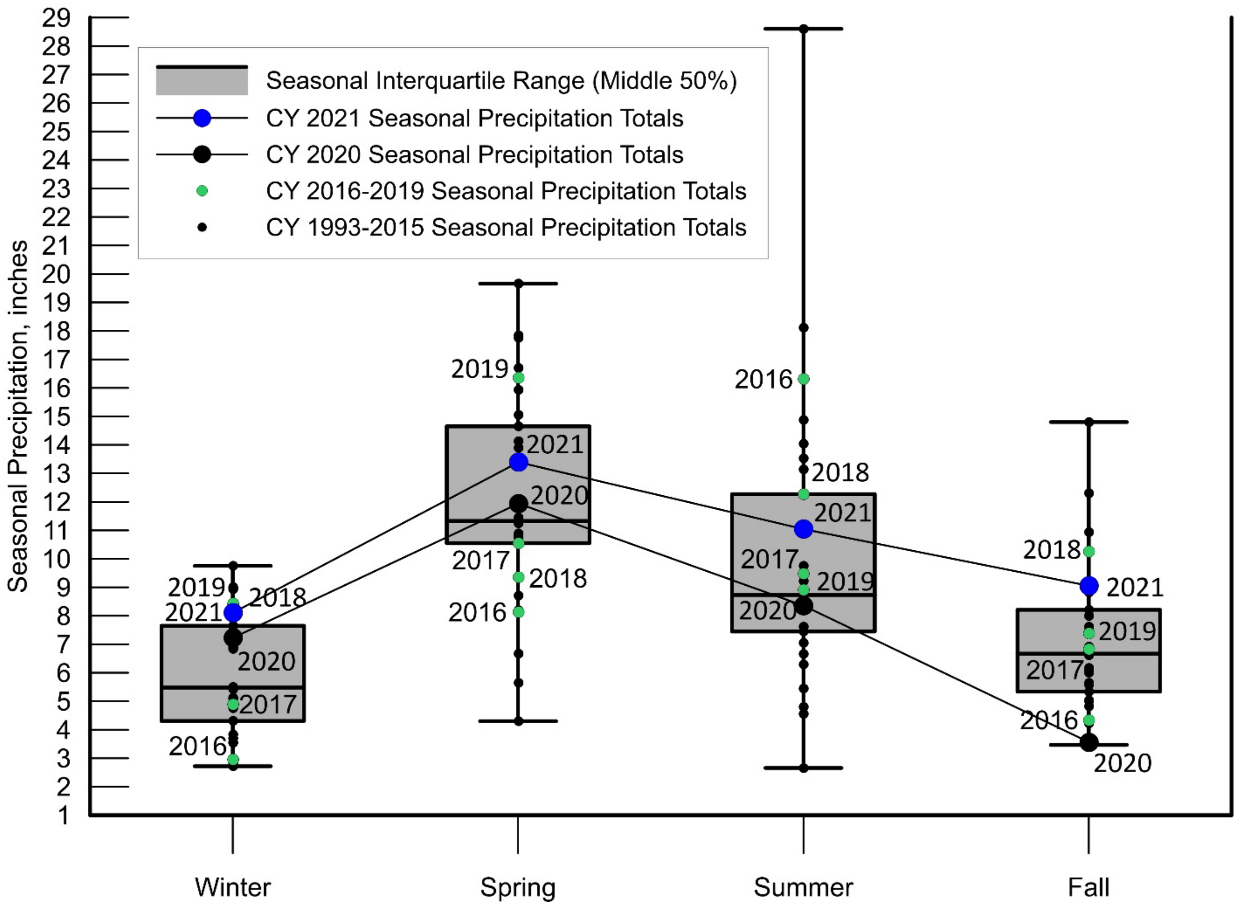


Figure 15. Seasonal Network Average Precipitation with Seasonal Totals for Each Calendar Year. Box Plots Show the Interquartile Range (Middle 50% of Values, Median (horizontal line within the box), Minimum, and Maximum Values at whisker ends.

Irrigation Water Use

The IVWA has provided the ISWS monthly estimated total of irrigation withdrawals since 1997. These data are calculated by the IVWA using power consumption data 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 2021 was approximately 47.4 billion gallons (bg), which is the twelfth highest irrigation amount for the observation period. In CY 2021, there were 2,302 known irrigation systems in Imperial Valley. The ISWS has recently completed efforts to generate an updated irrigation map for the IVWA area based upon 2017 aerial imagery. Figure 16 shows the location of center pivot irrigation systems in the IVWA study area. This work shows the number of center pivots to have increased between the years assessed (2012, 2014, and 2017).

The monthly estimates of irrigation withdrawals during the growing season are shown in Table 3; the right-hand column shows the ranking of total estimated gallons pumped from highest to lowest. CY2021 was near the middle, ranking twelfth overall with 47.4 bg pumped for the year. The higher-than-median precipitation during each season of CY2021 meant irrigation was not heavily relied upon. Still, the timing of precipitation—more in the winter and fall—meant that above average precipitation did not translate to below average irrigation as might be expected. Spring and early summer irrigation withdrawals were below average for May, June, and July. In August and September irrigation was higher than average at 36 % and 27% higher than average respectively. October returned to below average withdrawals.

Note that during CY2021, pumpage was also recorded for April and November and that this pumpage is included in the CY2021 annual total. This has not been necessary for past years; Table 3 may be reformatted in subsequent reports if this atypical pumpage continues.

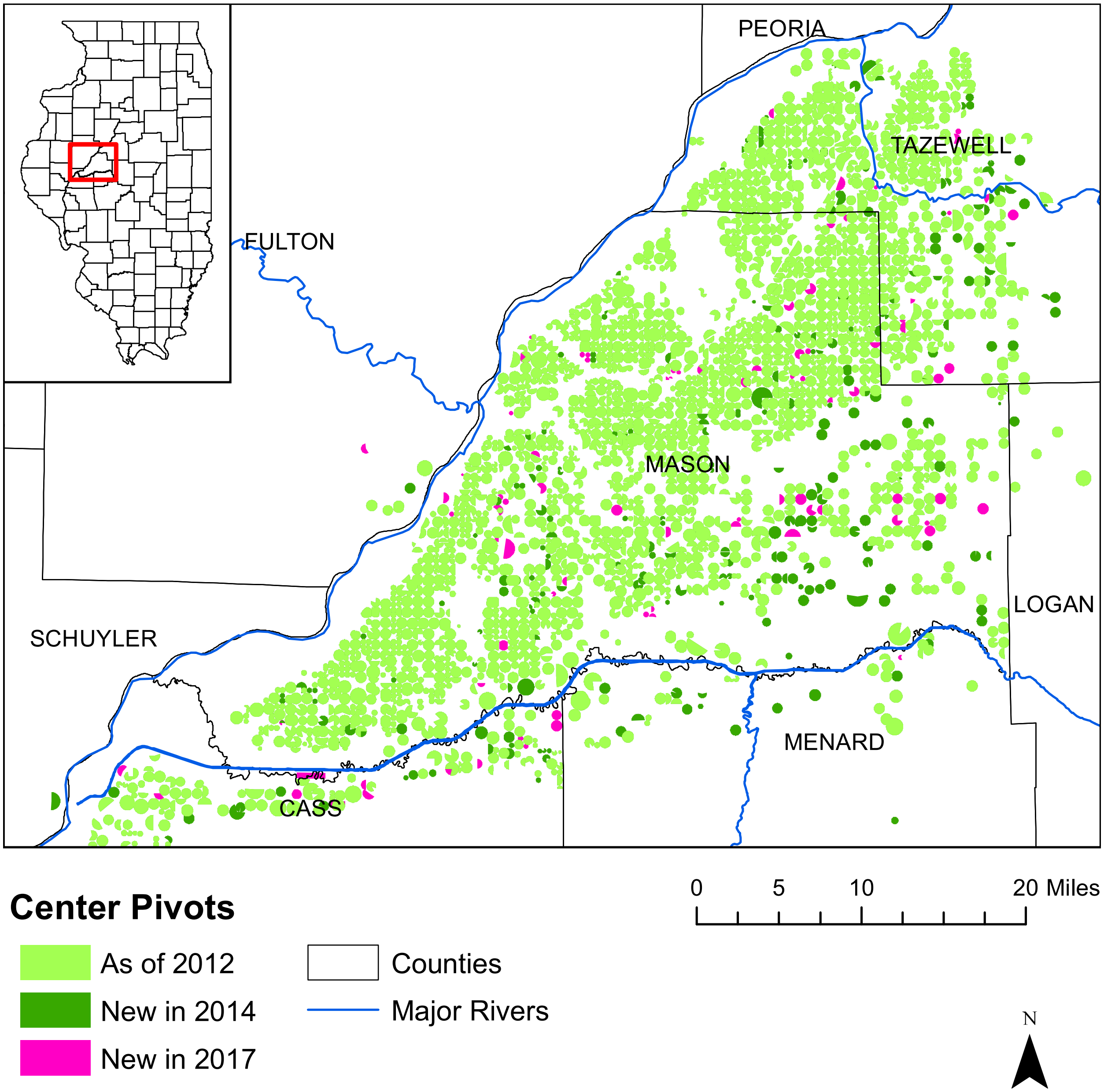


Figure 16. Location of Irrigation Systems within the IVWA in 2012, 2014, and 2017.

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*	*#*	*BG/system*	*Rank*
1995	2.6	14	10	11			37.6			20
1996	2	20	18	12			52.0			10
1997	2.6	19	14	2			37.6			20
1998	2.1	7.8	13	6.9			29.8	1622	0.018	25
1999	2.8	18	12	6			38.8	1771	0.022	19
2000	6.4	6	12	5.6			30.0	1799	0.017	24
2001	4.4	21	17	5			47.4	1818	0.026	12
2002	3.4	24	16	3.7			47.1	1839	0.026	14
2003	4.1	16	15	10			45.1	1867	0.024	15
2004	5.3	12	19	5.7			42.0	1889	0.022	17
2005	15	29	23	4.8			71.8	1909	0.038	2
2006	7.2	22	16	5.2			50.4	1940	0.026	11
2007	16	17	19	4.9			56.9	1971	0.029	6
2008	1.2	10	14.5	7.1			32.8	2014	0.016	22
2009	1.6	9.3	12.1	2.9			25.9	2054	0.013	27
2010	1.8	2.4	11.7	10.6			26.5	2077	0.013	26
2011	0.7	2.5	24.7	19.6	5		52.5	2100	0.025	8
2012	12.3	26.4	39.7	17.4	2.2		98.0	2160	0.045	1
2013	0.7	4.8	25	27.2	9.4		67.1	2293	0.029	3
2014	4.7	9.2	16.3	8.2	1.1		39.5	2169*	0.018	18
2015	1.6	2.2	9.8	17	0.9		31.5	2197	0.014	23
2016	2.8	23.4	10.9	6.6	1.4		45.1	2223	0.02	15
2017	1.7	22	17.3	14.2	6.2		61.4	2237	0.027	5
2018	6.5	16	19.3	8.7	1.6	0.3	52.1	2252	0.023	9
2019	0.5	4.2	25.5	18.1	4.3	0.3	52.6	2262	0.023	7
2020	0.5	15.2	19.6	22.8	4		62.1	2263	0.027	4
2021	0.6	13.5	14.2	14	4.7	0.2	47.4	2302	0.021	12
Average	4.1	14.3	17.2	10.3	3.7	0.3	47.4		0.023	

Note: During 2021, pumpage for April (0.01 bg) and November (0.2 bg) was recorded and these months are included in the annual total withdrawal.
*Total number of systems was updated during June 2014 by ISWS using aerial photography.

The estimated monthly irrigation pumpage is displayed graphically in Figure 17 along with average monthly network precipitation. These pumpage values show a tendency for lower irrigation amounts during times of increased 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 precipitation and irrigation rankings in Table 4 are both from highest to lowest.

In many years, the total precipitation is not a good indicator for how much irrigation was necessary. The magnitude and timing of rainfall events can greatly affect how much irrigation is needed. CY2021 ranked as the sixth highest network average precipitation of the 29-year record while irrigation withdrawals were nearly average. The timing of precipitation in CY2021 saw a wet March and October while the intervening period, largely the growing season, saw above-average rainfall. Rainfall and irrigation demands are better understood by examining the timing of precipitation during the growing season.

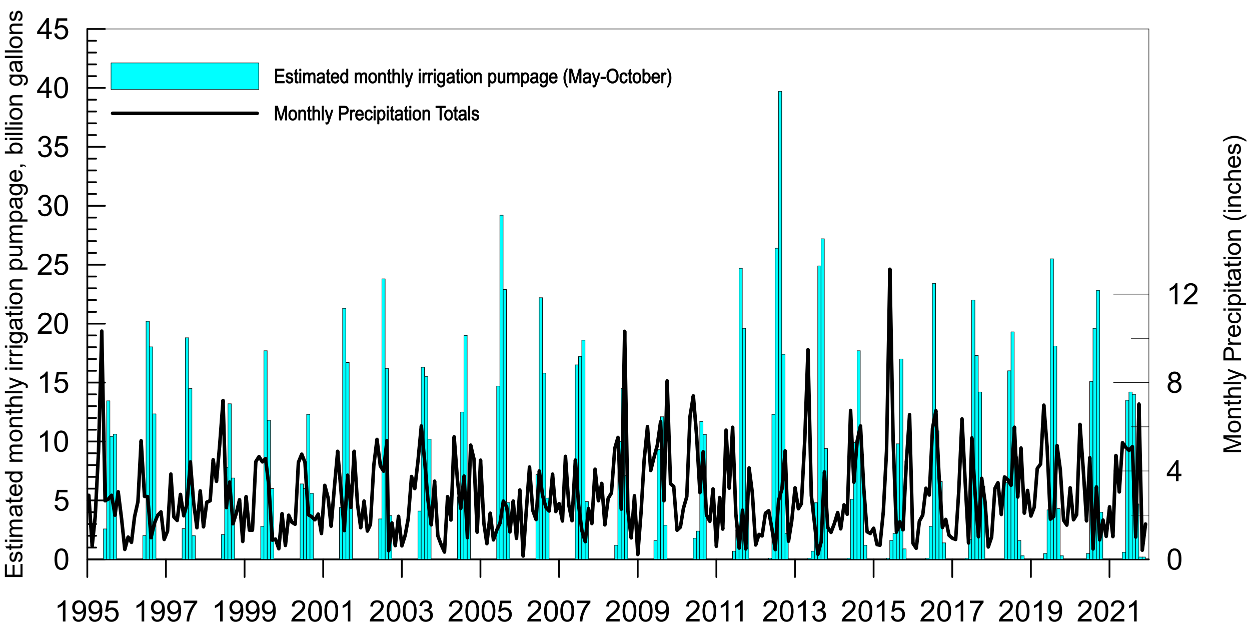


Figure 17. Estimated Irrigation Pumpage and Average Monthly Precipitation, IVWA.

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

Calendar Year	*Network average precipitation (in.)*	*Annual surplus (in.)*	*Est. total irrigation (billion gallons)*	*Rank*	
				Precipitation	*Irrigation*
1993	58.41	18.26	-	1	-
1994	32.48	-7.67	-	17	-
1995	36.27	-3.88	37.6	11	20
1996	25.03	-15.12	52.0	27	10
1997	29.20	-10.95	37.6	25	20
1998	38.71	-1.44	29.8	9	25
1999	31.16	-8.99	38.8	21	19
2000	28.40	-11.75	30.0	26	24
2001	35.19	-4.96	47.4	12	12
2002	33.37	-6.78	47.1	15	14
2003	34.30	-5.85	45.1	14	15
2004	32.72	-7.43	42.0	16	17
2005	22.63	-17.52	71.8	28	2
2006	31.06	-9.09	50.4	22	11
2007	30.18	-9.97	56.9	24	6
2008	42.62	2.47	32.8	4	22
2009	50.39	10.24	25.9	2	27
2010	42.24	2.09	26.5	5	26
2011	32.23	-7.92	52.5	18	8
2012	22.28	-17.87	98.0	29	1
2013	35.09	-5.06	67.1	13	3
2014	36.90	-3.25	39.5	10	18
2015	43.54	3.39	31.5	3	23
2016	31.74	-8.41	45.1	19	15
2017	31.74	-8.41	61.4	19	5
2018	40.11	-0.04	52.1	8	9
2019	41.08	0.93	52.6	7	7
2020	31.04	-9.11	62.1	23	4
2021	41.60	1.45	47.4	6	12

***Past versions of this table assessed precipitation by water year (October-September) for CY2021, this data has been reorganized by calendar year (January-December).**

1991 - 2020 30-yr average	**41.04 (Havana)**
1981 - 2010 30-yr average	**39.26 (Mason City)**
1981 - 2010 30-yr average	**40.15 (average of Mason City and Havana used to determine surplus)**
1993 - 2021 29-yr average	**35.23 (29-year IVWA network CY average)**

Groundwater Levels

In an unconfined groundwater system, like the Mahomet Aquifer in the Imperial Valley, water levels typically vary by season. The Mahomet Aquifer generally experiences its highest water levels in the study area during the spring and the lowest water levels 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. Precipitation is not high enough during this time to offset these processes and raise water levels in the aquifer. Most rainfall goes to replenish soil moisture which may eventually percolate deeper and replenish groundwater levels for subsequent irrigation withdrawals. Significant recharge to the aquifer occurs most often during winter and early spring months when there is little pumpage, temperatures—and therefore evapotranspiration—are low, and soil moisture is therefore more likely to be high. Overall, the recorded water levels from CY2021 do not indicate a significant increase or decrease in water levels, though many observation wells ended the year with higher-than-usual water levels after the significant October 2021 precipitation.

Observations from hourly hydrographs

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 CY2021 (January 1, 2021 to December 31, 2021), and contain all groundwater elevation or depth to water from land surface data as well as daily precipitation totals for those wells with rain gages nearby. The hydrographs created from hourly water level measurements have led to an increased understanding of the relationship between rainfall, irrigation, water levels, and recharge. They have also raised more questions which modelers at the ISWS are attempting to understand better.

MTOW-01A: The long-term hydrograph at MTOW-01A (Snicarte, 1958 to present) in Figure 18 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 2008 is shown in Figure 19. During the 1988-1989 drought, the water level fell to 40.5 feet below land surface in the Snicarte well. At the time, this was the only record of the well going dry in the Snicarte well's then 45-year history, 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. CY2021 saw above average water levels, but well below the highest peaks of the historic record such as 1993 and the period marked with "Groundwater Flooding" from approximately 2009-2011.

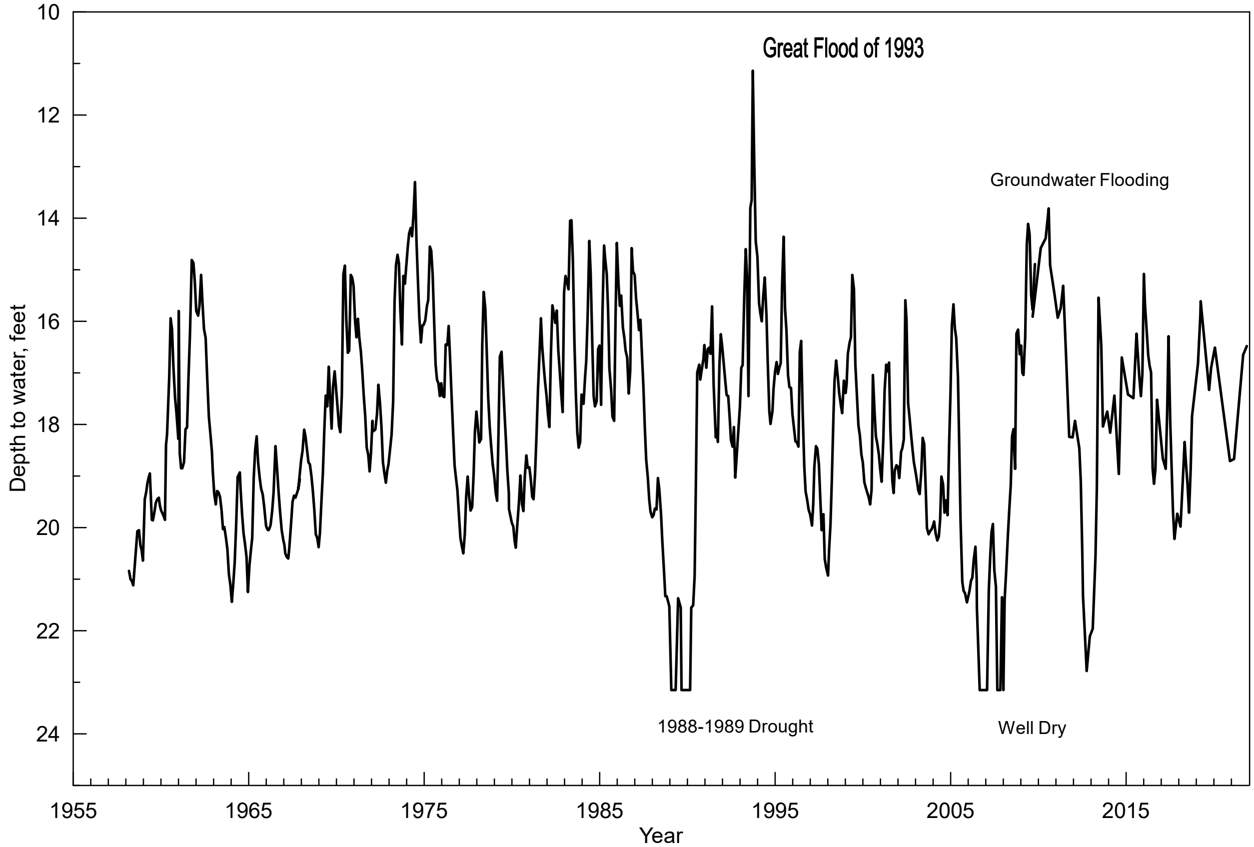


Figure 18. Groundwater Levels at the Snicarte Well (MTOW-1a), 1958-2021.

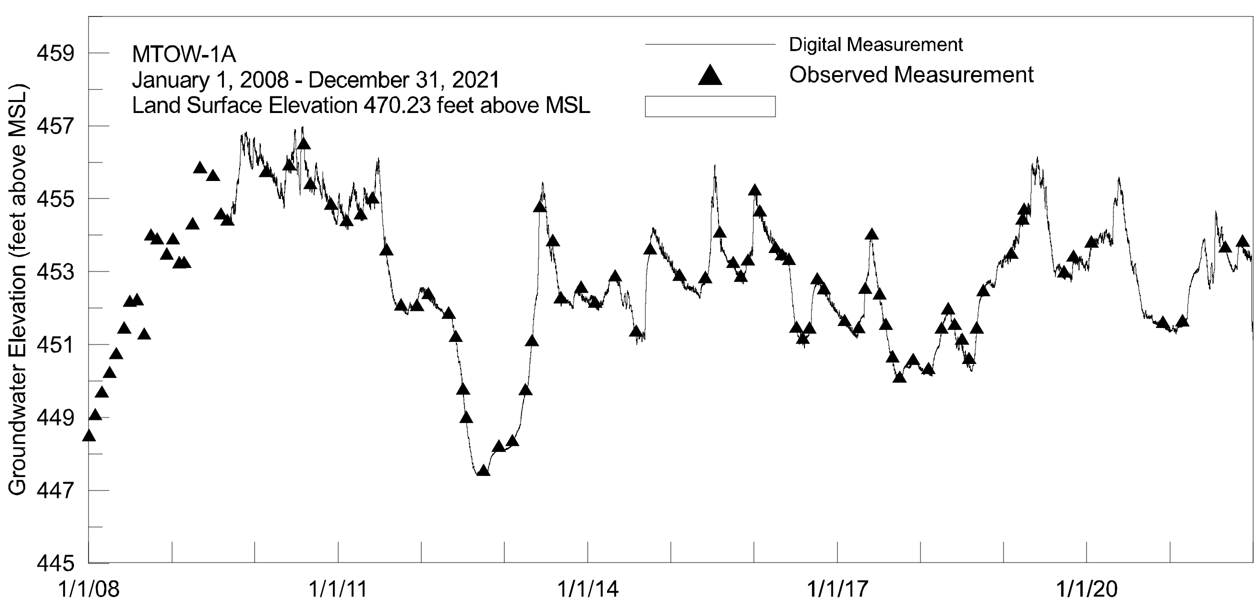


Figure 19. Groundwater Levels at the Snicarte Well (MTOW-1A), 2008-2021.

MTOW-02: Figure 20 shows the record of water levels for MTOW-02 during CY2021. An event similar to the June 1995 event occurred during October 2021. Water levels reached a peak of 509.46 ft, only 0.12 ft from land surface. 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 in an unconfined aquifer.

Please note that the October 2021 increase in water levels at MTOW-02 is remarkable, and not normally observed in similarly situated groundwater monitoring wells. While the sharp increase and slow recession certainly could be real, the ISWS has plans to investigate the integrity of the casing with a downhole camera and conduct a slug test on this well in the summer of 2022. These analyses will assist in determining if the well might have any alternative pathways of water to enter, like a degraded casing or pooled water at land surface during storm events, and that the well screen has not become clogged.

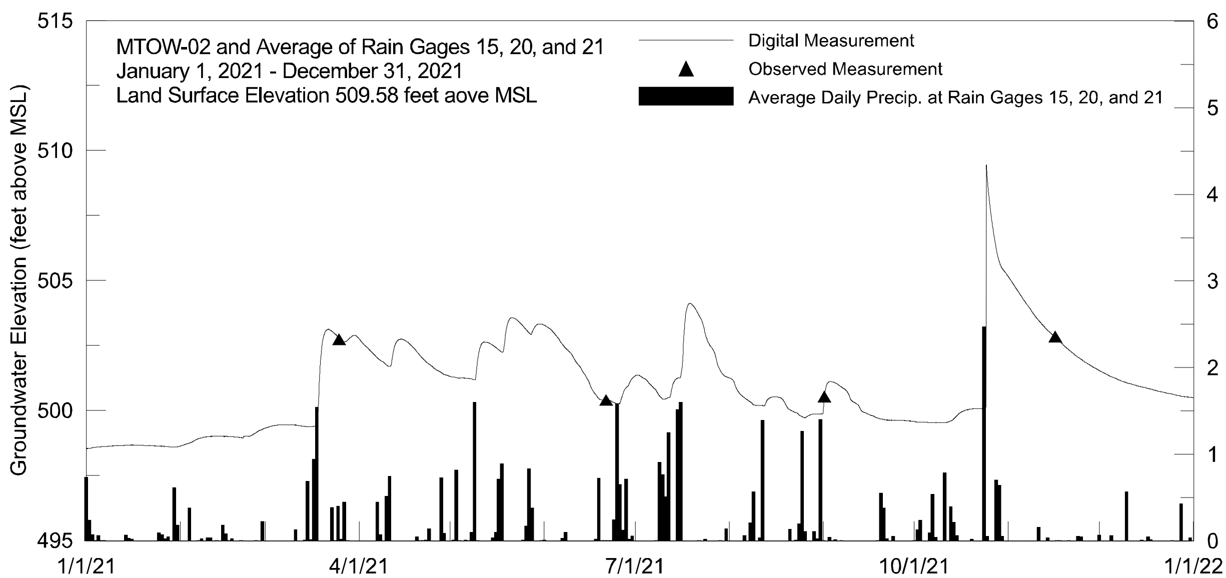


Figure 20. Groundwater Elevations at the Easton well, MTOW-02 and averaged precipitation at Rain Gages 15, 20, and 21, January 1, 2021 - December 31, 2021

MTOW-08: Figure 21 shows the entire period of record for MTOW-08, located within the village limits of Green Valley, IL. The highest observed head at this well occurred on June 27, 2010, with an elevation of 519.34 ft, 15.85 ft from land surface. In contrast, the lowest water levels were observed on March 11, 2013 at 504.82 ft, 27.17 ft from land surface. The difference in the maximum and minimum water level in 2021 was approximately 1.4 ft. For comparison, the difference between the lowest water level in the wake of the 2012 drought and the highest coming out of the drought, after several major precipitation events was 9.79 ft.

In Figure 22, which shows the response in water levels due to precipitation events in 2021, the relationship between rainfall and recharge is not easily observed as groundwater levels declined during some periods of heavy precipitation (for example, in the fall). Most of the events are very subdued and increases in water levels occur over months. The ISWS is currently working to model this event to try to better understand drivers of recharge in the Imperial Valley area. The leading hypothesis is that the combination of magnitude (~1.5 inches) and duration of the rain event (4-5 days) in late April/early May led to the more rapid response in groundwater levels.

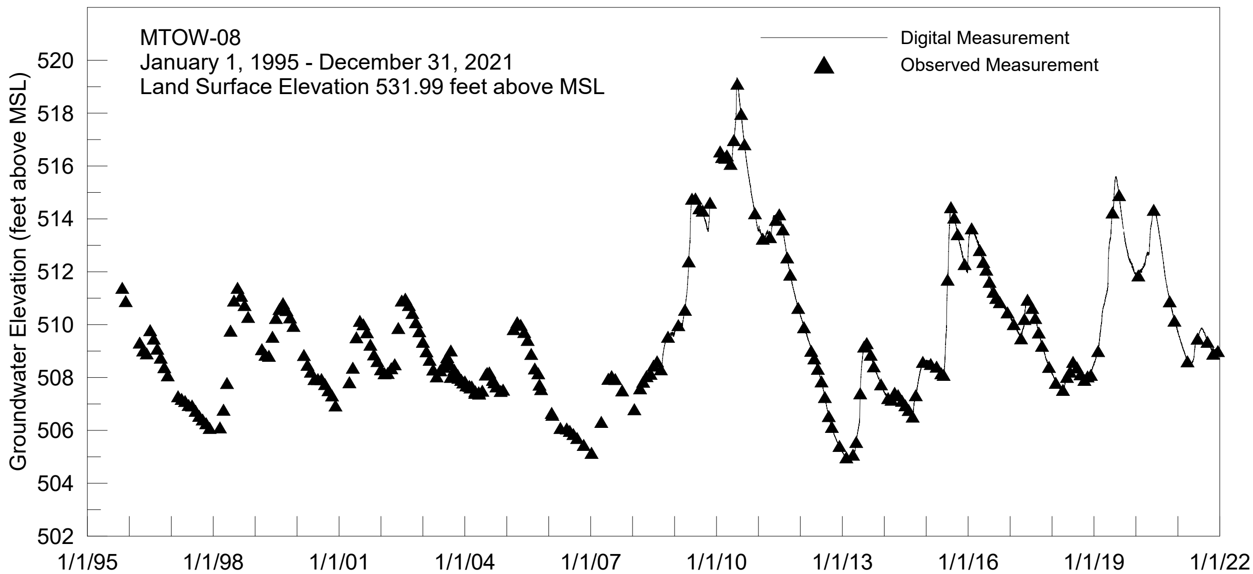


Figure 21. Groundwater Elevations at the Green Valley Well, MTOW-08, January 1, 1995-December 31, 2021.

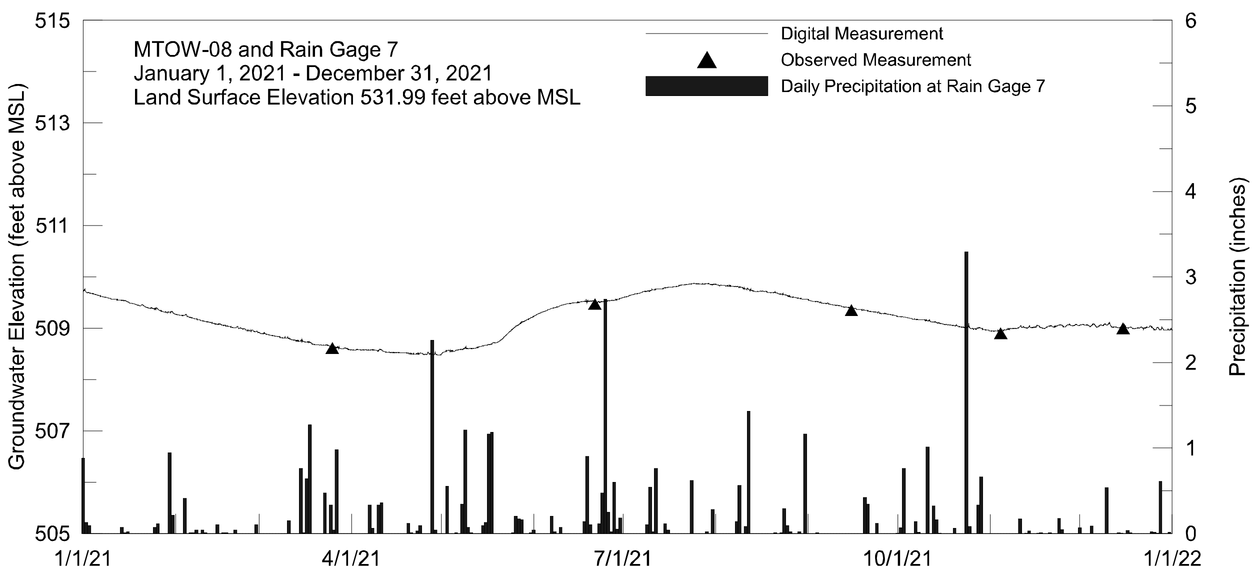


Figure 22. Groundwater Elevations at the Green Valley Well, MTOW-08 and precipitation at Rain Gage 7, January 1, 2021 - December 31, 2021

MTOW-17: MTOW-17 is a unique well in that it is within a few feet of an active irrigation well, allowing for a fine-scale understanding of the local impacts of irrigation. As seen in Figure 23, the impact of pumping on aquifer water levels is evident. Each "downward spike" on the hydrograph (seen from approximately June through September) is a pumping event from the nearby irrigation pivot. Each pumping event causes a short-term drawdown of about three feet after which water levels return to near-pre-pumping levels (usually within one foot).

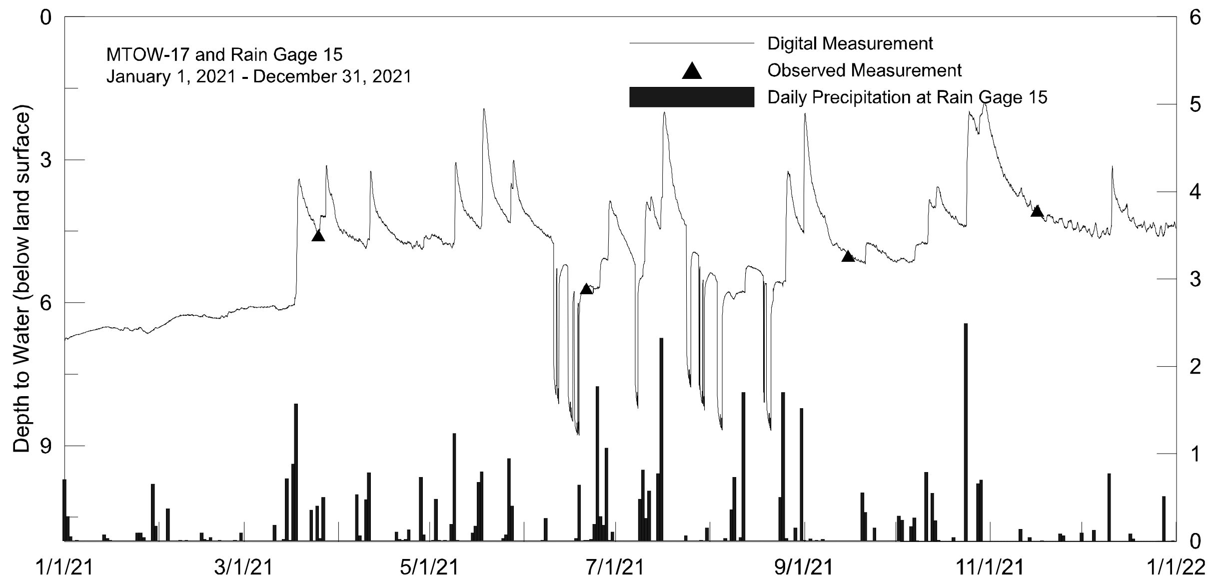


Figure 23. Groundwater Elevations and Precipitation at the Biggs Well, MTOW-17, January 1, 2021-December 31, 2021

MTOW-18: During 2021, MTOW-18 was added to the IVWA observation well network. MTOW-18 (a.k.a. Robinson Farm), much like MTOW-17, is an inactive 14 inch well located within a few feet of an active irrigation well. A digital datalogger and cell were installed on December 10, 2021. Because of the small amount of data available, a hydrograph was not created for this CY2021 report.

Non-contract related work at the Illinois State Water Survey

As part of ongoing efforts to make our data more accessible to the public, the ISWS has brought online two resources for the public to view groundwater data. The first is a monitoring network page specific to the IVWA groundwater well network that has direct links to the data by site:

> https://prairie-research.maps.arcgis.com/apps/webappviewer/index.html?id=5c9afbf271534bbf9f5cafed152440d4

The second is a more general mapped product that contains all of the ISWS monitoring wells across the state (and more!) with links to the same data (accessed after clicking on the wells):

> https://www.isws.illinois.edu/groundwater-science/groundwater-monitoring-well-networks/imperial-valley

In 2021, the ISWS started the process of updating the Mahomet Aquifer model, last published in Roadcap et al. 2013. In that version of the model, pumping was averaged over annual time steps (referred to as stress periods in the model). In this new version of the model, each year is broken up into two stress periods: four months from mid-May through mid-September where irrigation wells are active, and eight months where they are not active. As part of preliminary analysis of this new model operation, we investigated the stress period representing the year 2020 to see how much water levels changed from before and after the irrigation season. Figure 24 shows this change where darker green colors represent more drawdown (deepening water level) over the season. In the Imperial Valley Water Authority region, CY2020 water levels changed by less than five feet when comparing to springtime (pre-irrigation) and peak irrigation conditions. This five foot maximum variation is similar to what we have observed as the annual variation at the Biggs well. More detailed, fine tune calibration will be focused on in 2022, with a particular emphasis on changing river conditions.

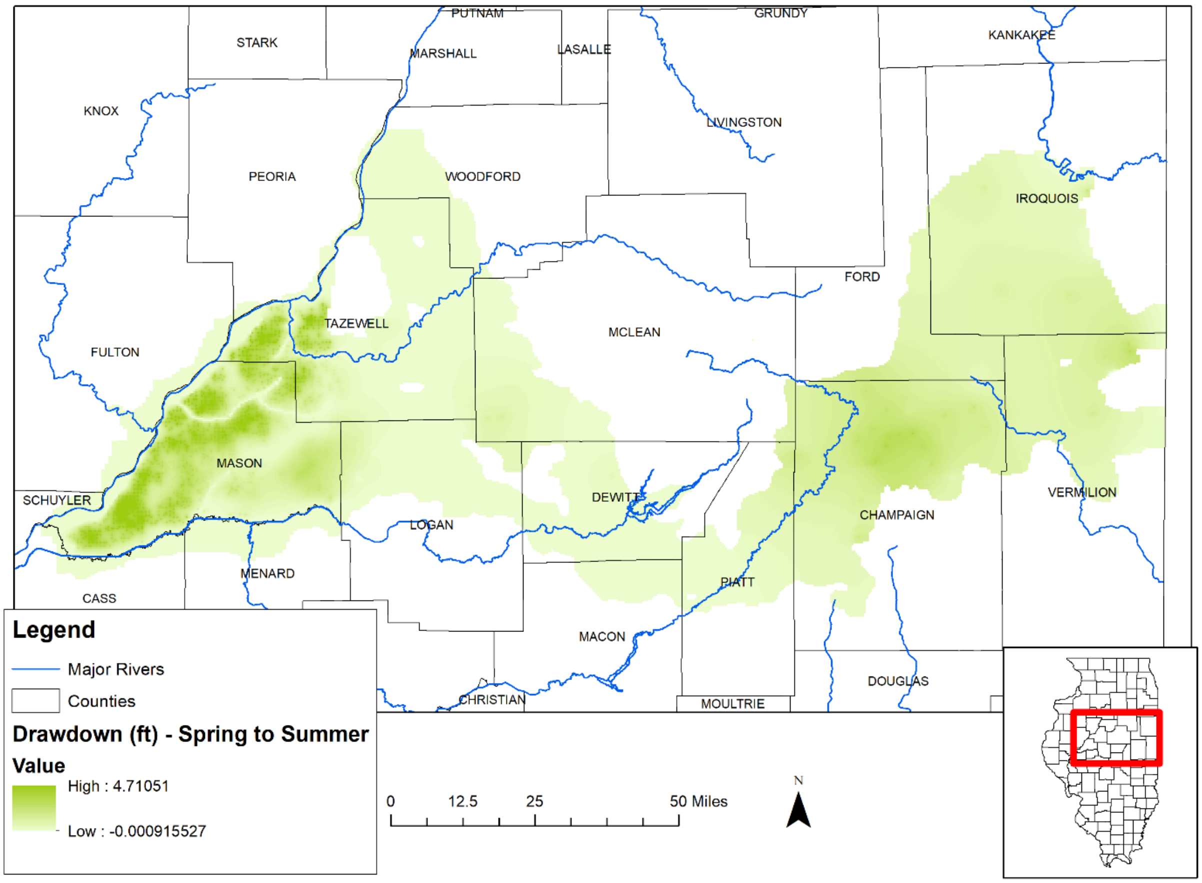


Figure 24. A map showing modeled drawdown within the Mahomet Aquifer for 2020 from pre- to post-irrigation season (positive values represent a decline in water levels).

The IVWA observation well network provides continuous water level measurements at 13 locations throughout the Imperial Valley. To obtain a wholistic, regional, hydrologic characterization, *spatial interpolation* methods estimate water level conditions between these observation points. Traditional spatial interpolation techniques do not incorporate important hydrogeologic aquifer properties such as geology (e.g., sandy or clayey substrate), nearby rivers, and land surface elevations which may impact water table elevations. Another method for estimating water levels throughout the region is to construct a traditional groundwater flow model. However, to ensure the model accurately depicts the aquifer conditions, the model would require precise records of aquifer withdrawals (location, timing, and amount), which is unavailable in the Imperial Valley. To provide improved calculations of regional hydrogeologic conditions in the Imperial Valley, the ISWS is developing a modeling framework (often referred to as the "Head-Specified Model" or HSM) that combines observations from the IVWA monitoring network with geologic parameters calibrated in traditional geologic models. As a result, the HSM provides an improved estimate of regional water levels by incorporating regional hydrogeology, while requiring less data about regional aquifer withdrawals. The ISWS hopes to publish this work soon in a scientific journal; the resulting manuscript will be shared with the IVWA.

The ISWS is involved in a project in McLean county in Lexington, IL that focuses on water balances in an agricultural site. The ISWS's work involves modeling an approximately one-half square mile irrigated and tile drained field and the deployment of sensors for the purpose of characterizing the tile drain system. This project will help to better understand the roles of irrigation, precipitation, soil type, soil moisture, and tile drainage in groundwater recharge and will thereby improve modeling practices. Lessons learned from this work may be helpful in improving modeling accuracy in irrigated agricultural landscapes like the IVWA study area and may allow for better informed predictive scenario modeling.

Summary

During calendar year 2021 (CY2021), the Imperial Valley Water Authority rain gage network received 41.60 inches of precipitation, 6.60 inches more precipitation than the 28-year network average of 35.00 inches. Before 2018, years with more precipitation generally resulted in less irrigation. However, in 2018, 2019, and 2021, precipitation and irrigation amounts were both above average. During the last 10 years, the variability in amount of monthly precipitation in the growing season has increased. Some months have received much less precipitation than usual and other months received much more precipitation than usual. When this happens during the same year the annual precipitation totals do not provide a clear picture of water needs. Larger precipitation events during the summer have occurred earlier or later than normal in the season, while critical growing months have had less precipitation leading to more irrigation to support crops. During CY2021, March was the wettest March, and October the 2nd wettest October, while November was the driest November in the last 29 years. Monthly precipitation totals for May – August were above average, therefore, analysis of the timing and intensity of precipitation events bears closer investigation.

CY2021 saw an increase in irrigation systems from 2,263 in CY2020 to 2,302 systems in CY2021 (an increase of 39). This increase is the largest since 130 were added in CY2013 in the wake of the 2012 drought. It is unclear if these increases are driven by the adoption of new management practices, changes in the economic landscape, or changes in precipitation totals and/or timing. The total estimated groundwater withdrawals in CY2021 were the 12th highest overall coming in just below the 29-year average at 47.4 bg. Water levels within the aquifer are continuing to be evaluated as data is collected. CY2021 did not show any significant increases or decreases in water levels across the observation well network.

The measurements collected by the IVWA precipitation and groundwater observation networks over the past 29 years have proven to be a valuable data set for better understanding the groundwater system in the Imperial Valley and the Mahomet Aquifer as a whole. The partnership of the IVWA and ISWS helps to ensure the aquifer's continued productivity today and into the future. In addition to this very direct and practical purpose, these observation networks have also served as an excellent test bed for research at the ISWS and its efforts to better understand systems like the Mahomet aquifer—which are critical natural resources for supporting agriculture here in Illinois and across the globe.

Complementary groundwater flow modeling efforts are ongoing, in collaboration with the Illinois Department of Natural Resources Office of Water Resources. These models are intended to evaluate seasonal trends in groundwater throughout the state and assess the impact of future demand scenarios on available supply. This modeling will include updates to Roadcap et al. (2013) and the head specified models. IVWA will have the opportunity to review all updated model results in advance of their publication; this local stakeholder feedback is essential in the modeling process.

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

Sincerely,

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Appendix A. Hydrographs, Imperial Valley Observation Well Network

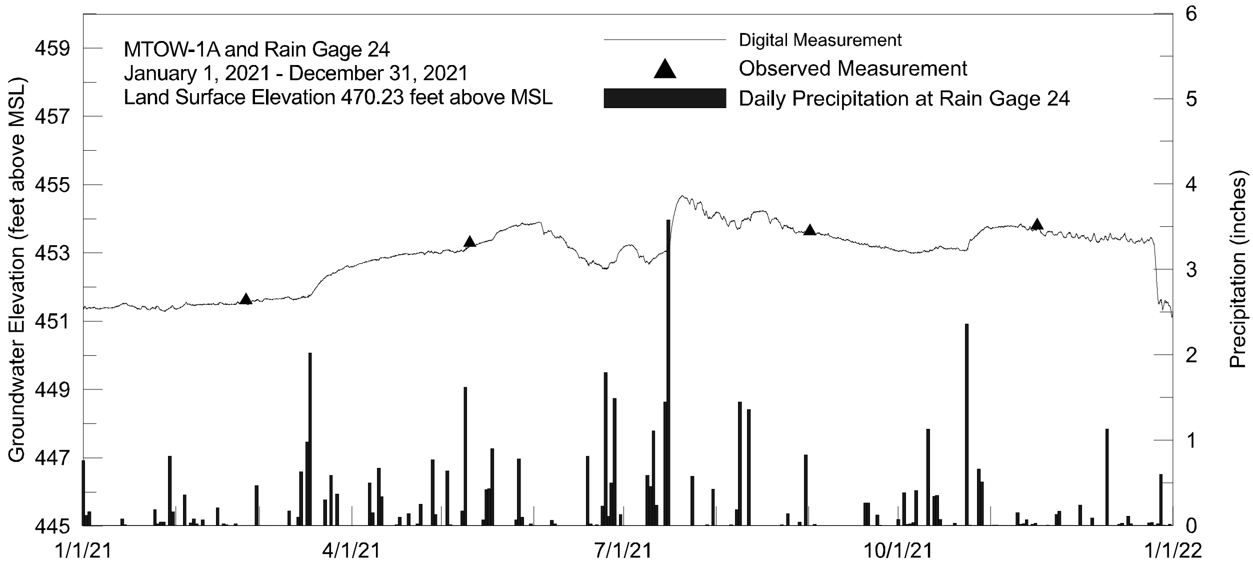

Figure A-1. Year 29 Groundwater Elevation and Precipitation for MTOW-01A

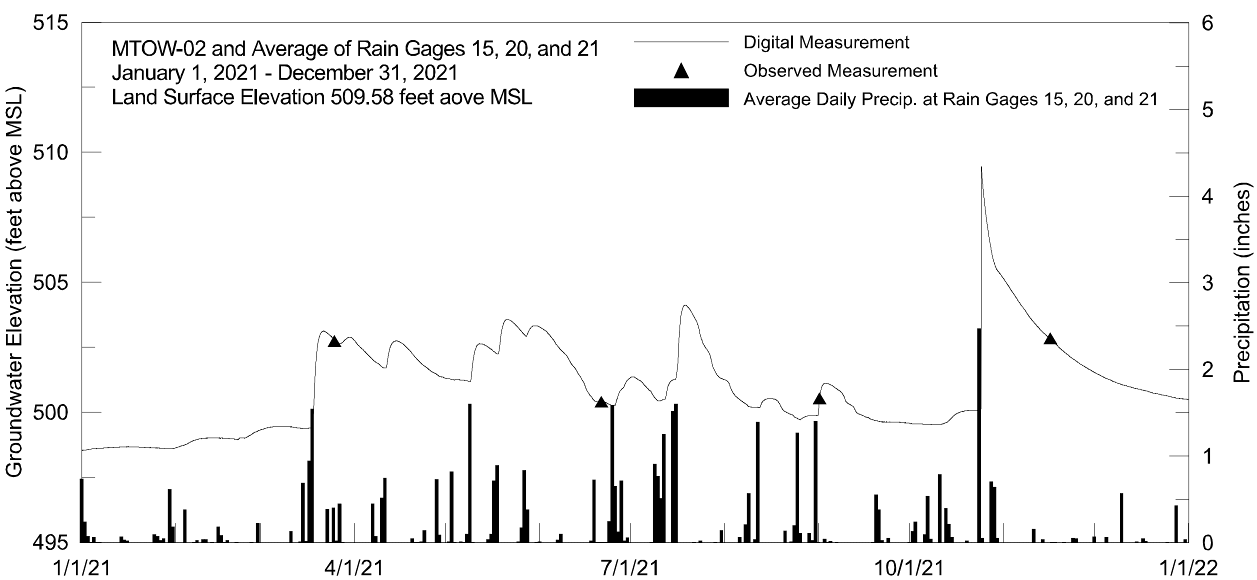

Figure A-2. Year 29 Groundwater Elevation and Precipitation for MTOW-02

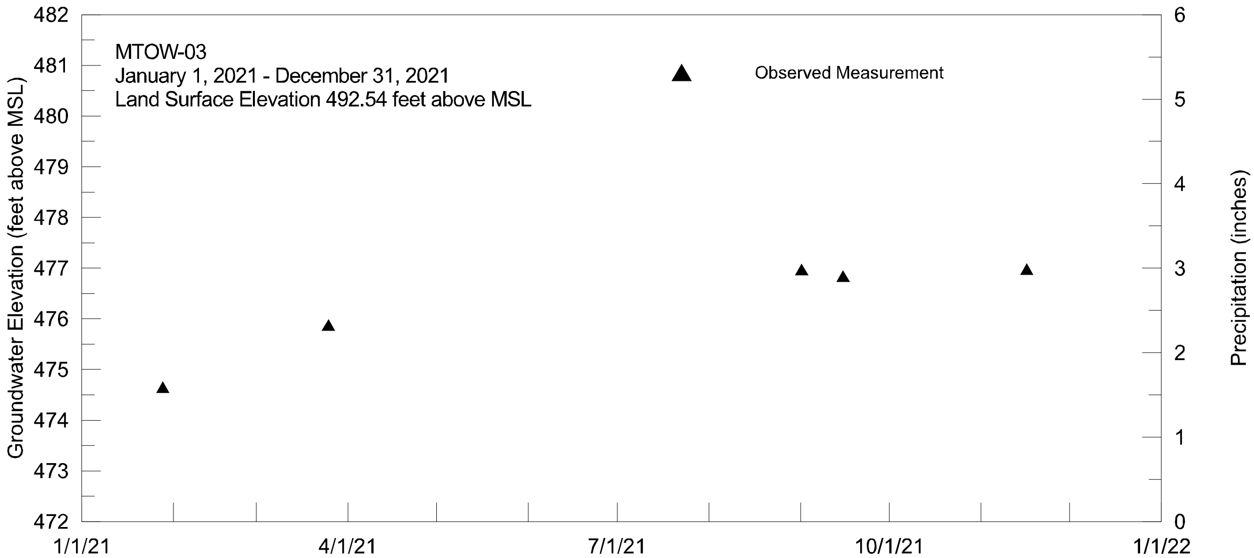

Figure A-3. Year 29 Groundwater Elevation for MTOW-03

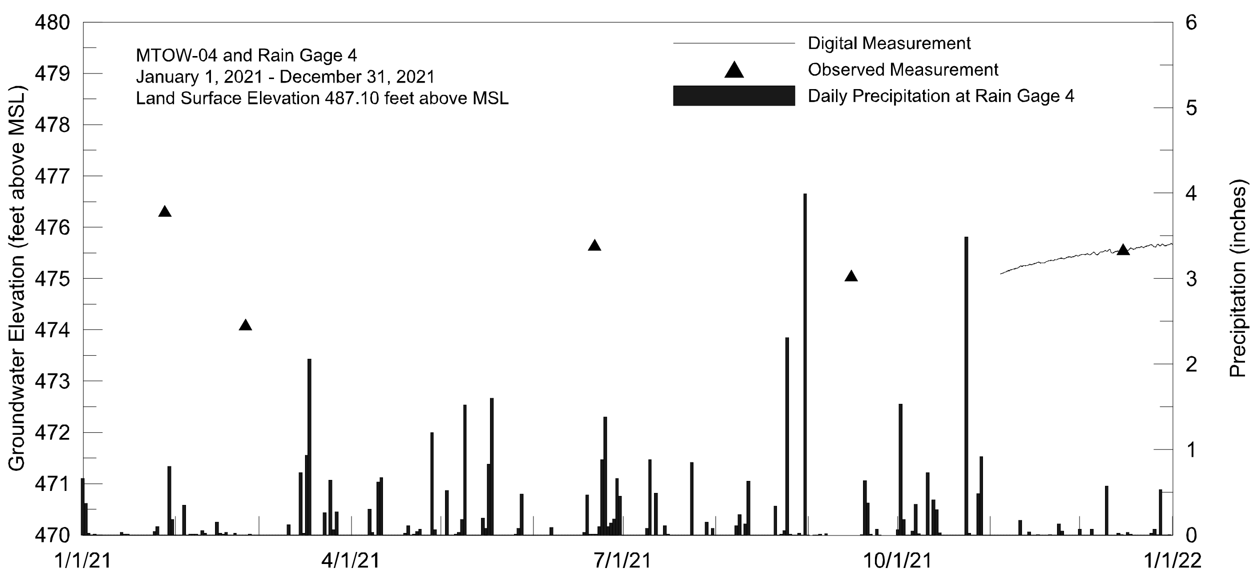

Figure A-4. Year 29 Groundwater Elevation and Precipitation for MTOW-04

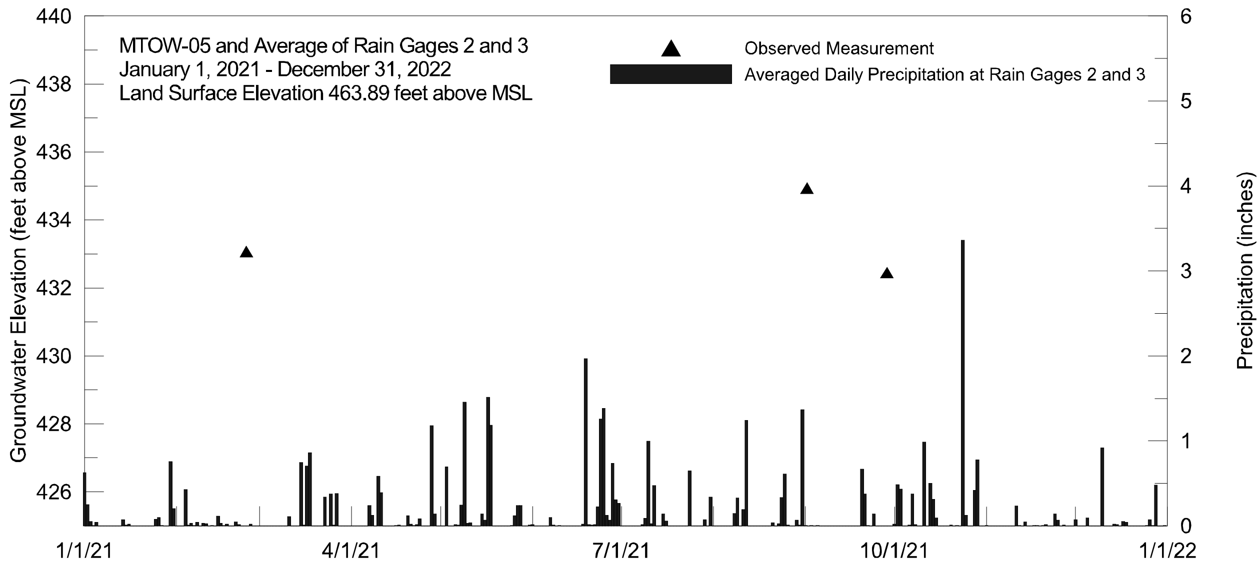

Figure A-5. Year 29 Groundwater Elevation and Precipitation for MTOW-05 (not continuous recorder)

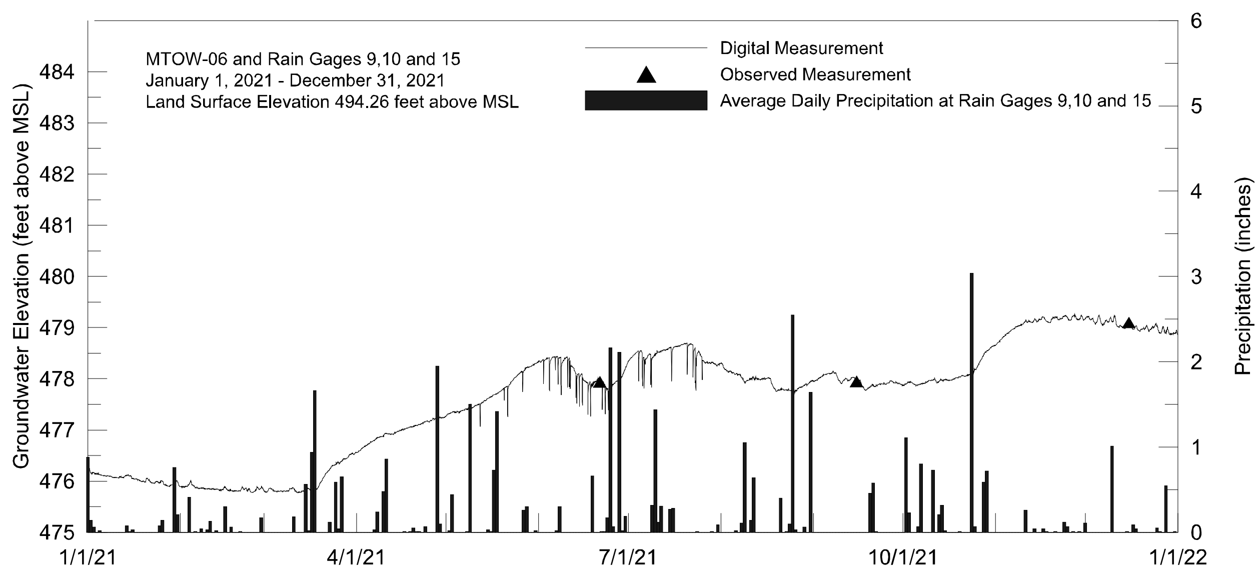

Figure A-6. Year 29 Groundwater Elevation and Precipitation for MTOW-06

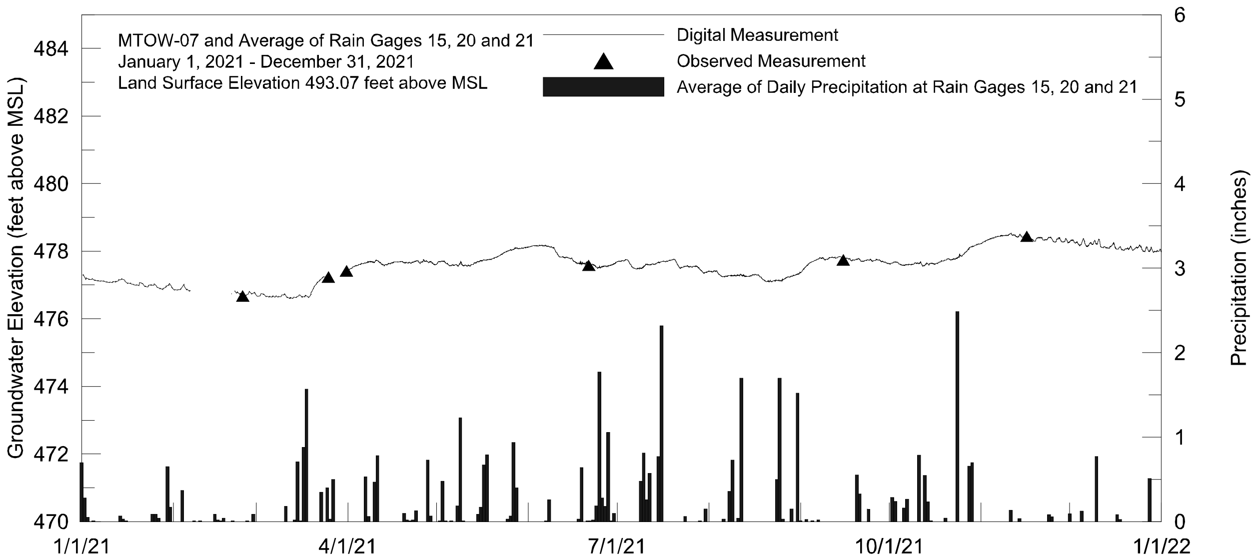

Figure A-7. Year 29 Groundwater Elevation and Precipitation for MTOW-07

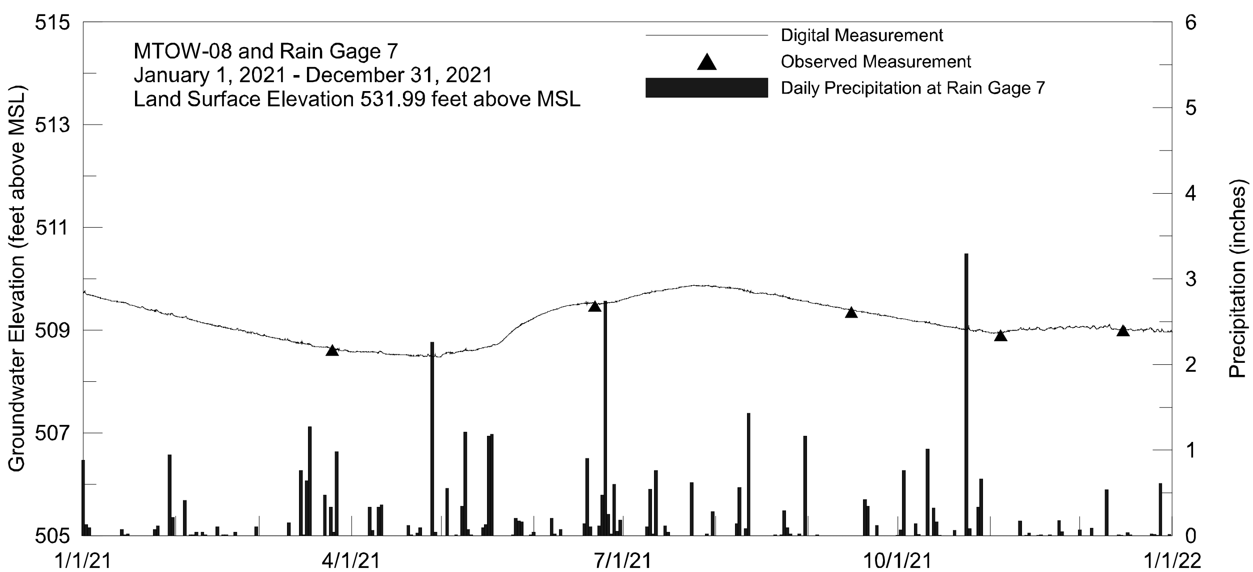

Figure A-8. Year 29 Groundwater Elevation and Precipitation for MTOW-08

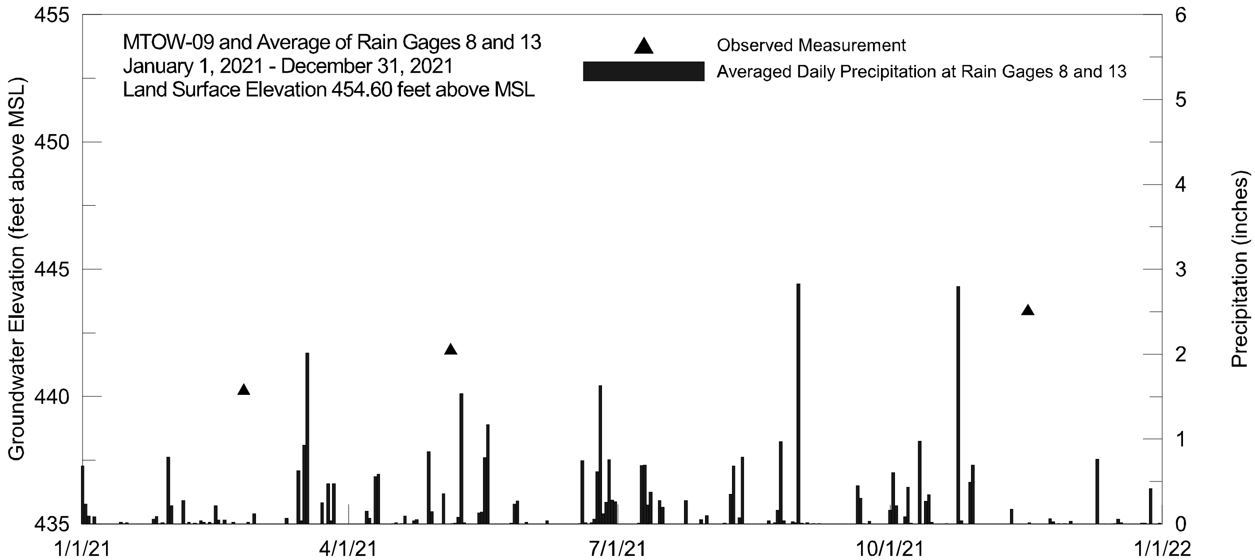

Figure A-9. Year 29 Groundwater Elevation and Precipitation for MTOW-09 (not continuous recorder)

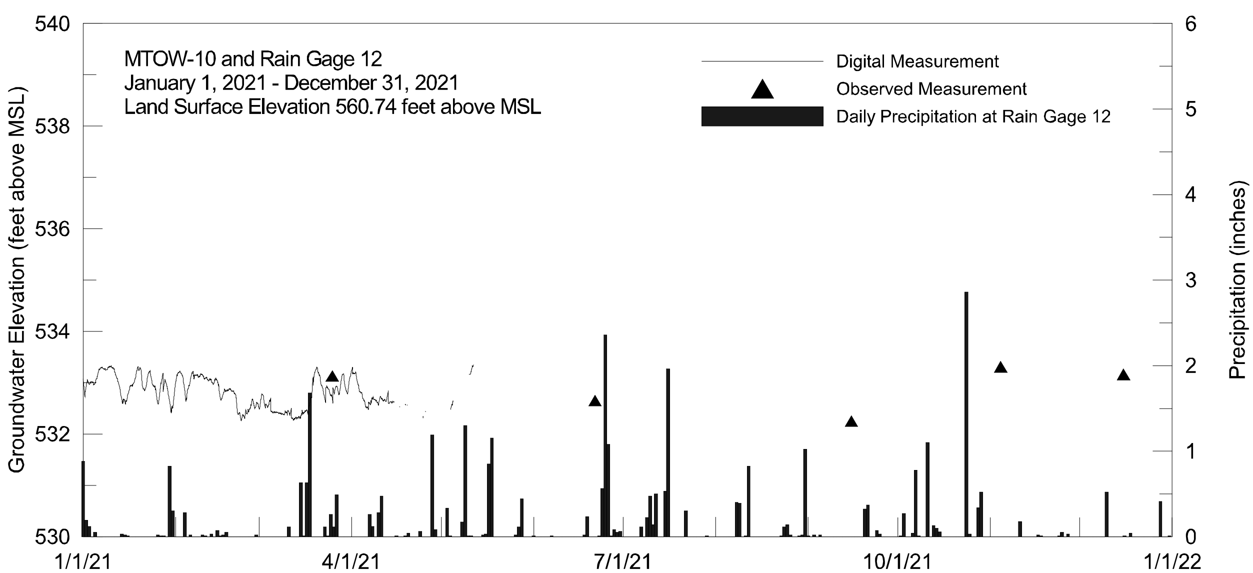

Figure A-10. Year 29 Groundwater Elevation and Precipitation for MTOW-10

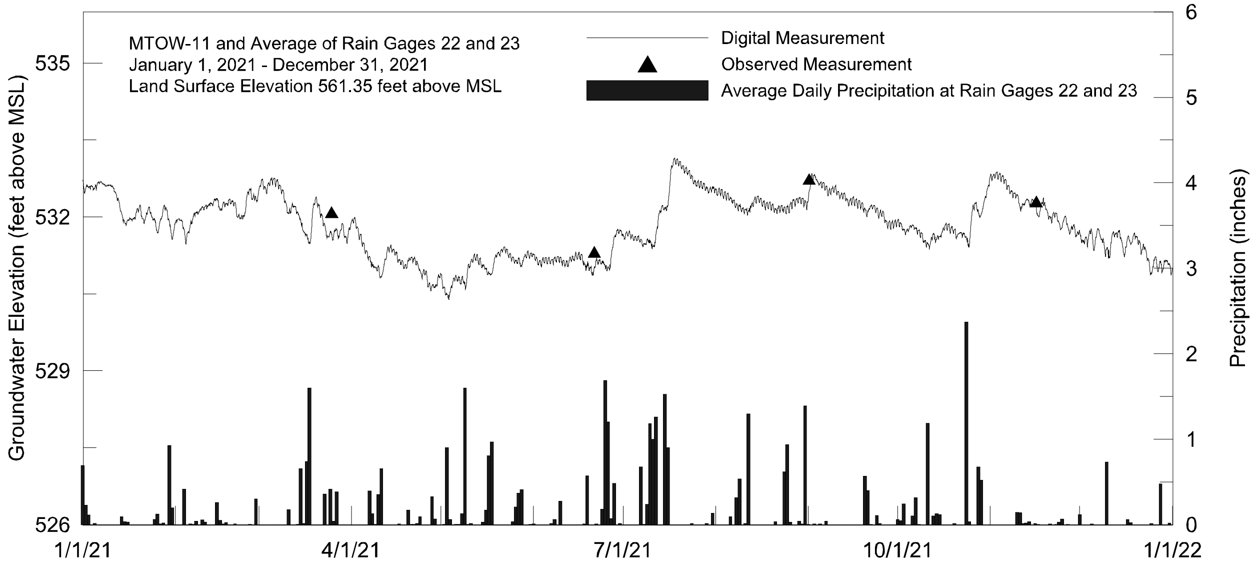

Figure A-11. Year 29 Groundwater Elevation and Precipitation for MTOW-11

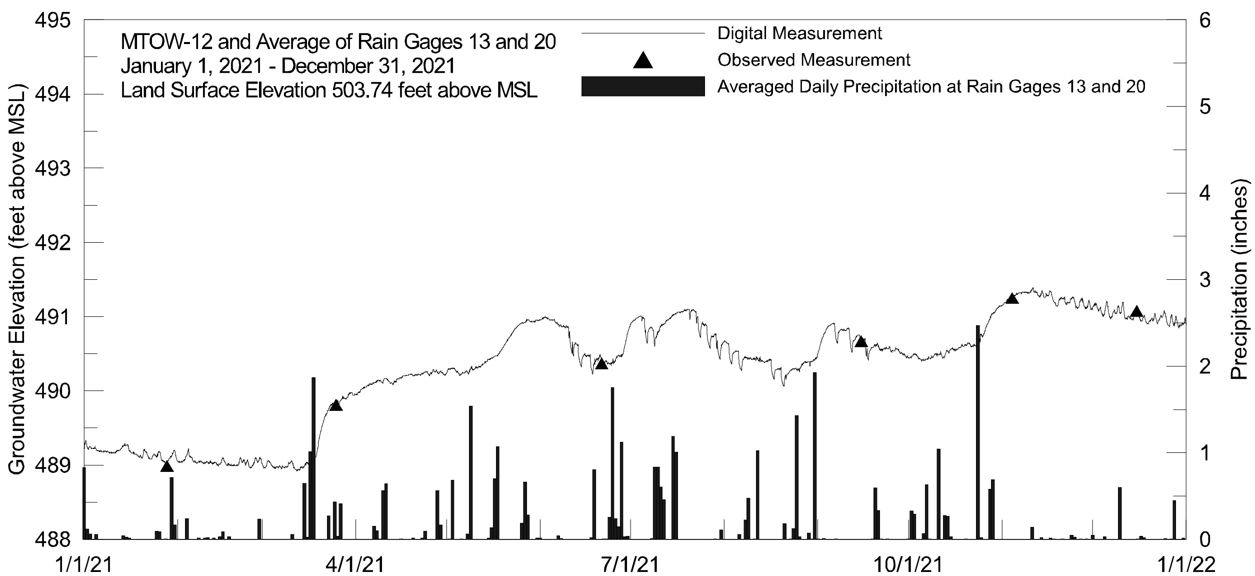

Figure A-12. Year 29 Groundwater Elevation and Precipitation for MTOW-12

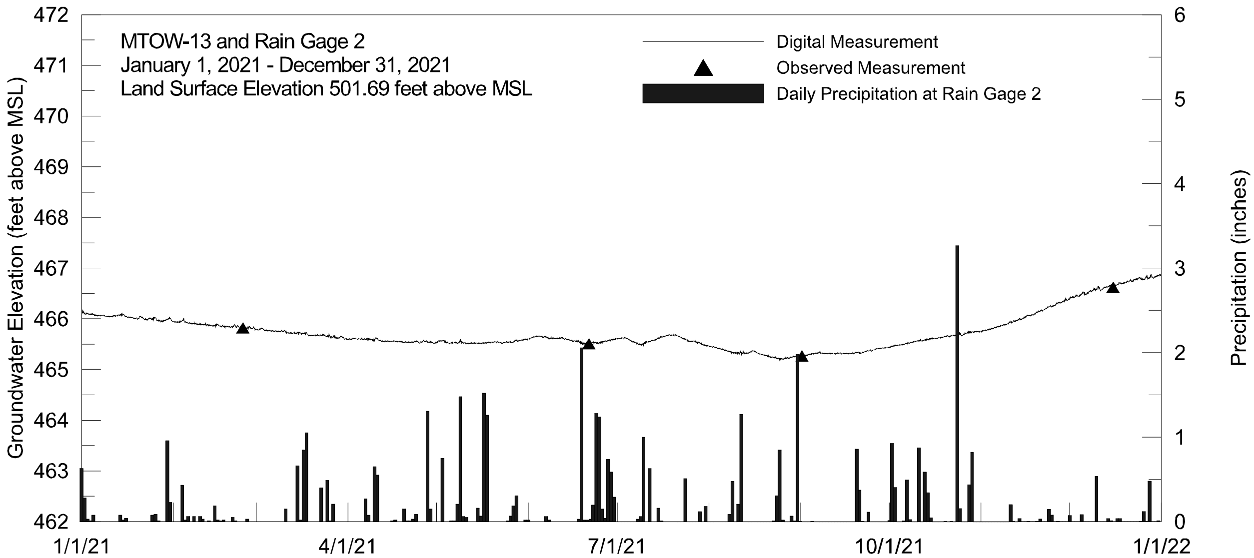

Figure A-13. Year 29 Groundwater Elevation and Precipitation for MTOW-13

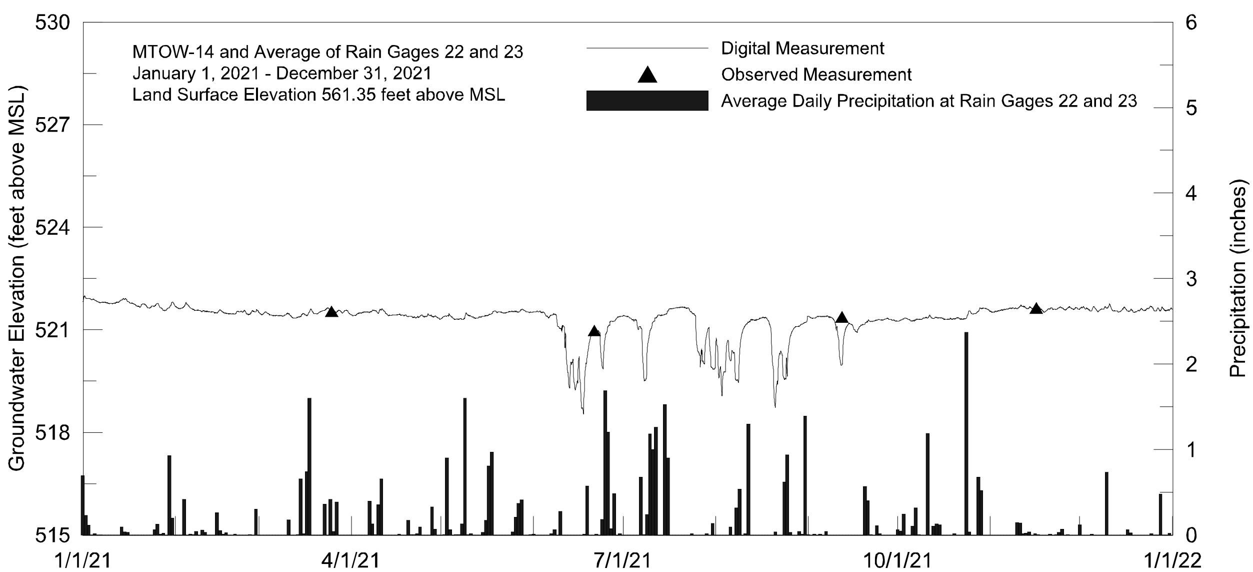

Figure A-14. Year 29 Groundwater Elevation and Precipitation for MTOW-14

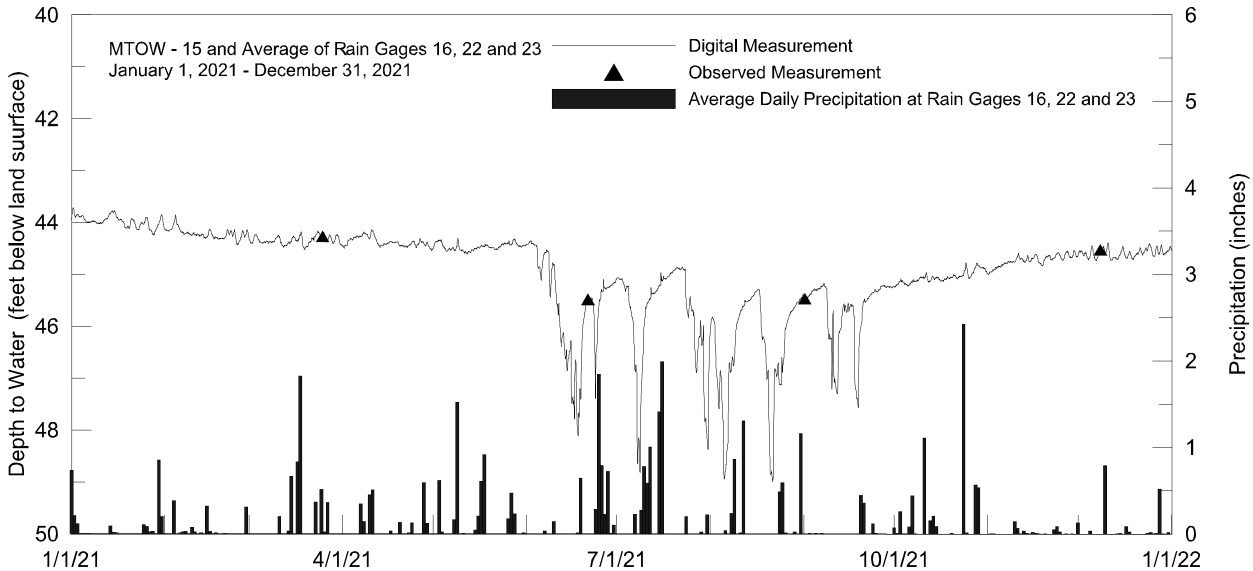

Figure A-15. Year 29 Groundwater Elevation and Precipitation for MTOW-15

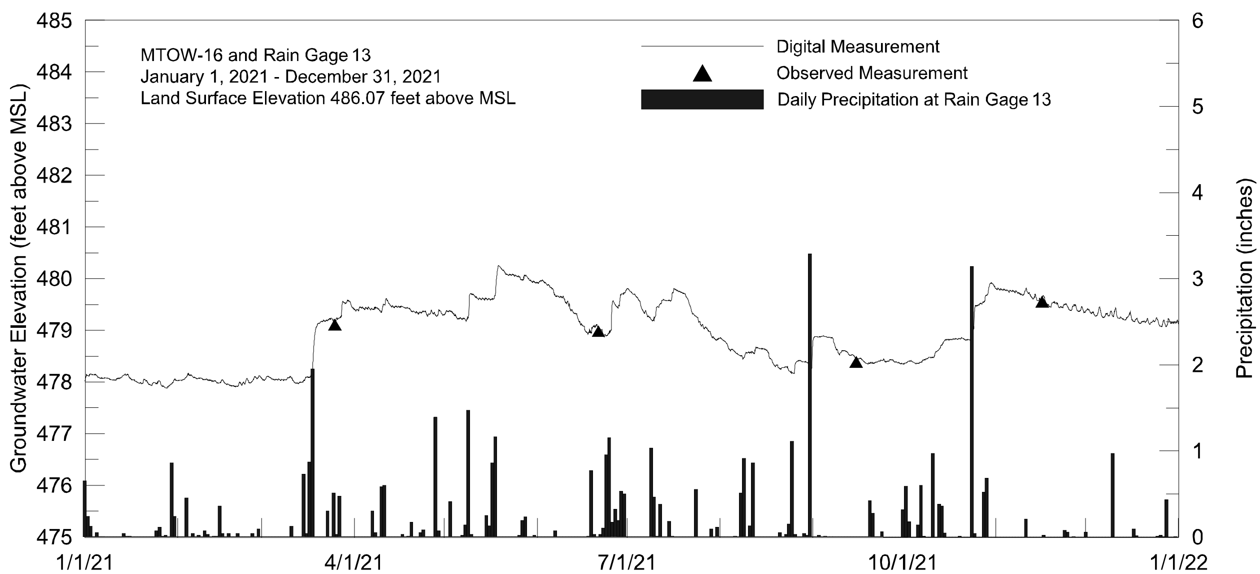

Figure A-16. Year 29 Groundwater Elevation and Precipitation for MTOW-16

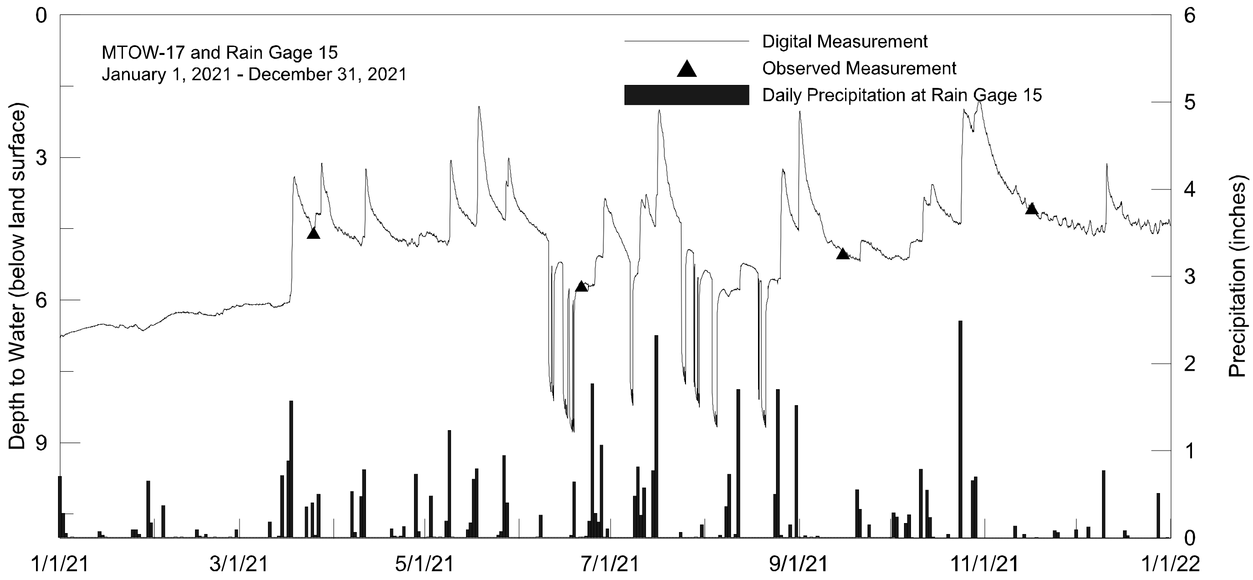

Figure A-17. Year 29 Groundwater Elevation and Precipitation for MTOW-17

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 dataset 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.

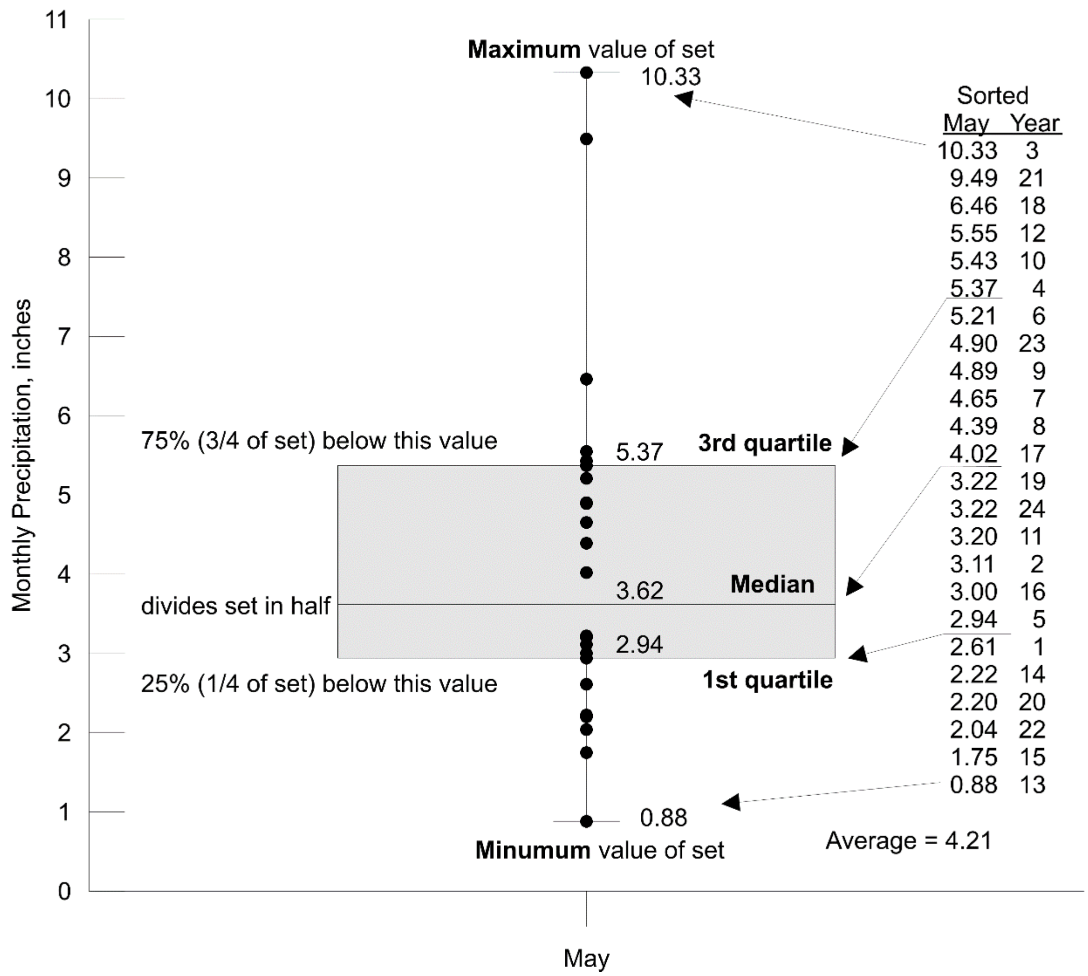

Figure B1. Features of an Example Box-Whisker Plot and Quartiles Using May Data for the Imperial Valley