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Report of Investigation 123

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Front cover: *Dry conditions on the Sangamon River as viewed from the Old Route 48 Bridge near Monticello.*

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CONTENTS

Tables

Figures

Chapter 1: Identifying and Characterizing Drought in Illinois

Introduction

Drought severity is generally defined by its impacts (Changnon et al., 1996). Such impacts can range from comparatively short-term effects on agriculture and horticulture to long-term effects on shallow groundwater and surface water supplies, and include a variety of associated socio-economic losses and environmental damages. As described in this report, the primary impact of the 2012 drought in Illinois was to agriculture. Significant precipitation deficits, leading to much-reduced soil moisture and worsened by extreme high temperatures, stressed crops, pasture, and livestock. Corn yields in particular were noticeably reduced throughout large portions of the state, and some of that crop was tainted with aflatoxins. The drought also posed concerns about water resources and water supply that may have developed into greater specific threats had the drought lasted longer. The developing potential for water supply shortages was lessened, and in some cases removed entirely, after abundant precipitation produced by the remnants of Hurricane Isaac occurred at the end of August 2012. Fish kills associated with low stream levels, high water temperatures, or algal blooms were reported in numerous streams and rivers. In a few cases in northeastern Illinois, water quality treatment problems emerged related to excessively high amounts of algae in rivers. Although the drought also diminished rural groundwater supplies and caused navigation concerns on some major rivers, ultimately the overall impacts to these resources were limited by the relative brevity of the drought.

This report focuses on 1) the scientific data that describe the climatic and hydrologic conditions during the drought; 2) analyses and descriptions of drought impacts; and 3) the interpretative steps taken by the Illinois State Water Survey (ISWS) to identify the emerging drought conditions in the 2012 spring and early summer, leading to an official declaration by the Governor's Office and State Water Plan Task Force and the convening of the Governor's Drought Response Task Force (DRTF). A previous report, *The Drought of 2012* (IDNR, 2013), was jointly prepared by the Illinois Department of Natural Resources (IDNR) and DRTF, focusing on state agency activities and responses during the drought, general impacts, and associated technical and policy issues for Illinois agencies.

Although impacts are the central theme of any drought, they do not often provide the most consistent quantitative measures regarding the severity and historical context of a drought. Impacts can vary substantially depending on locality and the timing and duration of the drought's precipitation deficit. Human-related factors can also change over the years, making it difficult to directly compare the effects of different drought events. For example, crop yields are often the best available measure regarding agricultural impacts, but yield totals and their drought susceptibility have changed substantially over time with improvements in hybrids. Similarly, over time, water supply systems can become more or less susceptible to drought effects as a community's population and industry change, or as supplemental supplies become available or unavailable.

For this reason, scientists also turn to long-term climatological and hydrological records for comparison when characterizing the relative severity of a drought. Measures of the 2012 drought (climatic or hydrologic measurements taken during the drought and their associated statistics) are used to describe the drought; for example, 1) the statewide precipitation from January to July 2012 was the third driest such period when compared to historical records dating back to 1895; and 2) 5 of the 15 wells in the ISWS's shallow groundwater monitoring network experienced record low water levels for several months during the 2012 drought. Although measures such as these are important for providing reference points and context in describing the drought, they do not necessarily correspond directly or correlate to specific impacts associated with the drought. Thus it remains problematic to characterize a drought's severity with either a single metric or category of impact. In this report, an attempt has been made to distinguish between such quantitative measures of drought with the actual impacts to humans or the environment.

Drought Indices and Terminology

There is no uniformly accepted terminology for drought. The U.S. Drought Monitor (USDM) has become the most widely accepted source for identifying drought conditions in the United States, and uses what appears to be easy-to-understand drought severity levels (progressing from "abnormally dry" to "exceptional drought"). But, as described later in this section, a "severe" drought in Illinois, as classified by the USDM, in many instances, can represent a somewhat common event that produces few notable impacts. Thus, depending upon the index or source, a given drought or dry episode could be described as being anywhere in the range from a moderate to severe or extreme drought event.

The common characteristic of drought, regardless of location, is the associated lack of precipitation. Thus, the available metrics or indices to describe drought severity are typically based mostly or entirely on meteorological measurements. Three such indices and their application to Illinois conditions are described in this chapter.

Precipitation Deviation from Normal

Changnon (1987) proposed two categories of precipitation (or meteorological) drought severity for Illinois: "moderate drought" and "severe drought." These two categories are defined by the departure of precipitation from the expected average over specified time periods as identified in Table 1.1. Changnon (1987) also placed an areal-expanse requirement on the precipitation deviation, indicating that the size of the region falling below the precipitation thresholds defined in Table 1.1 should be more than

Table 1.1 Severity of Illinois Precipitation Droughts (Changnon, 1987) Expressed as a Percent of Normal Precipitation

Duration (months)	Moderate drought (%)	Severe drought (%)
3	45–60	≤44
6	56–70	≤55
12	70–80	≤69
24	78–90	≤77

Table 1.2 Severe Droughts in Illinois Using the Changnon Criteria, 1900–2015

Based on Statewide Normal Precipitation		
1901–02	1936	1976–77
1908	1940–41	1988–89
1914–15	1953–54	2005–06
1930–31	1963–64	2012
1933–34		
Additional Regional Droughts Covering at Least 40 Percent of Illinois (based on climate division normal precipitation)		
1923	1980–81	
1944–45	1992	

40 percent of the state. It can be argued that the percentages for the three-month and six-month periods in Table 1.1 should apply to the warmer seasons of the year when precipitation is normally at its greatest. Because normal precipitation is low in the fall and winter, it is difficult to create much of a precipitation deficit during those seasons. For example, the statewide normal total precipitation from December through February is 6.97 inches; a precipitation of 60 percent of normal would relate to a three-month precipitation deficit of just 2.79 inches. Meanwhile, the normal total precipitation from June through August is 11.85 inches; 60 percent of that summer normal would yield a much larger deficit of 4.75 inches. Easterling and Changnon (1987) noted this problem in their study with many three-month drought periods starting in the fall season, but that this was, "to some extent, an artifact of the drought definition technique" of using percentages of normal instead of precipitation deficits from normal. In addition, the demands on soil moisture are greatly reduced during the colder months of the year after crops are harvested and vegetation becomes dormant.

If only warm season precipitation values are used for shorter durations, then a moderate drought, as defined by Changnon (1987), would be expected to have a cumulative precipitation deficit of 5 inches or more. Similarly, a severe drought would be expected to have a precipitation deficit of at least 7 inches for a three-month period, 10 inches for a six-month period, and 12 inches for a 12-month period. Consequential impacts to groundwater and surface water resources are typically associated with sizeable cumulative precipitation deficits (Winstanley et al., 2006). ISWS hydrologists have informally noted that a 10-inch deficit is a rough threshold for encountering such water resource impacts.

From precipitation frequency maps provided in Changnon (1987) for a 12-month period, it can be suggested that moderate droughts occur roughly once in four to five years for each individual climate region across Illinois. Similarly, severe droughts occur on average about once in eight years in southern and central Illinois and once in 10 years in northern Illinois. Table 1.2 lists the drought years that qualify as severe events based on the Changnon criteria. The 1999–2000 drought fell slightly outside of the criteria envelope for regional drought.

Palmer Drought Severity Index

The Palmer Drought Severity Index (PDSI) is calculated based on precipitation and temperature data, as well as a calculated local available water content (awc) of the soil based on that data. The objective of the PDSI is to provide measurements of moisture conditions that were standardized so that comparisons using the index could be made between locations and between months. It is most effective at indicating impacts sensitive to soil moisture conditions, such as agriculture (Willeke et al., 1994). The index was developed by W.C. Palmer in 1965, and was the first comprehensive drought index developed in the U.S. (National Drought Mitigation Center). The PDSI is purely a quantitative index and thus is not influenced by either perceived conditions or observed drought impacts. The four categories of drought corresponding to the PDSI are "mild drought" (-1 to -1.99), "moderate drought" (-2 to -2.99), "severe drought" (-3 to -3.99), and "extreme drought" (-4 or less).

The National Oceanic and Atmospheric Administration (NOAA) defines nine climate divisions in Illinois, shown in Figure 1.1, that are used to aggregate and report regional climate data. The U.S. Department of Agriculture (USDA) also uses these same divisions as crop reporting districts. Table 1.3 describes the number of years since 2000 in which at least one climate division in Illinois has been designated by the PDSI as being in drought. Extreme drought has occurred in at least one climate division of Illinois in five years, representing four separate events: 2000, 2003, 2005–2006, and 2012. From 2000 to 2015, each individual climate division has received an extreme drought classification at least once and up to three separate years with an average value of roughly two such droughts for each division. Thus, for the 16 years, the extreme PDSI drought classification is expected to occur for each division roughly once in eight years on average.

Similarly, for each climate division the PDSI severe drought classification has occurred an average of three times during the 16 years (roughly once in five years) and the moderate drought classification an average of 5.7 times (once in three years). At least one division has experienced a severe PDSI drought in 8 of the 16 years, and a moderate PDSI drought in 13 of the 16 years.

Table 1.3 Number of Years (2000–2015) Each Illinois Climate Division Has Been Identified as Being in Drought, According to the PDSI

Drought Severty	NW	NE	W	C	E	WSW	ESE	SW	SE
Extreme	2	3	3	3	1	1	1	1	1
Severe	2	4	4	3	4	5	2	3	1
Moderate	4	5	9	7	4	5	5	6	6

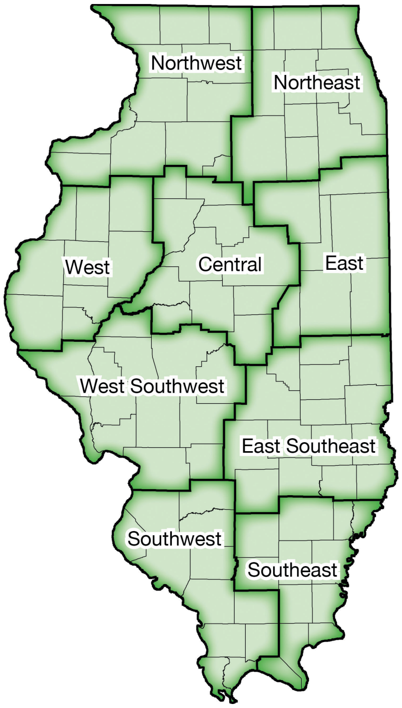


Figure 1.1 Illinois Climate Divisions

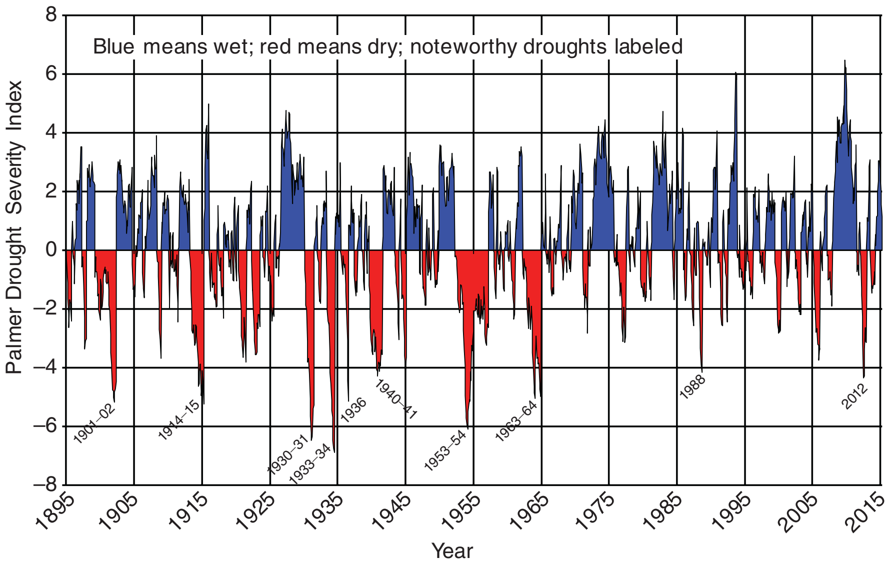


Figure 1.2 Monthly Palmer Drought Severity Index values for Illinois using statewide-averaged data, 1895–2015

Historical PDSI values Figure 1.2 provides the calculated PDSI values for the 1895–2015 period using statewide averages. As shown in this figure, 10 historical drought events (1901–1902, 1914–1915, 1930–1931, 1933–1934, 1936, 1940–1941, 1953–1954, 1963–1964, 1988, and 2012) are shown to have PDSI values of less than -4, considered extreme drought. Thus, such droughts may be expected to occur roughly once in 10 to 11 years on average.

When the PDSI values are examined for individual climate divisions in Illinois for the 1900–2015 period, the PDSI's extreme classification is shown to occur for 10 additional drought events, giving a total of 21 events (Table 1.4). However, this list is irrespective of which region of Illinois was affected by an event.

Whereas an extreme PDSI drought might be expected to occur once in 10 to 11 years on average for any specific region of Illinois, the list in Table 1.3 indicates that an extreme PDSI drought might be expected to occur *somewhere* in Illinois roughly once in five to six years.

Table 1.4 indicates that from the mid-1960s through the 1990s, a reduced frequency of PDSI extreme droughts occurred. Also, since the mid-1960s there have been fewer multi-year drought events, and the average number of climate divisions per event has been reduced. The number of climate divisions shown in Table 1.4 measures the areal extent of a drought but not that drought's severity or impact. This tendency for less frequent droughts is reflected in the statewide precipitation records as well. The records show the average annual precipitation in the first 64 years of the 20th century to be 9 percent drier than the average annual precipitation since 1965.

Table 1.4 Drought Events Classified as Extreme by the PDSI for One or More Climate Divisions in Illinois, 1900-2015

Drought Event	CDs*
1901-1902	7
1908-1909	5
1910-1911	3
1914-1915	8
1920-1921	3
1923	2
1930-1931	9
1933-1934	9
1936	7
1940-1941	5
1944-1945	5
1953-1954	6
1956-1957	3
1963-1964	8
1977	2
1981	1
1988-1989	5
2000	1
2003	1
2005-2006	4
2012	8

*CDs = Number of Illinois Climate Divisions with an Extreme Classification

Comparison to the Changnon (Precipitation Deviation) Categories When the PDSI and Changnon (1987) drought classifications are compared, it is obvious that the designated moderate and severe categories do not match up well and occur with different frequencies. However, this is primarily a difference related to terminology. When comparing drought events listed in Tables 1.2 and 1.4, the events listed for the Changnon severe category appear to match up very well with the PDSI extreme category. Furthermore, when computed using statewide data, the PDSI extreme category occurs with roughly the same frequency as the Changnon severe category (once in 8 to 11 years). Similarly, the PDSI severe category occurs roughly as often as the Changnon moderate category (once in five years).

As will be discussed later with regards to the Illinois Drought Response Task Force, drought conditions were officially "declared" in Illinois during three separate events over the past 16 years: 1999–2000, 2005–2006, and 2012. In retrospect, the PDSI extreme category appears to effectively coincide with the occurrence of official drought conditions in Illinois for most cases. However, the timing of the PDSI extreme designation tends to be delayed, coming after a drought would have already been recognized by state agencies, scientists, and water managers. For example, during the 2012 drought, the PDSI extreme category was not designated for Illinois until the end of July. With the 2005 drought, the extreme designation (for northern Illinois) did not occur until October of that year, four months after the State of Illinois had already declared the existence of the drought. Similarly, for the 1999–2000 drought, the extreme designation (west-southwest Illinois) did not occur until March 2000. Thus, the PDSI extreme designation is not very effective for identifying the onset of drought. That designation, however, does appear to do well during the later stages of drought, identifying continuing dry conditions such as associated with lingering hydrologic effects.

U.S. Drought Monitor

The U.S. Drought Monitor is a composite index that includes a number of quantitative indicators including the PDSI, the standardized precipitation index, soil moisture modeling results, and observed streamflow. In addition, the USDM also considers qualitative assessments (local reports) from a large number of expert observers including State Climatologists; thus it is not strictly a quantitative product. As described by the USDM literature, "the community of drought observers lends credibility to the state-of-the-art blend of science and subjectivity that goes into the map." The USDM is produced jointly by the National Drought Mitigation Center, the USDA, and the NOAA.

The USDM uses five levels of drought severity, beginning with abnormally dry (D0), to moderate (D1), severe (D2), extreme (D3), and ending with exceptional (D4) and highlights these levels on a color map. The USDM map indicates whether drought is short-term (S), fewer than six months in duration, and primarily affecting agriculture, or long-term (L), more than six months, and affecting hydrology, ecology, and water supplies.

The USDM was initiated in January 2000. Table 1.5 lists the number of instances since that time when the individual climate divisions of Illinois have been categorized as in moderate drought (D1) to exceptional drought (D4). Only those instances are listed when at least half (50 percent) of the climate division had reached the designated level of drought, with one exception. The exceptional (D4) drought occurrence in 2012 in southeastern Illinois is listed here, but in fact was estimated to have covered only 49 percent of the SE climate division.

As designated by the USDM, there have been only two extreme droughts in Illinois, in 2005–2006 and 2012. The 2005–2006 drought was primarily located in northern and west-central Illinois, and thus the extreme drought affected only a portion of climate divisions in Illinois. As a result, Table 1.5 shows that individual climate divisions received an extreme drought classification with an average value of 1.5 events during the 16-year period from 2000 to 2015. Based on this relatively short sample of years, the D3 extreme drought classification is estimated to occur for each division roughly once in 10 to 11 years.

For individual climate divisions, the D2 severe drought classification has occurred an average of four times during the 16 years (roughly once in four years) and the moderate drought classification an average of eight times (every other year, on average). But across Illinois, at least one climate division has experienced a severe USDM drought in 10 of the 16 years, and a moderate USDM drought in 12 of the 16 years. Thus, in most years, some region in Illinois is considered by the USDM to have experienced severe drought.

Although the USDM includes a classification for long-term droughts of over six months, by all appearances the USDM for Illinois instead focuses predominantly on shorter-term meteorological and agricultural effects and gives less overall consideration to long-term water storage concerns. In both the 2005–2006 and 2012 droughts in Illinois, for example, regional concerns about low water levels in water supply reservoirs and groundwater continued for many months after the drought level had been downgraded by the USDM. The 1999–2000 drought, in particular,

Table 1.5 Number of Years (2000-2015) that Each Illinois Climate Division Has Been Identified as Being in Drought, According to the U.S. Drought Monitor. In each case, at least 50 percent of a division has achieved the designated drought severity.

Drought Severity	NW	NE	W	C	E	WSW	ESE	SW	SE
Exceptional (D4)	0	0	0	0	0	0	0	0	1
Extreme (D3)	2	1	2	2	1	2	1	1	1
Severe (D2)	5	4	6	6	4	4	2	3	4
Moderate (D1)	7	6	10	10	8	7	7	8	7

was by far the most threatening drought to water supplies in Illinois since 1989, but was not recognized as an extreme event by the USDM (or for that matter by other precipitation-centric indices). Water storage considerations appear to be given greater consideration by the USDM for the western United States.

The drought severity categories defined by the USDM appear to match up roughly with the PDSI categories. A comparison of Tables 1.3 and 1.5 indicates that the extreme category represents an event that is likely to occur roughly once in 8 to 11 years for any given location in Illinois, with the PDSI designation having a slightly higher frequency. For any given climate division in Illinois, the severe category is expected to occur roughly once in four years using the USDM designation and roughly once in five years with the PDSI. However, for both indices, a region somewhere in Illinois is likely to receive the severe drought designation roughly every other year.

The USDM is likely to identify drought conditions, such as an extreme event, sooner than the PDSI, in part because of feedback from the community of drought observers. In this respect, the USDM is regarded the better tool for identifying the onset of drought. Although the sample size is small, the USDM may not be as effective as the PDSI in recognizing longer-term hydrologic effects of drought. In a drought's later stages, it is observed that the USDM is more likely to downgrade a drought event sooner than the PDSI.

Official Drought Designations in Illinois

The DRTF was created in 1983 under the recommendation of the State Water Plan Task Force (SWPTF) to provide an organized multi-agency approach in dealing with drought problems in Illinois. During times of drought, the DRTF is convened either by the Governor or by the Director of the IDNR Office of Water Resources (OWR) so that the existing state and federal programs for drought and emergency interruption of supplies may be organized and in a state of readiness. Thus, the process of convening the DRTF essentially creates an official or declared state drought condition. The DRTF is co-chaired by the Director of the OWR and the Manager of the Public Water Supply Section of the Illinois Environmental Protection Agency (IEPA). Other typically represented agencies include the ISWS, the Illinois Department of Agriculture, the Illinois Department of Public Health, the IDNR Division of Fisheries, the Illinois Emergency Management Agency, the Illinois Commerce Commission, the Illinois Department of Commerce and Economic Opportunity, the U.S. Geological Survey, and the Office of the Governor. Each agency has technical expertise and capabilities in specific areas of drought management and assistance.

In its first 15 years of organization, the DRTF was convened on seven different circumstances. In most of these circumstances, dry conditions leading the DRTF to convene were either short-lived or localized. In two cases, the DRTF convened following heat waves unrelated to a lack of precipitation, including the Chicago heat wave of July 1995 which was responsible for 739 heat-related deaths. In retrospect, for only one of the seven first circumstances (the 1988–1989 Illinois drought) did the DRTF meet during what today would be clearly recognized as a noteworthy drought episode.

Since 1999, the DRTF has been convened only three times: during the 1999–2000, 2005–2006, and 2012 droughts. In each of these cases, the drought concerns were not short-lived; rather, in all cases the drought concerns continued to escalate beyond the convening of the DRTF, leading the DRTF to continue addressing drought concerns for six months or longer. In the early stages leading to these droughts, the ISWS played a critical role in monitoring the developing dry weather conditions and the level of decline in water supplies and other resources being affected, identifying projected impacts, communicating these observations with the Director of the OWR, and ultimately advising when conditions have advanced to the stage requiring attention and response from the DRTF. The ISWS has a continued role in providing updates on the dry weather and hydrological conditions during each DRTF meeting until drought concerns have dissipated.

In several other notable dry periods (2003, 2007, 2011), the ISWS issued press releases or drought advisories, describing developing dry conditions in various regions of Illinois. But in these cases, the ISWS, in consultation with OWR, assessed that the dry conditions either did not have sufficient areal impact or had not yet progressed to the stage of a declared drought.

Identifying the Onset of Drought in Illinois

The ISWS and SWPTF have established a strong, positive record in the early and reliable identification of drought conditions in Illinois. Although it is recognized that the USDM will continue to provide an important and the most visible resource for tracking dry conditions, the watchfulness and ongoing assessment of climatic and hydrologic conditions by the ISWS have allowed Illinois to successfully identify and forecast the tangible impacts for which state agencies must be prepared and responsive. As documented in the following, the ISWS and DRTF have been able to declare recent Illinois drought conditions in advance of what could have occurred by referring to the USDM alone, under the assumption that the USDM's extreme drought designation is roughly equivalent to a declared Illinois drought:

- The ISWS issued two press releases in spring 2012, on April 10 and May 25, discussing the state's dry conditions. The May 25 release was labeled as a "drought advisory," indicating that there was greater than a 50 percent probability that drought impacts would occur in the summer. On June 19, the ISWS gave the SWPTF an assessment indicating that drought impacts were imminent, resulting in the activation of the DRTF. In comparison, less than one-third of Illinois was considered by the USDM to be in severe drought on June 19, and it was not until July 24, 2012 when it designated most of Illinois in the extreme drought category.

- In 2005, the DRTF was activated on June 26, again with the ISWS recommendation. In comparison, the USDM designated extreme drought conditions on July 5 of that year.
- In 1999, the DRTF convened in July with regards to heat wave conditions in Illinois, and then reconvened from November 1999 to June 2000 to address developing water supply concerns in the state. Although the USDM did not begin to issue drought condition maps until January 4, 2000, it never designated extreme drought conditions that year for Illinois, and did not designate severe drought until February 29, 2000.

Furthermore, in declaring an official drought condition for Illinois, the ISWS and DRTF deem that it is important that such declarations not happen often for episodes or short-lived dry conditions that do not produce substantial impacts. Such "false alarms" would unnecessarily use State resources and could produce a "cry wolf syndrome" in which drought declarations would carry less weight and the potential that they might be disregarded or less regarded by the public, state agencies, and others tasked with addressing drought concerns. Although quick reversals in weather patterns or misdiagnoses of developing drought conditions by the ISWS and DRTF are possible, such circumstances have not occurred since the 1990s when the criteria for convening the DRTF were not as well defined.

Monitoring of developing climatic and hydrologic conditions by the ISWS offers several advantages in early identification of drought in Illinois compared with the use of a national index, specifically 1) the ability to project conditions using weather forecasts; 2) the evaluation of seasonal factors affecting drought impacts and hydrologic conditions; and 3) having detailed information and hydrologic data concerning local or regional impacts. The areal or regional coverage of a drought, including an assessment of how many communities might be experiencing impacts, is also a considered factor when deciding the seriousness of a drought event.

Projecting Near-Future Conditions and Impacts

The USDM and PDSI are based solely on observational data and information, unaffected by the likelihood or prognosis of future or developing conditions. In contrast, during abnormally dry conditions, the ISWS often attempts to evaluate how soil moisture, streamflow, reservoir levels, and crop conditions may be expected to change in future weeks, particularly when faced with a fixed dry-weather pattern that includes a 14-day National Weather Service forecast showing little or no opportunities for rainfall. Although the National Weather Service releases monthly and seasonal temperature and precipitation forecasts, the skill of these forecasts, especially for summer rainfall, is too low to provide any guidance beyond 14 days. In nearly every case, when the ISWS issues a drought advisory or recommends that the DRTF convene, it is made in circumstances when there are very few opportunities for rain in the 14-day forecast. Because appropriate responses to drought conditions by Illinois agencies often require preparation, the ability to project the onset of impacts can be critical. When the DRTF was convened on June 19, 2012, it was expected that agricultural impacts and other concerns were likely to materialize by early July.

Effect of Seasonality when Identifying and Projecting Impacts

Drought impacts can vary substantially depending on which season precipitation deficits occur. Most readers will readily understand the effects of drought seasonality with regards to agriculture, particularly corn and soybean crops. Precipitation deficits in the cool seasons have an especially low agricultural impact in Illinois because there are relatively few acres of cool-season agriculture such as pasture and winter wheat.

Drought seasonality also greatly affects impacts to water resources and supply. The greatest rates of decline in soil moisture, stream, reservoir, and shallow groundwater levels occur during the summer when evapotranspiration rates (and water withdrawals) are typically greatest. Water levels will typically continue to decline, although at a slower rate, in the fall and early winter before soil moisture has been replenished. Streams and rivers typically experience their lowest flows in the fall, whereas reservoirs and groundwater can continue to decline through early winter. But once fall and winter precipitation has allowed soil moisture to rebound, more of the precipitation occurring in winter and spring replenishes streams, reservoirs, and shallow groundwater. Even during the worst hydrologic droughts, such as occurred in the 1950s, levels in water supply reservoirs will typically level off, and often partially rebound between January and May. The greatest concern during the most extreme droughts is that the amount of replenishment in reservoirs and shallow groundwater will be insufficient to avoid shortages during a second summer and fall season of drought. Furthermore, water supply droughts in Illinois would likely never begin in January to May because there is limited potential during this time to diminish streams, reservoirs, and groundwater storage.

For descriptive and interpretative purposes, Illinois droughts fall into three conceptual types:

> *Drought onset in early season (May–June)* These droughts usually occur after an abnormally dry spring, with low precipitation typically beginning in March and precipitation deficits accumulating to 5 to 6 inches or more by the end of May. Even following such dry springs in Illinois, there is usually sufficient moisture in the soil to provide for early crop growth. Impacts to corn and soybeans may not become evident until the latter half of June, and it is at this time that the ISWS and DRTF would likely decide to convene if little or no rainfall is in the forecast. In other words, given the seasonal nature of soil moisture in Illinois, it is unlikely that any new drought would be declared prior to June. If dry conditions persist into mid-summer, the early-season drought is the type most likely to

produce substantial damages to crops, particularly to corn if sufficient water is not available in the short time-frame in July when tasseling and silking occur. Water supply reservoirs could begin to show early drawdowns unseasonably early, by mid-June to early July, creating the threat that reservoir supplies could continue to diminish throughout the remainder of the year, potentially leading to shortages in certain supplies by winter. The 1988, 2005, and 2012 droughts are all examples of early summer droughts, and in each case the call for the DRTF to convene occurred in June.

Drought onset in mid-season (July–August) Mid-season droughts are characterized by extremely low precipitation amounts in July and August, often creating a precipitation deficit of 5 to 6 inches in the summer months alone. Analysis by Easterling and Changnon (1987) indicate that events with large precipitation deficits in the summer are the ones most likely to extend through the winter and spring, developing into a multi-year drought episode. The 1913–1915, 1930–1931, and 1953–1954 droughts are examples of mid-season droughts that turned into multi-year episodes. These droughts typically have near-normal precipitation or moderate deficits leading into the early summer. The most intense precipitation deficit may occur late enough in the summer so that there is adequate soil moisture for crucial crop development (corn tasseling and silking) to avoid the most severe crop damages. Water levels in streams, reservoirs, and shallow groundwater would typically drop precipitously in late summer, potentially threatening the few water supplies that are susceptible to short drought episodes, but the biggest water resource threat is the potential development into a multi-year drought. For these events, drought conditions might not be declared or recognized until late July or early August.

Drought onset in late season (September-December) These late-season droughts are less common and can occur stealthily because their onset happens after the heat of the summer and during months when precipitation is normally low. There are few if any agricultural concerns, and the recognition of the drought is almost entirely driven by low reservoir levels. In the 1999–2000 drought, it was not until November (the driest month in the drought) when low water levels became a concern to the DRTF. With these droughts, there is a low threat that water supply shortages might occur in its first year; rather, the greatest threat is the possibility of a multi-year episode. The spring of 2000 was particularly dry, and it was not until late May and early June 2000 when water levels in Lake Springfield and other affected water supply reservoirs in that region of the state saw recovery.

Identifying Impacts and Specific Concerns Regarding Agriculture and Water Resources

The primary role of the ISWS during the onset of drought conditions in Illinois has been to translate available climatic and hydrologic data to identify emerging and potential drought impacts and determine if these impacts have crossed a threshold in which the DRTF needs to be activated and state agencies alerted. Some of the information available to ISWS scientists for this evaluation, such as precipitation data, U.S. Geological Survey (USGS) streamflow data, and USDA crop progress and condition reports, are information sources also used by the USDM. The ISWS will also query state agencies and local contacts about specific concerns. The ISWS often receives information from well drillers around Illinois when shallow groundwater wells are experiencing problems and need to be drilled deeper. But the ISWS also contributes its own sets of data and analyses that provide valuable insight into drought processes and context with regard to certain historical drought episodes.

As part of its Water and Atmospheric Resources Monitoring program (WARM), the ISWS maintains long-term records of many climatic and hydrologic variables that can be valuable in diagnosing the onset of drought conditions. The three most pertinent sets of data in WARM are 1) the soil moisture monitoring network; 2) the shallow groundwater wells network; and 3) the surface water reservoir observation network. The long-term records provided for each network allow ISWS scientists to compare and contrast current events, such as a developing drought situation, to similar observations in historical dry years. The reservoir observation network also provides information on which reservoirs and regions are experiencing drawdown and how soon communities are likely to be concerned about their available supplies. The ISWS has also developed water budget models for nearly every community reservoir supply in Illinois, and with these models can project reservoir drawdown and compare them with simulated conditions associated with historical drought episodes. As drought conditions are emerging, the month-end water supply reservoir observations are often supplemented with additional queries to the water treatment operators at these and other lakes. Once the DRTF is activated, the IEPA maintains constant contact with these operators.

Real-time streamflow data from the USGS are also evaluated. A reliable symptom of drought conditions is the occurrence of streamflow that is in its lowest 10th percentile for a specific date. Although reports of low-percentile streamflows provide an effective warning, they usually must occur in mid-summer to correlate with specific low flow impacts on streams (such as fish kills or water supply intake problems). For example, low-percentile flows occurred in spring 2012. However, flows are typically highest in spring in Illinois, so a relatively low flow in spring still represents sufficient water to avoid the kinds of low-flow conditions or impacts more often found in summer. Thus again, ISWS scientists attempt to focus less on data metrics and give greater emphasis to emerging impacts.

Some regions of Illinois are more susceptible to significant impacts than others. For example, regions of Illinois that depend on reservoirs and shallow groundwater for their water supplies are more likely to have drought-related impacts. In contrast, water supplies in northwestern Illinois are predominantly provided by bedrock aquifers that are well buffered from the impacts of drought. If a precipitation deficit in that region does not affect agriculture, it is very possible that there could be few or no hydrologic impacts; thus the need for an official drought declaration might be circumvented despite the region being categorized by other available drought indices.

Summary

The USDM will likely continue to be the primary resource that many agencies and the public will use for information regarding drought. But it is highly recommended that users understand that the terminology associated with the USDM (and PDSI) drought categories, such as moderate or severe drought, is subjective and semantic and may not necessarily correspond to tangible drought impacts. The severe drought category, in particular, is a designation that occurs in some portion of Illinois as frequently as every other year, often describing a comparatively undeveloped drought condition having limited overall impact to agriculture or water resources. This is not to infer that impacts cannot occur within the severe drought category, but, if so, they are more likely to be local and isolated incidents.

The USDM's extreme drought category, on the other hand, more accurately reflects an Illinois drought condition in which tangible impacts have developed to a threshold requiring state agency preparation and responses. Thus, this category more closely identifies circumstances that would cause the DRTF to convene, and would therefore essentially amount to a State of Illinois official declaration of drought.

Identification of emerging drought conditions in advance is crucial for convening the DRTF and preparing state agencies for response to drought impacts. The USDM products are based entirely on current observed conditions, and thus do not project how droughts or dry conditions are apt to develop in the near future. In contrast, the ISWS specifically examines weather and climate forecasts to provide a prognosis of drought conditions and impacts including not only current observations, but also climatic and hydrologic analysis and prediction. The drought prognoses and thresholds that the ISWS and SWPTF have used since 1999 successfully provide an early identification of emerging drought impacts, often well in advance of an extreme drought designation from either the USDM or PDSI.

Of equal concern is that Illinois' drought declarations show discretion and restraint, so that when the DRTF convenes, there should be a high likelihood or inevitability that tangible impacts or credible threats and concerns are forthcoming. Important additional factors in the ISWS drought evaluations are the knowledge and familiarity of its scientists regarding 1) specific ongoing and developing impacts in Illinois; 2) areas of concern based on past drought episodes; and 3) influence of drought seasonality on the development and progressions of agricultural and hydrologic impacts.

Chapter 2: Drought Conditions, Causes, and Predictability across the Central U.S.

Introduction

The central U.S. drought of 2012 was widespread and devastating for the region. A 2015 report (Fuchs et al., 2015) provided a damage assessment for Colorado, Illinois, Indiana, Iowa, Kansas, Kentucky, Michigan, Minnesota, Missouri, Nebraska, North Dakota, Ohio, South Dakota, and Wyoming. Longer-term drought prevailed in many states in the West and Southwest as well. A National Centers for Environmental Information (NCEI) report on billion-dollar weather and climate disasters listed the 2012 drought as a $31.2 billion loss across the U.S., primarily from widespread damage to corn, soybeans, forage crops, and pasture (NCEI, 2016).

This chapter reviews the regional aspects of the 2012 drought using regional precipitation deficits and U.S. Drought Monitor maps and examines the causes of this drought and its predictability. A more detailed description of the drought in Illinois is provided in Chapter 3.

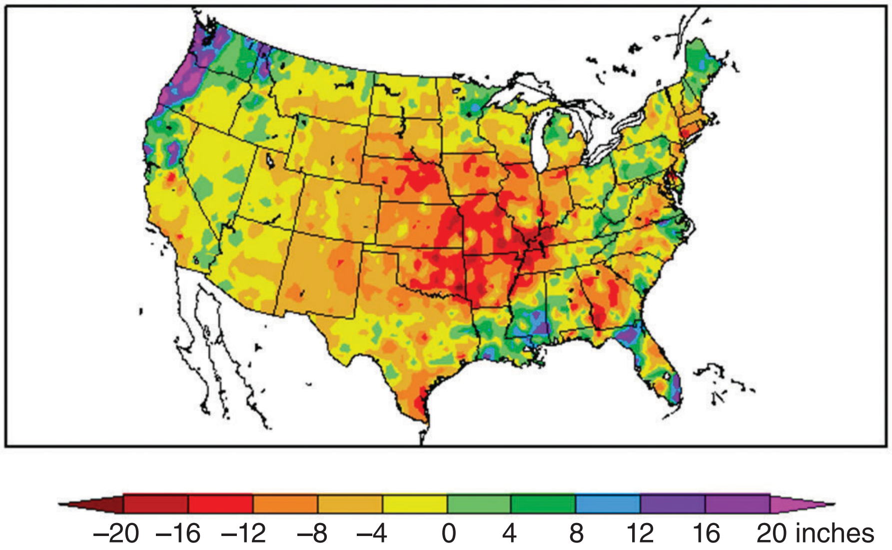


Figure 2.1 Map of U.S. precipitation anomaly in inches during 2012

Regional Precipitation

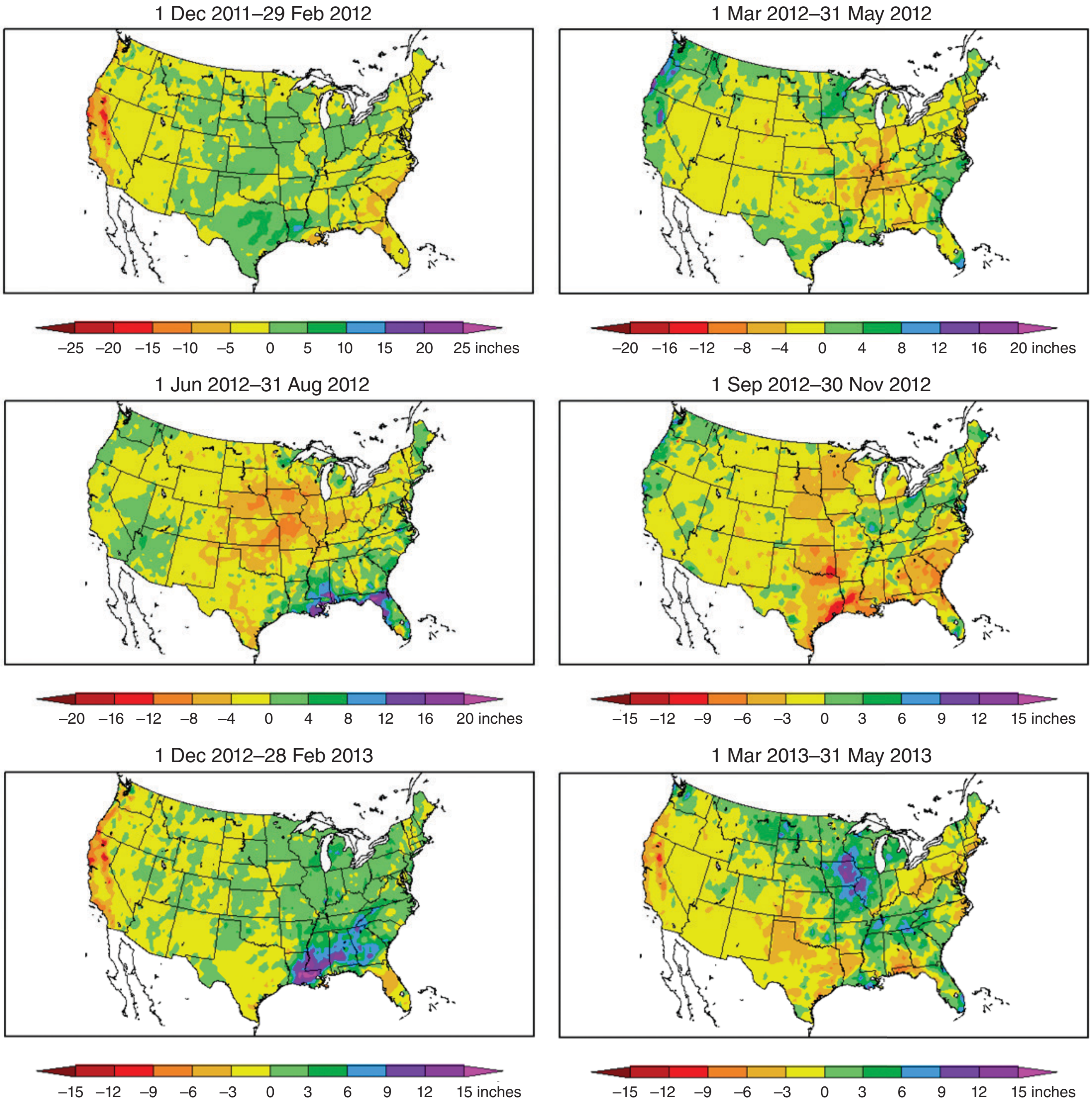
A large portion of the conterminous United States experienced drought conditions to varying degrees during 2012. In terms of precipitation departures from normal, the driest conditions occurred in the Great Plains and Midwest. Since precipitation departures are a defining feature of drought and one of many factors included in the assessment of the USDM, this section provides a discussion of regional precipitation anomalies.

The total precipitation departure from normal for 2012 (Figure 2.1) illustrates the widespread dryness across much of the United States. The Great Basin was near normal to slightly below normal, while drier conditions were experienced eastward toward the Rocky Mountains. The Great Plains, Texas to the Dakotas, were 4 to 12 inches below normal in most locations with some drier isolated areas. The mid-Mississippi River valley was the driest, and some areas, especially Missouri, Illinois, Arkansas, and western parts of Kentucky and Tennessee, were 12 to 16 inches or more below normal. The Southeast U.S. and Mid-Atlantic piedmont also were below normal, as well as parts of New England. The abnormally wettest locations were the coastal Pacific Northwest, Gulf Coast of Mississippi and Louisiana, and parts of Florida.

An examination of seasonal precipitation (Figure 2.2) showed when deficits occurred. Winter 2011–2012 was near normal, within 5 inches, for most of the nation. The Great Plains and Midwest experienced near- to above-normal precipitation. Meanwhile, the East and West Coasts of the U.S. experienced below-normal precipitation. This anomalous pattern nearly reversed in spring 2012. The Great Basin averaged 0 to 4 inches below normal, while the mid-Mississippi River valley from Illinois to Tennessee averaged as much as 8 inches below normal. The West Coast and Atlantic Southeast received much-needed relief. Conditions in the Great Plains and Midwest rapidly deteriorated in summer 2012. Locations from Texas to Minnesota, including Illinois, averaged 8 inches below normal, while parts of Nebraska, Kansas, Missouri, and Iowa were 12 inches below normal. The Gulf Coast was soaked with above-normal rainfall from Hurricane Isaac. The tropical cyclone remnants made its way to the Midwest, contributing to the above-normal precipitation in Illinois, Indiana, and Ohio during fall 2012.

Meanwhile, the Great Plains and upper Midwest, including northern Illinois and the Gulf Coast, remained largely dry in fall 2012. Precipitation was above normal for the Midwest and eastern half of the U.S. during winter 2012–2013. By spring 2013, the Midwest was exceptionally wet with precipitation 3 to 6 inches above normal. Western Illinois and Iowa received up to 15+ inches above normal precipitation, essentially ending any remaining concerns of drought across the Midwest.

Focusing on the Midwest, monthly maps of percentage-of-normal precipitation show the progression of the drought as well as the spatial and temporal variability across the region (Figure 2.3). The beginning of 2012 was largely characterized by extremes in precipitation on a regional scale. The Ohio River valley was wet, while eastern Kansas


1 Dec 2011–29 Feb 2012

1 Mar 2012–31 May 2012

1 Jun 2012–31 Aug 2012

1 Sep 2012–30 Nov 2012

1 Dec 2012–28 Feb 2013

1 Mar 2013–31 May 2013

Figure 2.2 Seasonal precipitation departures in inches from the 1971–2000 mean in the contiguous United States

received almost no precipitation. Illinois was in between the two extremes with near-normal precipitation across the state, except for western Illinois, which was related to the dryness to the west. This precipitation pattern reversed in February. Kansas, Nebraska, western Iowa, southern Minnesota, and eastern South Dakota were inundated with precipitation, while locations farther east, including Illinois, saw less than 75 percent of normal precipitation. March and April were also relatively dry in Illinois compared with neighboring states. Missouri and Minnesota received a surplus of springtime precipitation. From April through July, the Midwest grew increasingly dry as larger portions of the Midwest fell below 50 percent of the normal monthly precipitation. Most of the region was dry during August, although parts of central Illinois and Indiana received near-normal rainfall. However, the greatest reduction in the drought was made by the remnants of Hurricane Isaac, which gave central Illinois and Indiana, southeast Missouri,

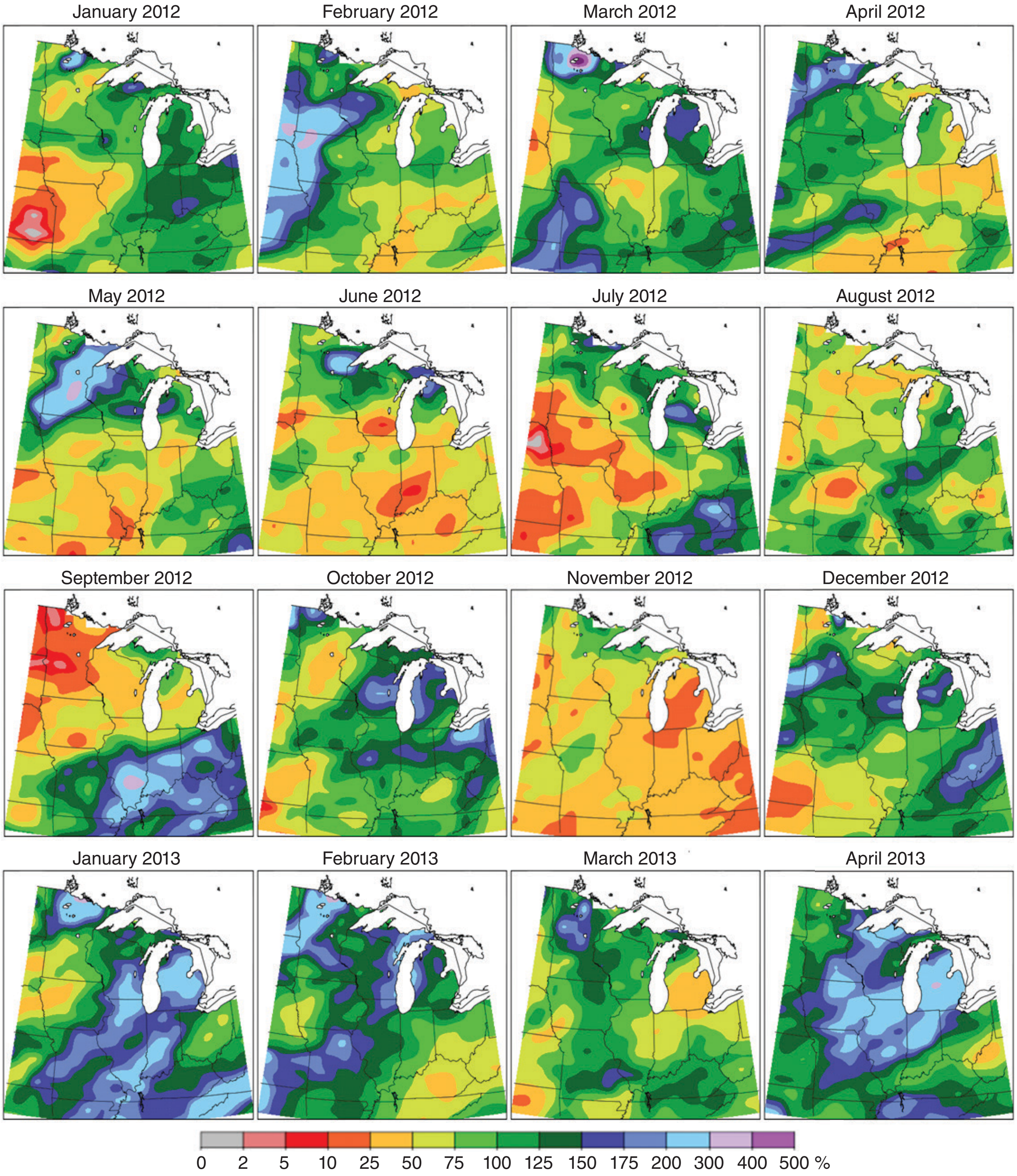


Figure 2.3 Percent of mean precipitation by month, January 2012–April 2013, based on the 1971–2000 climatological mean for the U.S. Midwestern region

and western Kentucky an abundance of rainfall at the beginning of September. Precipitation also increased across the region during the month, allowing south-central Illinois to receive up to four times the normal precipitation for September. After near-normal precipitation in October, another wave of dry conditions engulfed the region in November. A secondary dry spell can occasionally be observed after a major drought event (Changnon, 1987). As precipitation increased across the Midwest during winter 2012–2013, the drought slowly receded westward. January, February, and April 2013 were notably wet for many Midwestern states including Illinois, which received two to three times the normal precipitation during these months. This wet period signified the end of the drought for Illinois and the Midwest.

U.S. Drought Monitor

USDM is a map product collaboratively provided by federal agencies. These maps are updated weekly. The process behind the USDM is explained in more detail by Svoboda (2002). Figure 2.4 shows USDM maps from the first update of each month, April 2012 to March 2013, the approximate period when drought conditions were experienced in Illinois. Abnormal dryness first appeared in western and central Illinois with the March 27, 2012 USDM update, on the heels of a waning but historic 2011 drought in the southern plains of Texas and a moderate/severe drought that had developed in the upper Midwest, Southern Plains, and Northern Plains during the winter. These conditions persisted through April and early May as abnormal dryness began in Illinois. By June, droughts in the upper Midwest and southern plains had vastly improved; however, the once patchy abnormal dryness in Illinois had filled in the central U.S. along with patches of moderate drought in Arkansas, Kansas, Missouri, Iowa, and Illinois. Localized severe drought conditions had developed near the confluence of the Ohio and Mississippi Rivers. By June, the drought accelerated rapidly. Most of the Mississippi and Ohio River valleys experienced drought to varying degrees during July and August, including a vast majority of the contiguous U.S. The worst of the drought during these months occurred in a region that stretched from western Indiana through southeast Illinois, western Kentucky, southeast Missouri, and most of northern Arkansas. Another sizeable portion of exceptional drought enveloped parts of the central plains, including Kansas and Oklahoma. These harsh conditions occurred in the context of the extreme drought that engulfed much of the central U.S.

A small amount of relief arrived in the second half of August. Hurricane Isaac came ashore August 28, 2012 on the southeastern coast of Louisiana and tracked northwestward into the parched center of the country. The storm's winds weakened as it progressed inland through Arkansas, Missouri, and Illinois; however, much-needed rain fell across these states during the first three days of September. Between August 31 and September 3, as much as 5 inches of rain fell in the mid-Mississippi and lower Ohio River valleys with local higher totals. While Isaac did not erase drought from the Midwest, the storm at least ameliorated the situation.

Conditions improved only slightly in the Midwest through the end of 2012. Exceptional drought conditions were widespread in the Great Plains from South Dakota to Oklahoma. Patches of extreme drought were seen from Minnesota to Arkansas, including a swath through far northwestern Illinois. Through autumn, drought conditions diminished substantially in Ohio, Michigan, Indiana, and Kentucky. Recovery was slow to propagate westward. Remarkable improvements arrived in Illinois during late January into February 2013. As of the April 9, 2013 USDM update, Illinois was officially drought free, though most of the western half of the United States remained in some stage of drought.

Possible Causes of the 2012 Drought

Hoerling et al. (2014) conducted a detailed observational and modeling study of the 2012 drought. Potential climatic causes such as sea surface temperature patterns and increases in greenhouse gasses did not play significant roles in the drought. Instead, this was a classic warm season central U.S. drought dominated by meteorological features. The first two of these features were the reduced atmospheric moisture transport from the Gulf of Mexico and reduced cyclone and frontal activity in the spring. The drought persisted and intensified in summer as normal summer convective precipitation (i.e., thunderstorms) was inhibited as high pressure dominated the region in July and August. By the second half of August, this pattern had begun to breakdown, allowing rains to return to the Midwest.

Predictability

One question of any significant drought event is: Could it have been foreseen? Unfortunately, predicting drought is an extremely difficult task that requires not only the identification of large-scale circulation features in advance, such as a persistent ridge of high pressure, but also the impacts of local feedbacks such as the drying of the land surface, which are not well measured or understood.

The National Weather Service routinely issues short-term temperature and precipitation forecasts. However, a group within the National Weather Service, called the Climate Prediction Center (CPC), issues monthly and seasonal average temperature and precipitation forecasts for the United States. Figure 2.5 shows the seasonal precipitation issued in January 2012 prior to the onset of the drought. In this figure, the contours on the maps indicate the total probability percentages of precipitation falling into one of three categories: above (A), below (B), and the near-normal category (N).

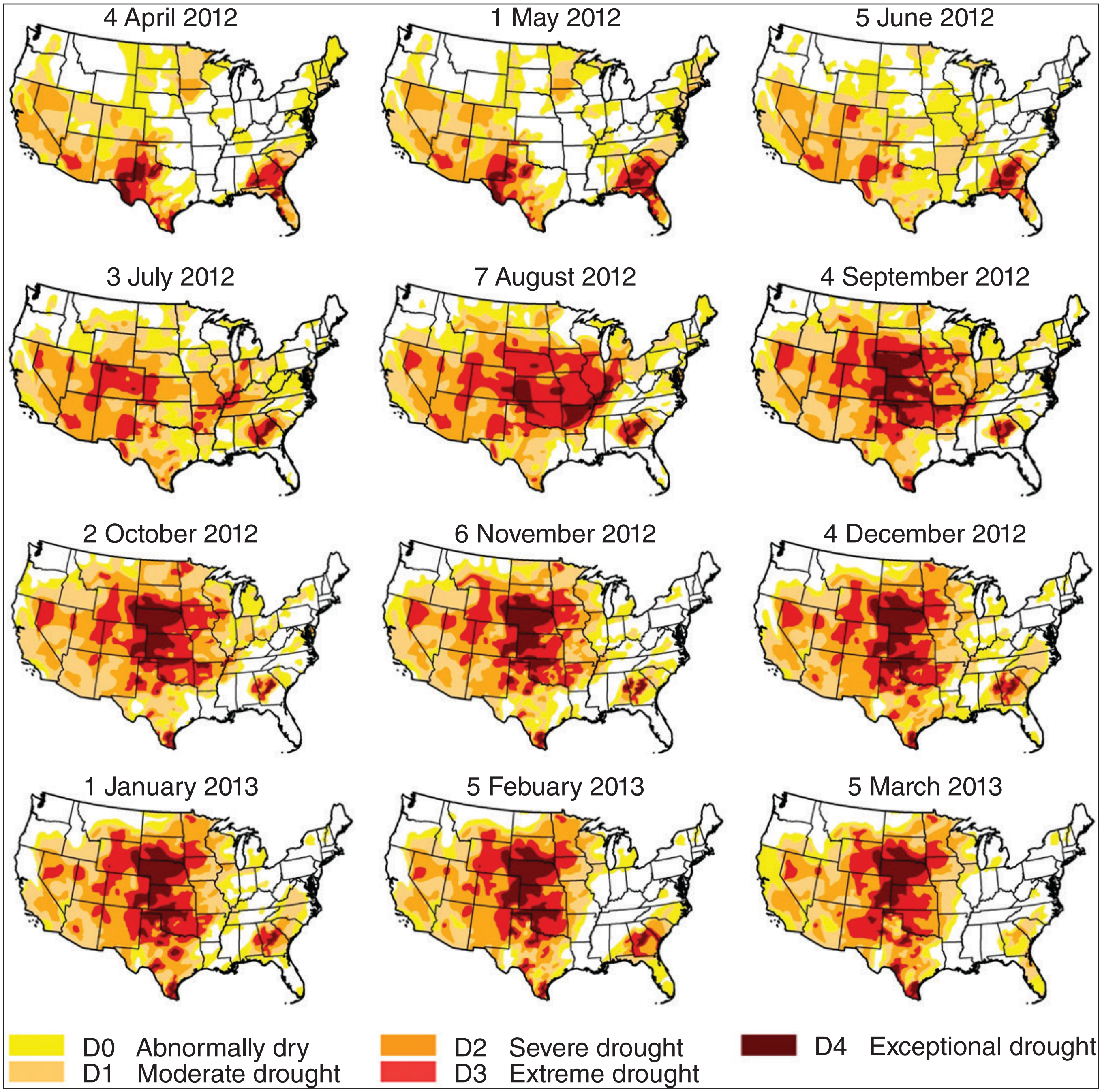


Figure 2.4 Time evolution of the U.S. Drought Monitor indices from April 2012 to March 2013. The U.S. Drought Monitor is updated every Tuesday.

At any point on the map, the sum of all three probabilities is 100 percent. Shading indicates probabilities exceeding 33.3 percent in that particular category. The three categories are defined from the 30-year climatology from 1981 to 2010. The coldest or driest third of the climatology (10 years) defines the B category, the warmest or wettest third (10 years) defines the A category, and the remaining 10 years in between define the N category. In regions where no climate prediction tools favor the chance of either above- or below-normal conditions, the region is labeled "EC," meaning equal chances of above-, below-, or near-normal conditions. For example, an area with brown shading with the "B" label and a contour of 50 percent would indicate a 50 percent chance of below-normal precipitation for that region, which is a much greater risk of dryness than expected by chance (33.3 percent).

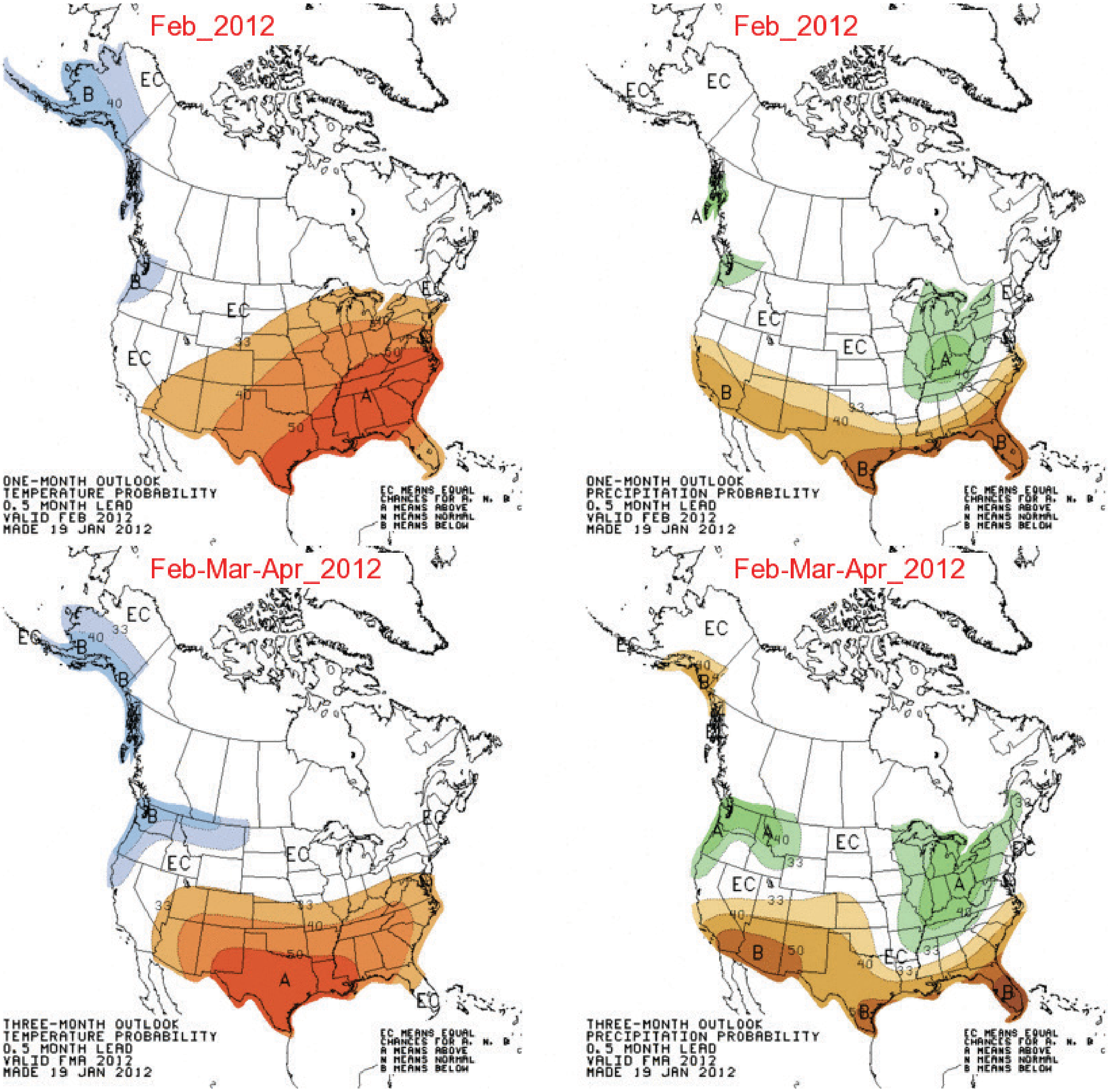


Figure 2.5 Monthly and seasonal forecasts of temperature and precipitation issued by the Climate Prediction Center in January 2012

While the monthly and seasonal (three-month) outlooks issued by the CPC are not specifically designed to forecast upcoming droughts, they can indicate an increased risk of being drier and/or warmer than normal, which could lead to drought conditions at some point. The monthly forecast for February (Figure 2.5) shows much of the eastern two-thirds of the U.S. with an increased chance of above-normal temperatures. There was an increased chance of above-normal precipitation in the Great Lakes region and an increased chance of below-normal precipitation extending from California to the Carolinas. For the three-month forecast of February–April, the southern U.S., including the southern half of Illinois, had an increased chance of being warmer than normal. Meanwhile, the Great Lakes and Ohio River Valley had an increased chance of above-normal precipitation. An examination of Figure 2.3 shows that the Great Lakes/Ohio River Valley region actually received below-normal precipitation during this period.

The forecast released in mid-April for May and May–July is shown in Figure 2.6. The forecast for one and three months shows the Midwest in equal chances (EC) for above, below, and near-normal temperatures and precipitation.

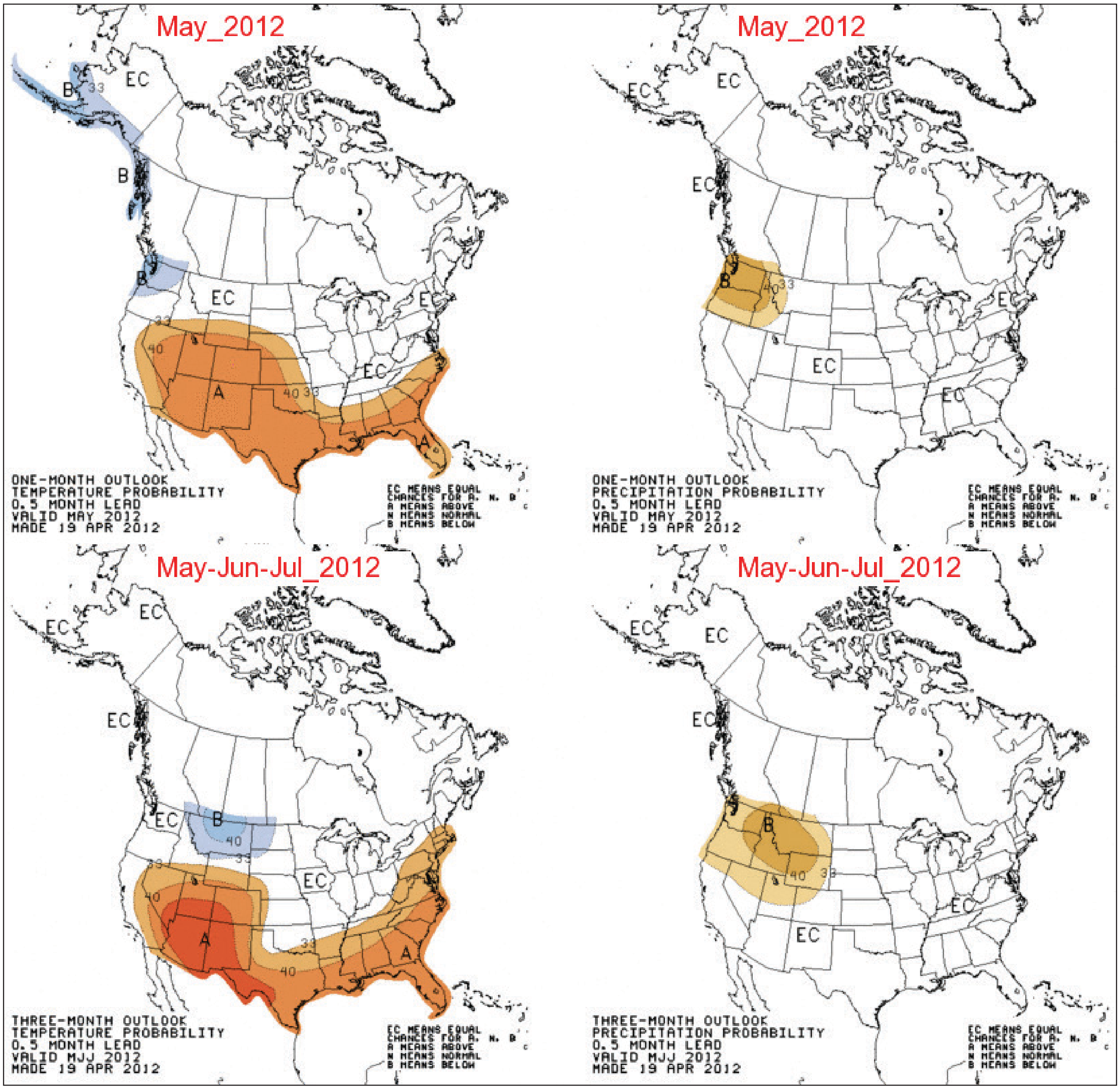


Figure 2.6 Monthly and seasonal forecasts of temperature and precipitation issued by the Climate Prediction Center in April 2012

The forecast released in mid-June for July and July–September (Figure 2.7) finally showed the Midwest with an increased chance of above-normal temperatures, driven primarily by the reductions in soil moisture already evident in June. The July forecast also shows a relatively small area of the Midwest with an increased chance of below-normal precipitation. The July–September precipitation forecast shows equal chances of above-, below-, and near-normal conditions across the central U.S. In reality, the western half of the Midwest received below-normal precipitation, while the eastern half received above-normal precipitation. This was largely due to the effects of Hurricane Isaac, which were beyond the ability of the forecasters to predict in mid-June.

Hoerling et al. (2014) examined the potential predictability of the 2012 drought and found that precipitation trends in the region did not show any trend towards an increased risk of such a short, intense drought. In fact, they called the 2012 drought a "climate surprise from such empirical evidence alone." In the near-term, conditions

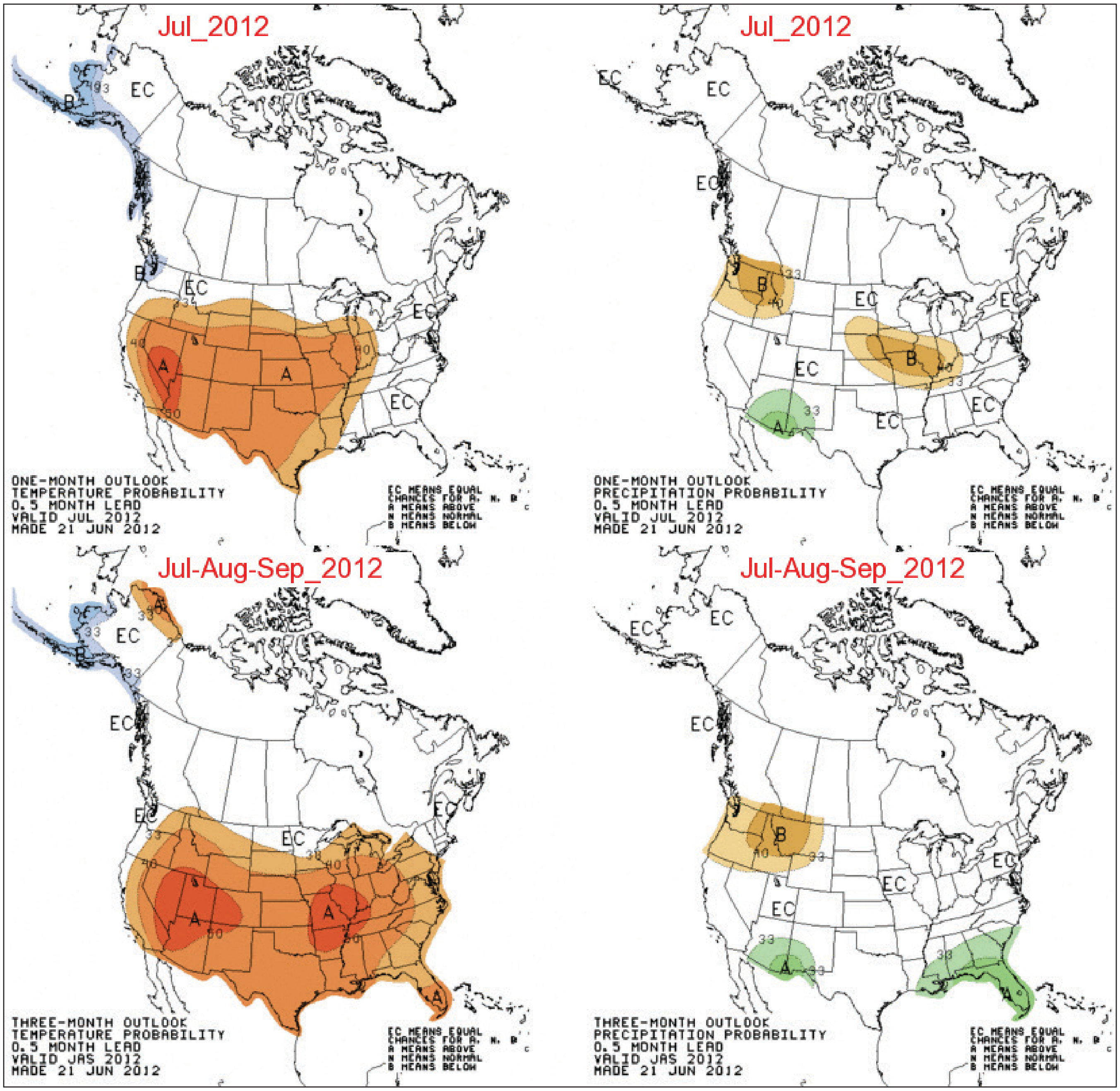


Figure 2.7 Monthly and seasonal forecasts of temperature and precipitation issued by the Climate Prediction Center in June 2012

even through the end of April were near- normal across the region with no widespread pattern of dryness. Based on their careful analysis of observations and extensive climate modeling, they concluded that this extreme drought event would have been very difficult to forecast.

Summary

The drought in Illinois was part of a larger-scale drought across the central U.S. in 2012. Although Illinois was hard hit by the drought, most of the U.S. experienced drought conditions throughout 2012 with the largest precipitation deficits in the Central Plains and Midwest.

The winter 2011–2012 was near to above normal on precipitation. Once spring arrived, drier conditions developed across parts of the Midwest. By summer, the drought was widespread across the central U.S. Recovery began in the eastern parts of the Midwest in the fall, aided by Hurricane Isaac. However, full recovery for the central region did not occur until the following winter and spring. The 2012 drought appeared to be due to natural variability and not related to sea surface temperature patterns or long-term climate change. A spring with less atmospheric moisture and a lack of low-pressure systems and cold-warm fronts was followed by a summer dominated by high pressure that inhibited normal thunderstorm activity. Prior to the onset of the drought, monthly and seasonal precipitation and temperature forecasts did not indicate an increased risk of either below-normal precipitation or above-normal temperatures in the Midwest. An assessment afterwards concluded that there were no warning signs of the impending drought.

Chapter 3: Climate Conditions in Illinois

Introduction

The drought of 2012 was one of the most severe to strike Illinois since the 1988 drought. This chapter discusses weather and climate factors associated with the 2012 drought and how it compared with historical conditions. In general, dry conditions were seen in west-central Illinois as early as fall 2011. However, the drought became fully developed only in the spring and summer of 2012 before coming to an abrupt end in September and October.

Precipitation and Temperature

Daily average statewide precipitation measurements were collected from the National Weather Service Cooperative Observer Network. Additional precipitation data were compiled from the all-volunteer Community Collaborative Rain, Hail, and Snow (CoCoRaHS) network and from National Weather Service radar-estimated precipitation. These were aggregated by the National Climatic Data Center into monthly averages by climate division and by state for ranking considerations. Statewide records of temperature and precipitation extend to 1895 in Illinois. References to "average" or "normal" refer to the standard 1981–2010 averaging period, unless otherwise noted.

2011

Despite a wet spring across Illinois in 2011, the region between Interstates 70 and 80 experienced below-average precipitation, and some areas in west-central Illinois experienced much-below-normal precipitation in July and August. Precipitation in those areas was 4 to 6 inches below normal. Other areas between Interstates 70 and 80 were 2 to 4 inches below normal. This intense dryness was coupled with temperatures 2 to 4 degrees above normal, resulting in high rates of evapotranspiration. Evapotranspiration (ET) is a combination of the evaporation of water from land and water surfaces and transpiration from plants. The combination of planting delays because of the wet spring and the hot, dry summer resulted in corn and soybean yields that were below the five-year average in many Illinois counties.

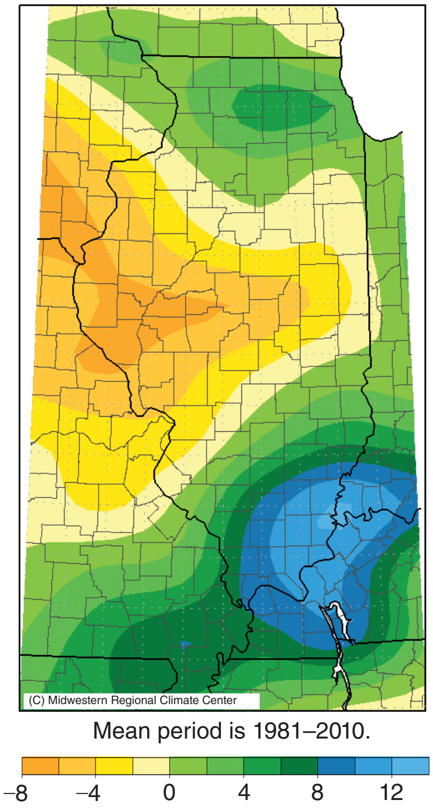


Figure 3.1 Precipitation departures from normal for July 1 to December, 31, 2011, showing the dryness present in western Illinois

Although conditions eased somewhat in the fall with the return of precipitation and cooler temperatures, the second half of 2011 remained dry. In particular, the area between St. Louis, Moline, and Decatur remained 4 to 6 inches below normal through the end of December (Figure 3.1). As a result, this area was already primed for severe drought impacts in 2012.

January–April 2012

For the rest of Illinois, the drought began in 2012. Figure 3.2 shows the monthly statewide precipitation departures during 2012. Precipitation was below normal for each month from January through April. Although none of the four months was exceptionally dry (Table 3.1), together the statewide average precipitation was 8.58 inches, which was 2.28 inches below normal and the 28th driest January–April on record.

Another key factor in the early stages of the 2012 drought was the extensive warm weather at the beginning of the year. Monthly temperature departures for the state (Figure 3.3 and Table 3.2)

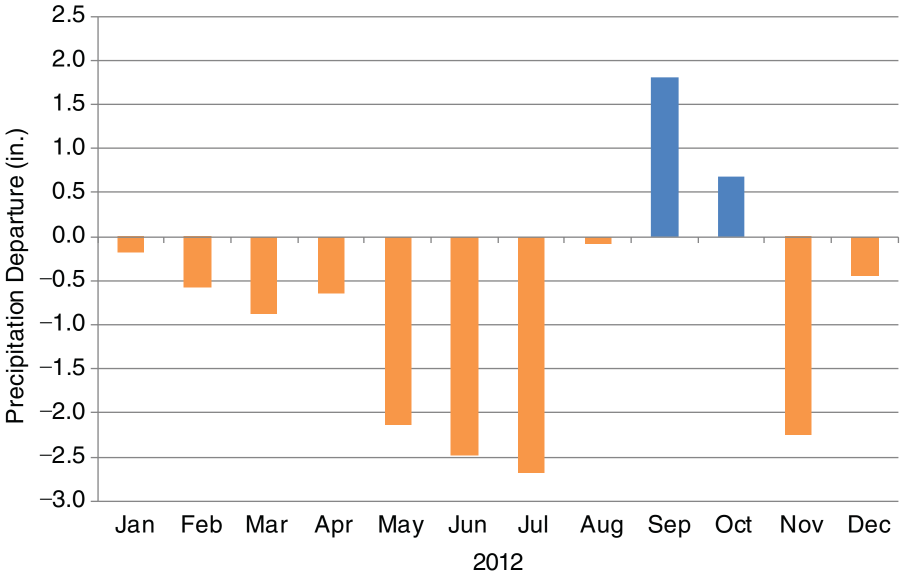


Figure 3.2 Monthly precipitation departures from the 1981–2010 average for Illinois in 2012

Table 3.1 Illinois (statewide) Precipitation Rankings by Month and Year for 2012. Period of rankings spans 1895–2012.

Period (2012)	Rank	Precipitation (in)	Normal (in)	Departure (in)	% normal
January	66th driest	1.89	2.07	−0.18	91
February	40th driest	1.48	2.06	−0.58	72
March	30th driest	2.08	2.96	−0.88	70
April	48th driest	3.13	3.78	−0.65	83
May	21st driest	2.47	4.60	−2.13	54
June	8th driest	1.73	4.21	−2.48	41
July	4th driest	1.40	4.08	−2.68	34
August	65th driest	3.50	3.59	−0.09	97
September	17th wettest	5.04	3.23	1.81	156
October	23th wettest	3.93	3.24	0.69	121
November	14th driest	1.21	3.47	−2.26	35
December	61th driest	2.25	2.69	−0.44	84
January–December	10th driest	30.11	39.96	−9.85	75

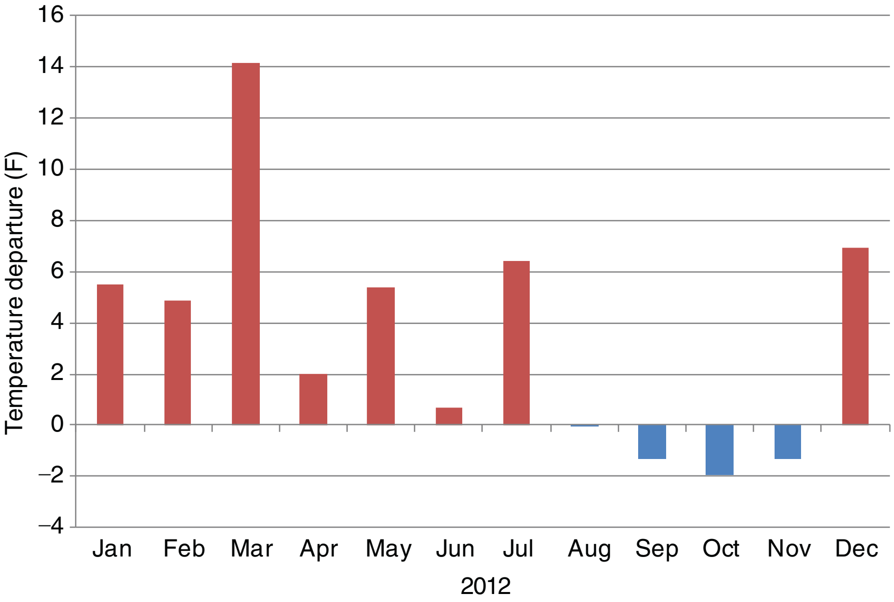


Figure 3.3 Monthly temperature departures from the 1981–2010 average for Illinois in 2012

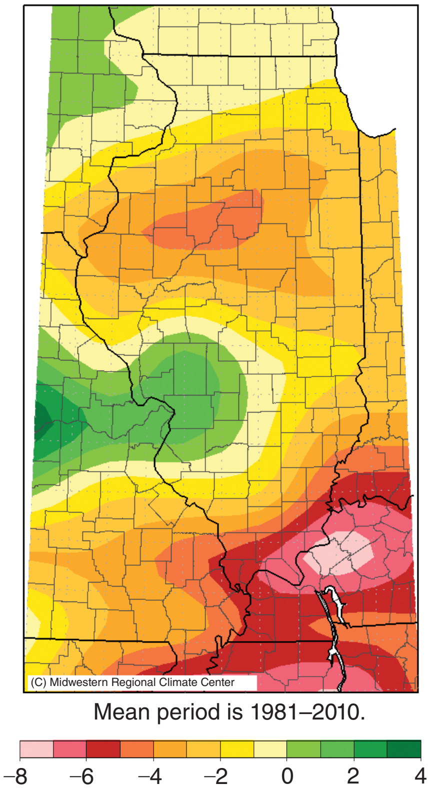
show that January, February, March, and April were all well above normal on temperatures. Although all four months were warmer than normal, March was outstanding as the warmest March on record and 14.2 degrees above normal Temperatures in the 70s and 80s were common in March. This warm start to 2012 meant that the below-normal snowfall from the winter was long melted. In addition, soils remained unfrozen, which allowed water to drain quickly, and rivers and streams were unimpeded by ice. Furthermore, above-normal temperatures increased the evaporation rates, which are historically low during this time of year.

Spatially, precipitation was below normal across most of Illinois from January to April (Figure 3.4). One area with the driest conditions was east of Moline where precipitation was 3 to 4 inches below normal. However, hardest hit was far southern Illinois where precipitation was 3 to 7 inches below normal. The only area with above-normal precipitation in Illinois during this time was to the east of St. Louis.

Although 2012 started out hot and dry, precipitation was only slightly below normal in April, suggesting a chance for a last-minute recovery before the growing season. Unfortunately, April was only a temporary pause in the developing drought. This situation illustrates one of the challenges in monitoring droughts when the brief return of precipitation may signal a false drought recovery. It is now clear that this drier and warmer four-month stretch set the stage for rapid deterioration of conditions later by depleting soil moisture, as well as lowering water levels in rivers, lakes, and streams during a time of the year when they are typically highest.

Table 3.2 Illinois (statewide) Average Temperature Ranking by Month and Year for 2012. Period of ranking spans 118 years, 1895–2012.

Period (2012)	Rank	Temperature (°F)	Normal (°F)	Departure (°F)
February	14th warmest	35.8	30.9	4.9
January	12th warmest	31.9	26.4	5.5
March	1st warmest	55.5	41.3	14.2
April	20th warmest	54.6	52.6	2.0
May	6th warmest	68.1	62.7	5.4
June	42nd warmest	72.6	71.9	0.7
July	2nd warmest	81.8	75.4	6.4
August	58th warmest	73.6	73.6	0.0
September	37th coolest	64.9	66.2	−1.3
October	29th coolest	52.5	54.4	−1.9
November	58th coolest	41.2	42.5	−1.3
December	6th warmest	36.8	29.9	6.9
January–December	1st warmest	55.9	52.4	3.5



(C) Midwestern Regional Climate Center

Mean period is 1981–2010.

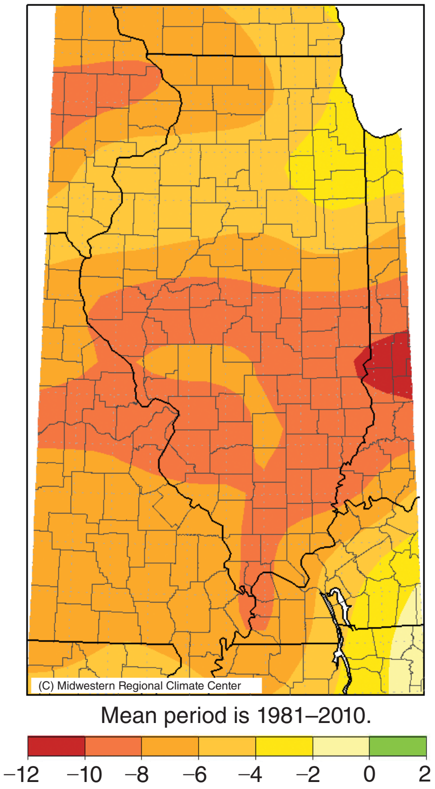
Figure 3.4 Precipitation departures from normal from January 1 to April 30, 2012, showing the dryness in north-central Illinois and southeastern Illinois

May–July 2012

After the brief recovery in April, May was much drier with only 2.5 inches of precipitation, 58 percent of normal, and the 21st driest May on record. Even drier conditions prevailed in June and July as only 1.8 inches of precipitation fell in the eighth driest June on record, and 1.5 inches fell in the fourth driest July on record.

These three months combined represent the core of the drought in terms of both the lack of precipitation and subsequent impacts, especially in agriculture. The three-month total precipitation was 5.60 inches, 43 percent of normal, and the third driest May–July on record (Table 3.3 and Figure 3.5). The driest May–July on record was 1936 with 4.95 inches, 38 percent of normal. The second driest was 1988 with 5.25 inches, 41 percent of normal. Spatially, the precipitation deficits were widespread and severe during this period (Figure 3.5). In general, much of central and southern Illinois were 8 to 10 inches below normal, while northern Illinois was 6 to 8 inches below normal.

Temperatures were above normal for winter, spring, and summer (Table 3.4). March through May was outstanding with temperatures 7.2 degrees



(C) Midwestern Regional Climate Center

Mean period is 1981–2010.

Figure 3.5 Precipitation departures from normal for May 1 to July 31, 2012, showing the widsepread dryness across the state

Table 3.3 Illinois (statewide) Precipitation Ranking by Season. Period of rankings spans 118 years, 1895–2012.

Period	Rank	Precipitation (in)	Normal (in)	Departure (in)	% Normal
December–February 2012	66th driest	6.72	6.82	−0.10	99
March–May	17th driest	7.68	11.34	−3.66	68
May–July	3rd driest	5.60	13.02	−7.42	43
June–August	6th driest	6.63	11.88	−5.25	56
September–November	37th wettest	10.18	9.94	0.24	102
December–February 2013	11th wettest	8.71	6.82	1.89	128

Table 3.4 Illinois (statewide) Average Temperature Ranking by Season/Three-Month Periods. Period of rankings spans 118 years, 1895–2012.

Period	Rank	Temperature (°F)	Normal (°F)	Departure (°F)
December–February 2012	4th warmest	34.5	29.1	5.5
March–May	1st warmest	59.4	52.2	7.2
June–August	11th warmest	76.0	73.6	2.4
September–November	33rd coolest	52.9	54.4	−1.5
December–February 2013	15th warmest	32.0	29.1	2.9

above normal and the warmest spring on record. This is a typical feature of droughts in Illinois: elevated temperatures, which further increase the stress of drought on water supplies, crops, livestock, and humans. On average, 100-degree weather is rare in Illinois, occurring only one to two days on average in southern Illinois and only once every two years on average in northern Illinois. However, as Figure 3.6 shows, 100-degree days were numerous and widespread across Illinois. Southern Illinois experienced 15 to 20 days, central Illinois experienced 10 to 20 days, and northern Illinois experienced 2 to 10 days with temperatures of 100 degrees or more.

By the end of July, precipitation deficits for 2012 had reached 12 to 15 inches below normal for counties along the Wabash and Ohio River valleys (Figure 3.7). Areas to the east of St. Louis and in northern Illinois fared better with deficits of 6 to 9 inches. The rest of central and southern Illinois faced precipitation deficits of 9 to 12 inches.

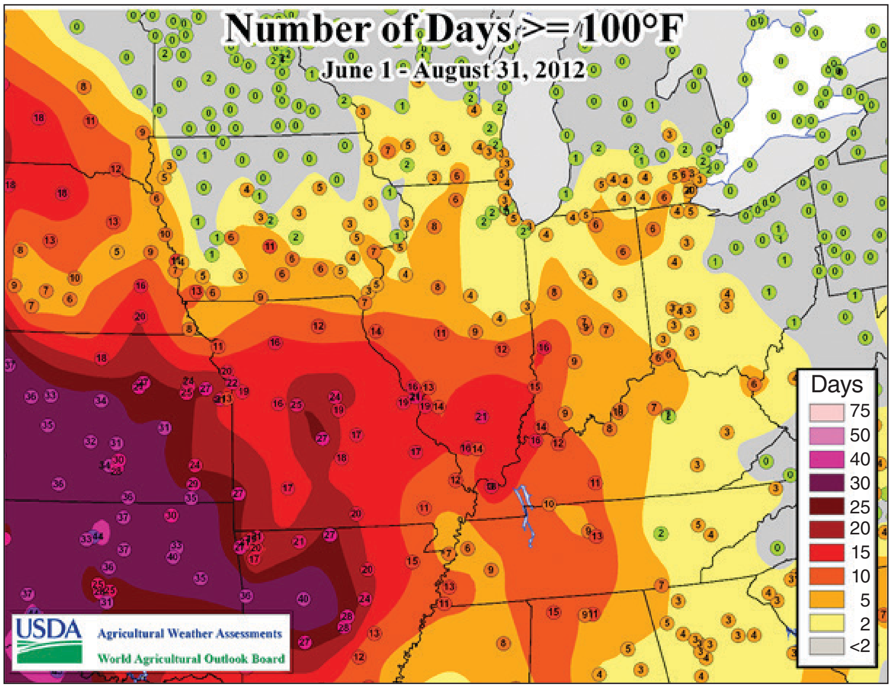
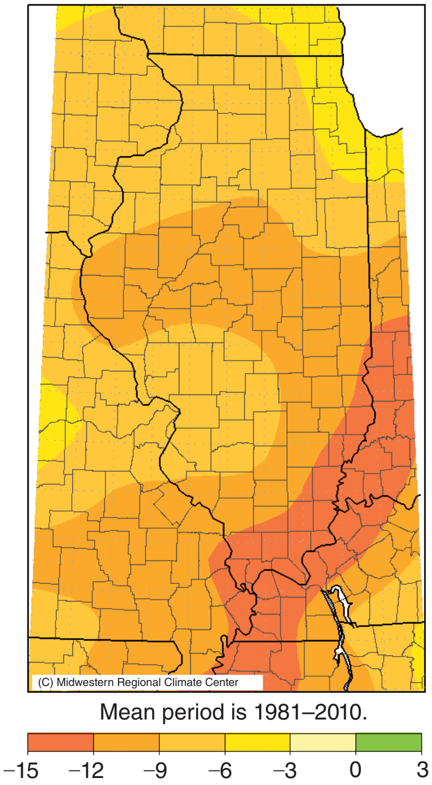


Figure 3.6 Map showing the number of days at or above 100 degrees from June 1 to August 31, 2012

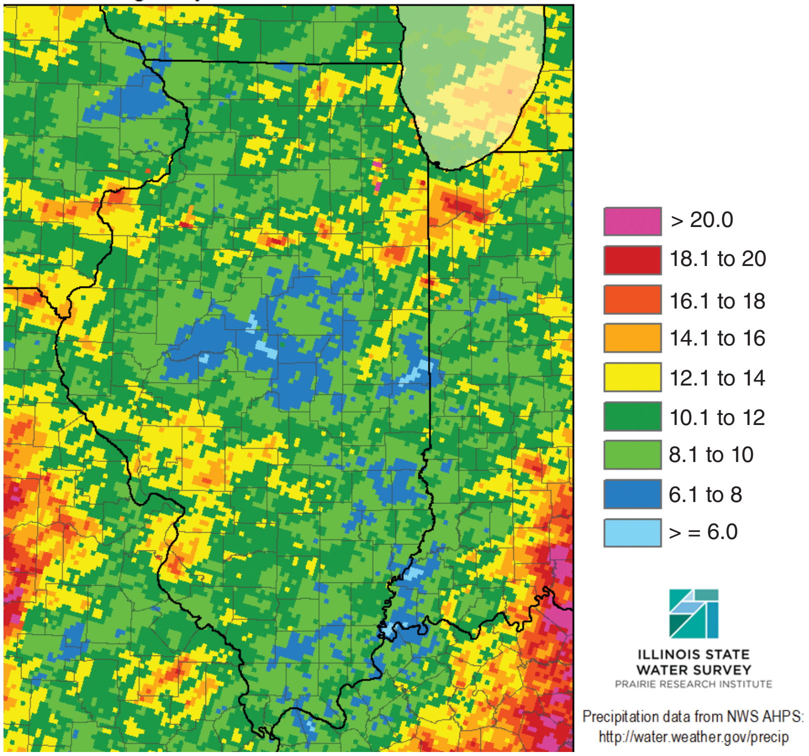


Mean period is 1981–2010.

Figure 3.7 Precipitation departures from January 1 to July 31, 2012, showing widespread dryness with the largest departures in southeastern Illinois

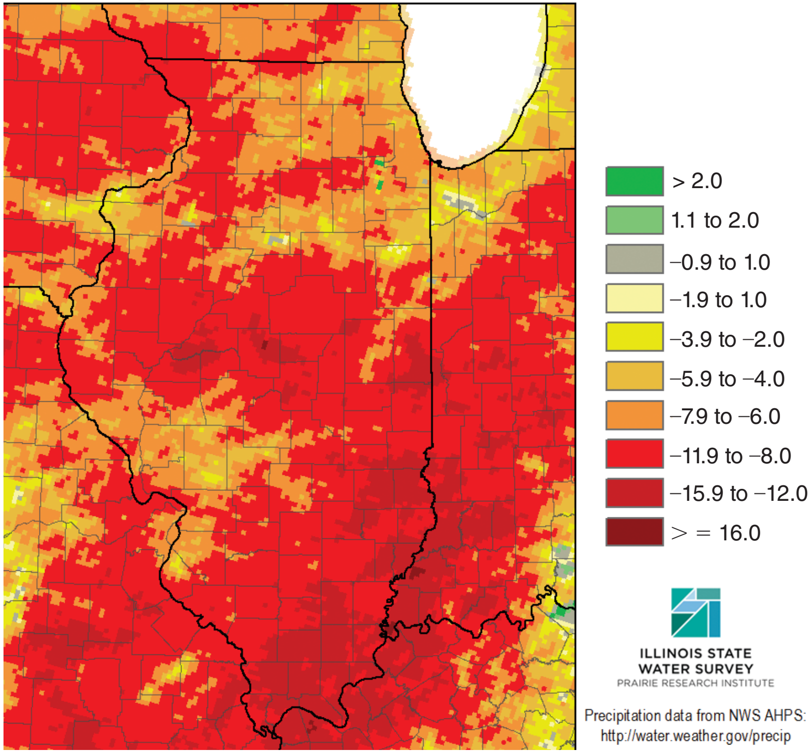
A newer monitoring product provided by the National Weather Service uses raingage data to adjust the radar-estimated precipitation estimates. This product is called the Multi-sensor Precipitation Estimate (MPE). By itself, the radar-estimated precipitation has a resolution of 4 km. However, it is limited in accuracy by assumptions about the drop size distribution within the storm (i.e., all large drops or small drops), nearby storms blocking out storms behind them, and the curvature of the earth. The role of the sparse and irregularly spaced raingage network is to recalibrate the radar estimates using equations. The result is a high-resolution, moderately accurate estimate of precipitation.

The MPE maps for the total precipitation (Figure 3.8) and the departure from normal (Figure 3.9) feature the precipitation deficits during the heart of the drought from March through July. The higher resolution reveals that even during the worst of the drought, a few



Precipitation data from NWS AHPS:
http://water.weather.gov/precip

Figure 3.8 Radar raingage precipitation from March through July 2012. The resolution of this product is 4 km.



Precipitation data from NWS AHPS:
http://water.weather.gov/precip

Figure 3.9 Radar raingage precipitation departure from normal (inches) for March through July 2012 areas did see precipitation amounts close to normal. These areas included from Moline to St. Louis on the Illinois side, a stretch along Interstate 80, and some parts of Kankakee and Iroquois counties. Although the precipitation was still below normal in those areas, the effect of timely precipitation amounts made an enormous difference in reducing the agricultural impacts in those areas.

Evapotranspiration

The lack of precipitation is the primary factor for producing a drought, but evapotranspiration can play a critical role as well. Evapotranspiration rates can be higher than average during the initial stages of drought due to the increased temperatures, sunshine, and wind. This wide imbalance between reduced supply and increased demand can rapidly use up available water in the landscape. In fact, evapotranspiration rates will drop with the depletion of soil moisture and surface dryness.

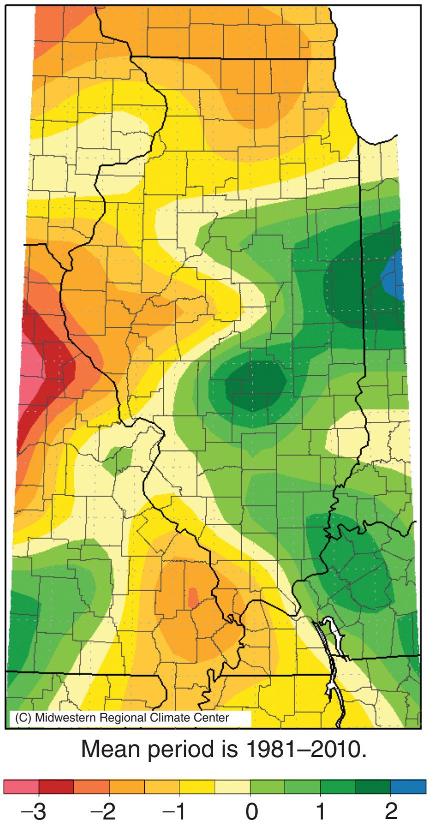
Although evapotranspiration data are limited in time and space, what are available indicate very high rates during the 2012 drought. One basic measure of evaporation is the water level in a 3-foot evaporation pan. Some of the longest complete records are from Champaign and extend back to 1980. For 2012, the evaporation rate was 0.5 inches above average for May, 1.5 inches above average for June, 2.2 inches above average for July, and 1.8 inches above average for August. That is 6 inches above the 1980–2014 average for Champaign and represents about one-and-one-half months of summer precipitation. The total water loss from the evaporation pan in July 2012 was 8.83 inches, the most of any month on record for the site.

Although evaporation can be measured from an evaporation pan, measuring transpiration is considerably more difficult because measurements have to be made from the leaves of the relevant vegetation. One instrument deployed in Champaign at the beginning of the 2012 growing season was a reference evapotranspiration gage. This instrument is an evaporimeter, resembling a raingage, only modified with a ceramic evaporating cup covered in a green canvas to simulate the albedo and leaf properties of a cut-grass covered surface. The gage is filled with distilled water, and water loss readings are made daily. When compared with daily precipitation readings, a water balance for the season can be constructed.

During the 2012 growing season, readings began in May, and evapotranspiration rates quickly outpaced the incoming precipitation, resulting in a water deficit. By May 31, the water deficit was 2.6 inches, meaning that 2.6 inches more water left the evapotranspiration instrument than the amount that fell in the nearby raingage. By June 30, the water deficit was 6.5 inches and by July 31 it had reached 12.5 inches. The worst deficit occurred on August 9 at 13.8 inches. However, some rains kept the deficit from growing and even reduced it slightly by August 31 with a deficit of 12.2 inches. With the rains in September and October, the water deficit started to ease with a reading of 9.1 inches on September 30 and a reading of 4.1 inches on October 30 when the gage was taken down for the season to prevent freeze damage. By comparison, the water balance in Champaign for 2013 was positive through the end of August before a dry spell caused a late-season deficit of 3 inches.

August 2012

The first signs of relief from drought conditions occurred in August, in particular the second half, when most of the state began to see both temperatures and precipitation that were close to normal. In fact, eastern and southern Illinois saw above-normal precipitation for the first time in 2012 (Figure 3.10). The regions receiving above-normal precipitation experienced moderate increases in soil moisture and streamflow. Although this precipitation was too late in the growing season for corn, it appeared to have some benefit for soybeans.



Mean period is 1981–2010.

Figure 3.10 Precipitation departures from August 1 to 31, 2012, showing the return of precipitation, especially in eastern and southern Illinois

Hurricane Isaac and Drought Recovery

On September 1-3, 2012, the remains of Hurricane Isaac tracked across the Midwest, bringing widespread and heavy precipitation across the region (Figure 3.11). Although it does not happen often, tropical systems can reach Illinois on occasion. By the time they arrive here, they are generally weaker while still bringing widespread precipitation. A detailed precipitation map based on radar and calibrated by precipitation gages (Figure 3.12) shows how extensive the precipitation was in Illinois. Much of central and southern Illinois received 2 to 4 inches of precipitation over a three-day period. Because the precipitation was slow and steady and spread out over three days, most was able to soak into the soil, recharging the topsoil and subsoil. The precipitation extended all the way up to Interstate 80 before stopping.

In the two-week period from August 27 (before Hurricane Isaac) to September 9, U.S. Department of Agriculture's National Agricultural Statistics Service (NASS) reported that topsoil moisture in the "very short" category went from

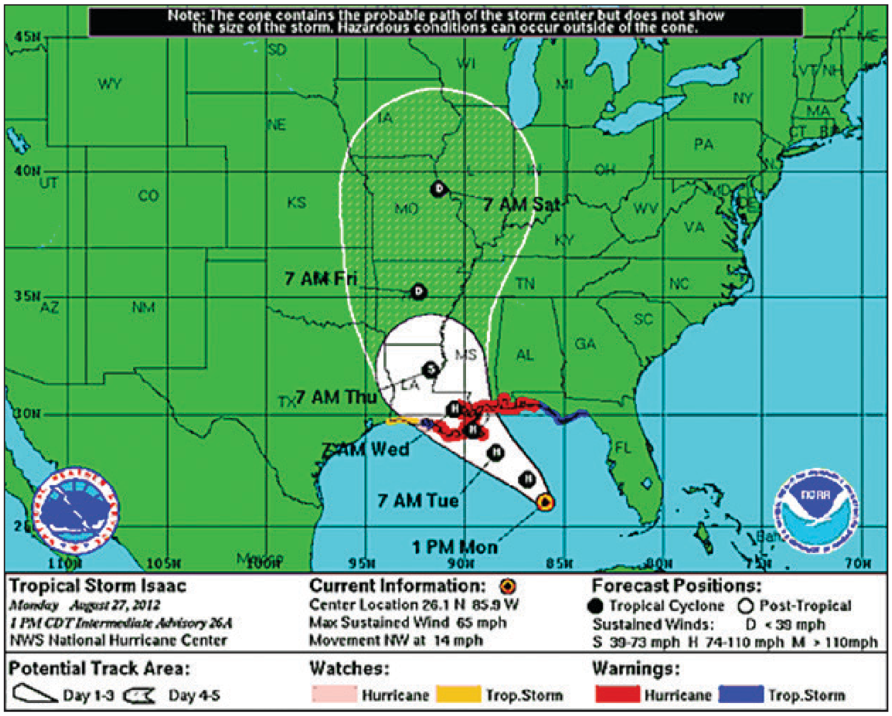


Figure 3.11 Storm track of Hurricane Isaac as it moved through Illinois over Labor Day weekend. Figure courtesy of NOAA National Hurricane Center.

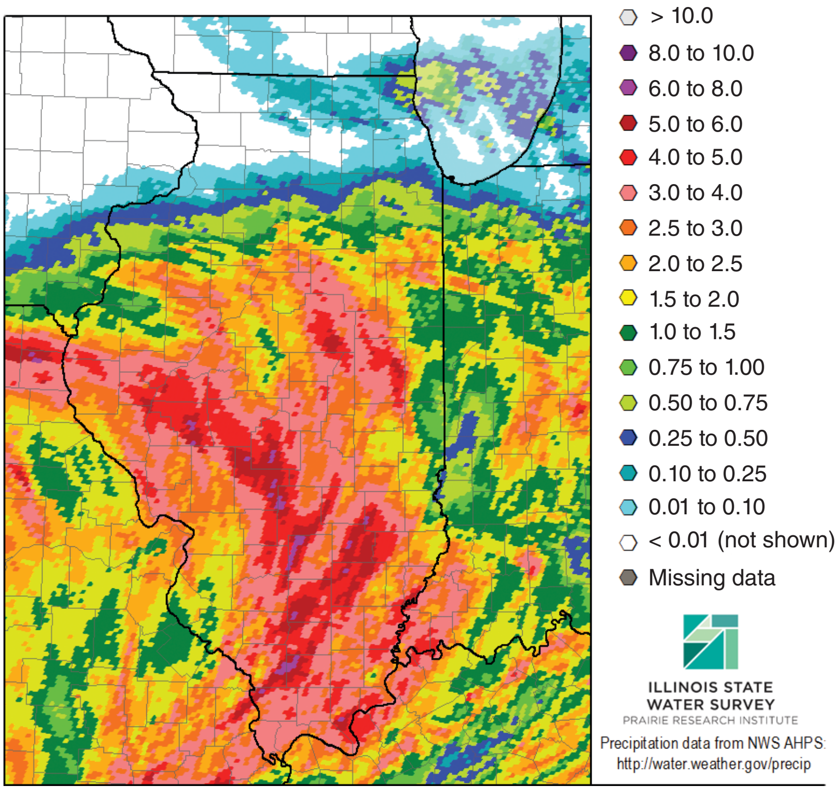


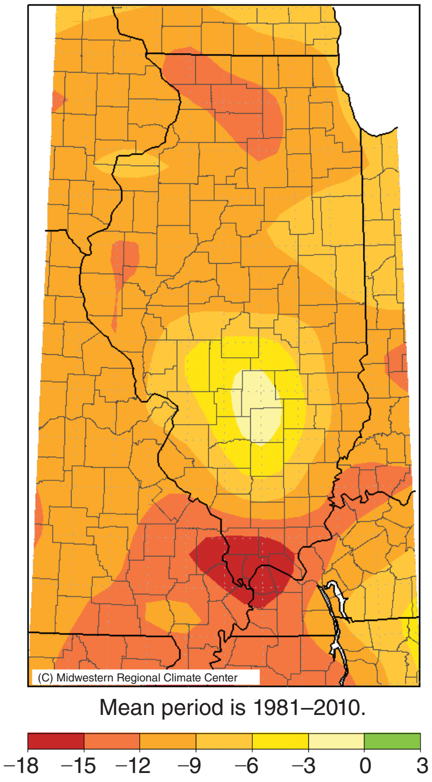
Figure 3.12 High-resolution map of the precipitation from Hurricane Isaac. Many areas in central and southern Illinois received 2 to 4 inches over the course of three days.

57 to 16 percent. Topsoil moisture in the "short" category went from 30 to 31 percent, and topsoil moisture in the "adequate" category rose from 13 to 52 percent. Although these are qualitative categories based on field soil surveys, they illustrate how the topsoil showed significant improvement in short order. NASS considers topsoil to be the top 6 inches of soil. Subsoil moisture showed similar improvements over the same period with 74 percent of soils in Illinois in the very short category before the storm and 36 percent in that category after the storm. NASS considers subsoil to be the layer from 6 to 24 inches. In general, this layer is both slower to dry out and slower to recover than topsoil.

With the help of Hurricane Isaac, September finished with precipitation almost 2 inches above normal and the 17th wettest September on record (Table 3.1). September temperatures were 1.3 degrees below normal which helped relieve drought stress as well. In addition, October was wetter and cooler than normal. October precipitation was 0.7 inches above normal, while temperatures were 1.9 degrees below normal.

It is not unusual in past episodes of drought for brief periods of dry conditions to return. That was the case for November 2012 with only 1.24 inches of precipitation and the 14th driest November on record. Temperatures were 1.3 degrees below normal for the month. December was back to near-normal precipitation, while temperatures were 6.9 degrees above normal.

By the end of December, the precipitation deficits still remained sizeable in Illinois despite the wet fall (Figure 3.13). Most of the state was still 6 to 12 inches below normal, and a few counties in far southern Illinois were 15 to 18 inches below normal. However, above-normal precipitation prevailed in January and February 2013. Any lingering concerns of drought were gone after near record precipitation in spring 2013. April 2013 received 6.93 inches and was the third wettest April on record. May 2013 received 6.57 inches and was the 13th wettest May on record.



Mean period is 1981–2010.

Figure 3.13 Precipitation departures from normal by the end of 2012. While some areas were recovering from the drought, the deficits remained sizeable and were finally erased in spring 2013.

U.S. Drought Monitor

According to the U.S. Drought Monitor (USDM), Illinois experienced drought conditions statewide during the epic drought of 2012 to varying degrees. Some of the harshest drought conditions in the Midwest occurred in Illinois. Figure 3.14 puts into perspective the intensity and duration of the 2012 drought compared with recent dry and drought conditions since 2000. Dry conditions were quite common throughout the early and mid-2000s with a wet period in the late 2000s. Dryness came in spurts since 2010, mainly during summer months.

However, conditions in the summer of 2012 turned out to be more significant. Southeastern Illinois experienced exceptional drought conditions from mid-July to late August. At the drought's peak, about 8 percent of the state was affected by these conditions. This was the first time this century that Illinois experienced such conditions. About 81 percent of the state had at least extreme conditions at the peak of the drought, almost twice the spatial coverage than the 2005 drought. The drought of 2012 was not only intense but also brief compared with 2005. The onset of severe and extreme drought conditions spread rapidly after springtime precipitation failed. Extreme drought conditions covering more than 10 percent of the state lasted about a month in 2012 and nearly six months in 2005.

Comparison with Past Drought and Trends in Drought

The 2012 event is the most recent drought in Illinois history, but how does it compare to previous droughts and what are the trends over time? As already mentioned, it's hard to compare droughts directly because the onset, duration, and intensity of each major drought are unique.

One way to measure droughts over time is by using the Palmer Drought Severity Index (PDSI). It uses temperature and precipitation departures from average and a simple water-balance model to determine drought conditions. However, its drawbacks include its insensitivity to droughts shorter than about nine months and its undesirable bi-modal distribution (e.g., too wet or too dry, without many months in the middle). In any event, it is one of the few tools available that allow us to examine droughts back to 1895 on a somewhat

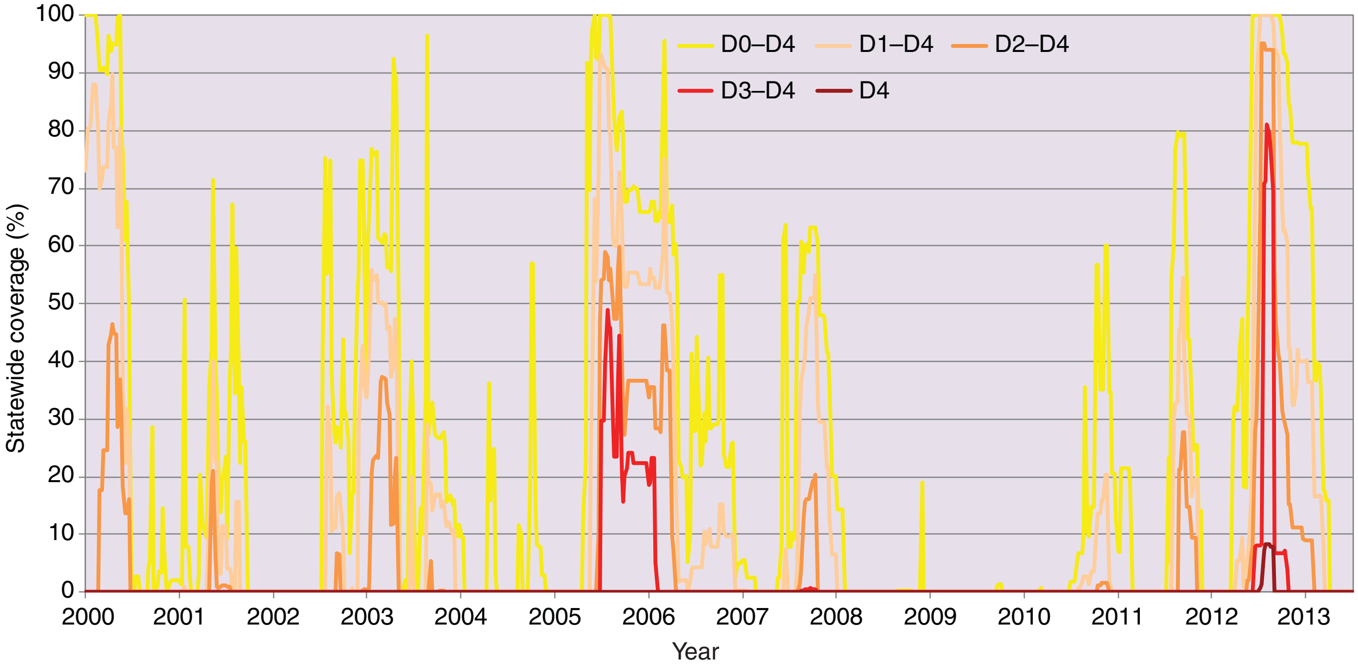


Figure 3.14 Time series of U.S. Drought Monitor indices Jan 4, 2000–Jul 9, 2013. Area percentage of Illinois under drought conditions. D0-D4, D1-D4, D2-D4, D3-D4, D4 correspond, respectively, with abnormally dry, moderate drought, severe drought, extreme drought, and exceptional drought conditions.

equal basis (Figure 1.2). From 1895 to 1965, according to the PDSI, droughts were quite common in Illinois. The years classified as extreme statewide droughts with a PDSI value of -4 and the number of months spent in extreme drought were: 1901–1902 (9 months), 1914–1915 (9 months), 1930–1931 (11 months), 1933–1934 (9 months), 1936 (2 months), 1940–1941 (5 months), and 1953–1954 (11 months). In addition, each of these droughts was considered lower-grade droughts for much of the time.

After 1965, droughts became less frequent and of a shorter duration. The droughts and the number of months considered "extreme" include: 1988–1989 (3 months), 2005 (1 month), and 2012 (2 months). All three cases had substantial agricultural impacts, and in the case of the 1988–1989 event, substantial water supply impacts by modern standards. However, none of the three events were that extraordinary by pre-1965 standards. Given the impacts and disruptions seen in recent droughts, it is hard to determine the magnitude of the impacts on modern-day Illinois of a 1930–1931 or 1953–1954 type of drought.

Summary

Illinois was one of several focal states to be affected by the historic U.S. drought of 2012. An examination of precipitation and temperature observations indicated several key features of the drought's impact on Illinois. Data for Illinois indicate that 2012 was the warmest year on record with a mean temperature of 55.9 degrees (3.5 degrees above normal) and the 10th driest year with 30.11 inches of precipitation (9.85 inches below normal). The year began with near-normal precipitation on the heels of an abnormally wet start to the 2011–2012 cold season. March experienced record warmth with relatively dry conditions, resulting in the rapid drying of soils across Illinois. Some improvements were seen in April but were quickly lost during an abnormally dry May. Conditions rapidly deteriorated through the summer months. At its worst, the May–July period was the third driest on record, only slightly less severe than in 1936 and 1988. The precipitation in late August and September, and in particular the remains of Hurricane Isaac, marked the turning point in the 2012 drought. However, complete recovery from the 2012 drought did not occur until the heavy rains of the following spring.

Chapter 4: Soil Conditions

The Illinois Climate Network (ICN) monitors soil temperatures and moisture levels hourly at each of its 19 stations. The locations of these monitoring stations are shown in Figure 4.1. These measurements are part of a wide array of weather and soil parameters monitored at each station that provide a larger view of current conditions and long-term trends as well as specific conditions related to events such as the 2012 drought. Most of the ICN sites also provide shallow groundwater observations combined with soil and enhanced weather observations that provide unique long-term datasets available at only a limited number of other locations in the United States.

Soil Temperatures

Soil temperatures were higher than the long-term average across Illinois for the first eight months of 2012 (Figures 4.2 and 4.3). Soil temperatures at depths of 4 inches over sod averaged 61.3 degrees for January–August 2012, 4.2 degrees above the long-term average for the period. Temperatures were also higher at 8 inches, averaging 60.7 degrees for the period or 3.9 degrees above the long-term average. Soil temperatures dropped closer to normal levels for most of the last four months of 2012 with temperatures averaging 1.5 to 2.0 degrees above the long-term average.

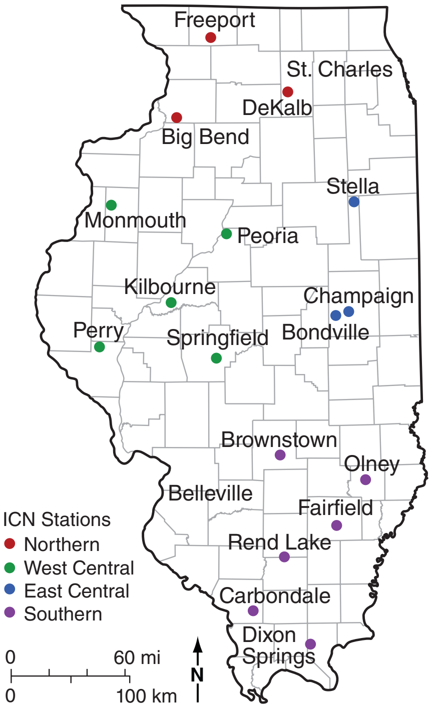


Figure 4.1 Locations of the 19 ICN monitoring stations

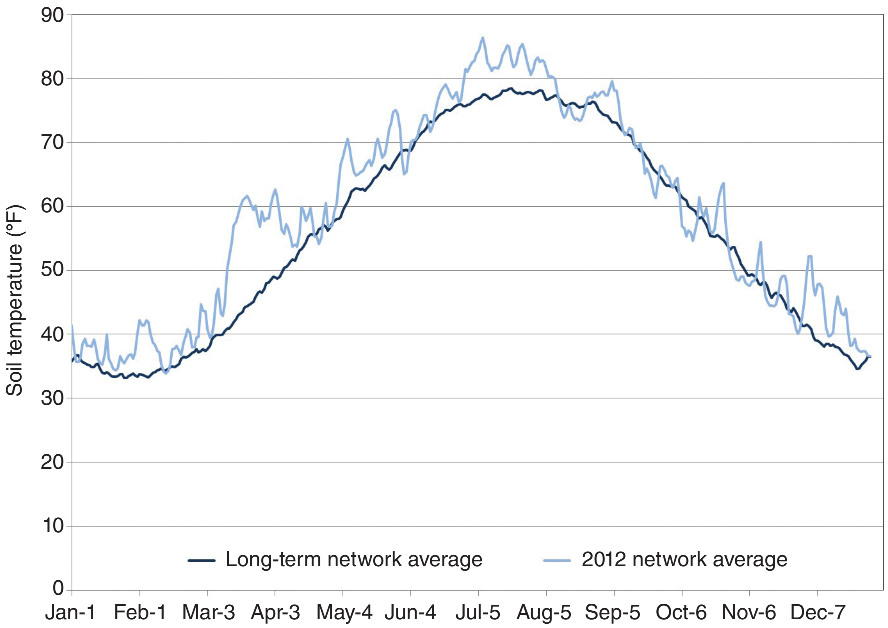


Figure 4.2 Average soil temperature for all ICN stations; 4-inch depth

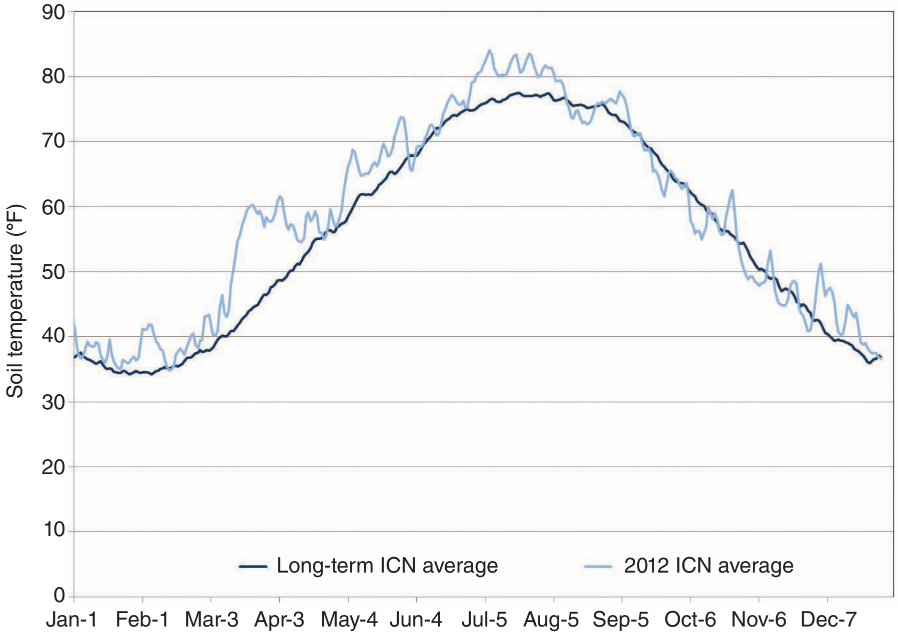


Figure 4.3 Average soil temperature for all ICN stations; 8-inch depth

Although soil temperatures were above normal for most of the first eight months of 2012, there were two periods with exceptionally high temperatures. One was in March 2012, when Illinois experienced its warmest March on record with an average air temperature of 55.5 degrees, 14.2 degrees above normal. The statewide average soil temperature that month rose above 60 degrees, more than 17 degrees above normal. Another exceptionally warm period was from late June into August, during which time the Olney station in southern Illinois recorded a maximum soil temperature at 4 inches under sod of 99.9 degrees. During July, four ICN stations (Olney, Carbondale, Springfield, and Brownstown) recorded record high soil temperatures at the 4-inch level under sod.

Soil Moisture

Figures 4.4 to 4.9 present the average soil moisture conditions for the 19 ICN sites in 2012 as compared with the previous eight-year monitoring period (2004–2011) at eight different levels of soil depth ranging from 2 inches to 50 inches. Regional averages were also computed and are shown in Figures 4.10 to 4.13.

The ICN average soil moisture from 2004–2011, shown in Figures 4.4 to 4.9, show the normal seasonal pattern of soil moisture in Illinois. Moisture in the shallower layers of soil is typically greatest in March and April, and then tends to decline throughout much of the growing season from late April through August as evaporation from the soil increases and vegetation takes water from the soil. The soil moisture at 2, 4, and 8 inches typically begins to recover immediately after the growing season. The soil moisture at 20 and 39 inches follows a similar seasonal cycle, but with a lagged effect. Soil moisture at 59 inches shows a scant seasonal pattern and is usually diminished only during abnormally dry years.

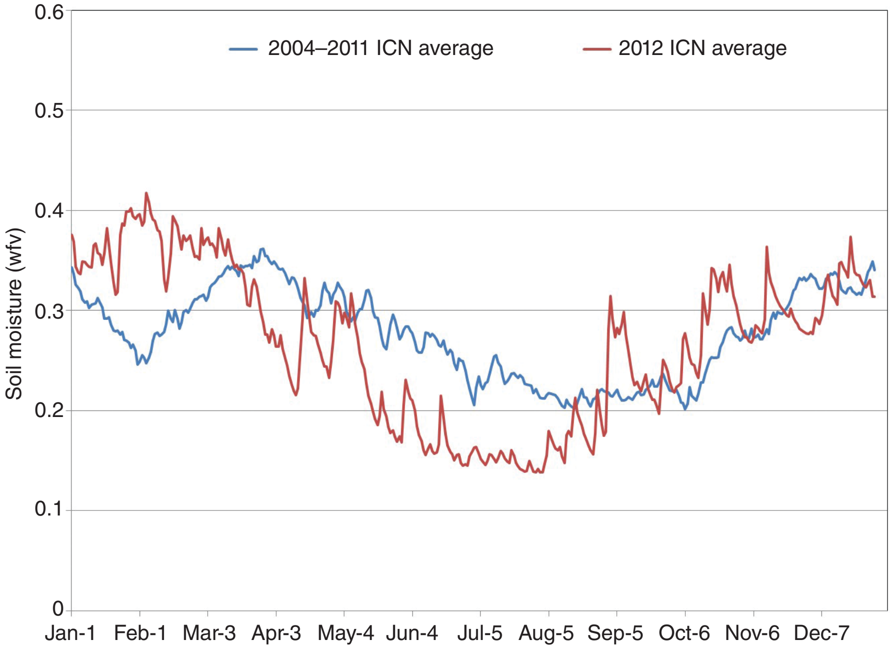


Figure 4.4 Average soil moisture at 2 inches; comparison of 2012 with the eight previous years

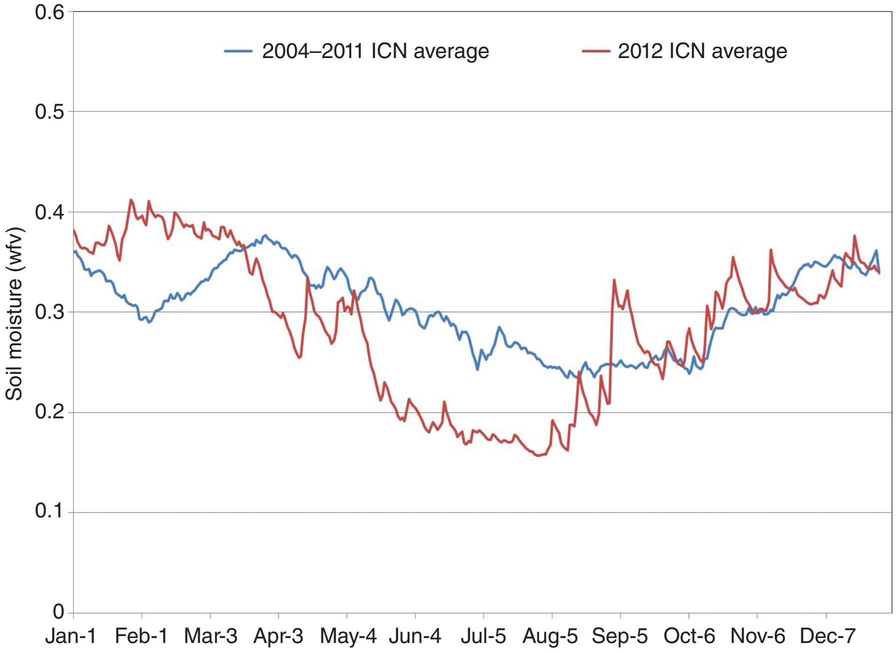


Figure 4.5 Average soil moisture at 4 inches; comparison of 2012 with the eight previous years

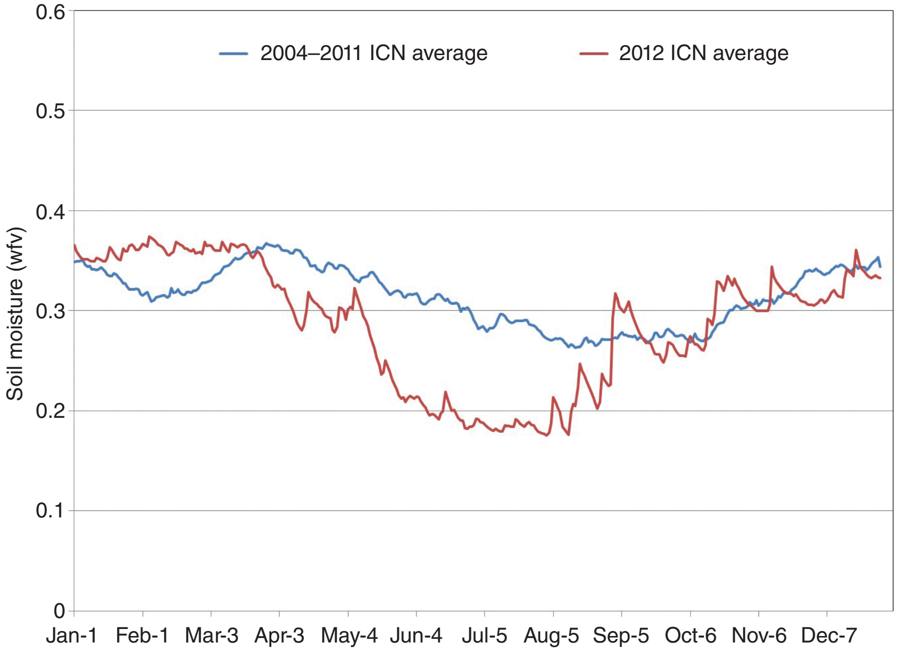


Figure 4.6 Average soil moisture at 8 inches; comparison of 2012 with the eight previous years

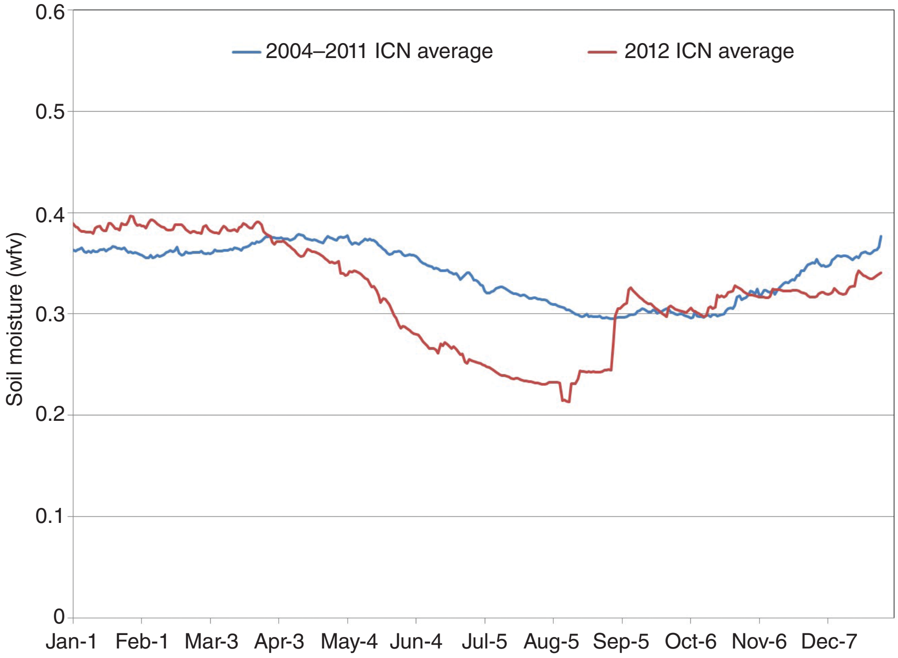


Figure 4.7 Average soil moisture at 20 inches; comparison of 2012 with the eight previous years

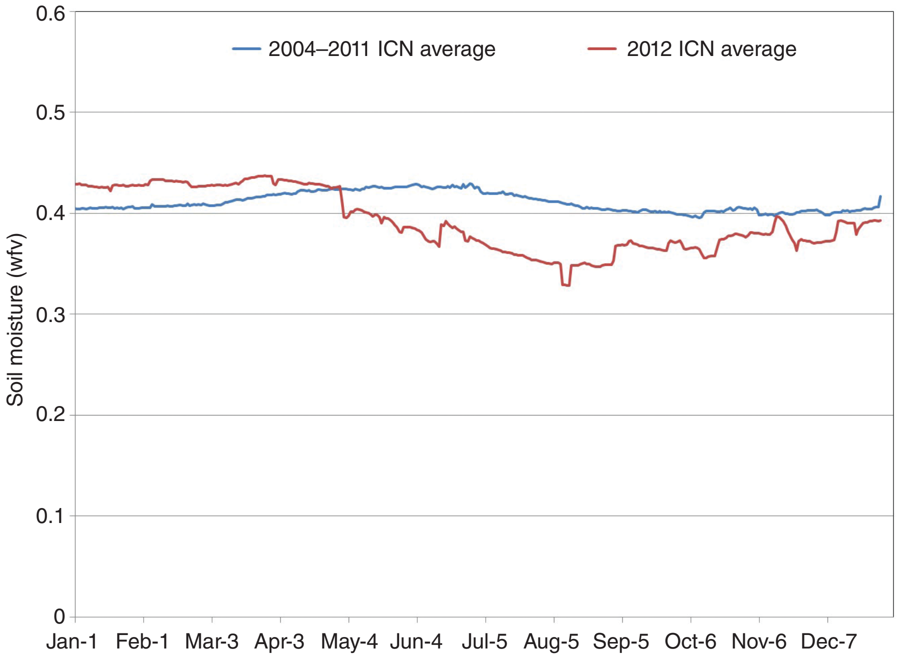


Figure 4.8 Average soil moisture at 39 inches; comparison of 2012 with the eight previous years

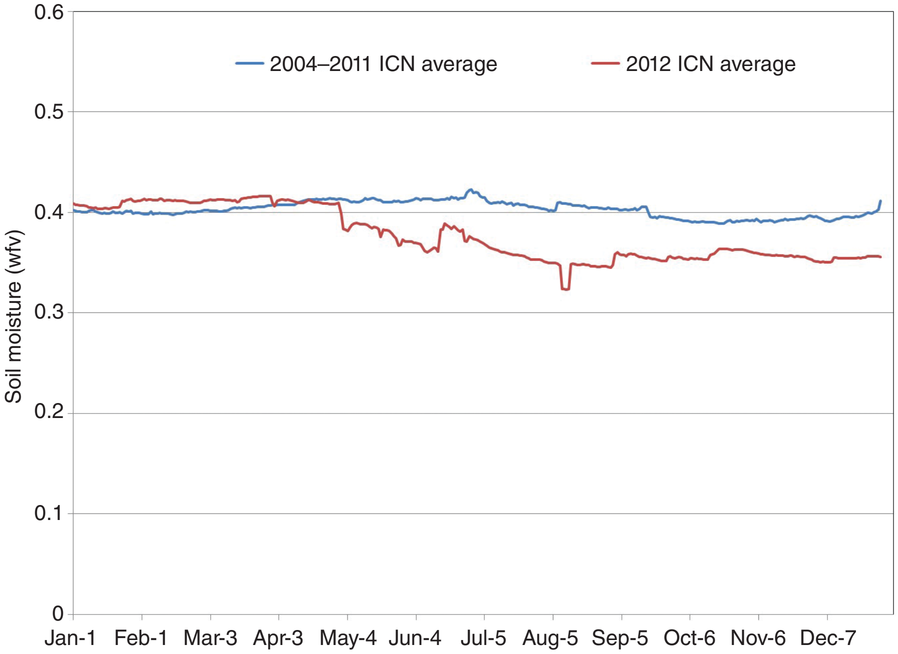


Figure 4.9 Average soil moisture at 59 inches; comparison of 2012 with the eight previous years

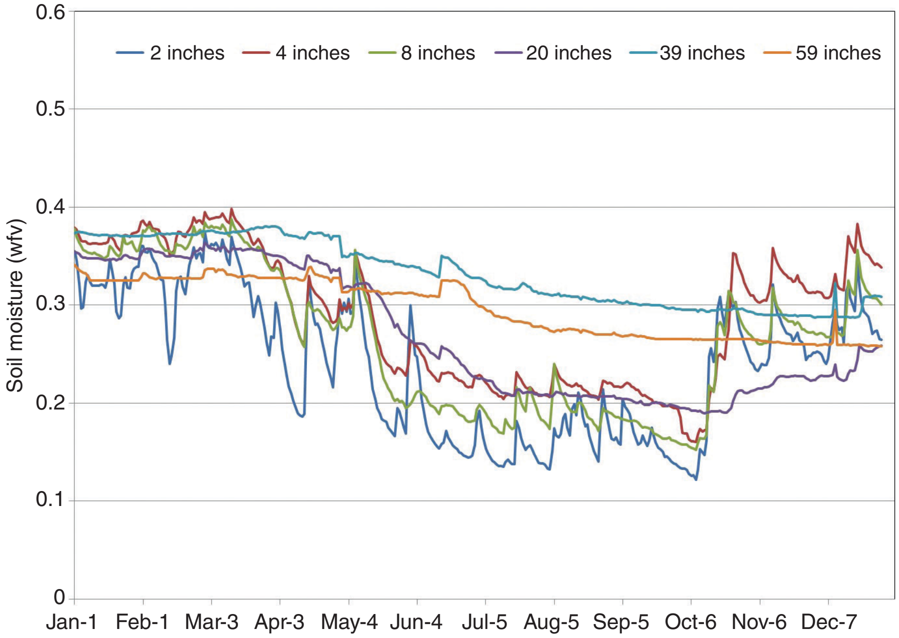


Figure 4.10 Average soil moisture for the ICN northern stations at six separate depths

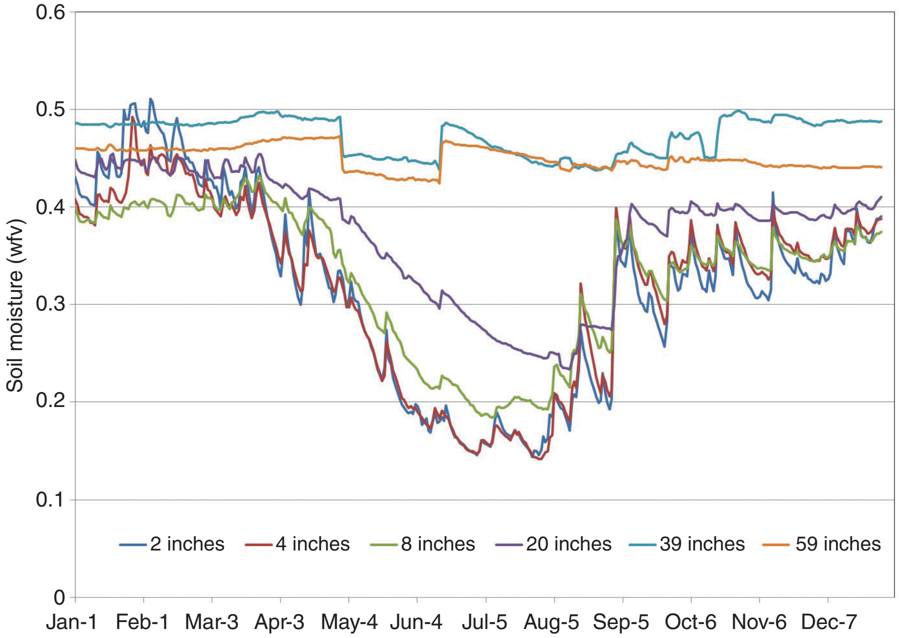


Figure 4.11 Average soil moisture for the ICN southern stations at six separate depths

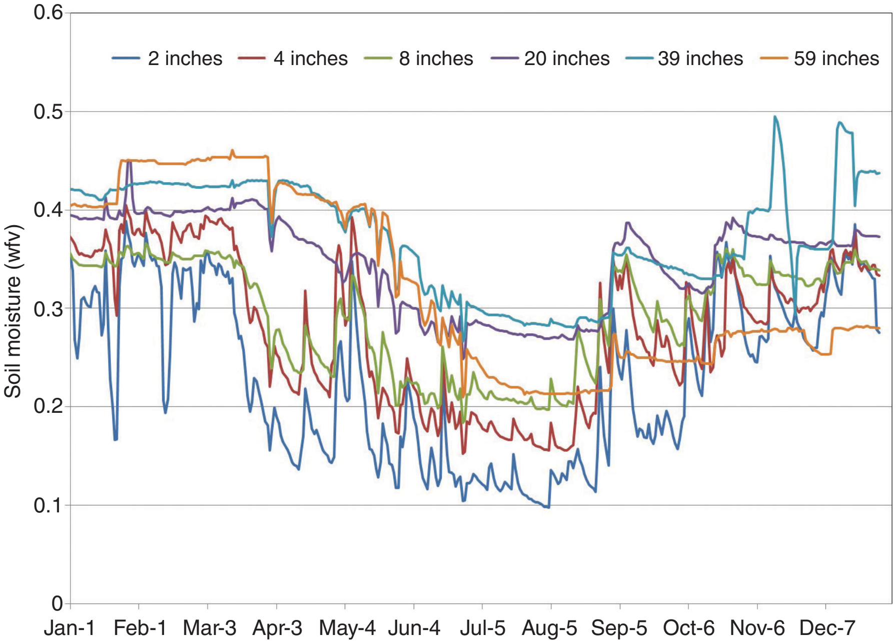


Figure 4.12 Average soil moisture for the ICN east-central stations at six separate depths

Figure 4.13 Average soil moisture for the ICN west-central stations at six separate depths

January–July 2012

Conditions in early 2012 began with higher-than-average soil moisture levels. At depths of 2 inches, moisture levels averaged 0.37 water fraction by volume (wfv) in January and February. The field capacity for silt-loam soils, the type found most regularly at ICN stations, is 0.36 wfv. The highest levels were measured in southern Illinois with a high of 0.51 wfv at the beginning of February.

Statewide, moisture levels began to decline as air and soil temperatures rose in March, first at the 2- and 4-inch depths, then followed one to two weeks later by declines at the 8- and 20-inch depths. Soil moisture levels at 39 and 50 inches began to decline in late April.

Soils continued to dry through spring and early summer 2012, reaching minimums in late July. Statewide moisture levels averaged 0.15 wfv at 2 inches in July, just at the wilting point for silt loam soils. Dry conditions extended through the 4- and 8-inch depths. However, significant amounts of water were still present at depths of 20 inches and greater. Moisture levels averaged 0.24 wfv at 20 inches and 0.36 wfv at 39 and 59 inches for July. Soil moisture in southern Illinois began to increase at the 2- to 20-inch depths in early August as precipitation levels rose. Slight increases occurred in the levels in central and northern Illinois.

Hurricane Isaac and Recovery

At the end of August, soil moisture levels at the shallower depths were already increasing in most of Illinois due to increased precipitation earlier in the month. ICN stations averaged 3.40 inches of rain between August 1 and 30, with the largest totals in southern and east-central Illinois. On August 30, soil moisture levels at 2 inches averaged 0.17 wfv. Conditions were wetter at deeper depths with moisture levels at 59 inches, averaging 0.35 wfv statewide.

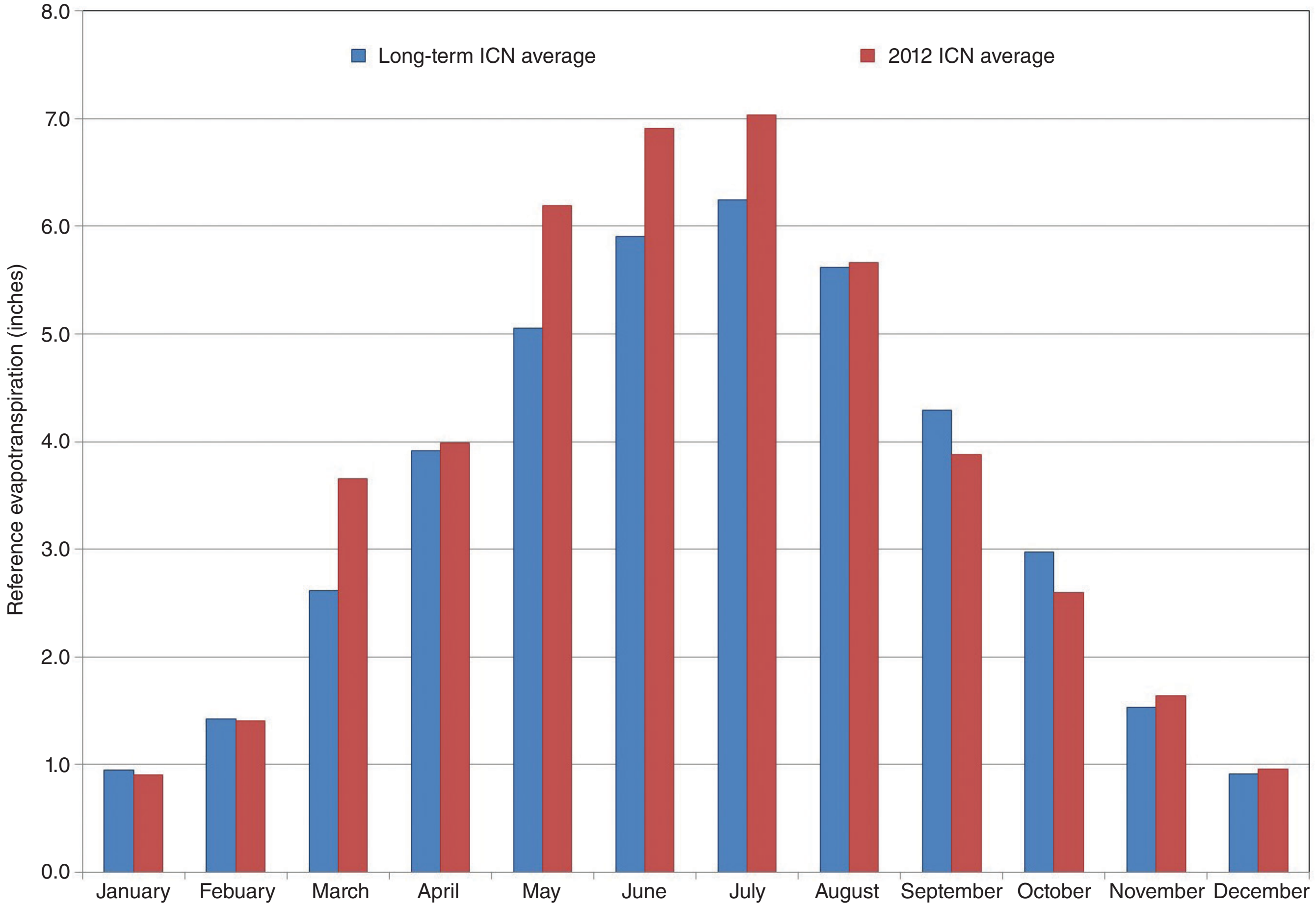


Figure 4.14 Average monthly reference evaporation; comparison of 2012 to 1989–2011

The remnants of Hurricane Isaac moved through Illinois on Labor Day weekend (August 31–September 3), bringing rain to most of the state. ICN averaged 3.03 inches of rain over the four-day period. Southern Illinois received the most with 4.34 inches, but the east and west-central regions also received more than 3 inches. Northern stations, however, saw little impact from the storm with a four-day precipitation average of only 0.03 inches.

Soil moisture levels followed similar regional patterns, reflecting the amount of precipitation from Hurricane Isaac. At 2 inches, the statewide average rose 71 percent over the period, from 0.17 wfv on August 30 to 0.29 wfv on September 3. The highest soil moisture increases were observed in southern Illinois where moisture levels at 2 inches rose 95 percent. At the Carbondale station, 2-inch soil moisture increased 190 percent over the course of the storm, from 0.13 wfv on August 30 to 0.38 wfv on September 3. The northern region, in comparison, saw no change in moisture levels. Two-inch soil moisture at the Freeport station measured 0.19 wfv on August 31 and 0.18 wfv on September 3.

The impacts were observed to depths of 20 inches. At the Fairfield station in southern Illinois, soil moisture at 20 inches increased 49 percent over the course of the storm. No significant changes were observed at depths of 39 and 50 inches over the time period, but moisture levels at 39 inches began a slow upward trend after the storm.

After the passage of Hurricane Isaac, moisture levels in September fell quickly as soils drained, with the greatest impacts at the 2- and 4-inch depths. By September 24, the statewide average at 2 inches had dropped 45 percent from the high on September 4. However, with the cooler air and soil temperatures of fall and winter, soil moisture levels at depths of 2 to 8 inches began to slowly increase through the end of 2012, particularly for southern and east-central Illinois. Meanwhile, northern soil moisture levels declined over September and into October. Rains in mid-October led to significant improvement at the 2- to 8-inch depths that continued through the end of 2012.

On average, levels at 39 inches also began a general upward trend after Isaac, slowly increasing over the last four months of the year. However, increases were limited primarily to southern and east-central Illinois. Moisture levels in west-central and northern Illinois continued to decline during the fall and early winter. At 59 inches, soil moisture levels, on average, showed no impact from the storm and remained steady through the end of the year. Full recovery at the lower soil levels did not occur until spring 2013.

Reference Evapotranspiration

Reference evapotranspiration (ET) is a method of estimating the ET demand rate using commonly measured weather parameters such as air temperature, relative humidity, and solar radiation. The ICN has calculated reference ET since its inception in 1989. Currently, ICN uses a modified Penman-Monteith equation for its calculations which assumes the ground is covered by a short crop of clipped grass as is found at most ICN stations.

In 2012, significant differences in reference ET from the long-term average began to appear in March with increasing air and soil temperatures. Statewide values averaged 3.7 inches for March 2012, 40 percent greater than the long-term average for the month. The higher ETs were seen throughout the state. Higher-than-normal ETs were also calculated for the months of May, June, and July 2012. However, the difference between the long-term and 2012 statewide averages decreased over the three-month period, falling from a 22 percent difference in May to a 13 percent difference in July.

Although soil moisture is not used to calculate reference ET, declining moisture levels would affect the processes of both evaporation and transpiration. Evaporation from the soil would decrease as the surface resistance of dry soil increases. Transpiration would also be expected to decrease during such conditions as plants have greater difficulty extracting water from the soil and begin to wilt.

The statewide average reference ET value declined in August to normal levels. The value remained near or below normal levels for the remaining four months of 2012.

Chapter 5. Streamflow Conditions

A low flow rate in rivers and streams is one of the more easily detected symptoms of hydrologic drought. However, low streamflow amounts do not necessarily occur during the drought's period of least rainfall (in contrast to high streamflow amounts that can usually be directly attributed to recent precipitation events). Instead, low streamflow amounts are more often associated with the progressive depletion of water that has been stored in a stream's watershed, particularly in regard to soil moisture and shallow groundwater. The lowest streamflow amounts occur following extended periods of below-normal precipitation, but also typically during the late summer and fall after the growing season has noticeably depleted soil moisture and surface and sub-surface storage. A map of the cumulative precipitation deficit for a region, such as shown for Illinois in Figure 3.9 for the period March 1 to July 31, 2012, identifies stream locations that are likely to experience well below normal flow amounts.

Two aspects of low streamflow are usually examined in regard to drought. The first aspect is the minimum flow level in the stream. Acute minimum streamflows typically produce the greatest environmental concerns, such as excessively high water temperatures and fish kills. Minimum flow rates are also pertinent to water supplies that need a consistent flow amount when withdrawing directly from a stream. For comparative and analytical purposes, the 7-day low flow (the flow rate during the lowest 7-day period during the year) is often used to represent the minimum condition. The second aspect examined is the average or cumulative flow amount that occurs over an extended period, such as a 6-month period during a drought. These average flow amounts are crucial for identifying the ability of a stream to replenish a water supply reservoir.

In this section, statewide streamflow conditions during the 2012 drought are discussed and comparisons are made with historical droughts to provide a perspective on its level of severity. Historical streamflow records are often used to characterize hydrologic droughts. The most extreme hydrologic droughts for most locations in Illinois occurred in the early and mid-20th century, particularly the 1930s and 1950s. In contrast, more recent droughts of 2005, 1999–2000, and 1988–1989 were less severe and affected only some regions and communities of Illinois (Winstanley et al., 2006). A statistical analysis of streamflows was conducted for a selected set of streamgages located throughout Illinois to assess flow conditions during the 2012 drought.

In Illinois, about 200 U.S. Geological Survey (USGS) streamgages have been used to monitor flow conditions statewide, of which 114 stations have more than 30 years of record. Streamgages that represent natural flow or those that exhibit minimal human influence are desirable for the streamflow analysis because they provide the best point of comparison to historical records, helping to identify impacts of climate variability in contrast to changes from anthropogenic activities such as reservoir storages, withdrawals, return flows, and major land use changes (Knapp, 1994). Most streamgages significantly affected by reservoir storages, withdrawals, and return flows were thus excluded from the analysis; however, a few streamgages with moderately altered low flows were included to provide more complete regional coverage in Illinois. In one case, the Sangamon River at Monticello, the low flow conditions represent a unique circumstance of altered flows related to groundwater-surface water interactions, which are discussed in more detail in Chapter 10: *The Decatur Case Study*.

Return flows from wastewater treatment plants are the most common type of human alteration of low streamflows. Wherever applicable, net return flow is computed as effluents to a stream minus withdrawals from the stream. Streamgages that have net return flows greater than 20 percent of their 7-day, 10-year low flows are assumed to exhibit human influences and thus are excluded from the analysis. In addition, only those stations that have at least 30 years of record are included in the streamflow statistical analysis. Consequently, 49 stations that satisfy these criteria were identified, as illustrated in Figure 5.1 and listed in Table 5.1, including their drainage areas and period of records used in the analysis. Streamflow statistics that best describe drought conditions, such as 7-day low flow and 6-month drought flow, were calculated for each of the 49 streamgages to characterize statewide streamflow conditions during the 2012 drought.

Comparison of the 2012 Low Flows to the Long-Term Statistics

Figure 5.2 illustrates the 2012 7-day low flow as compared to the 7-day, 10-year low flow (Q7,10) for the 49 streamgages used in this analysis. Streamgages are categorized into five groups based on the magnitude of the 2012 7-day low flow. Four categories are based on the expected recurrence interval of the 2012 event:

- The 2012 7-day flow is the lowest on record, which implies a recurrence interval of 30 years or greater (most of the 49 gaging records have more than 50 years of record).
- The 2012 7-day low flow is less than or equal to the Q7,10, thus having an associated recurrence interval of greater than 10 years.
- The 2012 7-day low flow is greater than the Q7,10, but less than or equal to the 5-year low flow, thus having an associated recurrence interval of between 5 and 10 years.
- The 2012 7-day low flow is greater than the 5-year low flow, thus having an associated recurrence interval of less than 5 years.

In addition, a separate fifth category is provided when the Q7,10 is zero:

- The 2012 7-day low flow is equal to zero and the Q7,10 is also equal to zero. In these cases, it is not possible from the 7-day flow to estimate a recurrence interval for the 2012 event. For nearly every streamgage

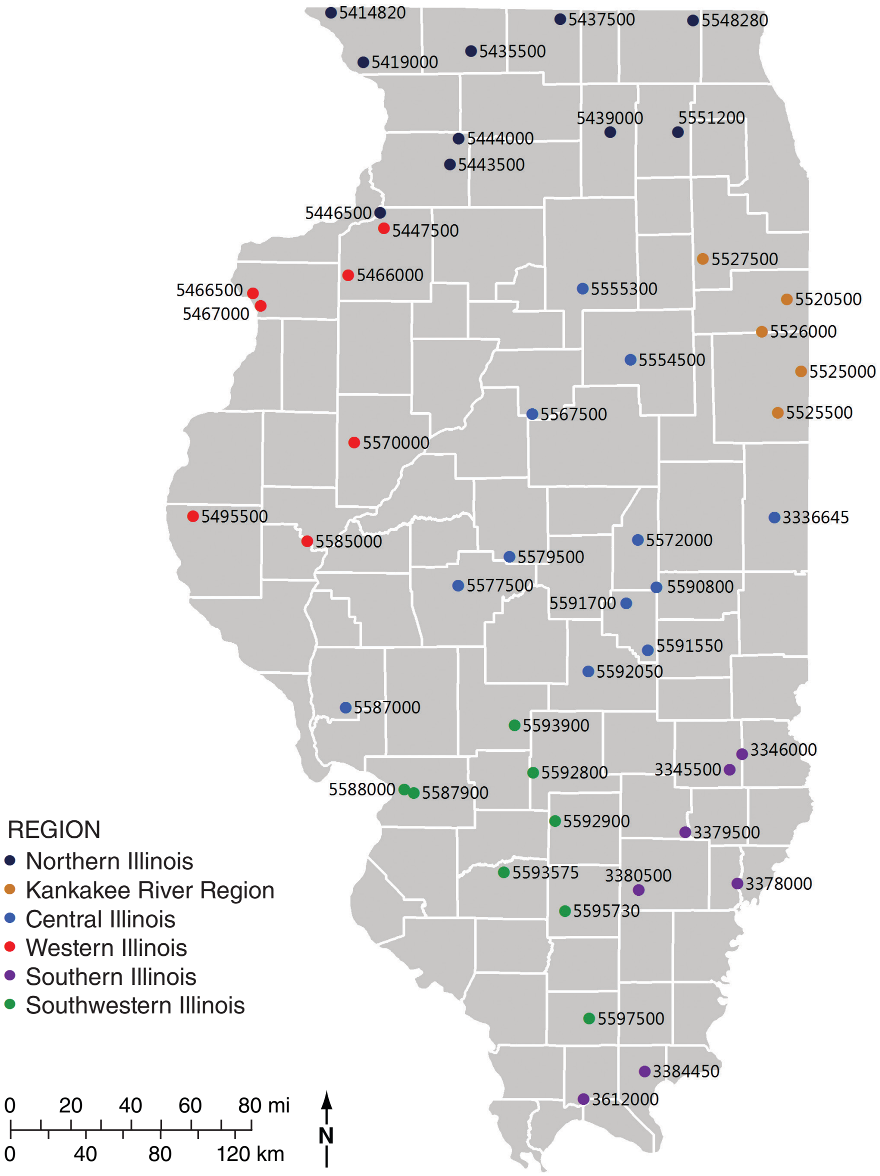


Figure 5.1 Location map of USGS stations used in streamflow analysis

that fits this category, flows in the summer or fall seasons decline to zero every 2 to 3 years. A zero low flow observation is equal to the lowest flow on record, and yet at the same time could be as common as a 2- or 3-year low flow event.

Of the 49, three streamgages located in central Illinois exhibited the lowest 7-day low flow on record. Six streamgages located in the northwestern, western, southwestern, and southeastern regions of the state had 7-day low flows less than their Q7,10. Nine of the streamgages located primarily in the northern half of the state had 7-day low flows less than their 7-day, 5-year low flows. Thirteen of the streamgages located in central, southwestern, and southeastern Illinois were zero and equal to their Q7,10 (i.e., category 5). The remaining 18 streamgages had 7-day low flows less than the Q7,10 but greater than or equal to their 7-day, 5-year low flows.

For each of the 49 streamgages, 6-month drought flows are computed and ranked in order of decreasing flow magnitude. The ranking of the 2012 6-month drought flow is illustrated in Figure 5.3 to provide insight into the severity of the 2012 drought throughout the state.

Streamgages are grouped into four categories based on the ranks of their 2012 6-month drought flow, which are 1 to 5, 6 to 10, 11 to 16, and greater than 16. The 2012 6-month flow is ranked in the lowest five on record for seven of the 49 streamgages used in the analysis, and four of these seven gages are located in central Illinois. The 2012 6-month flow is ranked in the lowest 10 on record in 15 of the 49 streamgages. Although Figure 5.3 does not show recurrence intervals, the respective 2012 6-month drought flow represents a recurrence interval of less than five years for more than half of the selected gages.

Comparison of the 7-day low flows with Q7,10 flows and the ranks of 6-month drought flows for the 49 streamgages used in this analysis suggest that streamflow conditions during the 2012 drought most greatly affected central Illinois. Most streams in southern Illinois became dry (zero flow) in 2012 as they often do during moderate to severe drought conditions; thus the 7-day low flow statistic in southern Illinois does not provide the opportunity in this case to differentiate historical droughts based on relative drought severity. Streamflow conditions during the 2012 drought are further described below for different regions of the state.

Northwestern and Northeastern Illinois

Of the 49 streamgages used in the analysis, 10 are located in northwestern and northeastern Illinois. The 2012 7-day low flow was less than the 7-day, 10-year low flow for two of the streamgages, namely, Apple River near Hanover and South Branch Kishwaukee River at DeKalb (see Figure 5.2), indicating that the 2012 7-day low flow amount is expected to occur less frequently than once in 10 years. For example, the 2012 7-day low flow for Apple River near Hanover is ranked the fifth lowest, having flow equal to 16.7 cubic feet per second (cfs), which is 27 percent less than the streamgage's Q7,10. At one other gage

Table 5.1 USGS Station Records used to Analyze Streamflow Conditions

Region	Station No.	Station Name	Drainage Area (sq. mi.)	Period of Record
Northern Illinois	05414820	Sinsinawa River near Menominee, IL	40	1967–2013
	05419000	Apple River near Hanover, IL	247	1934–2013
	05435500	Pecatonica River at Freeport, IL	1,326	1914–2013
	05437500	Rock River at Rockton, IL	6,363	1903–2013
	05439000	South Branch Kishwaukee River at Dekalb, IL	78	1925–2013
	05443500	Rock River at Como, IL	8,753	1914–2013
	05444000	Elkhorn Creek near Penrose, IL	146	1939–2013
	05446500	Rock River near Joslin, IL	9,549	1939–2013
	05548280	Nippersink Creek near Spring Grove, IL	192	1966–2013
	05551200	Ferson Creek near St. Charles, IL	52	1960–2013
Kankakee River	05520500	Kankakee River at Momence, IL	2,294	1905–2013
	05525000	Iroquois River at Iroquois, IL	686	1944–2013
	05525500	Sugar Creek at Milford, IL	446	1948–2013
	05526000	Iroquois River near Chebanse, IL	2,091	1923–2013
	05527500	Kankakee River near Wilmington, IL	5,150	1914–2013
Western Illinois	05447500	Green River near Geneseo, IL	1,003	1936–2013
	05466000	Edwards River near Orion, IL	155	1940–2013
	05466500	Edwards River near New Boston, IL	445	1934–2013
	05467000	Pope Creek near Keithsburg, IL	174	1934–2013
	05495500	Bear Creek near Marcelline, IL	349	1944–2013
	05570000	Spoon River at Seville, IL	1,636	1914–2013
	05585000	La Moine River at Ripley, IL	1,293	1921–2013
Central Illinois	05554500	Vermilion River at Pontiac, IL	579	1942–2013
	05555300	Vermilion River near Leonore, IL	1,251	1931–2013
	05567500	Mackinaw River near Congerville, IL	767	1944–2013
	05572000	Sangamon River at Monticello, IL	550	1908–2013
	05577500	Spring Creek at Springfield, IL	107	1948–2013
	05579500	Lake Fork near Cornland, IL	214	1948–2013
	05587000	Macoupin Creek near Kane, IL	868	1921–2013
	05590800	Lake Fork at Atwood, IL	149	1972–2013
	05591550	Whitley Creek near Allenville, IL	35	1980–2013
	05591700	West Okaw River near Lovington, IL	112	1980–2013
	05592050	Robinson Creek near Shelbyville, IL	93	1979–2013
	03336645	Middle Fork Vermilion River above Oakwood, IL	432	1979–2013

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Table 5.1 *Continued*

Region	Station No.	Station Name	Drainage Area (sq. mi.)	Period of Record
Southwestern Illinois	05587900	Cahokia Creek at Edwardsville, IL	212	1969–2013
	05588000	Indian Creek at Wanda, IL	37	1940–2013
	05592800	Hurricane Creek near Mulberry Grove, IL	152	1970–2013
	05592900	East Fork Kaskaskia River near Sandoval, IL	113	1979–2013
	05593575	Little Crooked near New Minden, IL	84	1967–2013
	05593900	East Fork Shoal Creek near Coffeen, IL	56	1963–2013
	05595730	Rayse Creek near Waltonville, IL	88	1979–2013
	05597500	Crab Orchard Creek near Marion, IL	32	1951–2013
Southeastern Illinois	03345500	Embarras River at Ste. Marie, IL	1,516	1908–2013
	03346000	North Fork Embarras River near Oblong, IL	318	1940–2013
	03378000	Bonpas Creek at Browns, IL	228	1917–2013
	03379500	Little Wabash River below Clay City, IL	1,131	1914–2013
	03380500	Skillet Fork at Wayne City, IL	464	1908–2013
	03384450	Lusk Creek near Eddyville, IL	43	1967–2013
	03612000	Cache River at Forman, IL	244	1922–2013

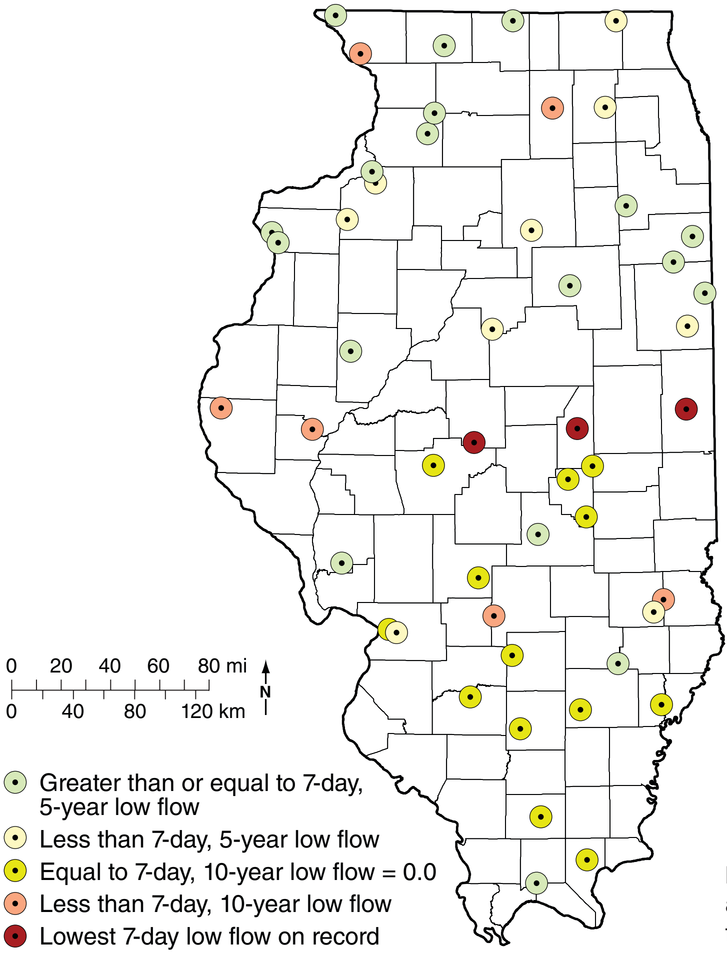


Figure 5.2 2012 7-day low flow as compared to 7-day, 10-year low flow for selected streamgages

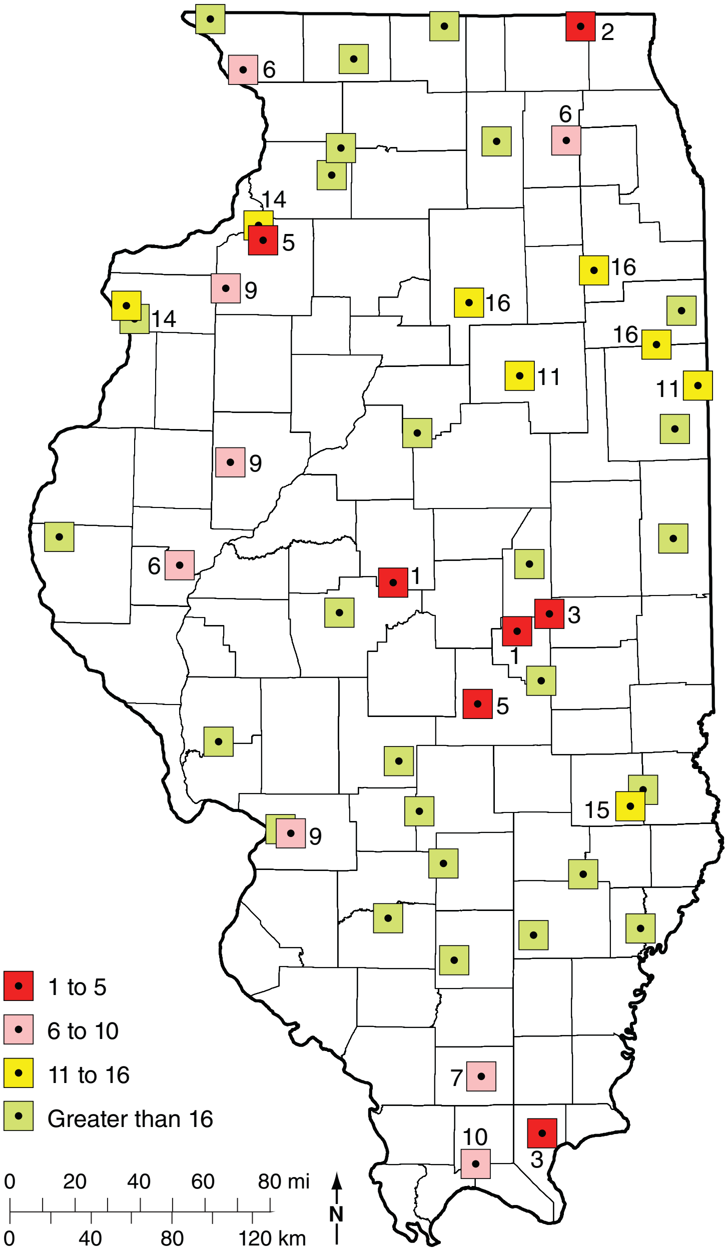


Figure 5.3 Rank of 2012 6-month drought flow for selected streamgages

(Nippersink Creek near Spring Grove), the 2012 7-day low flow was between the estimated 5-year and 10-year low flows. All other streamgages had 7-day low flows that were greater than their 5-year low flow.

In northwestern and northeastern Illinois, the 2012 6-month drought flow is ranked among the top 10 lowest in three of the 11 streamgages. The Nippersink Creek near Spring Grove streamgage had its second lowest 6-month flow on record (see Figure 5.3), equivalent to roughly a 25-year event. This streamgage was not in operation prior to 1966 when many of the region's worst droughts occurred, and its worst 6-month drought flow occurred in 2005. The 6-month flow in the Apple River near Hanover was its sixth lowest on record, roughly computing to a 10- to 15-year event. The 6-month flow in the South Branch Kishwaukee River at DeKalb also had its sixth lowest on record, corresponding to a 5- to 10-year event. All other streamgages experienced flows with recurrence intervals of less than a 5-year event. Thus, in summary, only a relatively small percentage of streamgages in northwestern and northeastern Illinois were appreciably impacted by the drought.

Kankakee River Region

Five streamgages in this region have at least 65 years of flow record with minimal human influences. The 2012 7-day low flow for Sugar Creek at Milford was 3.7 cfs and is ranked sixth on record. For the remaining streamgages, however, the 7-day low flows were above their respective 5-year low flows and not among the lowest 20 on record. Three of the region's gages had 2012 6-month drought flows ranked from 11th to 16th, but no gages were ranked in the lowest 10 on record. More than any other region, the Kankakee River area was least affected by the 2012 drought.

Western Illinois

The western Illinois region is considered herein to be that portion of the state west of the Illinois River and south of the Rock River. Seven streamgages in this region were selected using the criteria described earlier. For two of the gages (La Moine River at Ripley and Bear Creek near Marcelline), the 7-day low flow in 2012 was less than the Q7,10. The 7-day low flow at the Ripley gage, 2.7 cfs, was its second lowest on record. For another two gages (Green River near Geneseo and Edwards River near Orion), the 2012 low flow was less than a 5-year flow and greater than the Q7,10, but also within 20 percent of the Q7,10. Thus, the low flow response in the region was highly variable, but over half of the gages had flows that were approaching a 10-year condition or worse.

Similarly, four of the seven streamgages in the region experienced a 6-month low flow that is within each gage's top 10 on record. The Green River near Geneseo experienced its fifth lowest 6-month flow on record and the La Moine River at Ripley its sixth lowest on record, each with a recurrence interval of greater than 10 years. Both the Spoon River at Seville and Edwards River near Orion experienced their ninth lowest 6-month flows on record; with its longer record, this was also roughly a 10-year event for the Spoon River. The 6-month flows for two of the three remaining gages were within the top 15 on record. In summary, the streamflow statistics suggest that 2012 was roughly a 10-year drought event for western Illinois.

Central Illinois

Based on the criteria described before, 12 streamgages were selected to assess the drought of 2012 in central Illinois. Three of these gages experienced their lowest flows on record. For the Sangamon River near the Monticello streamgage, this was the only 7-day zero flow event in its 100 years of record. For the Lake Fork near Cornland, the 2012 7-day low flow was 0.33 cfs, which is the lowest on record and is only about one-tenth of its Q7,10. For the Middle Fork Vermilion River above Oakwood, the 7-day low flow was 1.76 cfs, which is the lowest on record and 50 percent less than its Q7,10. Four other gages had a zero 7-day low flow in 2012 equal to their Q7,10. All four gages had zero flow lasting at least 22 days, and West Okaw River near Lovington recorded zero flow for 88 days. The duration of zero flow for these four gages suggests associated recurrence intervals of 5 to 15 years. Regarding low flows, these statistics indicate that central Illinois was the region most greatly impacted by the 2012 drought.

The 2012 6-month drought flow was the lowest such event on record for two of the streamgages in the region, namely Lake Fork near Cornland and West Okaw River near Lovington. For the Lake Fork near Atwood and Robinson Creek near Shelbyville, the 6-month flows were the third and fifth ranked events, respectively. Collectively, this response is greater than for any other region in Illinois. For no other streamgages in the region is the 2012 6-month flow ranked as a top 10 event.

Southwestern and Southeastern Illinois

Streamflow analysis was performed for 15 streamgages located in southwestern and southeastern Illinois to assess streamflow conditions during the 2012 drought. In 9 of the 15 streamgages, the 2012 7-day low flow was 0 cfs and is equal to the Q7,10. Again, in these cases the duration of the zero low flow provides the only indication of the relative severity of the low flow condition. For five of the nine gages, the zero flow lasted 15 days or less, representative of a fairly common low flow condition with recurrence intervals of less than 5 years. On the other hand, three of the remaining four gages had zero flow durations of 59 to 74 days; for two gages (Lusk Creek near Eddyville and Rayse Creek near Waltonville) this was the second longest zero flow period on record, and for the East Fork Kaskaskia River near Sandoval it was the longest zero flow period on record. The highly variable rainfall in the region in August 2012 seemed to have a direct influence on the duration of the zero flow events. Locations with little rainfall had extended zero flow periods, whereas the zero flows were abbreviated at locations with sizeable rainfall.

Six of the remaining 15 gages in the region have a Q7,10 greater than zero. For one of these gages, Hurricane Creek near Mulberry, the 7-day low flow in 2012 was zero cfs, only the second time this has happened (the other occurring in 1988). For North Fork Embarras River near Oblong the 7-day low flow in 2012 (0.14 cfs) was also less than its Q7,10.

Figure 5.3 shows that only 4 out of the 15 streamgages in the southwestern and southeastern regions had 6-month drought flows in 2012 that are ranked in their respective 10 lowest events. The 2012 6-month drought flow is the third lowest on record for Lusk Creek near the Eddyville streamgage (roughly a 15-year event). The 6-month flows for Cache River near Forman, Cahokia Creek at Edwardsville, and Crab Orchard Creek near Marion were ranked in the lowest 7 to 10 events for their respective gages, in each case representative of a 5-year to 10-year event.

Comparison of 2012 Low Flows with Previous Droughts at Selected Gages

To showcase the severity level of the 2012 drought as compared with some of the historical droughts, eight streamgages were selected from areas in Illinois that were most greatly impacted by the drought. The historical droughts selected for comparison were the 1953–1955, 1963–1964, 1976–1977, 1980–1981, 1988–1989, and 2005 droughts. The selected streamgages were Green River near Geneseo, Spoon River at Seville, La Moine River at Ripley, Lake Fork near Cornland, Sangamon River at Monticello, Indian Creek near Wanda, Cache River at Forman, and Lusk Creek near Eddyville. All selected streamgages have records of 68 years or longer with the exception of Lusk Creek near Eddyville (1966–present).

For the eight selected streamgages, the 7-day low flows, 61-day low flows, and 6-month drought flows during the 2012 drought are compared with that of historical droughts to provide insight into the severity of the droughts. The comparisons listed in Tables 5.2–5.4 are provided by ranking each drought event within each streamgage's respective historical record. In addition to rank, Table 5.2 first provides the lowest 7-day flow (in cfs) for each drought. For example, the observed 2012 7-day low flow for Green River near Geneseo was 49 cfs, which ranks as the eighth lowest annual low flow in that gage's 80 years of record. Less extreme low flow events for any streamgage are described as having a ranking of greater than 12. Rankings are not provided for the Indian Creek and Lusk Creek 7-day low flows as zero flow (#1 tie) occurs in many years.

The lowest 6-month flow for the Cache River and Lusk Creek occurred from May through October 2012, whereas the lowest 6-month flow for the Lake Fork

Table 5.2 7-day Low Flows (in cfs) for Selected Historical Drought Periods

Stream gages	May 2012–Jan 2013	Jun 2005–Jan 2006	May 1988–Sep 1989	Aug 1980–Mar 1981	Aug 1976–Feb 1977	Jul 1963–Feb 1964	Jul 1953–Sep 1955
Green River near Geneseo	49.0 (#8)	39.0 (#5)	44.6 (#6)	171.0	23.9 (#1)	52.0	29.4 (#3)
Spoon River at Seville	31.9	25.9	6.8 (#2)	109.7	45.1	14.9 (#6)	20.4 (#10)
La Moine River at Ripley	2.7 (#2)	19.0	1.8 (#1)	11.3	10.8 (#12)	9.0 (#8)	10.0 (#11)
Lake Fork near Cornland	0.33 (#1)	3.9 (#12 tie)	0.96 (#2)	4.3	3.9 (#12 tie)	2.0 (#5)	1.3 (#3)
Sangamon River near Monticello	0.0 (#1)	4.0	0.07 (#2)	4.8	3.2	1.6 (#8)	1.0 (#4)
Indian Creek near Wanda	0.0*	0.1	0.0	0.0	0.0	0.0	0.0
Cache River at Forman	0.6	4.2	0.8	0.1	0.1	0.0 (#1tie)	0.2
Lusk Creek near Eddyville	0.0*	0.1	0.0	0.0	0.0	—	—

Table 5.3 Ranks of the 61-day Low Flow for Selected Historical Drought Periods

Stream gages	May 2012–Jan 2013	Jun 2005–Jan 2006	May 1988–Sep 1989	Aug 1980–Mar 1981	Aug 1976–Feb 1977	Jul 1963–Feb 1964	Jul 1953–Sep 1955
Green River near Geneseo	8	3	7	>12	1	>12	4
Spoon River at Seville	>12	8	1	>12	>12	5	>12
La Moine River at Ripley	8	>12	1	>12	10	5	7
Lake Fork near Cornland	1	6	5	>12	7	3	2
Sangamon River near Monticello	2	>12	1	>12	5 (tie)	5 (tie)	4
Indian Creek near Wanda	10	>12	5 (tie)	12	9	5 (tie)	1
Cache River at Forman	11	>12	>12	>12	>12	1	2
Lusk Creek near Eddyville	3	>12	>12	6	8	—	—

occurred from August 2012 through January 2013. Thus, the duration of the 2012 drought, listed in the left column of Table 5.2, is considered to have encompassed the months from May 2012 through January 2013. Similarly, the periods for the other selected historical droughts are July 1953 through September 1955, July 1963 through February 1964, August 1976 through February 1977, August 1980 through March 1981, May 1988 through September 1989, and June 2005 through January 2006.

As shown in Table 5.2, three streamgages in 2012 experienced their first or second lowest 7-day flows on record: the La Moine River at Ripley, Lake Fork near Cornland, and Sangamon River at Monticello. From the small selection of eight gages in Table 5.2 it might be concluded that 2012 low flows are roughly comparable to that of the 1988–1989 drought. However, as mentioned earlier, these eight streamgages were selected from areas in Illinois that were the most greatly impacted by the drought. If the sample selection criteria were reversed, it would show that a substantially larger number of streamgages experienced record low flows during the 1988–1989 drought. In the same manner, if the analysis were instead focused on the 1953–1955 drought, that drought would have been shown to have the overall greatest number of record low flows.

For low flows of longer duration, such as 61 days (Table 5.3) or 6 months (Table 5.4), the relative severity of the 2012 drought is shown to generally decrease. For only three of the selected streamgages is the 61-day low flow in 2012 shown to rank in the top five events on record. In contrast, for both the 1988–1989 and 1953–1955 droughts, low flows for five of the selected streamgages are ranked in the top five. For the 6-month flows, the 1953–1955 drought ranks in the top five for every

Table 5.4 Ranks of the 6-month Drought Flow for Selected Historical Drought Periods

Stream gages	May 2012–Jan 2013	Jun 2005–Jan 2006	May 1988–Sep 1989	Aug 1980–Mar 1981	Aug 1976–Feb 1977	Jul 1963–Feb 1964	Jul 1953–Sep 1955
Green River near Geneseo	5	2	7	>12	4	6	3
Spoon River at Seville	9	2	1	>12	>12	6	4
La Moine River at Ripley	6	8	1	>12	5	4	2
Lake Fork near Cornland	1	>12	7	8	5	3	2
Sangamon River near Monticello	>12	>12	10	>12	4	7	3
Indian Creek near Wanda	12	>12	3	>12	>12	7	1
Cache River at Forman	10	>12	>12	6	>12	1	4
Lusk Creek near Eddyville	3	>12	6	1	2	—	—

selected streamgage (except for the Lusk Creek gage that was not in operation in 1953–1955). Results for a few selected streamgages are described in more detail.

Lake Fork near Cornland

The continuing dry conditions in 2012 arguably affected the flows in Lake Fork more than any other affected gaged stream in Illinois. Its 7-day and 61-day low flows in 2012 were by far the lowest on record. The 6-month flow from August 2012 through January 2013 was also the lowest on record. Of the examined streamgages, only the West Okay Creek near Lovington also experienced its lowest 6-month flow on record, but its gaging record began in 1980 and thus does not include many of the worst droughts as identified in longer flow records. The factor that appears to have made the Lake Fork so dry relative to other locations is the extremely low precipitation (a 5-inch rainfall deficit) that the Logan County vicinity experienced in the latter half of 2011 prior to the onset of the 2012 drought conditions.

Lusk Creek near Eddyville

Southeastern Illinois was the region that experienced the earliest dry conditions and related impacts in 2012. Low flows on Lusk Creek began in late April, an unusual occurrence for the spring season, with its lowest 6-month flow occurring from May through October. Most of the rainfall associated with Hurricane Isaac passed to the west of Lusk Creek, such that at the time there was very little recovery from the zero-flow condition in the creek. The creek continued to have relatively low flow amounts until greater regional rainfalls occurred in January 2013.

Western Illinois Rivers

The La Moine, Spoon, and Green Rivers were subject to roughly similar levels of precipitation throughout the 2012 drought, although dry conditions first affected the southern part of the region (La Moine River) before moving north. The Spoon and Green Rivers also have noticeably higher levels of groundwater flow contribution, which tend to buffer and delay the impacts of dry conditions on flow amounts. Thus, whereas the La Moine River experienced its second lowest 7-day low flow on record, the Green River low flow was its eighth lowest, and the Spoon River its 24th lowest. This is another region where the impacts of Hurricane Isaac rainfall were modest, with low flow conditions continuing into the fall and not fully recovering until January 2013. As a result, the 6-month drought flow for all three gages falls into each streamgage record's top 10 (Table 5.4).

Comparison of 2012 Summer Flows at Selected Gages with Previous Droughts

The average flow for the period June 1 through August 31, 2012 was computed for the same eight selected streamgages. These computed flows were then compared to similarly-computed flows from the June-August period for all years of record at each gage and then ranked from lowest to highest flow. Table 5.5 shows the computed rankings for each gage. The average summer flows are specifically not described herein as low flows because they do not necessarily represent the lowest flow period within the 2012 drought. In a typical year, the lowest flows for many of these streamgage locations would not be expected to occur until the fall months, usually September and October.

When summer flows are examined alone, each of the eight stream locations are shown to have experienced flows that ranked in their respective lowest seven years on record. Furthermore, the five gages in southern and central Illinois all experienced mean summer flows that were either their first or second lowest on record. An examination of many other USGS streamgage records in southern and central Illinois show the same results, i.e., the first or

Table 5.5 Ranks of Summer (June-August) Mean Flows for Selected Historical Drought Periods

Stream gages	May 2012–Jan 2013	Jun 2005–Jan 2006	May 1988–Sep 1989	Aug 1980–Mar 1981	Aug 1976–Feb 1977	Jul 1963–Feb 1964	Jul 1953–Sep 1955
Green River near Geneseo	5	3	4	>10	>10	8	>10
Spoon River at Seville	7	6	1	>10	>10	5	>10
La Moine River at Ripley	3	8	2	>10	10	>10	>10
Lake Fork near Cornland	1	6	3	>10	7	2	5
Sangamon River near Monticello	1	>10	2	>10	>10	6	>10
Indian Creek near Wanda	2	>10	1	>10	>10	4	9
Cache River at Forman	1	>10	4	>10	>10	5	>10
Lusk Creek near Eddyville	1	>10	2	>10	3	—	—

second lowest mean summer flow. These results emphasize: 1) how extremely dry the streamflow conditions were for much of Illinois leading into the fall season; and, consequently, 2) how conditions substantially recovered for many locations immediately following the summer as most greatly influenced by the large amounts of precipitation from Hurricane Isaac. If precipitation amounts had instead remained moderately low leading into September and October (a normal drought progression), it is reasonable to conclude that low flows would have continued to decline into the fall season for most Illinois streams.

Low Flows in Large Rivers

Low flows on the Illinois and Mississippi Rivers also caused water management concerns during the 2012 drought. The primary concern on the Mississippi River was in maintaining water depths along the lower Mississippi River (downstream of St. Louis) as needed to support commercial navigation during the winter months following the drought (December 2012 and January 2013). These concerns are described in more detail in Chapter 11: *Navigation, Water Quality, and Environmental Impacts*.

On the Illinois Waterway (upper Illinois River, lower Des Plaines River, and Chicago Sanitary and Ship Canal) between Starved Rock Lock and Dam and Lockport, low river flow conditions caused several power industries to reduce production. Some of the newer power plants have low flow restrictions that require withdrawals to cease when river flows fall below a specified protected minimum flow. For the second year since the Chicago Sanitary and Ship Canal (CSSC) was constructed in 1900, summer flow in the upper Illinois River (at the USGS gage at Marseilles) fell substantially below 3000 cfs for multiple consecutive days. The other occurrence was during the 2005 drought.

These summer low flows in the Illinois Waterway reflect a substantial reduction in low flows coming from the CSSC, caused by the progressive reduction in Chicago's water use and wastewater effluents since the 1990s. Effluent discharges to the CSSC during the lowest flow periods are now about 40 percent less than they were roughly 20 years ago. With the ongoing reductions in Chicago's water use and effluent discharges, the ISWS estimates that Q7,10 in the Illinois River has been reduced from 3185 cfs to 1670 cfs over this period (see Table 5.6).

Table 5.6 ISWS Estimates of the 7-day, 10-year Low Flow on the Illinois River at Marseilles (cfs)

Year	Flow
1970	3,240
1980	3,200
1990	3,185
2001	1,990
2015*	1,670

*Designates a recent unpublished estimate.
Source: Kelly et al. (2016)

The recent reductions in low flow quantity have exposed another aspect of low flow characteristics in the Illinois Waterway, that being high-frequency flow fluctuations associated with gate operations of the waterway's locks and dams, which to a certain extent are initiated by hydropower operations upstream on the CSSC at the Lockport Dam. As shown in Figure 5.4, flows in the upper Illinois River can rise and fall rapidly in response to gate operations. These flow fluctuations are currently being analyzed by the ISWS (Kelly et al., 2016) to better understand their characteristics and determine: 1) if the fluctuations can be reduced through river management; and 2) if, and to what extent, the fluctuations should influence the manner in which protected minimum flows along the river are managed.

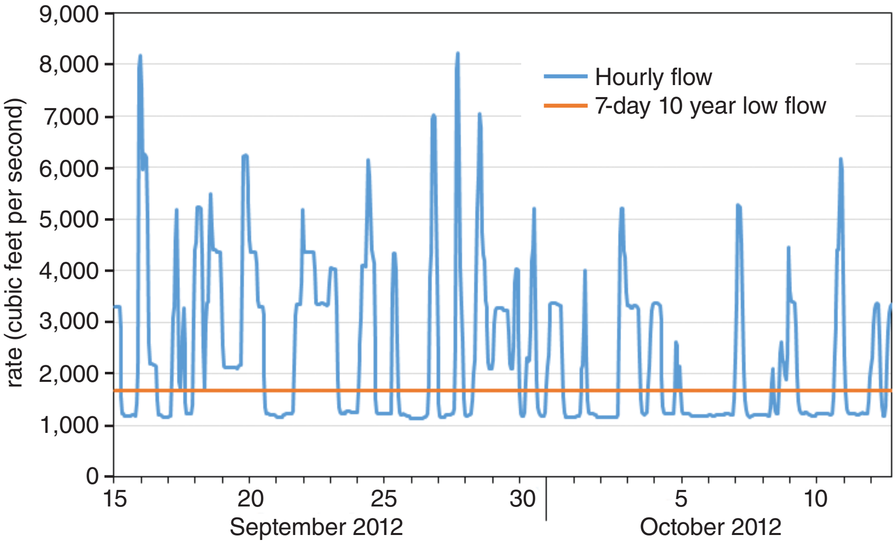


Figure 5.4 Hourly flow rates (cfs) at the USGS streamgage on the Illinois River at Marseilles compared to the 7-day low flow; September 15 through October 14, 2012

Chapter 6. Water Supply Reservoir Levels

Drought Impacts on Reservoir Levels

Reservoir and lake levels are strongly affected by the seasons, which is particularly the case with water supply reservoir levels. Summer is the season of greatest water usage (withdrawals from the reservoir) and highest evaporation. In early fall, stream inflows, which replenish the reservoir, are typically at their lowest. In late fall and winter, the least amount of water is used and stream inflows have typically begun to recover. In spring, stream inflows are typically the greatest and most reliable. Thus, in a normal year, levels in water supply reservoirs would be expected to decline in summer and early fall and begin to recover or fully recover in the fall and winter. The monthly average water levels for Lake Springfield are shown in Figure 6.1 as an example. Reservoirs that are not used for water supply typically have much less drawdown during droughts because there is no withdrawal or water diversion from the reservoir; in many cases such reservoirs have little or no drawdown during normal years.

In this chapter, the terms lake and reservoir are often used interchangeably. Reservoirs are generally artificial impoundments, which apply to all lakes used for water supply in Illinois except Lake Michigan. The term reservoir is typically used collectively, whereas most individual community water supply reservoirs are commonly referred to as lakes.

Droughts will affect various components of a lake's water budget; for example, drought can result in a noticeable increase in summer water withdrawals and evaporation. But the most substantial and influential impact of drought is reduced stream inflows. Below-normal stream inflows can cause lake levels to start falling sooner than normal in the summer, sometimes as early as June. If precipitation does not recover, low streamflow levels can continue well into the winter and spring following a drought year, delaying or preventing a reservoir from replenishing its storage. In most moderately severe droughts, stream inflows will still be of sufficient quantity for lake levels to replenish in the following winter and spring seasons (such as shown in Figure 6.1 for the 15-year drought). But during more extreme droughts, there may be insufficient inflow in the spring following a drought year to fully replenish the lakes before the next summer begins (see the 25- and 50-year droughts shown in Figure 6.1), with the lowest water levels typically occurring during the second year. In such cases, the drought is characterized as being a multi-year drought, i.e., having entered a second summer or dry season.

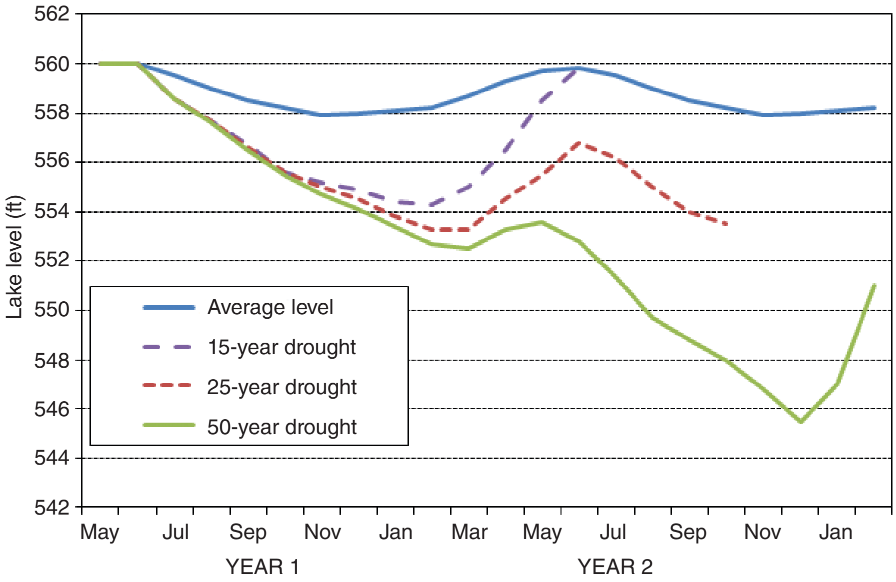


Figure 6.1 Expected water levels on Lake Springfield during an average year and during three drought episodes of various severity. For comparison, the minimum month-end lake level of Lake Springfield during the 2012 drought was roughly 556.2 feet, having occurred at the end of November

Most water supply lakes in Illinois were designed to withstand and provide water throughout a multi-year drought episode, such that the lowest lake levels may be expected to occur at least 18 months following the initial onset of lake drawdown. The Decatur water supply system is one of the few exceptions in Illinois, in that Lake Decatur could potentially experience shortages in as few as eight months following the onset of lake drawdown. The La Harpe off-channel reservoir, also examined in this report, is similarly susceptible to drought events lasting less than 12 months.

2012 Water Supply Lake Level Observations

Near the start of the 2012 drought, the Illinois Environmental Protection Agency (IEPA) began collecting weekly water level readings at many water supply reservoirs (lakes) throughout Illinois, from their regular contacts with water supply operators. In general, water levels were not obtained for systems that were not yet concerned with potential impacts caused by drought. Also, once the worst of the drought had passed, water levels were reported less frequently or, for many lakes, were discontinued entirely. The Illinois State Water Survey (ISWS) also maintains a long-term record of month-end water levels for 35 water supply lakes in Illinois which continued through the drought, and in some cases, those data are used in this report to supplement the IEPA observations.

Table 6.1 represents a composite record of the IEPA weekly readings for selected

Table 6.1 Observed Drawdowns in Water Supply Lakes, Feet Below Full or Target Pool Elevation (Underlined values with bold type identify minimum observed levels for the drought)

Community or System Name	2012 Date										
	6/19	6/26	7/3	7/10	7/17	7/24	7/31	8/7	8/14	8/21	8/28
Altamont	1.0	1.2	1.3	1.6	1.8	2.1	**2.4**	2.0	2.3	2.1	2.3
Bloomington	0.1	0.2	0.7	1.0	1.3	1.6	1.8	2.1	2.4	2.4	2.4
Carlinville	0.2	0.3	0.8	0.8	1.0	1.7	2.1	2.0	2.0	2.1	2.3
Carthage	0.0	0.0	0.5	0.5	2.2	2.8	3.5	3.8	3.9	4.5	3.7
Cedar Lake*	0.6	0.7	1.0	1.0	1.0	1.2	1.4	1.3	1.5	1.7	1.9
Coulterville	—	—	—	1.8	2.0	2.0	2.1	2.5	2.8	2.8	**3.0**
Decatur	0.2	0.5	0.9	1.2	1.7	2.1	2.6	2.9	3.3	3.4	**3.7**
Evergreen Lake*	2.4	2.9	3.2	3.6	4.0	4.5	4.8	5.2	5.3	5.8	**6.2**
Gillespie	0.5	0.5	1.0	1.5	1.7	1.8	2.3	1.7	2.0	2.4	2.2
Hillsboro*	—	—	1.7	2.7	2.9	3.8	4.0	3.7	4.1	4.1	**4.2**
Jacksonville	—	—	0.9	0.9	1.6	**3.0**	2.2	2.2	2.2	2.6	2.8
Kinkaid	—	1.1	1.2	1.3	1.5	1.6	1.8	1.7	1.9	1.9	2.0
La Harpe	0.5	0.5	1.3	1.3	2.0	2.2	2.5	3.1	3.3	3.6	3.8
Lake Lou Yaeger*	0.3	0.3	—	—	0.8	1.2	**1.5**	1.0	1.0	0.8	1.2
Mattoon	0.5	0.8	1.1	1.2	1.5	1.4	1.6	1.8	1.8	2.0	**2.2**
Mauvaise Terre Lake*	—	—	0.5	0.5	1.1	**1.2**	1.0	0.0	—	0.2	0.4
Mount Olive	0.8	—	1.4	1.8	2.0	2.1	2.5	2.7	2.5	2.7	**2.9**
Olney	0.6	—	1.1	1.2	1.3	1.5	1.6	1.8	1.9	2.1	**2.1**
Otter Lake	0.5	—	1.5	1.8	1.8	2.2	2.5	2.0	2.0	2.5	2.7
Palmyra-Modesto	0.7	—	0.7	0.8	1.0	1.0	1.1	0.8	1.3	1.0	1.3
Pana	—	—	1.1	1.1	1.5	1.4	1.6	1.8	1.8	2.0	2.4
Lake Paradise*	0.3	0.4	**0.6**	0.2	0.2	0.3	0.3	0.3	0.3	0.4	0.1
Pinckneyville	1.2	1.5	1.6	2.0	2.2	2.5	2.8	2.8	3.1	3.2	3.4
Spring Lake*	0.2	0.2	—	0.3	0.5	0.7	0.8	0.8	0.8	**1.2**	0.8
Springfield	0.2	0.5	0.8	—	1.5	1.9	2.4	2.6	2.9	3.0	3.4
Staunton	—	—	1.0	1.3	1.7	2.0	2.2	1.8	1.8	2.2	2.5
Vermont	—	0.5	0.9	1.1	1.2	1.2	1.0	1.0	1.2	**1.6**	1.5
Vienna Corr. Center	2.4	2.5	3.1	3.3	3.8	4.0	4.2	4.8	4.9	5.1	5.2
Waverly	—	—	—	—	0.8	0.9	—	1.0	1.1	1.2	**1.3**

	9/4	9/11	9/18	9/25	10/2	10/9	10/16	10/30	11/13	11/30	12/31
Altamont	0.6	0.2	0.4	0.6	0.6	0.7	0.8	0.8	—	1.2	1.0
Bloomington	2.0	2.3	2.7	3.2	3.9	**4.3**	—	3.7	—	4.3	4.1
Carlinville	2.2	2.6	2.3	2.2	3.0	—	—	3.5	—	4.0	**4.5**
Carthage	3.5	3.6	3.8	4.0	—	—	—	4.5	—	**5.2**	—
Cedar Lake*	1.3	1.4	1.6	2.0	2.0	2.2	2.3	2.2	2.2	2.5	**2.6**
Coulterville	—	—	—	—	—	—	—	—	—	—	—
Decatur	3.4	3.0	3.1	3.3	3.4	3.6	3.6	1.6	—	0.0	0.0
Evergreen Lake*	5.4	5.4	5.5	5.6	5.7	5.6	—	4.5	—	3.9	2.6
Gillespie	1.7	1.5	1.2	1.7	—	—	—	—	—	3.6	**3.6**

Continued on next page

Table 6.1 *Continued*

Community or System Name	2012 Date										
	9/4	9/11	9/18	9/25	10/2	10/9	10/16	10/30	11/13	11/30	12/31
Hillsboro*	0.0	—	—	—	—	—	—	0.0	—	0.1	0.0
Jacksonville	2.1	—	—	—	2.7	—	—	2.5	—	2.0	—
Kinkaid	1.6	1.7	1.8	1.9	2.0	2.0	2.0	1.8	1.7	2.0	1.6
La Harpe	3.9	4.1	4.2	4.5	4.7	4.8	4.8	4.8	5.0	**5.3**	—
Lake Lou Yaeger*	0.5	—	0.3	0.5	—	—	—	—	—	—	—
Mattoon	1.8	1.6	1.6	1.8	1.7	1.8	—	—	—	1.3	—
Mauvaise Terre Lake*	0.0	—	—	—	0.1	—	—	0.2	—	—	—
Mount Olive	2.5	—	2.7	—	2.3	—	—	1.8		0.9	0.9
Olney	1.8	1.5	1.4	1.8	1.2	1.2	1.3	1.2	1.4	1.5	1.5
Otter Lake	1.0	0.8	0.8	1.2	—	—	—	—	—	**3.2**	—
Palmyra-Modesto	0.8	0.7	0.5	0.8	—	—	—	—	—	**2.5**	—
Pana	2.3	2.2	2.3	—	2.4	—	—	2.8	—	**3.1**	3.0
Lake Paradise*	0.0	0.0	0.2	0.2	0.2	0.3	—	—	—	0.0	—
Pinckneyville	3.4	3.2	3.0	3.1	2.8	—	3.0	3.0	3.3	**3.5**	3.2
Spring Lake*	0.5	0.5	—	—	0.6	—	—	0.3	—	0.3	0.2
Springfield	3.0	3.0	3.1	3.3	3.4	—	—	3.6	—	**3.8**	3.3
Staunton	2.0	2.2	2.0	2.3	2.8	—	—	—	—	**2.8**	—
Vermont	1.2	1.2	1.0	1.3	—	—	—	—	—	—	—
Vienna Corr. Center	5.0	5.0	5.4	5.6	5.7	5.9	6.0	6.2	6.7	6.9	**7.1**
Waverly	0.7	0.7	—	1.0	—	—	—	—	—	—	—

*Cedar Lake is the primary water supply lake for Carbondale. Lake Evergreen is the second lake in the Bloomington water supply system. Lake Hillsboro is a supplemental source for the City of Hillsboro; Lake Glenn Shoals (not included) is the primary supply for that community. Lake Lou Yaeger is the primary water supply lake for Litchfield. Mauvaise Terre Lake is the second lake in the Jacksonville water supply system. Lake Paradise is the second lake in the Mattoon water supply system. Spring Lake is the primary water supply lake for Macomb.

lakes, supplemented when needed with month-end readings from the ISWS records. The locations of these lakes are shown in Figure 6.2. The observation dates shown in Table 6.1 are not exact. In many cases, for example, water levels were observed on the days leading up to the reporting date.

Except where noted by an asterisk, lake names in Table 6.1 are identical to the name of the community or water supply system that the lake serves. But in some cases, the lake levels shown do not fully represent the complete water supply available to that community's water supply system. For example:

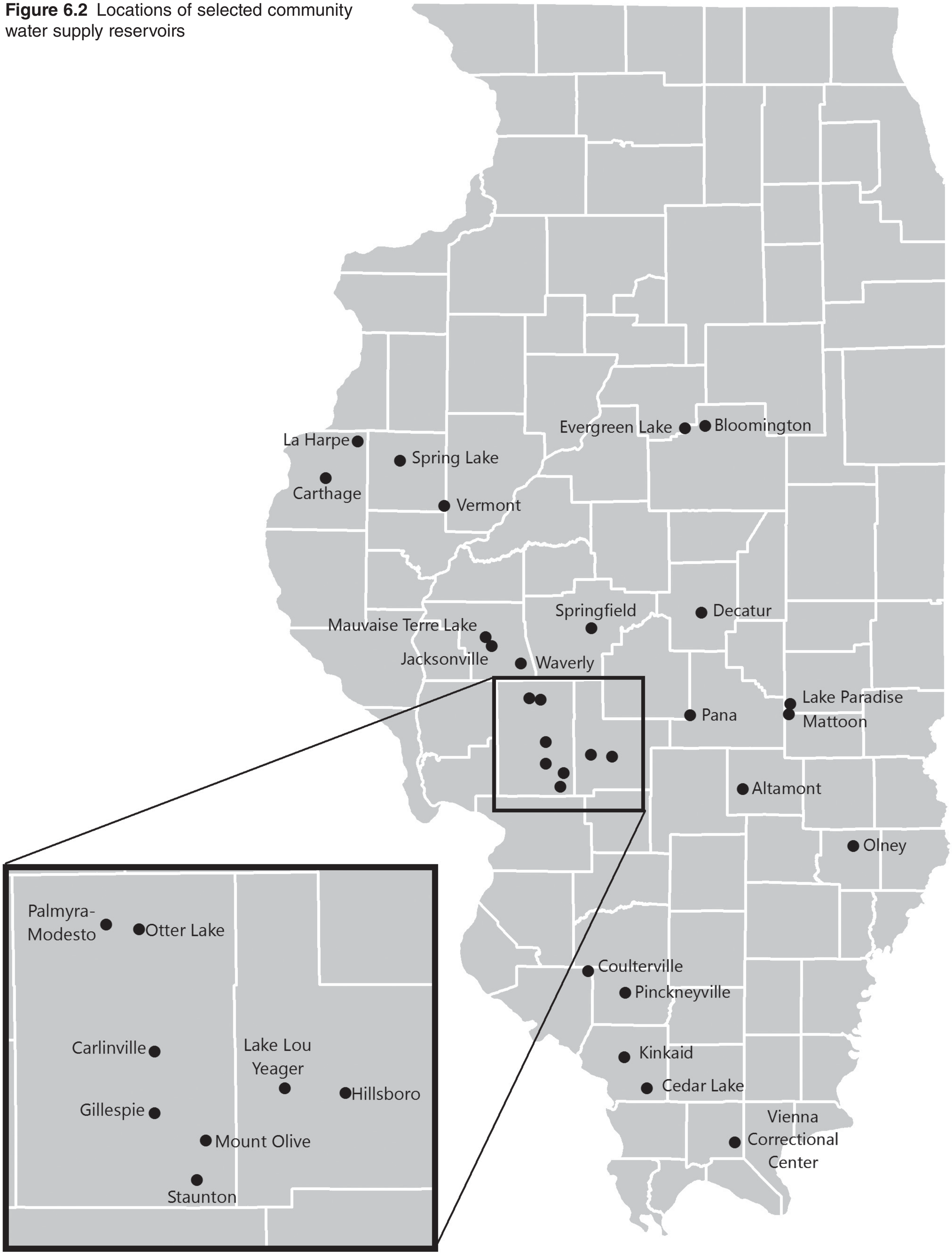
- Lake Hillsboro now serves only as a supplemental source of supply to the City of Hillsboro; lake levels were not available for Lake Glenn Shoals, which is that community's primary supply source.
- Carthage purchases a portion of its water from the Hamilton water supply system.
- Roughly 75 percent of the water supply for the City of Jacksonville comes from a groundwater resource. Thus, low water levels of Lake Jacksonville and Mauvaise Terre Lake (the city's second lake) do not fully represent the potential threat of drought to the Jacksonville water system.

The water depths in Table 6.1 that are highlighted in bold and underlined represent each lake's greatest drawdown during 2012. Roughly half of the water supply lakes experienced their lowest storage levels in summer 2012, either in July or August before the remnants of Hurricane Isaac passed over Illinois. Although water levels in many remaining water supply lakes rebounded with the precipitation brought by Isaac, water levels in these lakes continued to decline later in the fall. Thirteen of the water supply lakes listed in Table 6.1 did not experience their greatest drawdown until the end of November or into December. Thus, the low water levels and water supply condition of many lakes continued to be a concern into January 2013.

Volume of Loss in Water Supply Reservoirs

Because water supply lakes differ in a variety of dimensions, such as maximum depth, usable capacity, and

Figure 6.2 Locations of selected community water supply reservoirs



rate of withdrawal, it is also useful to describe the lake drawdown in terms of the amount of water lost from the lake compared to the total capacity of the lake. Listed in Table 6.2 is the maximum amount of volume lost during the drought for selected water supply lakes, expressed as a percentage of the total capacity of each lake at full pool. These lakes selected generally represent ones for which the ISWS has accurate measurements of lake capacity.

Table 6.2 shows that for most water supply lakes the volume of drawdown in 2012 represented only about 15 to 25 percent of the total lake capacity. These represent the reservoirs that were designed to supply water during multi-year droughts, and as such would not be expected to lose most of their volume during the first year of a drought. Also, for many of these cases, the maximum lake drawdown occurred in late August 2012 (prior to the passage of the remnants of Hurricane Isaac), such that the drawdown represents the impact of only two to three months of drought.

Although the City of Springfield enacted mandatory water restrictions in August 2012, and its lake continued to experience drawdown into the late fall, the volume of water loss (25 percent) never approached a critical condition. Figure 6.3 compares the 2012 water level in Lake Springfield to the 1988–1989 and 1999–2000 droughts as well as to the estimated 100-year drought condition. The initial two-month drawdown in Lake Springfield, from the end of June to the end of August, was as great as for either of the 1988–1989 and 1999–2000 droughts. However, the rate of decline slowed down considerably following the partial replenishment in early September from the remnants of Hurricane Isaac. A comparison of the Lake Springfield water levels in Figure 6.3 indicates that the 2012 lake level was never able to approach the low levels of the 1988–1989 and 1999–2000 droughts, not to mention an extreme water supply drought such as the 100-year drought. Based solely on Lake Springfield's minimum lake level, the 2012 drought would be calculated to have a recurrence interval of only three to four years.

Table 6.2 Maximum 2012 Loss in Volume for Selected Water Supply Lakes (Loss in volume expressed as a percentage of the capacity at full pool)

Community/System Name	
Altamont	35%
Bloomington	30%
Carbondale	15%
Decatur	45%
Gillespie	25%
La Harpe	55%
Litchfield	15%
Macomb	15%
Mattoon	10%
Mount Olive*	40%
Olney	15%
Otter Lake	15%
Palmyra-Modesto	15%
Pana	20%
Springfield	25%
Staunton	20%
Vienna Correctional Center	55%
Waverly	20%

*The value listed is only for the New Lake at Mount Olive for which water levels were reported. No values were reported for Mount Olive's second, older lake, which has a slightly larger capacity. Based on knowledge of the entire system, it is reasonable to conclude that its total 2-lake storage loss may be as little as half of that listed above.

The three water supply lakes that experienced a volume loss of 45 percent or more (Decatur, La Harpe, and the Vienna Correctional Center) are considered the water supply systems most threatened by the 2012 drought. The situations for each of these systems are examined in more detail in Chapter 9: *Water Supply and Water Use Impacts*.

Comparison to Past Droughts

The ISWS collects month-end water level observations for 14 of the lakes listed in Table 6.1. Nine of these water level records date back to the drought of 1988, thus covering at least 25 years of continuous record. The maximum drawdown levels during the 2012 drought were compared to the previous years of record for each of these nine lakes, and Table 6.3 shows the ranking of the 2012 drought within each record and also compares with the previously observed maximum drawdown. For Lake Bloomington and Evergreen Lake, both components of the Bloomington water supply system, a combined drawdown amount was used with a maximum combined amount of 9.9 feet

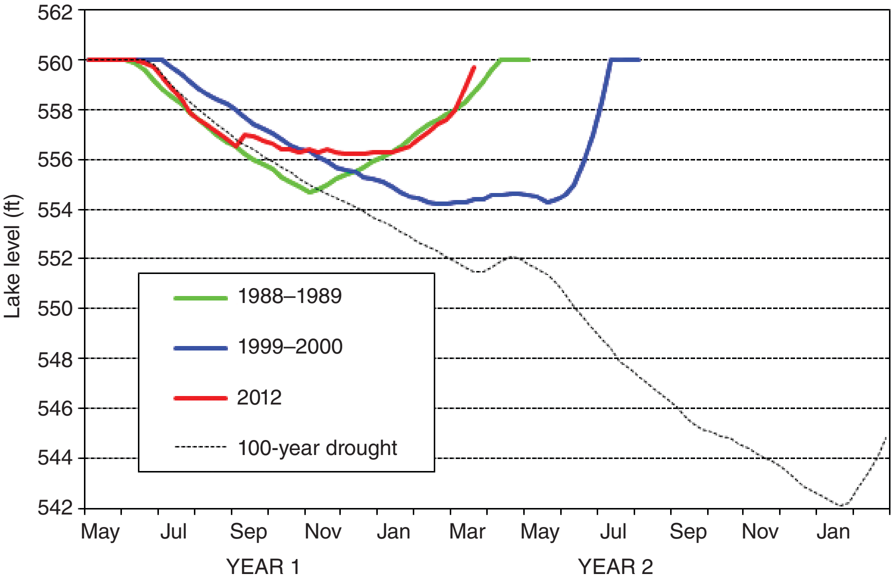


Figure 6.3 Comparison of 2012 lake levels to those of the 1988–1989 and 1999–2000 droughts

Table 6.3 Comparison of 2012 Drought Lake Drawdown to Previous Years of ISWS Records

Lake	Period of record	2012 maximum drawdown (feet)	Rank of 2012 event	Maximum drawdown on record (year)
Altamont	1983–present	2.3	18	6.7 (2006)
Bloomington*	1988–present	9.9	8	35.9 (1989)
Carlinville	1983–present	4.5	3	5.0 (1988 & 2000)
Decatur	1983–present	3.7	3	5.2 (1988)
Kinkaid	1988–present	2.0	3	3.4 (2002)
Mattoon	1983–present	2.2	5	2.8 (1985)*
Spring (Macomb)	1983–present	1.2	9	5.4 (1989)
Springfield	1983–present	3.8	10	5.7 (2000)

*Listed Bloomington drawdown is the combined amount for Lake Bloomington and Evergreen Lake. The water level observations for Lake Mattoon do not include the period from Oct. 1988 to Apr. 1993.

(occurring with the October 9, 2012 lake observations). Also note that the target or operating pool for several of these lakes has changed over their period of record; the drawdown is computed from the designated target pool at the time of the observation.

For three of the lakes listed (Carlinville, Decatur, and Kinkaid), the maximum drawdowns during the 2012 drought rank as the third worst for the respective lake over 25 to 30 years of record. This ranking would correspond to a drought recurrence interval of 8 to 10 years. For half of the lakes listed (Altamont, Bloomington, Spring, and Springfield) the 2012 maximum drawdowns rank no higher than the eighth worst on record, translating to a drought recurrence interval of no greater than three years. The vicinity of Altamont Lake received copious amounts of rainfall in August and September, thus greatly limiting the overall impact of the drought on that lake.

Lake Michigan

During 2012, the water level in Lake Michigan fell considerably below its normal level, such that by January 2013, the lake reached an elevation of 576 feet above mean sea level, the minimum recorded level since observations began in 1918. The monthly mean water levels for Lake Michigan during the 2012–2013 period are shown in Table 6.4. In March 2012, the lake level was only 1.0 foot below its long-term average for that month. This was not unusual, as Lake Michigan had generally been 1 foot or more below its long-term average for most of the previous decade. However, whereas the lake usually gains about 1 foot in elevation between early spring and mid-summer, in 2012 the lake had risen only 0.3 feet, and by August 2012, was 2.0 feet below its long-term average. By January 2013, when it reached its record low, the lake was 2.4 feet below its long-term average, after which the lake level started to recover.

Regional drought conditions in Illinois have very little influence on Lake Michigan levels, because very little of the water that enters the lake originates from Illinois. Instead, much of the watershed and streams that provide inflows into Lake Michigan and Lake Huron (the two lakes are connected by the Straits of Mackinac and share the same water level) are located in Michigan and the southern part of the Province of Ontario. The lack of precipitation in 2012 over these Great Lakes areas was not as severe as that in Illinois, whereas the unusually warm temperatures during the winter, spring, and summer of 2011–2012 appear to have been a significant factor leading to the low levels on Lake Michigan, influencing the record low ice cover in 2011–2012, record high summer lake temperatures in 2012, and above-normal evaporation rates from the Great Lakes.

Major Federal Reservoirs

Southern Illinois has three very large reservoirs that were constructed and are maintained by the U.S. Army Corps of Engineers (USACE), specifically Rend Lake, Lake Shelbyville, and Carlyle Lake. Although each of these lakes provides a water supply function, their primary operational purpose is for flood management, a function which can delay and alter the impacts of droughts on water levels. One of the additional major purposes of Lake Shelbyville and Carlyle Lake is to provide water for federal operation of the navigation industry on the Mississippi River system.

Table 6.4 lists the month-end reservoir levels for each of these three federal reservoirs. The target water elevation for Rend Lake is 405.0 feet above mean sea level; however, because there are no specific outlet facilities or gates that the USACE uses to regulate the target level, the lake level often remains above the target level following wet conditions until it slowly drains to a lower elevation. During the 2012 drought, Rend Lake did not recede to its target elevation until late July after which it continued to fall until early September (reaching a minimum elevation of 404.4 feet), at which point the remnants of Hurricane Isaac passed over the region and raised the water level. In summary, the overall impact of the drought on the lake was minimal.

Table 6.4 Monthly Elevations of Lake Michigan and the Federal Reservoirs

	Lake Michigan		Rend Lake	
	Monthly average (ft)	Departure from average (ft)	Month-end level (ft)	Departure from target level (ft)
March 2012	577.4	–1.0	408.0	+3.0
April 2012	577.5	–1.2	407.4	+2.4
May 2012	577.6	–1.4	406.6	+1.6
June 2012	577.7	–1.5	405.6	+0.6
July 2012	577.6	–1.7	404.9	–0.1
August 2012	577.3	–2.0	404.4	–0.6
September 2012	577.0	–2.1	404.9	–0.1
October 2012	576.6	–2.3	405.1	+0.1
November 2012	576.4	–2.3	405.0	+0.0
December 2012	576.2	–2.3	405.0	+0.0
January 2013	576.0	–2.4	408.5	+3.5
February 2013	576.1	–2.3	408.6	+3.6
March 2013	576.2	–2.2	410.0	+5.0
April 2013	576.6	–2.1	410.4	+5.4

	Lake Shelbyville		Carlyle Lake	
	Month-end level (ft)	Departure from target level (ft)	Month-end level (ft)	Departure from target level (ft)
March 2012	594.4	+0.4	443.4	+0.4
April 2012	596.6	+0.6	445.1	+1.1
May 2012	559.0	–0.7	445.5	+0.5
June 2012	598.8	–0.9	444.9	–0.1
July 2012	598.3	–1.4	443.9	–1.1
August 2012	598.3	–1.4	444.0	–1.0
September 2012	598.5	–1.2	448.3	+3.3
October 2012	599.2	–0.5	447.6	+2.6
November 2012	599.7	+0.0	447.7	+2.7
December 2012	598.9	+4.9	446.4	+3.4
January 2013	597.5	+3.5	447.6	+4.6
February 2013	595.5	+1.5	444.8	+1.8
March 2013	595.3	+1.3	443.9	+0.9
April 2013	608.6	+12.6	452.5	+8.5

For Lake Shelbyville and Carlyle Lake, the USACE has seasonal target water levels and can release or withhold water as needed to meet the multiple objectives of operation for each lake. In March 2012, the levels of both reservoirs were being maintained at the winter target levels, and in April began to increase their water levels to match their normal seasonal operations. Although Carlyle Lake was able to transition to its summer pool elevation (445 feet) by the beginning of May, Lake Shelbyville was unable to rise to its summer pool level (599.7 feet) because of the below-normal streamflow amounts in April, May, and June. The level of Lake Shelbyville remained over 1 foot below its target level throughout much of the duration of the drought, but was able to recover in October and November.

The level of Lake Carlyle also fell to roughly 1.0 foot below its target during

July and August. In early September, however, the path of Isaac was directly over Lake Carlyle and much of its contributing watershed, dropping as much as 10 inches of rain in some locations. Lake Carlyle quickly shifted from below normal to more than 3 feet above normal. After the passage of Hurricane Isaac and the end of the primary portion of the recreational boating season, the USACE decided to retain some of these flood waters (and maintain a higher-than-normal pool level) for possible use later in the year, in particular to supplement low flows in the Mississippi River. The release of water for this purpose later in the drought is described in Chapter 11: *Navigation, Environmental, and Water Quality Impacts*.

Chapter 7. Groundwater Conditions

Of all parts of the hydrologic cycle, groundwater is the least affected by drought. In describing drought impacts to groundwater, it is appropriate to separate shallow groundwater (commonly considered to be within 100 feet of the land surface) from the remaining (deeper) groundwater aquifers. Travel times for deeper groundwater in Illinois range from years to centuries; thus these aquifers, which provide most of the groundwater supply, are typically unaffected by the relatively short duration of droughts. Shallow groundwater levels, however, are depressed during droughts. Because soils are so dry, almost all rainfall will be retained in higher soil layers and evapotranspired, and scant amounts of recharge will reach the water table (the uppermost groundwater layer, which is "open" to the surface). Meanwhile, water tables will progressively drop during a drought as 1) shallow groundwater moves to replenish low flows in streams; 2) vegetation with deep roots induces uptake from groundwater; and 3) water is withdrawn from shallow wells (< 100 feet). Such shallow wells, in turn, can be vulnerable to water shortages.

In Illinois, shallow wells most vulnerable to drought include 1) large-diameter dug and bored wells; 2) sand points; and 3) shallow small-diameter drilled wells, all types typically drawing from shallow groundwater. Large-diameter dug and bored wells are common in rural areas where aquifers are nonexistent, especially in the southern half of Illinois. These wells basically serve as storage reservoirs for shallow groundwater. Even during summers with normal precipitation, they often go dry, and typically well owners must buy and transport water to their wells. Sand points and shallow small-diameter drilled wells are typically finished in shallow alluvial aquifers where water tables may be lowered because recharge is limited due to the lack of precipitation. Low water tables also mean there will be little groundwater discharge to streams and rivers during drought, contributing to abnormally low streamflows and decreased lake levels.

The drop in the water table caused by drought conditions will not in itself affect water availability in confined aquifers in the short-term. In this context, "confined" means where there is a relatively impermeable layer or layers, such as clay or rock, between the water-bearing layer and the land surface. However, increased withdrawals by other wells in the same layer may decrease water levels.

One challenge in determining the effects of drought on groundwater is separating decreasing water levels caused by lower recharge rates from the role of increased demand for groundwater. Increased demand during drought can be manifested in several ways. During the growing season for row crops, especially corn, the lack of rainfall will induce farmers to increase irrigation pumping. Decreasing streamflows during drought may cause some public water suppliers and industries to partially switch from surface water to groundwater sources. Both of these activities increase the amount of groundwater withdrawn during drought.

Groundwater Data Sources

Scientists have been measuring groundwater levels in Illinois for more than a century. However, the collection of groundwater-level data was not systematic or coordinated until the 1950s, following the drought of 1952–1955, when decisions were made to begin long-term collection of groundwater-level data from dedicated monitoring wells. The Illinois State Water Survey (ISWS) and other state agencies currently maintain several monitoring well networks in the state, some of which are described later. Since the last statewide drought in 2005, the number of monitoring wells outfitted with equipment that can collect almost continuous (hourly) groundwater-level measurements has expanded considerably, giving us a richer data set for evaluating the effects of drought on groundwater.

Monitoring Networks and Wells Used in this Report

Water Atmospheric Resource Monitoring Network (WARM)/Illinois Climate Network (ICN) ISWS maintains two networks, WARM and ICN, which monitor the natural short- and long-term fluctuations of shallow groundwater levels (i.e., the water table) across Illinois. Typically, these wells do not extend into highly productive aquifers; rather, they are constructed in fine-grained glacial materials containing thin lenses of sand. These observation wells are generally located in areas remote from pumping centers to minimize the apparent effects of human activities on groundwater levels. In a few cases, wells are located near regional irrigation centers (Snicarte) or suburban areas that use groundwater supplies (St. Charles, Crystal Lake). Nevertheless, the groundwater levels monitored in these observation wells generally represent conditions beneath non-irrigated agricultural land and water levels found in many shallow, rural domestic wells in Illinois.

The WARM network consists of 15 wells (Figure 7.1 and Table 7.1), most of which have been monitored since the early 1960s; four have been measured since the early 1950s. There are 17 ICN observation wells that were established beginning in the mid-1990s at each of the climate site locations (Table 7.2). The locations of the ICN stations are shown in Figure 4.1 (the Big Bend and Champaign ICN stations do not include wells).

McHenry County Network McHenry County in far northern Illinois is completely dependent on groundwater for its drinking water supply, and as such the county government has made a concerted effort to monitor groundwater conditions. Most of the groundwater comes from productive, unconfined glacial sand and gravel aquifers. There are currently 43 dedicated monitoring wells at 27 locations throughout the county, all finished in sand and gravel aquifers (Figure 7.2 and Table 7.3). At 12 of the locations, there are two or three nested wells at different depths.

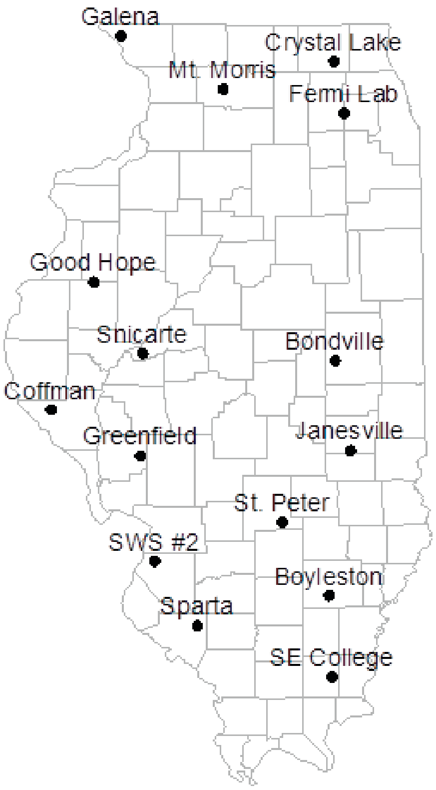


Figure 7.1 WARM network observation well locations

Most of these wells have transducers and data loggers that record water level measurements every 15 minutes, with data records extending back to 2009. The equipment is maintained by the U.S. Geological Survey (USGS), and the data are uploaded to their website in real-time. For this report, daily maximum values were downloaded from the USGS website.

Other Wells Other wells used in this study are shown in Figure 7.3 and Table 7.4. These wells are finished in either glacial sand and gravel aquifers or are water table wells. The water table wells are not part of the WARM or ICN networks, and have a much shorter period of record than wells in those networks. Many of these wells are part of the ISWS groundwater monitoring network for the Mahomet Aquifer. The Mahomet Aquifer is the principal source of water for many communities and irrigated growers in east-central Illinois (see Roadcap et al., 2011). More than 180 observation wells at 140 sites have been constructed

Table 7.1 WARM Network Shallow Observation Well Information. Well depth, case depth, screen length, land surface elevation, and measure point elevation in feet. Well diameter in inches. NS = not screen, i.e., well is a dug or bored well that is brick or tile-lined

ISWS ID	Well Name	Location	Start Date	Hydrologic Unit	Crop Reporting District	Well Depth	Case Depth	Screen Length	Well Diameter	Land Surface Elevation	Measure Point Elevation
21	Galena	08528N01W244H	1963	7060005	NW	25	25	NS	36	730	730.6
31	Mt. Morris	14124N09E341C	1960	7090005	NW	55	55	NS	8	925	925.0
41	Crystal Lake	11143N08E065B	1950	7120006	NE	18	11	7	6	892	895.8
53	Fermi Lab	04339N09E19.6E	1988	7120007	NE	15	10	5	6	762	766.3
61	Coffman	14904S06W265D	1956	7110004	WSW	28	28	NS	36	624	626.0
72	Good Hope	10907N02W068C	1980	7130010	W	30	20	10	4	765	765.0
91	Snicarte	12519N10W118B	1958	7130009	C	42	42	NS	36	485	486.5
132	Greenfield	06111N10W283A	1965	7130012	WSW	22	22	NS	48	610	610.0
143	Janesville	02911N09E182D	1968	5120112	ESE	11	11	NS	36	722	723.5
153	St. Peter	05105N03E171H	1965	7140202	ESE	15	15	NS	60	597	598.0
171	Sparta	15705S05W054F	1960	7140105	SW	27	4	NS	48	511	512.0
181	SWS No.2	16302N09W268F	1952	7140101	SW	80	77	3	6	419	421.1
202	SE IL College	16509S07E094B	1984	5140204	SE	11	11	9	6	380	381.0
221	Boyleston	19102S07E177B	1984	5120115	SE	23	23	NS	36	405	405.5
1120	Bondville	01918N07E023G	1982	7140201	E	21	11	10	6	700	701.8

Table 7.2 ICN Shallow Groundwater Network Well Information. Well depth and land surface elevation in feet

Well Name (ID)	Local Site	Location	Year Drilled	Well Depth	LS Elevation
Belleville (FRM)	SIU Agronomy Farm	16301N07W23	1996	15.0	436
Bondville (CMI)	ISWS BEARS Research Site	01919N07E02	1997	20.0	697
Brownstown (BRW)	UI Brownstown Agronomy Research Center	05106N02E03	1996	15.0	581
Carbondale (SIU)	SIU Ag Research Farm	07709S01W31	1997	25.5	450
DeKalb (DEK)	UI Northern Illinois Ag. Center	03739N03E23	1996	24.5	869
Dixon Springs (DXS)	UI Dixon Springs Ag. Center	15112S05E33	2006	50.0	541
East Peoria (ICC)	Illinois Central College	17926N04W13	2005	41.5	703
Fairfield (FAI)	Frontier Community College	19102S07E02	1997	21.0	446
Freeport (FRE)	Highland Community College	17726N07E03	1996	25.8	869
Ina-Rend Lake (RND)	Rend Lake Community College	08104S03E31	1997	21.0	427
Kilbourne (SFM)	UI River Valley Sand Farm	12520N09W27	1996	47.5	499
Monmouth (MON)	UI Northwestern Ag Research Center	18711N03W27	1996	27.0	751
Perry (ORR)	UI Orr Ag Research Center	14903S04W15	1996	20.0	676
Olney (OLN)	Olney Central College	15904N10E33	1997	19.0	450
St. Charles (STC)	UI St. Charles Horticulture Center	08940N08E31	1996	21.1	742
Springfield (LLC)	Lincolnland Community College	16715N05W26	1997	20.0	581
Stelle (STE)	Village of Stelle	05329N09E35	1997	17.0	699

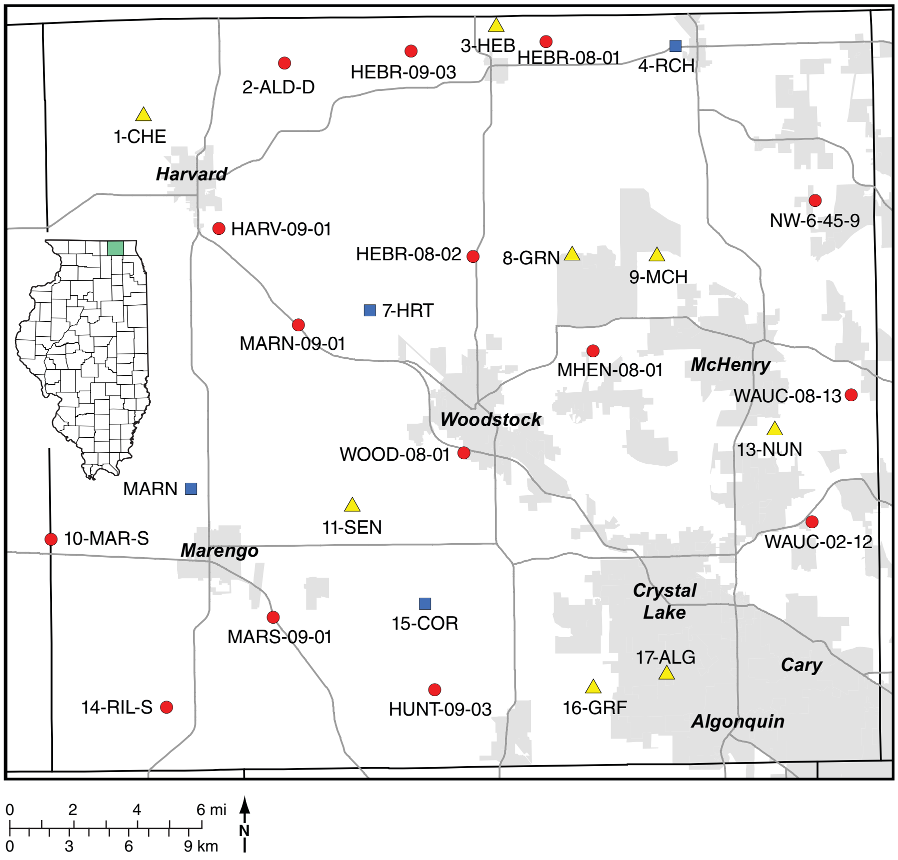


Figure 7.2 Location of monitoring wells with continuous water level data in McHenry County. Red circles indicate locations with single wells, yellow triangles with two nested wells, and blue squares with three nested wells.

across the aquifer as part of numerous hydrogeological investigations, and are measured quarterly by the ISWS except during the drought when extra rounds of water level data were collected at many of the wells. Approximately 25 wells are equipped with transducers and data loggers.

Groundwater Levels during the 2012 Drought

WARM/ICN Historical month-end measurements were used to establish mean monthly groundwater levels for the WARM shallow groundwater network. The long period of record allows a comparison of current water levels to those of past drought periods. Mean monthly water levels were calculated for the period of record (start dates in reported Tables 7.1 and 7.2)

Table 7.3 McHenry County Monitoring Wells. Well depths, water level depths, and difference between minimum and maximum depth in feet over the course of the 2012 drought. Negative depths indicate the water level rises above the land surface, i.e., flowing artesian conditions.

Well ID	Well Depth	Date Minimum	Minimum depth	Date Maximum	Maximum depth	Days Max-Min	Diff Max-Min
1-CHE-D	110.8	3/13/2012	5.56	9/4/2012	9.39	175	3.83
1-CHE-S	40.3	3/13/2012	5.57	9/7/2012	9.53	178	3.96
2-ALD-D	344.4	4/25/2012	218.67	1/24/2013	226.27	274	7.60
3-HEB-D	94.4	4/1/2012	-13.87	2/5/2013	-10.34	310	3.53
3-HEB-I	66.3	4/1/2012	-13.86	1/28/2013	-10.20	302	3.66
4-RCH-D	176.0	4/1/2012	10.35	10/4/2012	15.78	186	5.43
4-RCH-I	98.3	4/2/2012	10.34	9/29/2012	17.92	180	7.58
4-RCH-S	24.0	3/15/2012	4.91	12/5/2012	11.15	265	6.24
7-HRT-D	165.7	4/28/2012	35.39	11/28/2012	45.80	214	10.41
7-HRT-I	114.9	4/25/2012	34.31	1/9/2013	43.18	259	8.87
7-HRT-S	62.3	4/24/2012	33.97	1/9/2013	42.99	260	9.02
8-GRN-D	153.1	3/28/2012	16.63	7/8/2012	22.89	102	6.26
8-GRN-I	70.3	4/24/2012	5.29	1/26/2013	9.46	277	4.17
9-MCH-D	180.0	5/2/2012	52.88	7/8/2012	62.86	67	9.98
9-MCH-S	25.9	3/18/2012	9.53	12/21/2012	15.38	278	5.85
10-MAR-S	20.3	3/13/2012	2.35	9/30/2012	6.99	201	4.64
11-SEN-D	153.2	4/16/2012	3.63	10/9/2012	7.41	176	3.78
11-SEN-I	75.4	4/16/2012	2.58	10/12/2012	6.51	179	3.93
13-NUN-D	152.2	5/7/2012	45.90	7/9/2012	50.38	63	4.48
13-NUN-I	113.0	5/7/2012	46.16	7/9/2012	50.65	63	4.49
14-RIL-S	20.4	3/19/2012	6.25	10/14/2012	10.57	209	4.32
15-COR-D	116.1	3/18/2012	7.65	10/12/2012	12.00	208	4.35
15-COR-I	103.3	3/18/2012	7.92	12/12/2012	12.23	269	4.31
15-COR-S	55.1	3/18/2012	7.64	10/12/2012	12.01	208	4.37
16-GRF-D	139.1	3/16/2012	19.09	10/4/2012	27.86	202	8.77
16-GRF-I	99.0	3/14/2012	12.95	10/5/2012	26.44	205	13.49
17-ALG-D	187.8	2/1/2012	92.46	7/13/2012	119.43	163	26.97
17-ALG-S	47.3	3/1/2012	-1.31	10/13/2012	6.90	226	8.21
HARV-09-01	120.1	3/24/2012	31.23	1/27/2013	36.67	309	5.44
HEBR-08-01	145.3	3/19/2012	27.40	1/28/2013	31.69	315	4.29
HEBR-08-02	100.3	3/14/2012	9.97	10/2/2012	13.58	202	3.61
HEBR-09-03	120.6	4/1/2012	23.63	1/24/2013	30.05	298	6.42
HUNT-09-03	150.7	3/18/2012	23.79	11/14/2012	31.92	241	8.13
MARN-09-01	100.7	4/24/2012	31.66	12/5/2012	38.10	225	6.44
MARN-09-02	110.6	4/20/2012	16.71	1/8/2013	22.92	263	6.21
MARN-10-03	160.0	3/23/2012	26.63	1/24/2013	33.38	307	6.75
MARN-10-04	82.0	4/20/2012	17.03	1/8/2013	23.08	263	6.05
MARS-09-01	190.3	4/20/2012	69.84	10/15/2012	79.93	178	10.09
MHEN-08-01	103.3	5/9/2012	33.59	1/28/2013	36.17	264	2.58
NW-6-45-9	73.0	6/2/2012	32.72	2/20/2013	37.80	263	5.08
WAUC-02-12	192.3	3/28/2012	91.50	7/5/2012	122.89	99	31.39
WAUC-08-13	105.3	5/11/2012	20.81	2/10/2013	24.25	275	3.44
WOOD-08-01	202.3	4/2/2012	77.35	7/13/2012	83.24	102	5.89

through December 2011 at each well, and departures from those means were computed for each month from January 2012 through April 2013. These data were analyzed to show groundwater levels prior to and following the drought period defined by the precipitation data presented in Chapter 3. Because the period of record for the ICN observation well network is relatively short in relation to the WARM network, no analysis was conducted for those data. However, trends observed for those wells are discussed below.

WARM Shallow Groundwater Network, Deviations from Normal Departures of measured groundwater levels from the corresponding mean monthly water levels were calculated for a 16-month period beginning in January 2012. During drought conditions, the uppermost soils can become so dry that almost all rainfall will be retained in the higher soil levels. Very little precipitation reaches the water table, which continues to decline. In order for rainfall to positively affect the water table (i.e., recharge), the dry pore spaces of the upper soil must become saturated. After the upper soil moisture is replenished, water will then move deeper and

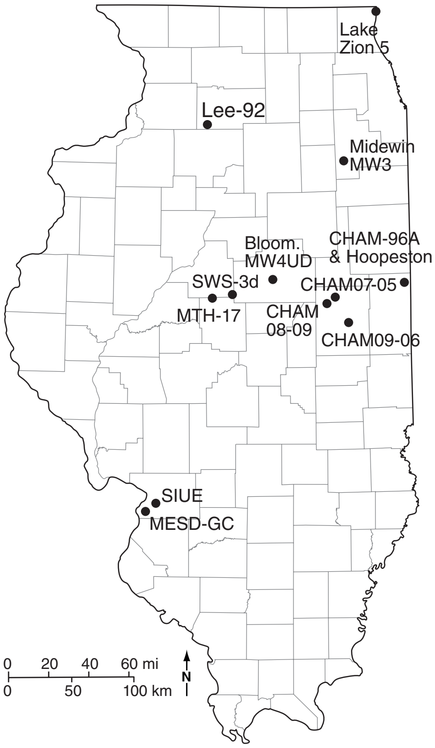


Figure 7.3 Other monitoring wells with continuous water level data shown in this report. There are nested wells at CHAM08-09, Lee-92, MESD-GC, and MTH-17

recharge the water table. This causes a lag in shallow groundwater level increases. For this reason, a 16-month overview of shallow groundwater levels was needed. Table 7.5 lists the mean monthly and statewide deviations from normal for the 15-well WARM network. Figure 7.4 depicts these deviations in graph form. Statewide, below-normal deviations lasted 14 months during the drought of 2012. Above-normal deviations were reported in January 2012 and were not reported again until April 2013.

Statewide monthly deviations from normal are shown in Figures 7.5a-p. These figures indicate the most affected portions of the state during this drought were the west-central and central areas of Illinois. Large below-normal departures began in the west-central part of Illinois at Greenfield in Greene County. These departures spread east across the state and by May 2012, no above-normal departures were reported in Illinois. June, July, and August continued the below-normal trend. The southern part of the state showed some improvement in September and October, but that improvement was short-lived. Below-normal departures engulfed the entire state once again in November and December 2012. January groundwater levels showed improvement in the southwestern and eastern half of Illinois, which continued through April 2013. The northwestern part of Illinois continued to report below-normal deviations in February and March 2013. Deviations below normal were still reported in April at Mt. Morris (Ogle Co.) and Snicarte (Mason Co.), but the overall trend into April 2013 was positive.

WARM Shallow Groundwater Network, Groundwater Levels From January 2012 through April 2013, five wells experienced record low water levels during several months. Three wells, Bondville (Champaign Co.), S.E. College (Saline Co.), and Coffman (Pike Co.), reported record low levels for eight, eight, and six months, respectively. Two other wells, Fermi Lab (DuPage Co.) and Janesville (Cumberland Co.), experienced four and two months of record low groundwater levels, respectively. All totaled, 28 monthly record low water levels were reported during January 2012 through April 2013 among these five stations. Figure 7.6 shows water levels in the Coffman well, one of the five wells that had record low groundwater levels during this period. The hydrographs plot mean levels and monthly highs and lows with the depth to water measurements for January 2012 through April 2013.

Comparison to Past Droughts

Shallow groundwater information was compared to past droughts reported in 1980, 1988, and 2005. The WARM network of observation wells was implemented in response to the drought of 1952. Of the five wells that reported record low water levels in 2012, only two, Coffman and Janesville, have monthly data that span the droughts of 1980, 1988, and 2005. Hydrographs of water levels from these wells are presented in Figures 7.7 and 7.8, respectively. Monitoring at the other three wells began in the 1980s.

The water level information and the hydrographs indicate that the 2012 drought caused more record low monthly water levels than any of the past droughts during which these wells were being monitored. The deviations from normal (Figures 7.5a-p) confirm that the Coffman well area in Pike County was hardest hit in regard to below-normal shallow groundwater levels. Deviations from normal began in January 2012 and lasted into March 2013, a 15-month period. Six record low months were reported for this well from June 2012 through December 2012 (Figure 7.6). The Janesville well located in Coles County had only two record low water levels in June and July, 2012; however, its long period of record (since 1968) suggests that the shallow groundwater levels at that location were the lowest since the 1950s.

The observation well data from the wells with shorter periods of record also indicate that the impact of the 2012 drought was major and felt throughout much of Illinois. Three other WARM network observation wells on the eastern side of the state (Fermi Lab, Bondville, and SE College) reported their lowest water levels during 2012, with records dating back to the 1980s.

A comparison of the deviations from normal for water levels in WARM wells from the three most recent statewide droughts (1980, 1988–1989, 2005) with the 2012 drought is shown in Figure 7.9. A value less than zero indicates a drop in the water table relative to the average level. With respect to the water table, the 2012 drought was of shorter duration than the previous droughts, and the maximum deviation in 2012 (~-3.0 feet) was not as great as for the droughts of 1988–1989 and 2005. The steepness of the decline in the first few months of the 2012 drought, however, was greater than

Table 7.4 Other Monitoring Wells Discussed in this Report. Well depths, water level depths (WL), and difference between minimum and maximum depth in feet over the course of the drought. All wells completed in sand and gravel aquifers.

County	Well Name	Well depth (ft)	Min WL	Min date	Max WL	Max date	WL diff	Days diff
Champaign	CHAM08-09A	265.0	49.34	1/24/2012	59.03	8/1/2012	9.69	190
Champaign	CHAM08-09WT	19.6	7.27	2/6/2012	12.08	8/31/2012	4.81	207
Champaign	CHAM09-06	108.5	29.93	5/9/2012	33.49	8/16/2012	3.56	99
Champaign	CHM-96A	351.0	44.84	3/2/2012	61.43	7/30/2012	16.59	150
Champaign	CHAM07-05	162.0	29.70	5/25/2012	35.92	8/6/2012	6.23	74
Lake	Lake Zion 5	21.8	4.09	5/8/2012	6.50	12/8/2012	2.41	214
Lee	Lee-92E	173.0	22.78	4/12/2012	59.68	8/4/2012	36.9	114
Lee	Lee-92F	22.0	3.01	3/13/2012	10.80	1/28/2013	7.79	321
Madison	MESD-GCD	98.5	13.92	5/2/2012	16.86	1/26/2013	2.94	269
Madison	MESD-GCWT	23.8	13.89	5/2/2012	16.84	1/27/2013	2.95	270
Madison	SIUE	43.5	30.99	5/8/2012	35.85	10/24/2012*	≥4.86	≥169
McLean	Bloomington WL MW4UD	11.5	2.21	5/13/2012	6.58	8/26/2012	4.37	105
Tazewell	MTH-17N	152.0	34.00	1/12/2012	37.18	8/5/2012	3.18	206
Tazewell	MTH-17WT	20.2	10.12	6/12/2012	14.67	1/10/2013	4.55	212
Tazewell	SWS-3d	252.0	33.36	2/4/2012	43.89	8/6/2012	10.53	183
Vermilion	Hoopeston	146.0	22.40	5/24/2012†	29.01	8/8/2012	≥6.61	≥76
Will	Midewin USFS MW3	11.7	0.40	5/7/2012	9.40	10/27/2012	9.00	173

*Record ends on this date

†Records missing prior to this date

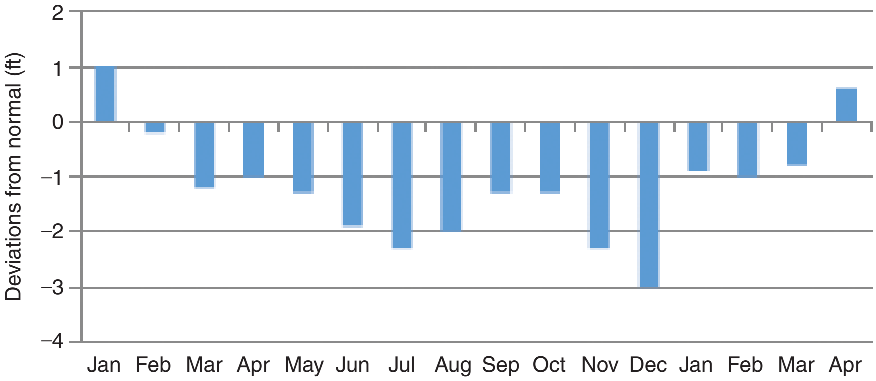


Figure 7.4 2012–2013 average groundwater deviations of water levels from normal for the 15-well WARM Network, January 2012 through April 2013

for the previous droughts and suggests that, without the occurrence of Hurricane Isaac (September 1–2, 2012), this drought was becoming a very serious drought with respect to groundwater levels. But the composite effect shown in Figure 7.9 illustrates that the 1988–1989 drought was the drought with the greatest overall effect on the state in regard to both the maximum average drawdown in the water table and the duration of low water table conditions.

Illinois Climate Network Shallow Groundwater Observation Wells

The water level information for the ICN wells has been grouped into four regional areas that divide Illinois based on the station location (Figure 4.1). Hydrographs for the ICN shallow wells within the west central region are shown in Figure 7.10. Groundwater levels in all wells declined starting around March 2012 and lasted into and beyond December. Dry conditions of the 2012 drought are reflected in all of the water level graphs for this network. The typical recharge season for shallow groundwater is in the fall and spring of each year; however, the drought of 2012 changed this pattern and noticeably pushed it into the early months of 2013. The water level response in the Kilbourne well was more gradual than for the other wells because it is finished in a sand deposit and thus behaves more like an aquifer than a typical water table well.

McHenry County Water levels in all of the monitoring wells in McHenry County declined during 2012 and, for many wells, into 2013. The minimum depth to water (maximum water table elevation) in 2012 occurred between

Table 7.5 WARM Shallow Groundwater Network Deviations of Water Levels from Normal (feet), January 2012 to April 2013

Well	County	Jan-12	Feb-12	Mar-12	Apr-12	May-12	Jun-12	Jul-12	Aug-12	Sep-12	Oct-12	Nov-12	Dec-12	Jan-13	Feb-13	Mar-13	Apr-13
Galena	Jo Daviess	1.41	1.21	1.29	0.48	0.02	−0.54	−0.81	−0.46	−0.65	−0.44	−0.59	−0.55	−0.54	−0.48	−0.31	0.81
Mt. Morris	Ogle	4.48	3.36	3.42	1.52	0.32	−0.89	−1.44	−2.39	−3.09	−3.67	−4.57	−5.45	−6.24	−5.61	−6.12	−3.39
Crystal Lake	McHenry	1.82	1.74	1.37	0.72	0.15	−0.74	−0.84	−0.81	−0.94	−1.14	−1.50	−1.74	−1.70	−1.29	−0.97	0.24
Fermi Lab	DuPage	2.38		−2.35	−2.98	−2.36	−2.20	−1.65	−1.97	−3.29	−3.94	−4.05	−3.79	1.86	−0.60	−1.65	2.07
Good Hope	McDonough	1.03	0.32		0.47	0.43	−0.33	−2.56	−3.64	−3.94	−3.02	−4.46	−4.87	−0.25	−2.25	0.67	1.23
Snicarte	Mason	−0.89	−1.06	−1.56	−2.17	−1.53	−4.28							−3.29	−4.57	−3.81	−2.84
Coffman	Pike	−2.95	−5.37	−7.53	−6.77	−5.65	−5.95	−5.72	−5.24	−5.08	−4.76	−6.43	−7.10	−4.15	−5.86	−3.13	1.04
Greenfield	Greene	−5.2	−5.83	−5.66	−2.74	−1.83	−2.46	−3.29	−2.68	−2.27	−2.76	−3.92	−5.91	−6.23	−5.60	−2.49	0.58
Janesville	Cumberland	1.49	−0.31	−0.74	−0.7	−0.73	−1.78	−2.36	−1.38	0.46	0.94	−0.31	−0.05	0.38	2.15	−0.29	1.50
St. Peter	Fayette	1.10	0.28	0.45	1.03	−0.42	−0.75	−1.43	0.26	2.64	2.57	0.71	0.85	0.82	0.82	0.86	0.97
SWS #2	St. Clair		2.26		2.51	0.57	0.28	−0.95	−0.93	−0.74	0.89	0.35	−0.21	1.79	2.13	2.10	3.35
Boyleston	Wayne	1.59	−0.27	−0.90	−0.39	−0.54	−0.43	−0.75	−1.17	1.75	0.30	−1.73	−3.53	1.37	0.68	0.61	0.59
Sparta	Randolph	5.10	2.02	−0.13	−1.18	−1.95	−2.16	−1.57	−0.56	3.82	2.00	0.57	−0.42	3.91	2.95	1.95	2.51
SE College	Saline	1.48		−2.02	−3.21	−3.59	−3.69	−3.25	−3.11	−2.96			−5.61	−3.03	0.11	−0.21	0.04
Bondville	Champaign	1.37	−0.82	−1.78	−2.18	−2.01	−2.57	−5.46	−4.41	−3.46	−4.08	−4.16	−2.91	1.80	1.80	0.32	0.14
Deviation From Normal		1.02	−0.19	−1.24	−1.04	−1.27	−1.90	−2.29	−2.04	−1.27	−1.32	−2.31	−2.95	−0.90	−1.04	−0.83	0.59

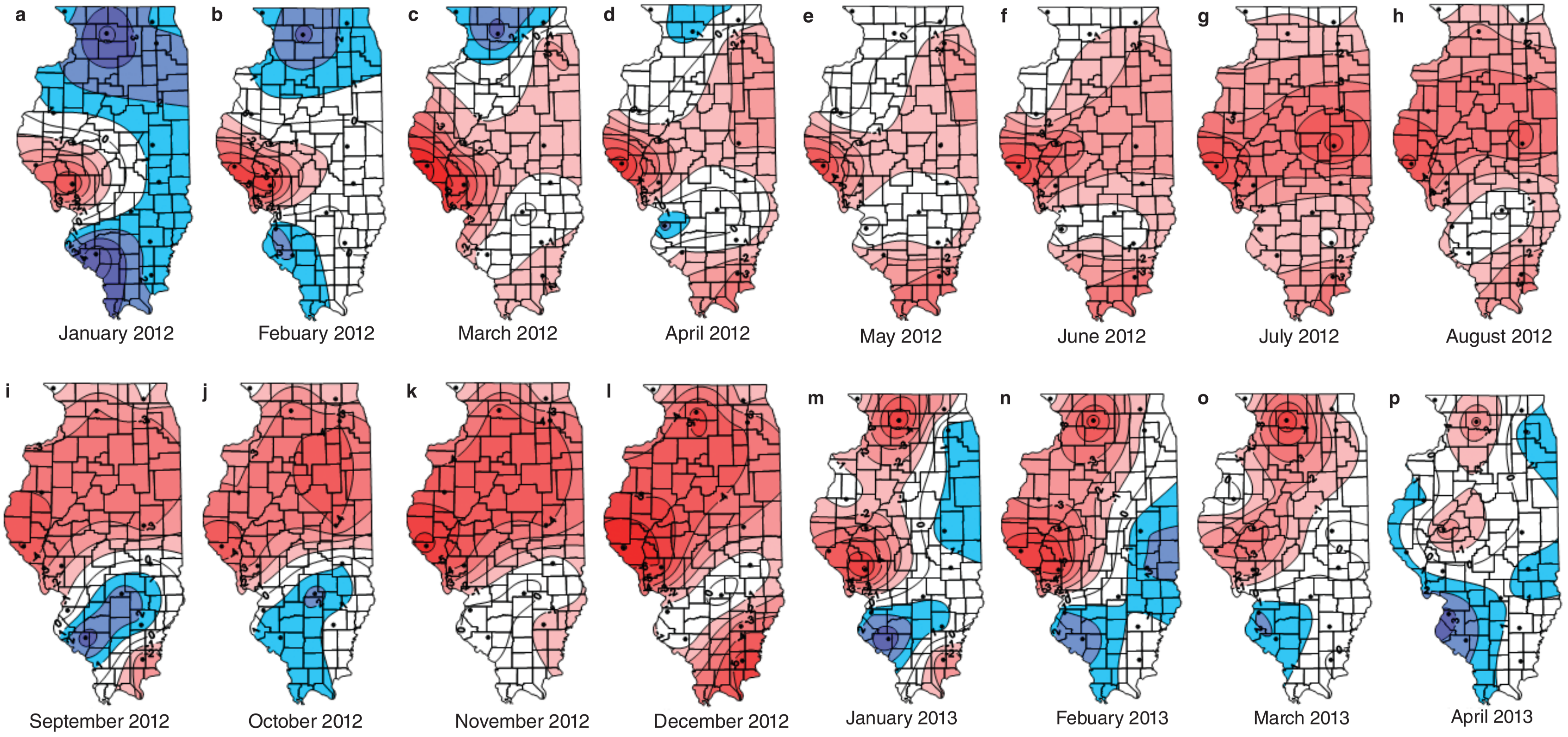


Figure 7. 5a-p Deviations from normal. Contours in feet. Blue indicates above-normal conditions, red indicates below-normal conditions.

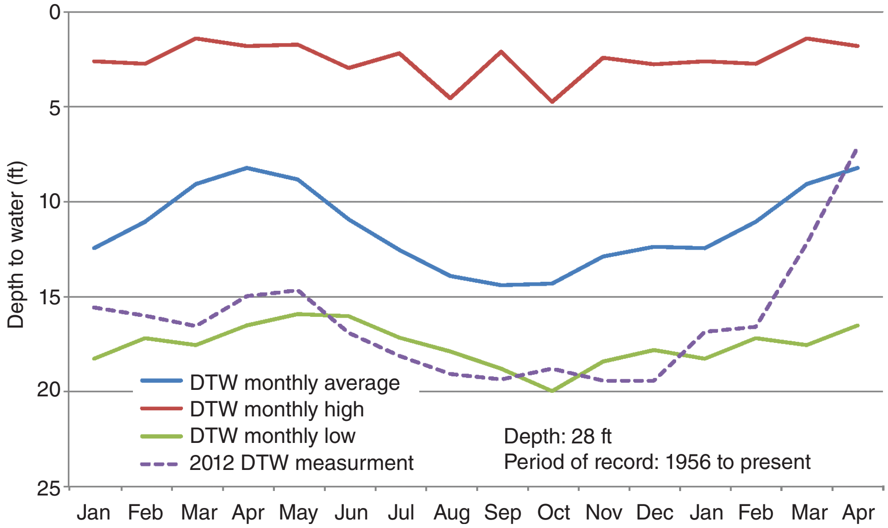


Figure 7.6 Water levels at Coffman observation well, January 2012 through April 2013

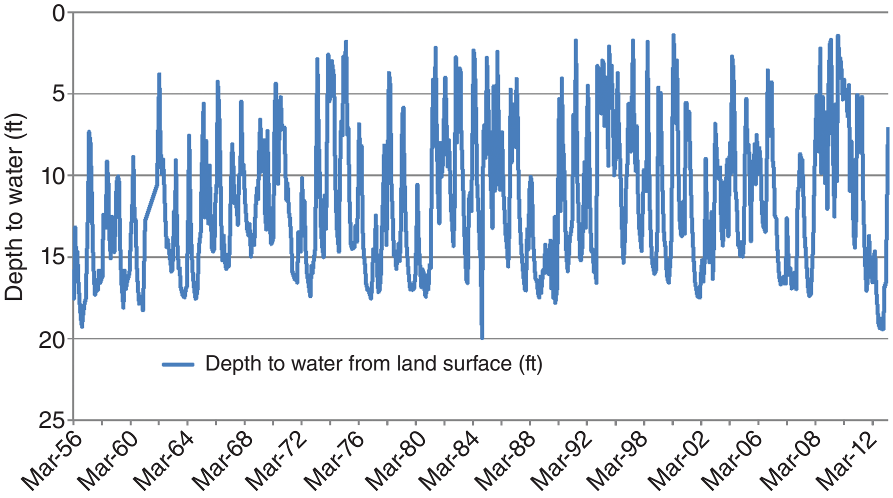


Figure 7.7 Depth to water at Coffman observation well, March 1956 to April 2013

mid-March and early May in all the wells but one (NW-6-45-9), where the minimum occurred in early June. The maximum depth to water, corresponding to the lowest water table, occurred between early July 2012 and early February 2013. The number of days between the minimum and maximum measurement varied from 63 to 315, with a median of 214 days. The difference between the minimum and maximum measurement at an individual well varied from 2.58 to 31.39 feet, with a median value of 5.85 feet. Information for each monitoring well in McHenry County is in Table 7.3.

The hydrograph for monitoring well 15-COR-S is shown in Figure 7.11 for the period of record at the well (2009–2014). The figure shows how much lower groundwater levels were in much of 2012 and the start of 2013 than in non-drought years.

Generally, wells where the maximum depth occurred in August or September 2012 identify as either water table wells or wells influenced by irrigation pumping. Wells with the greatest drop in groundwater levels during 2012 were 17-ALG-D and WAUC-02-12, which are close to municipal and commercial wells in Lake in the Hills, Crystal Lake, and Island Lake.

Other Monitoring Wells Water level information for other monitoring wells in the state with continuous measurements, including the depth and date of minimum water level observations, are included in Table 7.4. The minimum depth to water in 2012 occurred between late January (CHAM08-09A) and mid-June (MTH-17WT). The maximum depth to water occurred between August 2012 and January 2013. The number of days between the minimum and maximum measurement varied from 76 to 321, with a median of 198 days. The difference between the minimum and maximum measurement at an individual well varied from 2.41 to 36.90 feet. The two wells that had the greatest decrease in groundwater levels (Lee 92E and CHAM08-09A) also recovered the most rapidly; these wells were clearly under the influence of nearby irrigation pumping (Figure 7.12).

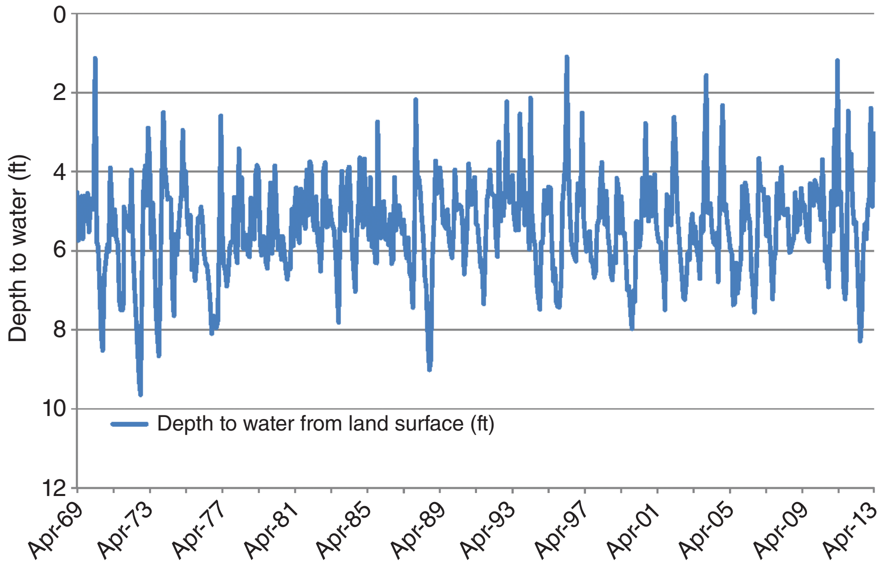


Figure 7.8 Depth to water at Janesville observation well, April 1969 to April 2013

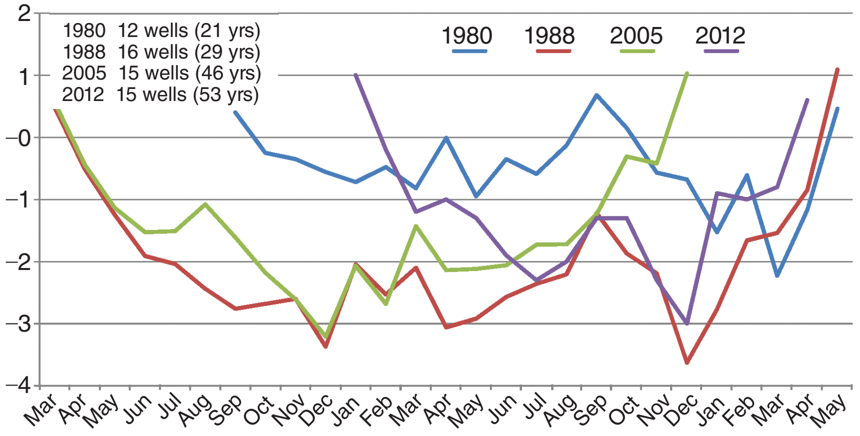


Figure 7.9 Deviations from normal for water levels for WARM wells for the following periods: Sept 1980–May 1982, March 1988–May 1990, March 2005–December 2006, and January 2012–April 2013. Average deviation for all WARM wells in the network for each specific drought.

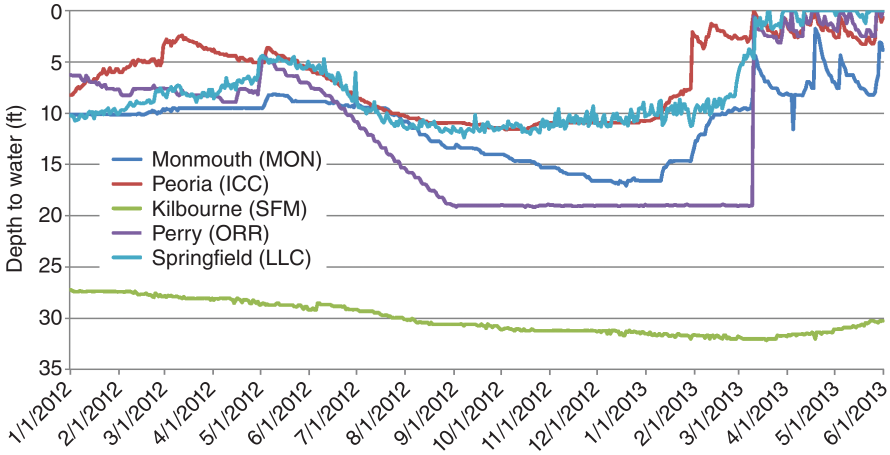


Figure 7.10 ICN Central West Group Observation Wells, January 2012 through June 2013. The flat line for Perry between September and March represents a period when the water table dropped below the sensor height.

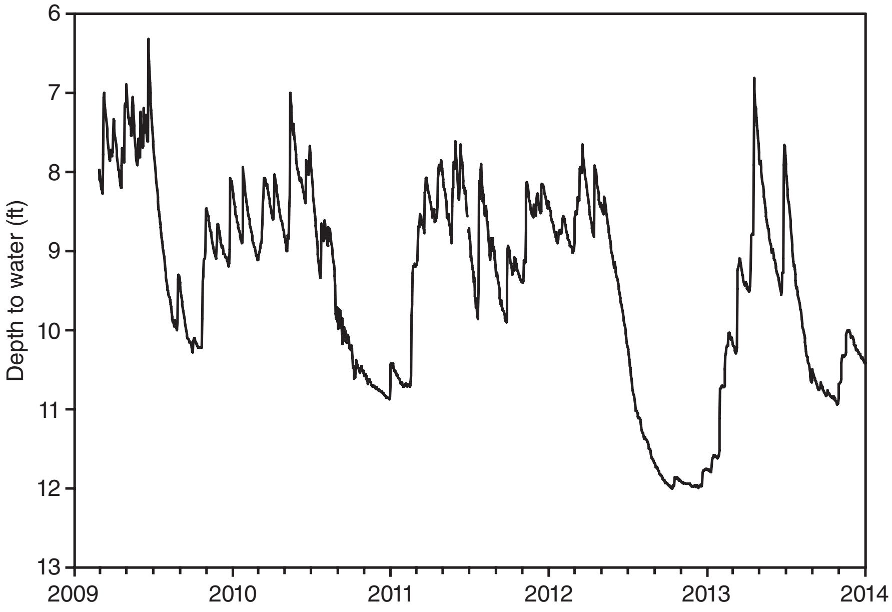


Figure 7.11 Hydrograph for period of record for McHenry County monitoring well 15-COR-S

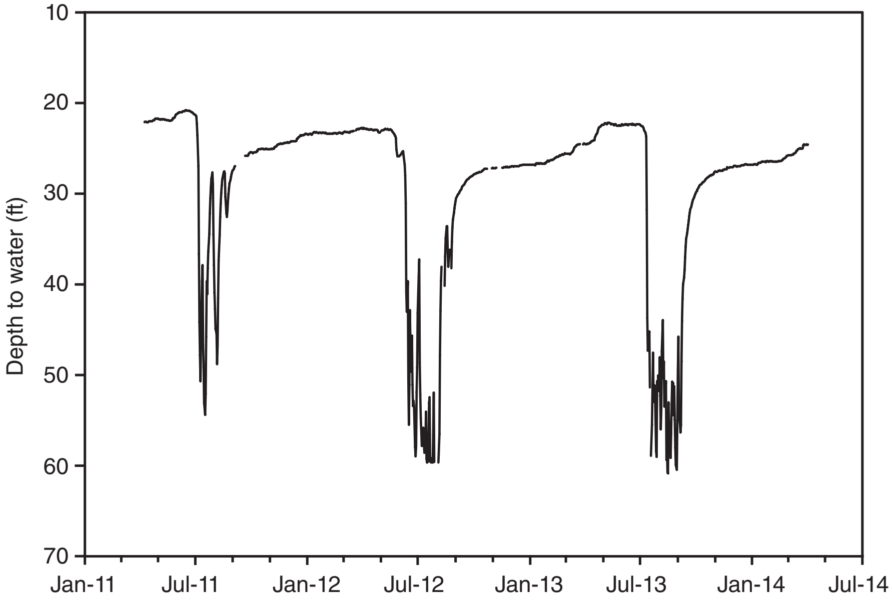


Figure 7.12 Hydrograph between 2011and 2014 for a monitoring well in Lee County showing the effects of irrigation pumping in the summer months. Between July 29 and August 3, 2012, the water level dropped below the transducer on five days, thus the maximum depth to water is unknown; the transducer was lowered in the well prior to 2013.

Chapter 8. Agriculture and Irrigation Impacts

Crop Damages

The 2012 drought in Illinois had the most impact on the agricultural sector. These impacts were the most significant since the 1988 drought, and the 2012 precipitation deficits were in many ways similar to the dust bowl drought years of 1934 and 1936. Statewide, corn yields were reduced to an average of 105 bushels per acre (National Agricultural Statistics Service), which is 66 percent of the yield in 2011 and roughly 60 percent of the trend average. The National Agricultural Statistics Service (NASS) calculated the projected trend average using a simple linear regression analysis of yields from previous years. Soybean yields were reduced to 43 bushels per acre, which is 89 percent of the yield in 2011. The number of corn acres cut for silage doubled as it became evident that particular fields would not produce a measurable yield. Hay production was reduced as well. The lower yields and higher hay prices increased costs for livestock producers.

As a result of 2012 crop damages, Illinois farmers received roughly $3.5 billion in crop insurance payouts (September 2013 Report from the U.S. Department of Agriculture [USDA] Risk Management Agency), the greatest portion ($3.2 billion) of which was associated with damages to the corn crop. Farmers in adjacent states of Iowa and Indiana received $2 billion and $1.5 billion, respectively, and the nation's total crop insurance payout for 2012 was $17.4 billion.

Corn

Six states experienced corn crop losses in excess of 30 percent below average based on USDA crop statistics: Illinois, Indiana, Kansas, Kentucky, Missouri, and Tennessee (http://farmdocdaily.illinois.edu/2013/02/locating-the-2012-drought.html). Based strictly on a statewide percentage loss, Kentucky experienced the greatest corn crop damage with an overall 53 percent loss compared to its computed trend average. However, Kentucky has comparatively few acres planted in corn–less than 10 percent of the respective acreage in Illinois. When total production is considered, the loss of the 2012 corn crop in Illinois exceeded that from the other five states combined. Southern Illinois appears to have been the epicenter of the 2012 drought in terms of crop damage.

Figure 8.1 shows the 2012 average corn yields for Illinois by county, illustrating the considerable impact to the crop in southern and south-central Illinois. The average corn yield in the southwest Illinois crop reporting district, for example, was only 43 bushels per acre, equivalent to a 70 percent loss when compared to the trend average of more than 140 bushels per acre. The northwest Illinois crop reporting district had the highest average yields in the state, but the district's average yield of 140 bushels per acre was still roughly 15 percent lower than its trend average.

Figure 8.2 shows the average annual corn yields in Illinois since the late 1960s (National Agricultural Statistics Service [NASS]). Average yields in the state have increased considerably over the years. As such, the severity of a drought to crop yields is normally evaluated by comparing yields to the average trend line. Using this evaluation, the drought years of 1988 and 2012 are considered to have the greatest negative effects on corn yields in the past 50 years, with reductions in yields of 43 and 40 percent, respectively.

The hot, dry summer caused higher-than-normal levels of aflatoxin in the corn crop. Aflatoxins are a group of chemicals produced by a certain family of mold fungi that thrive in hot, dry conditions and can be harmful or fatal to livestock. In addition, they are considered carcinogenic to both animals and humans. As a result, the Illinois Department of Agriculture required extensive oversight in the handling and blending of corn containing aflatoxin to dilute concentrations to acceptable levels.

Soybeans

Into August 2012 it appeared that soybean yields would also be heavily damaged by the drought. However, the higher rainfall amounts that occurred by early September allowed a significant recovery of the crop, such that the statewide average yield of 43 bushels per acre was only about 10 percent below the NASS expected trend average.

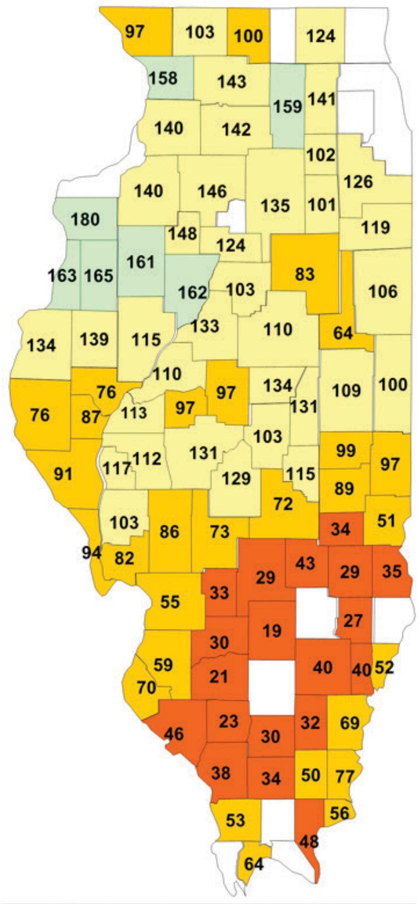


Figure 8.1 Average 2012 corn yield (bushels per acre) for Illinois counties (taken from the FarmDocDaily Newsletter, Dept. of Agricultural and Consumer Economics, University of Illinois)

The difference in recovery from dry conditions between the soybean and corn crops is related to each crop's growth pattern. The corn crop follows a relatively strict timeline, and lack of moisture at crucial times can heavily damage the crop, whereas soybeans have a greater ability to adjust their growing schedule and fill out if moisture

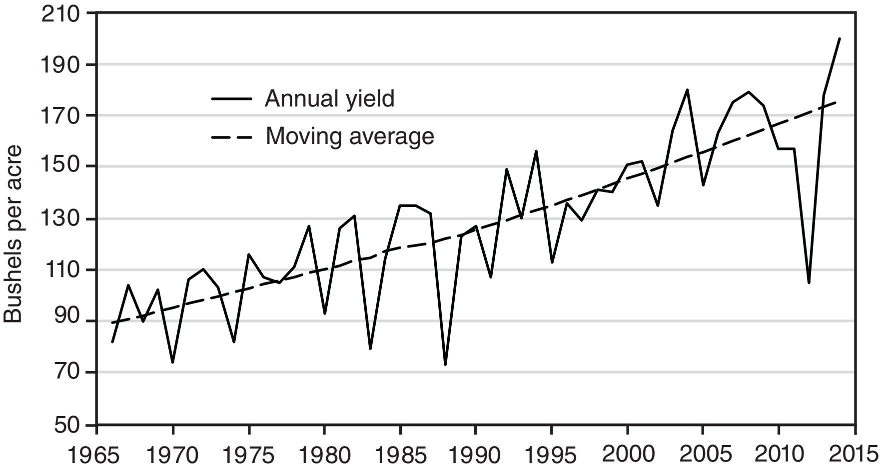


Figure 8.2 Illinois average corn yields, 1966-2014

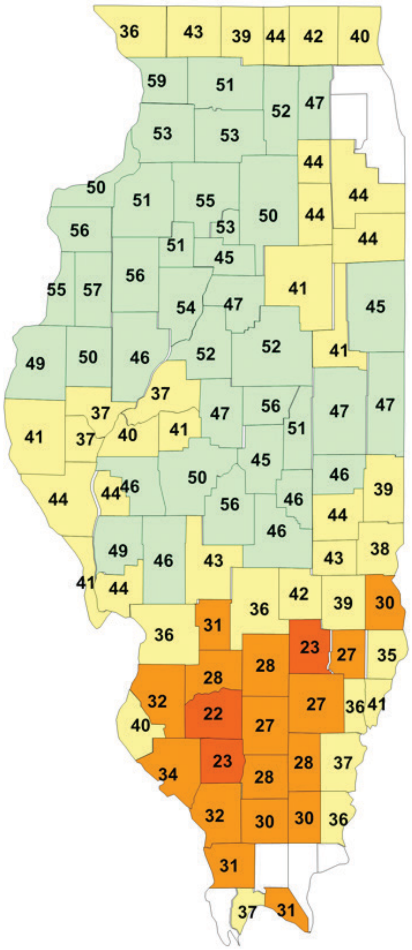


Figure 8.3 Average 2012 soybean yields (bushels per acre) for Illinois counties (taken from the FarmDocDaily Newsletter, Dept. of Agricultural and Consumer Economics, University of Illinois)

becomes available at a later date. In contrast to the 2012 drought, the 1988 drought experienced continued dry conditions from early summer through September and early October. Thus, the 1988 soybean crop had no chance to recover and remained damaged, with an average yield in Illinois (27 bushels per acre) that was more than 30 percent below the expected average yield for that year.

Figure 8.3 shows the 2012 average soybean yields for Illinois by county. Many counties in southern and south-central Illinois had average yields below 30 bushels per acre (and a few had less than 25 bushels per acre), roughly associated with a 40 percent reduction from the average trend. In contrast, however, much of the remainder of Illinois had soybean yields that were similar to their expected averages, with a number of counties having yields in excess of 50 bushels per acre.

Other Agricultural Impacts

Livestock

The increase in livestock feed prices, coupled with diminished pasture production and hay shortages, created hardships for hog and cattle producers in Illinois. Many operators were forced to send breeding animals to slaughter to reduce herd sizes. As a result, the subsequent increase in meat supply caused livestock prices to drop. Unlike corn and soybean producers, livestock producers typically do not have access to insurance to protect against financial losses caused by drought.

Transportation of Agriculture Commodities

In Illinois, agriculture relies heavily on the Mississippi and Illinois Rivers as a source of reliable and economic movement of corn, soybeans, fertilizer, and other agricultural commodities. The low river stages on the Mississippi River below St. Louis in the fall and winter months were of special concern, and are addressed in Chapter 11: *Navigation, Environmental, and Water Quality Impacts*.

Fertilizer Transport

The reduced uptake of nutrients by crops, especially nitrogen, is one of the secondary impacts of the 2012 drought. Poor crop growth, and in some cases total crop failure, resulted in the reduced uptake of nutrients from soils. The primary concern was that these extra nitrates would make it into the rivers and streams the following spring. On the other hand, more carryover of nitrates through the winter and following spring could potentially reduce the need for applications in the following growing season. Unfortunately, field measurements in spring 2013 indicated that although the drought-related residual nitrates had stayed in the field, they had moved deeper into the soil, becoming unavailable for crops. As those nitrates moved out of the soil and into field tiles, nitrate levels on the Illinois River rose in March 2013 and remained high through June.

Rural Wells

Several agriculture-related water issues arose during the 2012 drought. One of the earliest impacts at the farm level was the drawdown of shallow groundwater wells (typically less than 50 feet below the land surface). As a result, many farmers resorted to hauling water from nearby municipalities at great expense. As the drought progressed, many municipalities restricted bulk water sales over concerns of their own water supplies. There were several complaints of deeper high-capacity wells, associated with irrigation operations, pumping hard enough to drop neighboring farms' well levels.

Expansion of Irrigation

Agricultural water shortages and diminished crop yields experienced during recent droughts such as in 2005 and 2012 have become a driving force in the continuing increase in the number of irrigators in Illinois, typically leading to the development of new irrigation sites in the years following a drought. Additional driving factors related to the increase in irrigated acres are 1) commodity prices, mainly for corn, making irrigation more cost-effective when prices are higher; and 2) requirements by seed corn companies that there be guaranteed yields in seed corn contracts. The combination of the drought and high commodity prices in 2012 triggered a significant expansion of irrigated acres across Illinois that continued in 2013. The trend in expanding irrigation acreage was at least temporarily halted by 2016 as a result of a drop in corn prices.

Historically, Illinois has not been considered a major irrigation state because of its typically abundant rainfall (36–49 in/yr) and organic-rich soils which hold moisture well. However, there are certain regions of the state where irrigation has been historically present and concentrated, most notably in the glacial and alluvial river valleys along the major rivers in Illinois (Mississippi, Illinois, Wabash, Ohio, Kankakee, and Rock Rivers). These regions have sandy soils that do not hold moisture well and thus require supplemental irrigation for adequate crop yields. In recent years, however, there has been an increase in irrigated acres for other areas in Illinois, including areas with more organic-rich soils where one would not expect much irrigation.

A survey of center pivot irrigation completed by the ISWS in 2012 determined that there are approximately 540,000 irrigated acres in Illinois and approximately 6,000 center pivot irrigation systems. The distribution of center pivot irrigation by county is shown in Figure 8.4. Data for the 10 counties with the largest numbers of acres under center pivot irrigation in 2012 are shown in Table 8.1. As noted earlier, most of the heavily irrigated areas are those along river valleys where sandy soils are common and groundwater is the predominant source of water. Other forms of irrigation, such as ditch, subsurface, and lateral line irrigation, do exist in Illinois, but are limited, and data on acreages are not readily available.

Impacts of Irrigation on Water Resources

During abnormally dry years, there is always a substantial increase in the frequency and amount of water applied to crops at existing irrigation facilities. In some cases the increased use of irrigation water during a drought can overuse and negatively affect the availability of the water resource from which the pumping occurs. The effect of irrigation on water supply availability is a common drought concern, particularly with groundwater sources. Ad hoc irrigation from surface sources, such as a farmer temporarily pumping from a hose or pipe dropped into a nearby river, also occurs during a drought and can cause noticeable reductions in low streams, but is rarely documented, and thus in many situations can only be inferred.

During the drought of 2012, irrigation pumping appeared to be the cause of interrupted service to private well owners and other groundwater users in several counties, including reports from Champaign, Iroquois, Lee, and Whiteside Counties. An extensive cone of depression associated with irrigation pumping was reported near the junction of Lee, Whiteside, and Bureau Counties, which may also have affected low flows in the nearby Green River. A case study on such impacts in Champaign and McLean Counties is presented in this chapter.

Among the few regulations of irrigation in Illinois is the Water Use Act of 1983 (amended; Public Act 096-0222). Controls on irrigation are limited to four counties in east-central Illinois, those "through which the Iroquois River flows" and those "with a population in excess of 100,000 through which the Mackinaw River flows." The affected counties are Iroquois, Kankakee, McLean, and Tazewell. If a well owner in these counties has an interruption in service due to pumping by a high-capacity well (>100,000 gallons per day), they may file a complaint with the local Soil and Water Conservation District. The Soil and Water Conservation District, with the assistance of the ISWS and Illinois State Geological Survey, are authorized to determine impacts of withdrawals on other water users. After such an investigation, the Soil and Water Conservation District "may recommend to the [Illinois] Department of Agriculture that the Department restrict

Table 8.1 Ten Highest Ranked Counties Irrigated by Center Pivot in 2012

County	Acres Irrigated by Center Pivot	County's Crop Acreage (%)
Mason	135,684	49.60%
Whiteside	60,122	14.80%
Tazewell	42,250	12.80%
Lee	26,476	6.70%
Cass	25,852	14.90%
White	22,469	7.60%
Lawrence	20,100	10.40%
Gallatin	19,381	10.40%
Henderson	17,569	10.30%
Kankakee	13,842	3.60%

the quantity of water that a person may extract from any high-capacity well within the District's boundaries," until conditions return to normal. It should be noted that the legislation refers to any high-capacity well, not only to irrigation wells, although in practice, irrigation wells are the most likely source of conflicts in these regions. As far as we know, the Department of Agriculture has never used their authority to restrict any high-capacity wells in Illinois.

Case Study: Irrigation in Champaign and McLean Counties Although Champaign and McLean Counties have organic-rich soils and are not among the top irrigation counties in Illinois, they have seen a significant increase in irrigation over the past 10 years. This increase is largely attributed to more irrigation requirements by seed corn companies that want a guaranteed crop in a dry year. Irrigation has also been observed on some soybean fields.

In northern Champaign County, over 50 irrigation pivots were identified in 2012 in the Rantoul area, many of which had been constructed since 2007. According to the well records, some of these wells were test pumped at rates of between 1.4 and 3.6 million gallons per day (mgd). Assuming the irrigation systems are pumping 1.4 mgd, the collective pumping rate for all systems in Champaign County is on the order of 70 mgd, or twice the rate of the public and industrial users in the county. The irrigation pumping differs, however, in that it is not operated on a continuous basis (24/7) and occurs only seasonally. Thus, the overall annual volume of irrigation pumping is comparatively less, with drawdown recovery occurring in the off-season. Although the irrigation growth in McLean County is not as pronounced, a cluster has developed in the southwestern part of the county near the village of McLean.

Most of the irrigation water in Champaign and McLean Counties comes from wells that draw from the Mahomet Aquifer. Sharp drops in summer water levels are shown in the hydrographs of observation wells in Champaign County (Figure 8.5). The irrigation systems near these observation wells were heavily used during the dry periods in

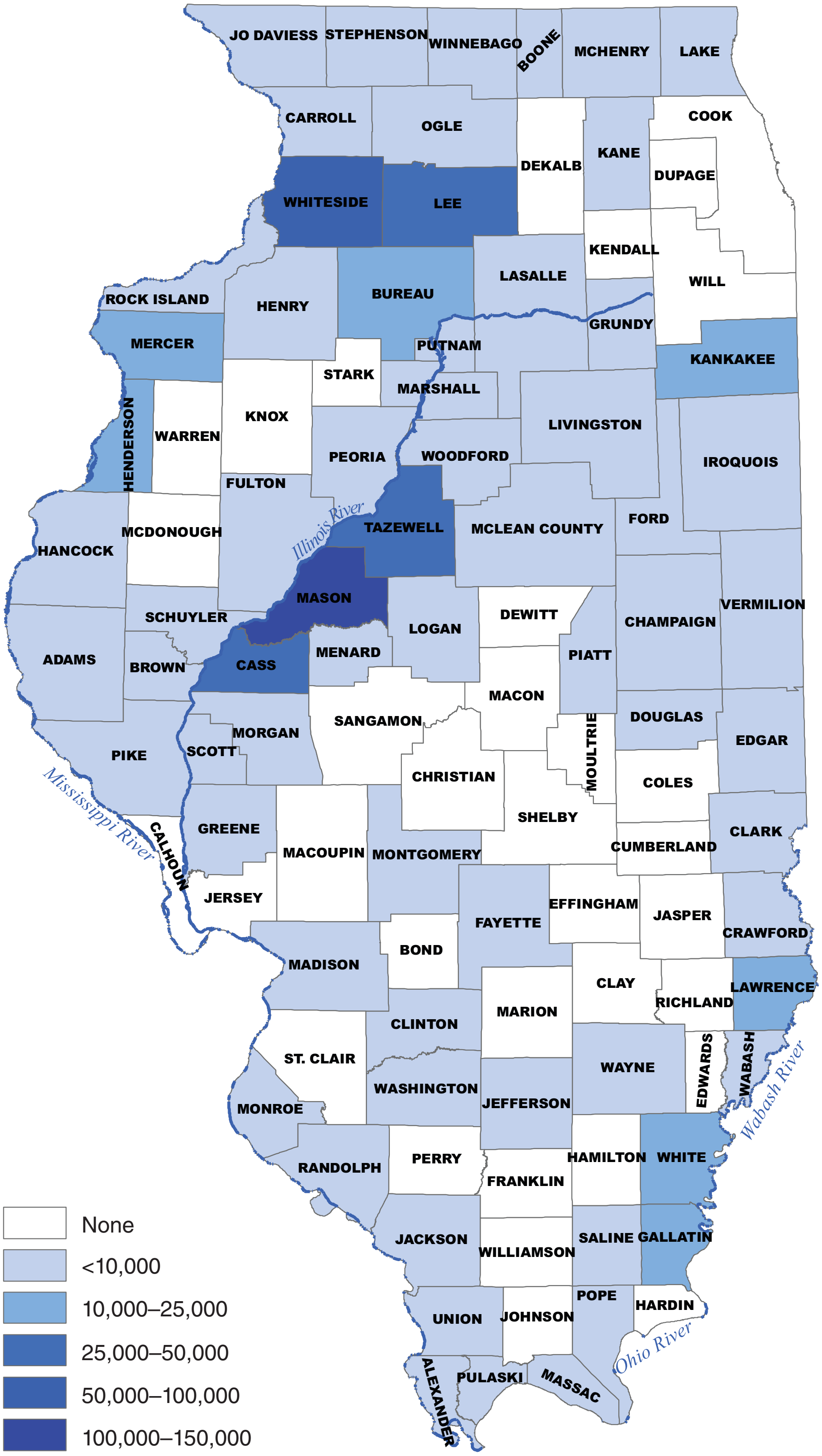


Figure 8.4 Amount of center pivot irrigated acres in Illinois in 2012 per county

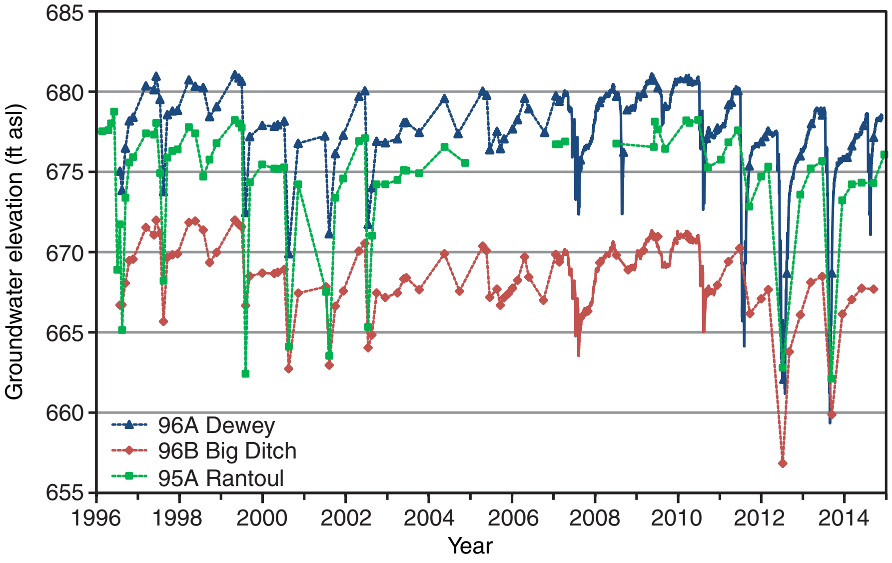


Figure 8.5 Hydrographs from wells CHM-95A, CHM-96A, and CHM-96B

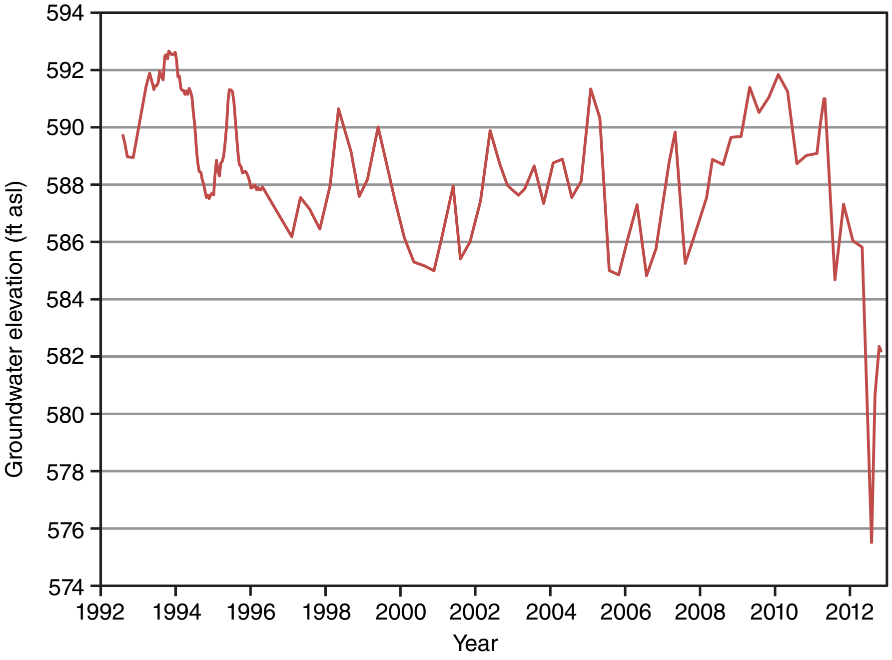


Figure 8.6 Hydrograph between 1992 and 2013 for monitoring well SWS-3d in McLean County

the summers of 2011 and 2013, but not during the relatively wet summers of 2009, 2010, and 2014. In 2012, the sharp water level decreases and increases in well CHM-96A at Dewey indicate that the nearby pumping wells were started between May 25 and June 25 and were shut off between August 1 and August 24. A sharp drop in water levels was also observed around the Village of McLean where several irrigation systems have been installed since 2009. In the quarterly measurements from a nearby monitoring well (Figure 8.6), the summer of 2012 was the first time a significant amount of drawdown had been observed in this portion of the aquifer.

Figures 8.7 and 8.8 show changes in drawdown in the Mahomet Aquifer during two time periods in the 2012 drought 1) from March through July; and 2) from late July through September. The impact of the 2012 drought on water levels in the Mahomet Aquifer from March through July was largely a response to changes in demand from irrigation in the central and eastern portion of the aquifer.

The summer drawdown was widespread throughout the northern half of Champaign County and into Ford and Vermilion Counties with the greatest drawdowns of more than 12 feet occurring immediately north and west of Rantoul. The summer drawdown in southwestern McLean County was less widespread but also had a maximum amount exceeding 12 feet. The irrigation systems were not used after the rainfall associated with Hurricane Isaac (which provided roughly 3 inches of rainfall to this portion of Illinois), so a sharp water level recovery was observed in the September 2012 measurements (Figure 8.8).

Other Regional Impacts to the Mahomet Aquifer In the heavily irrigated Imperial Valley region in Mason and Tazewell Counties, water levels did not drop by more than 4 feet during the growing season. The Mahomet Aquifer in this region is near the surface and is unconfined. Whereas drawdown in confined conditions is related to the reduction of pressure in a fully saturated aquifer, drawdown in unconfined aquifers is related to active dewatering and a drop in the water table. For the same volume of withdrawal, drawdown is generally much less in unconfined aquifers. Furthermore, when rain does occur, there is a much more immediate recharge with a near-surface unconfined aquifer.

The Imperial Valley Water Authority, which covers all of Mason County and about six townships in Tazewell County, has been estimating their irrigation pumping for the past 10 years using estimation methods that rely on electric power consumption. Figure 8.9 shows the amount of irrigation in the Imperial Valley region between 2004 and 2013. Almost 100 billion gallons of groundwater were estimated to have been used for irrigation during 2012 because of the

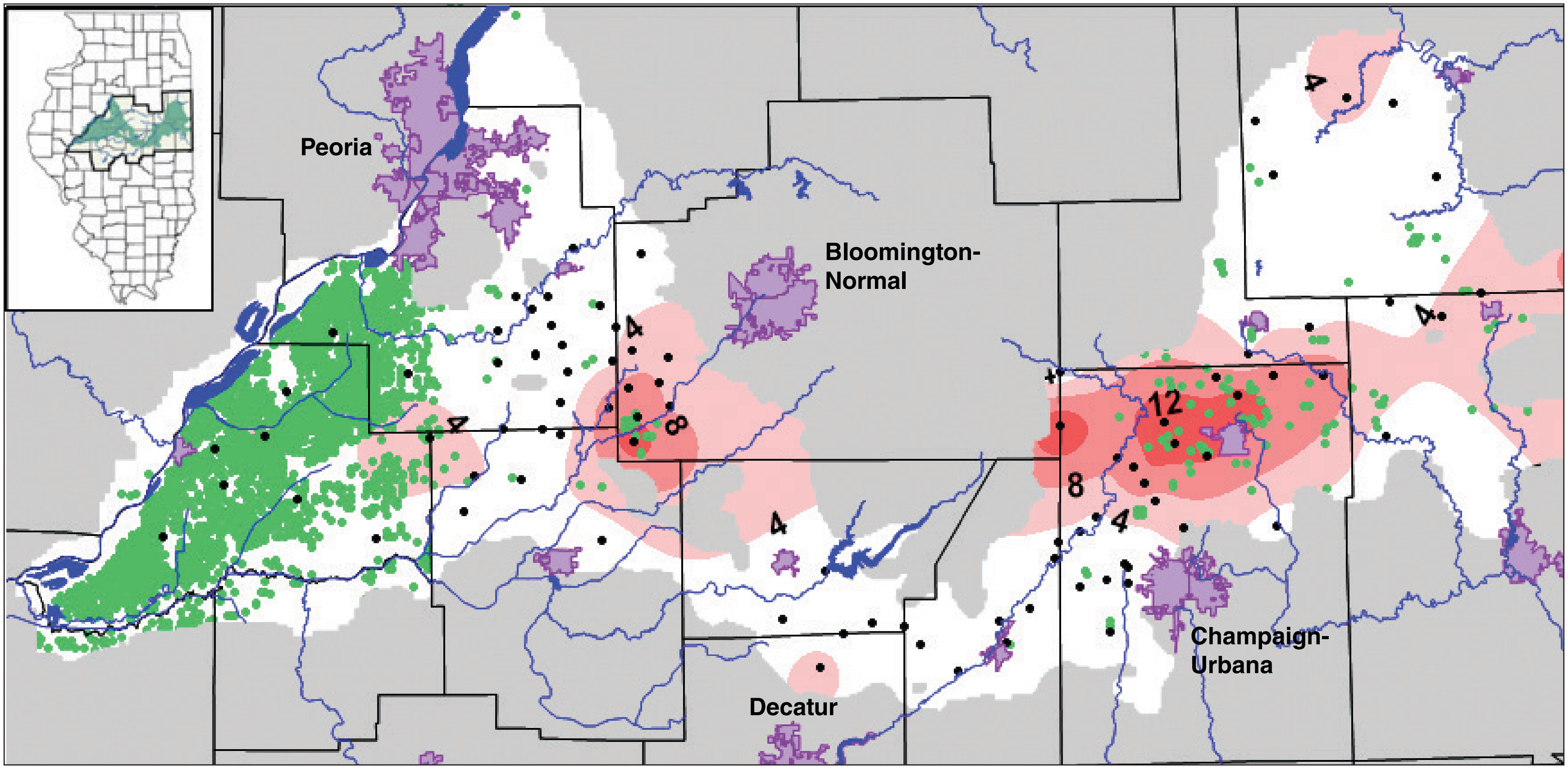


Figure 8.7 Drawdown (ft) in groundwater levels in the Mahomet Aquifer from March to July 2012. Observation wells are represente d with black dots and irrigation wells are represented with green dots.

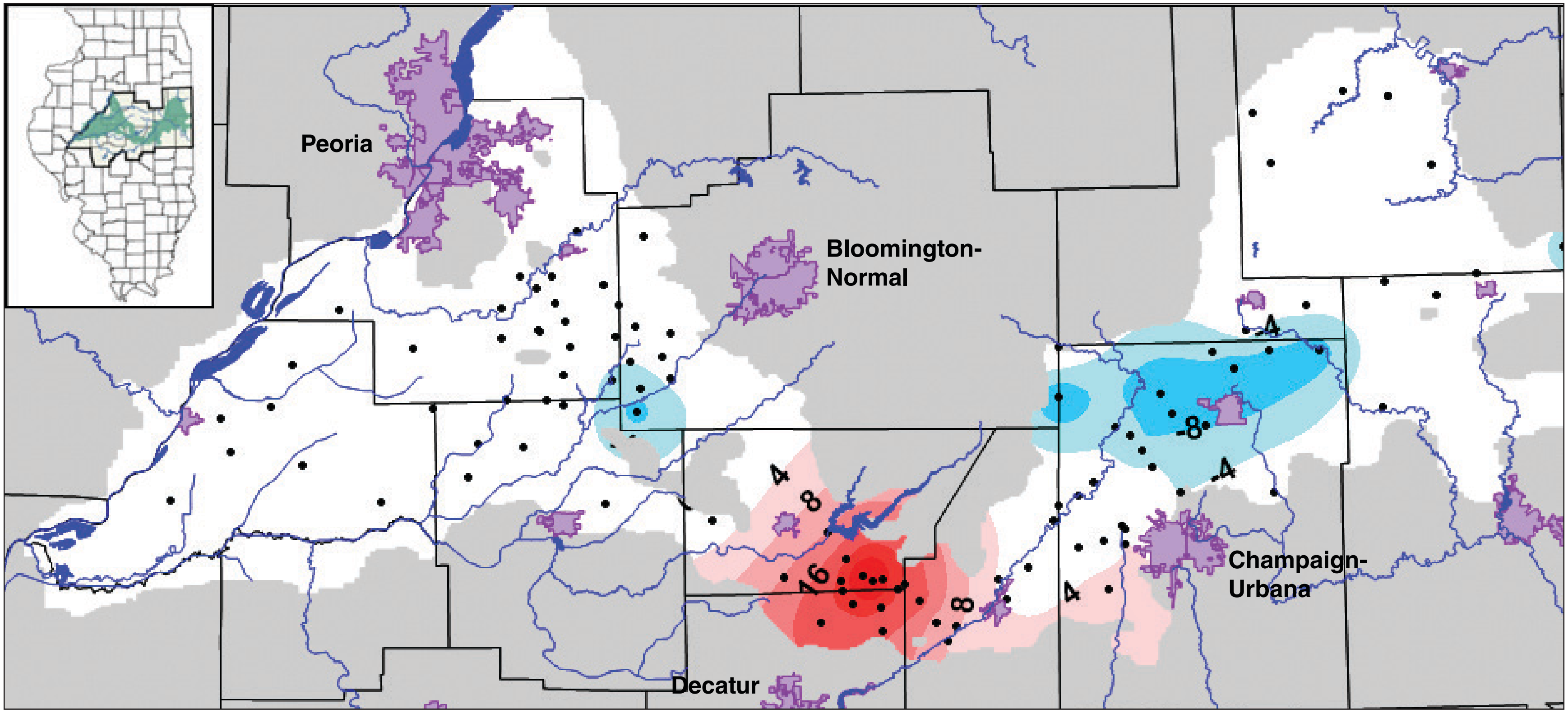


Figure 8.8 Drawdown (ft) in groundwater levels in the Mahomet Aquifer from July to September 2012. Observation wells are represented with black dots. Blue regions are where water levels have recovered.

drought conditions, almost twice the median amount pumped during this period (51 billion gallons).

From late July through September, additional drawdown in the Mahomet Aquifer was mostly in response to the operation of the Decatur emergency wellfield (Figure 8.8). The influence of this drawdown to the water availability to Decatur is addressed in the upcoming Chapter 10: *Water Supply Case Study: The City of Decatur*. Although Champaign-Urbana (Illinois American Water Company) is a large user of the Mahomet Aquifer water, their use is year-round, and groundwater levels in a portion of the aquifer remained relatively static; little additional drawdown occurred during the drought.

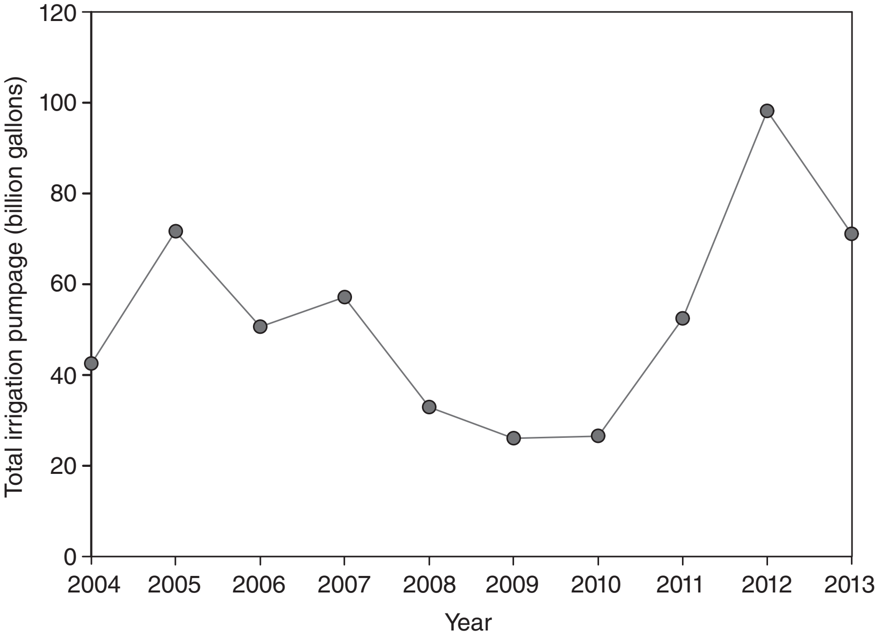


Figure 8.9 Total annual irrigation pumping in the Imperial Valley of Illinois between 2004 and 2013

Chapter 9. Water Supply and Water Use Impacts

Community and Domestic Water Supplies

Community Water Use and Conservation

Table 9.1 lists the monthly amount of water use in 2012 for 22 selected Illinois communities. As with all recent drought events, water use was elevated for most of the communities during the early months of the drought. Water use for both June and July 2012 show this pattern. Most of the increases are associated with outdoor water uses, such as lawn watering. Rates were particularly high in July, even after some communities had enacted voluntary conservation measures because of the high temperatures and low precipitation during that month. In September, much of Illinois experienced substantial recovery in soil moisture as a result of the passage of Hurricane Isaac, thus eliminating the need for lawn watering for most locations in the state. As a result, water use through the remainder of the year dropped to base levels typically experienced during cool seasons.

According to available Illinois Environmental Protection Agency (IEPA) records, at least 11 Illinois community surface water systems (Bloomington, Carlinville, Carthage, Decatur, Gillespie, Hillsboro, Jacksonville, La Harpe, Lake of Egypt Water District, Mt. Olive, and Springfield) enacted either mandatory or voluntary conservation measures during the 2012 drought because of low reservoir levels. The earliest voluntary conservation measures of the year were enacted in early July by Springfield and Hillsboro, with most other communities following suit in mid- to late July. Mandatory conservation was later enacted by roughly half of these communities, most commonly in late July or August. Most of the community conservation measures focused on the restriction of outdoor water uses, and thus were most effective during the summer. As part of the conservation effort, some communities also suspended bulk water sales, in many cases turning away rural residents situated outside of a community's service area who were seeking water because of dwindling well supplies.

Most affected large communities have existing drought action plans that identify triggers (such as specified low reservoir levels) for enacting conservation measures. For example, Decatur initiated voluntary measures on July 17, shortly after Lake Decatur had fallen to an elevation of 613.0 feet. Because their lake level was dropping quickly, only

Table 9.1 Monthly Water Use in 2012 for Selected Illinois Community Systems (Monthly total expressed as an average daily rate in million gallons per day)

Community	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
Altamont	0.22	0.20	0.20	0.22	0.25	0.29	0.27	0.25	0.22	0.21	0.22	0.21
Aurora	15.8	15.2	15.1	15.3	17.9	22.3	23.3	20.0	18.1	15.9	14.3	14.8
Batavia	2.7	2.6	2.5	2.7	3.3	4.7	4.6	3.7	2.8	2.8	2.6	2.7
Carlinville	0.85	1.10	1.05	1.11	1.15	1.02	1.16	0.96	0.85	0.83	0.79	0.76
Centralia	3.4	3.3	3.4	3.6	3.8	4.3	4.7	4.0	3.6	3.5	3.4	3.5
Champaign	18.2	18.6	18.7	19.5	22.2	24.3	28.2	23.6	21.1	19.6	18.2	17.9
Danville	7.2	7.1	7.1	6.9	8.0	8.4	9.2	8.3	7.5	7.2	6.8	7.0
Decatur*	34.7	33.3	33.9	35.4	38.0	41.5	42.4	35.5	32.7	32.0	33.5	33.0
Highland	1.0	1.0	1.0	1.0	1.3	1.5	1.9	1.5	1.3	1.3	1.2	1.2
Hillsboro	0.88	0.88	0.91	0.92	1.05	1.24	1.34	1.21	1.10	0.97	0.96	0.85
Kinkaid-Reeds	1.9	1.9	1.8	1.9	2.3	2.4	2.5	2.1	2.0	1.8	1.9	1.8
Marquette Heights	0.16	0.16	0.17	0.17	0.20	0.20	0.22	0.18	0.17	0.17	0.16	0.17
Mattoon	2.1	2.1	2.2	2.1	2.3	2.4	2.7	2.3	2.1	2.0	2.0	2.0
Mt. Olive	0.19	0.20	0.19	0.18	0.24	0.24	0.26	0.24	0.22	0.19	0.18	0.19
Normal	3.5	3.8	3.6	4.0	4.6	4.8	5.4	4.5	4.3	4.2	3.7	3.4
Pontiac	1.7	1.6	1.6	1.7	1.9	2.1	2.1	1.9	1.8	1.7	1.6	1.6
Salem	0.9	0.9	0.9	0.9	1.0	1.2	1.3	1.1	1.0	1.0	0.9	0.9
Springfield	19.7	19.8	19.9	20.8	25.2	29.2	36.3	29.5	23.1	18.8	17.7	18.6
Sterling	1.5	1.5	1.5	1.5	1.6	1.7	1.8	1.6	1.6	1.5	1.5	1.4
Streator	1.7	1.7	1.7	1.8	2.0	2.1	2.4	2.1	1.9	1.9	1.9	2.0
Taylorville	2.0	2.1	2.0	2.0	2.1	2.2	2.4	2.2	2.1	2.1	1.9	1.9
Tuscola	0.32	0.32	0.32	0.33	0.40	0.41	0.49	0.42	0.38	0.37	0.39	0.37

*Includes self-supplied industrial use withdrawn from Lake Decatur.

one week later Decatur enacted mandatory measures in anticipation of the lake falling below an elevation of 612.0 feet. In a similar fashion, Bloomington initiated voluntary measures in mid-August after the combined drawdown of their two reservoirs (Lake Bloomington and Evergreen Lake) exceeded 8 feet. On the other hand, Springfield's conservation responses were enacted well in advance of the trigger levels identified in that city's drought management schedule (with mandatory conservation enacted on August 10), and instead appeared to be associated with a heightened public awareness of the rapidly developing drought conditions in central Illinois.

An examination of water use rates in Table 9.1 shows a reduction in use for all communities between July and August 2012. Some of this reduction can be attributed to conservation measures for those communities that were restricting water use. However, it is also expected that a sizeable amount of the reduction was related to weather conditions. Late June and July were both dry and very hot with average temperatures 8 to 10 degrees F warmer than in August, and thus higher water use rates would be expected. For example, Decatur had 10 days in June and July when the daily water use exceeded 45 million gallons per day (mgd), with a maximum daily use of 47.5 mgd on June 28. On the other hand, Springfield set its record high daily water use of 40.3 mgd on July 26. It is also noted that many of these days of maximum water use occurred after voluntary conservation measures had been enacted by their respective cities, illustrating the strong relationship between water use and the weather, but also bringing into question the overall effectiveness of voluntary measures (as opposed to mandatory measures).

A number of suburbs in the metropolitan Chicago area and outlying communities that use Lake Michigan or groundwater supplies also were enforcing water restrictions, typically in the form of odd-even lawn watering schedules, so that substantial increases in summer water use rates did not 1) surpass the ability of each water system to treat and distribute water; or 2) cause the community to exceed the amount of water allocated to it by Illinois Department of Natural Resources (IDNR) as part of the Lake Michigan diversion process. The Northwest Water Planning Association (NWPA) region, representing most of the five-county region (DeKalb, Kane, Kendall, Lake, and McHenry Counties) to the north and west of Chicago, has developed a model ordinance for outdoor water use restrictions for communities. Some of the communities in the NWPA region and others in the Chicago-Lake Michigan service region have been using such ordinances even in non-drought years, and report generally favorable responses. In fact, several community water suppliers in the NWPA region reported that they did not have a significant increase in water demand during summer 2012, unlike during previous droughts.

Concerns with Adequacy of Supply

Most community water supplies in Illinois have adequate reserves to meet the demands of users during a drought. The public water needs for most of the Chicago metropolitan area, for example, are provided by water taken from Lake Michigan. Although the total amount of water withdrawn from the lake is managed by the State and limited by Supreme Court decree, the availability of that water is essentially unaffected by drought conditions. Much of the remaining northern part of Illinois is supplied by deep groundwater resources; and, although certain locations may have concerns with either infrastructure capacity or sustainability, the available sources are greatly buffered from the impacts of drought. Communities that use a third source of supply, large rivers, usually withdraw only a small portion of the river's minimum flow and thus are able to maintain a reliable supply for users during a drought.

The primary community concerns regarding supply adequacy during a drought involve those systems associated with surface water reservoirs and shallow groundwater sources. About a million residents of Illinois obtain their water from these resources, most of these from surface water reservoirs. Previous studies by the Illinois State Water Survey (ISWS) have identified 25 community reservoir supply systems that are considered susceptible (inadequate or at risk) to shortages during cases of extreme drought, those being droughts that are comparable in magnitude to some of the worst droughts of the past century. These 25 community systems provide water to roughly 400,000 Illinois residents in central and southern Illinois.

Water levels in most Illinois reservoirs dropped rapidly during summer 2012 starting in June, as described in Chapter 6: *Water Supply Reservoir Levels*. In September 2012, reservoir levels rebounded following the passage of Hurricane Isaac. For roughly half of the affected reservoirs, the rebound was sufficient such that water levels did not return to the minimum levels that had been experienced in August; but, for the other half, the reservoirs continued to drop during the fall season such that minimum water levels did not occur until November or December. Even in these latter cases the threat of an extended extreme drought was never again as acute as it was earlier during summer 2012.

The three water systems that experienced the most tangible threats to their adequacy in 2012 were: 1) La Harpe, a small community in western Illinois; 2) the Vienna Correctional Center in southern Illinois; and 3) the City of Decatur in central Illinois. From size alone, problems facing the Decatur system posed the greatest concern as it supplies water to approximately 87,000 people and is the primary source of water for industrial applications including Archer Daniels Midland (ADM). An expanded analysis of the Lake Decatur water supply situation is included in a separate case study in the following chapter. The concerns facing the smaller systems of La Harpe and the Vienna Correctional Center are addressed in the paragraphs below.

La Harpe The City of La Harpe is located in the northeastern corner of Hancock County in western Illinois. Its water system serves about 1400 people, with an average water use of roughly 110,000 gallons per day (gpd). The city's off-channel storage reservoir (La Harpe Lake) typically provides more than half of the water (roughly 65,000 gpd), with the remainder coming from the city's uptown well. During the early part of the 2012 drought, water use had increased to above 120,000 gpd (reportedly peaking at 141,000 gpd), with the lake supplying the increase in demand. In August, after the city called for conservation, the usage was reduced to about 100,000 gpd. Later in the fall when low water levels in the reservoir became a concern, the city increased the proportion of water being supplied by the city well to about 60 percent. IDNR conducted a bathymetric survey of La Harpe Lake in August 2012 to identify the capacity of the lake. The lake's capacity had previously never been measured. Although the IDNR-measured capacity (99.7 acre-feet) is nearly identical to previous estimates of 99 acre-feet, the survey removed an uncertainty in the capacity that had been clouding previous calculations of yield. Another source of uncertainty was the amount of water that could be pumped into the lake during a drought from the South Branch La Moine River (also known as the South Branch Crooked Creek), which is located adjacent to the lake. In December 2012, the ISWS conducted a reconnaissance survey of the South Branch and nearby streams to identify potential alternatives for a stream withdrawal.

By early December, the water level in the reservoir had fallen to 5.4 feet below full pool, corresponding to a 55 percent loss of storage in the lake. At that time, there was roughly 8.5 million gallons of storage available above the water system's intake in the lake, which is situated about 9 feet below the full pool level. Flows in the nearby South Branch La Moine River are usually pumped to replenish the storage in the lake, but the creek had been mostly dry since July. Although the remaining storage above the intake could be calculated to be equivalent to a 5.5-month supply (at an assumed draft of 50,000 gpd), this calculation does not account for evaporation losses or for the incremental recovery of flows in the South Branch La Moine River that undoubtedly would have occurred in spring 2013 even if the drought were to have continued. At the time, one of the water supply alternatives available to the city was to interconnect with the Dallas Rural Water District (DRWD) on an emergency basis. But as the level of La Harpe Lake began recovering in January 2013, an immediate interconnection became unnecessary. Although the pipeline connection to DRWD was constructed one year later, La Harpe had not been purchasing any water. There appeared to be limitations to the amount of water that can be supplied by the DRWD, suggesting that the connection will not become the primary water source for La Harpe.

An additional solution to lessen La Harpe's vulnerability to drought could be to establish a flow intake on a nearby stream in addition to that already provided by the South Branch La Moine River. In its December survey, the ISWS identified that flow was available in both the main stem of the La Moine River (located roughly 1 mile north of La Harpe Lake) and in La Harpe Creek (located 2 miles south).

Vienna Correctional Center The Vienna Correctional Center (VCC) and its sister facility, the Shawnee Correctional Center, are located 7 miles east of Vienna (Johnson County) in southern Illinois. The water supply for both facilities is provided entirely by the VCC lake, serving roughly 4000 people with a reported average water use of roughly 1 mgd. During the 2012 drought, the facility was able to reduce its average water use to roughly 0.7 mgd.

The IDNR conducted a bathymetric survey of the Correctional Center's lake in September 2012, which measured the capacity of the lake to be 580 acre-feet at an elevation of 375 feet, which is 5 feet below the full pool level. The projected full capacity at 380 feet based on this measurement is 940 acre-feet (306 million gallons). A sedimentation survey conducted by the ISWS in 1996 had previously estimated the lake's capacity to be 1084 acre-feet. After accounting for the rate of sedimentation between the 1996 and 2012 measurements, there is roughly a 10 percent difference between the two surveys because of their different methodologies and instrumentation. The recent IDNR measurement is accepted here as the more accurate estimate of the lake's capacity.

An ISWS water budget model of the VCC lake was used to estimate the response of the lake to varying climate inputs, with particular emphasis on previous historical drought sequences. Figure 9.1 shows the simulated monthly water level for the VCC lake if the 1953–1954 drought of record were to occur today, i.e., using the present-day lake volume and rate of water use. Also shown for comparison are the observed monthly water levels for the 2012 drought. The comparison suggests that until the end of August 2012 (at which time the remnants of Hurricane Isaac passed over the area) the lake drawdown was following a pattern similar to the expected condition during the drought of record. From September through December, the rate of lake drawdown slowed down considerably, reaching its minimum level (7.1 feet below normal) at the end of December. Concerns about low lake levels continued into early winter; however, based on historical streamflow records in the region, some recovery from dry conditions has always occurred in southern Illinois during the winter and spring months. The illustrated lake level response during one of the driest winters on record (1953–1954), shown in Figure 9.1, indicates that replenishment in water levels, provided by watershed and groundwater inflow, could be expected from January to May. As it turned out, with above-normal precipitation, particularly that occurring in January 2013, the lake became fully replenished by March 20, 2013 (IDNR, 2013).

Problems with Water Quality

During a drought, there are often modest changes in the chemistry of the source water that can cause taste and odor issues and occasionally require adjustments in water treatment. Whereas the flow in streams and rivers classically originates from surface runoff, during drought conditions the majority of the flow in natural settings typically comes from shallow groundwater sources instead, and thus has a

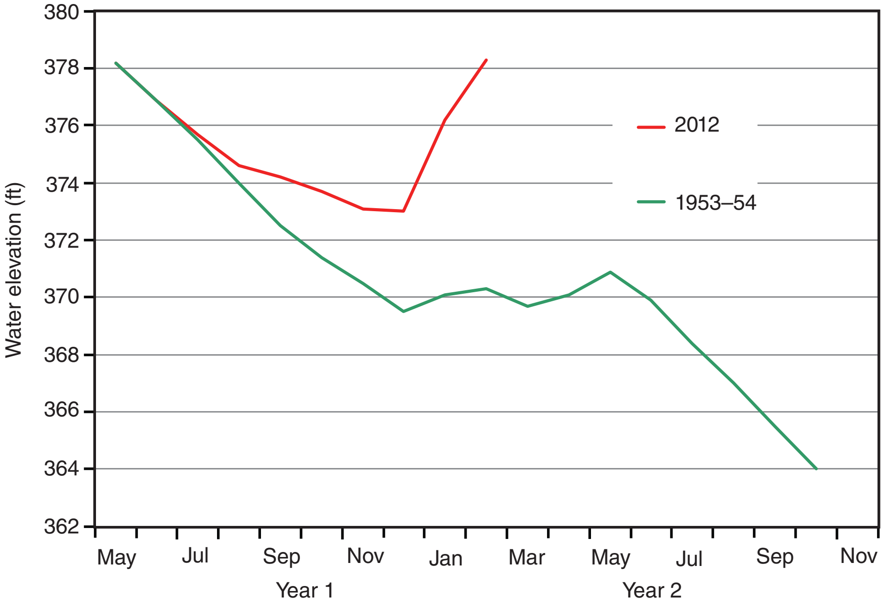


Figure 9.1 Comparison of observed lake levels in the 2012 drought to simulated levels if weather conditions similar to the 1953–1954 drought were to occur with the present water supply system at the Vienna Correctional Center

different quality than normal surface runoff. In Illinois, shallow groundwater generally has very low concentrations of nutrients such as nitrate and phosphate, which are often otherwise elevated in surface waters. On the other hand, groundwater may have higher levels of iron, manganese, and other metals. For certain rivers and streams in Illinois that receive treated wastewaters, the wastewater can become a predominant source of flow during low flow periods, and thus also produce substantially different quality conditions than during normal flows. But such changes tend not to cause water quality concerns of a serious nature, which makes the problem on the Fox River, described below, such a unique circumstance.

In 2012, extensive algal blooms on the Fox River in northeastern Illinois created a highly unusual water treatment problem for the two water supply systems (Elgin and Aurora) that use the river as a water supply source. The amount of algae in the Fox River is typically high during dry periods. Much of the reason for this is because the pools created by the low-head dams along the river provide an ideal environment for algal growth, particularly during low flow (low stream velocity) conditions. But the algal counts in 2012 were exceptionally high, with a reported 1,850,000 cells per milliliter measured in September of that year. Although the Fox Chain of Lakes, located upstream of Elgin and Aurora, is a known source of seed organisms for algae, there is no known analysis that has identified the specific causes of the excessively high amounts of algae during the 2012 drought other than associating it with unseasonably warm temperatures during the preceding winter and spring.

The water treatment problems were particularly challenging for the City of Elgin, for which the Fox River is the predominant source of supply. The City of Aurora was experiencing similar problems, but with less acute concerns because it blends the Fox River water with an equal or greater amount of groundwater. For Elgin, the algal problem began in March 2012 during a period of very warm weather and following one of the warmest winters on record. In June the problem reemerged and became serious enough so that the algae was blocking all of the filters at the Elgin plant. The problem was eventually resolved by significantly increasing the amount of traditional chemicals (alum and soda ash) in the settling (pre-sedimentation) and softening basins, continuous washing of the plant's filters, and also adding high molecular-weight polymers both at the intake to the treatment plant and in the filtering process.

Some potential water quality effects can also lag well beyond the end of a drought. Most fertilizer applied in 2012 was not taken up by crops, thus it may have been available for leaching when wetter conditions returned in the winter and spring. In late spring 2013, the cities of Elgin and Aurora, which both use water from the Fox River, reported unprecedented levels of geosmin, a bacterially derived organic compound with an unpleasant aroma. There was speculation that this occurrence was associated with the drought and dry soil conditions in 2012, although no direct link was ever made.

Rural (Domestic) Groundwater Supplies

In several parts of the state, domestic well owners and smaller rural communities reported interruptions in service for their wells during summer 2012. This is not an uncommon occurrence for dug and bored wells, even in non-drought summers, but in 2012 these wells were running out of water a month or two earlier than usual. For some shallow drilled wells, there were reports of well owners drilling deeper to obtain more water. But in most cases water supplies were typically maintained by purchasing and "hauling" potable water from nearby community water supplies. However, during the height of the drought there were reports of community water systems refusing to sell to water haulers, particularly when that community was restricting water use because of a perceived threat to the adequacy of their own supply.

In other rural regions, irrigation pumping appeared to be the cause of interrupted service. As reported earlier, irrigation appeared to interfere with nearby wells in several counties, specifically Champaign, Iroquois, Lee, and Whiteside. In most cases during the drought of 2012, interrupted service was restored in affected wells by lowering the pump.

Industrial and Power Plant Supplies

The information available on industrial water supplies during the 2012 drought, including impacts on power generation, comes predominantly from the biweekly reports of the Illinois Commerce Commission that were submitted to the Drought Response Task Force during summer 2012. This information was summarized and included in the Illinois Department of Natural Resources report on the 2012 drought (IDNR, 2013). The following material is taken verbatim from that report.

"The coal industry depends on a constant water supply to suppress coal dust as coal is mined. These coal mine operations draw water from numerous sources, including local impoundments, rivers and streams, and federal reservoir allocations. A coal mine in Washington County experienced shortages of available water in August and requested access to water from state park lakes. The mine was able to obtain water to sustain their operations through their own initiatives.

Power plants depend on water supplies to provide cooling water which is essential to the generation of electricity. Closed system plants are those that utilize cooling towers or maintain cooling ponds. Cooling pond plants maintain an adequate water supply to sustain operations for a limited time period. Cooling tower plants still need a small supply of make-up water. Open cycle plants require a continuous supply of cooling water from adjacent waterways, most of which is immediately returned to the water source.

Low flow conditions during 2012 resulted in the need to limit make-up flow and/or to decrease power generation at many power generating facilities in order to stay in regulatory compliance and maintain safe unit operation.

Nuclear power plants such as Braidwood Station that withdraws water from the Kankakee River reached its low flow threshold specified in their DNR Public Water withdrawal permit and withdrawal of water was temporarily suspended. The Kendall 1200-MW combined cycle combustion gas turbine station draws water from the Illinois River, and its withdrawal of that water was severely restricted when the Illinois and Kankakee river flows reached low flow limits set by permit. Three open-cycle fossil fueled plants on the Chicago Sanitary and Ship Canal/Lower Des Plaines River and one on the Mississippi River were required to reduce power production during critical demand periods in response to extremely low river flow conditions, which were further exacerbated by frequent level manipulations by upstream entities.

Low river flows coupled with prolonged periods of above average air and water temperatures also challenged power plants to meet their National Pollutant Discharge Elimination System permits (NPDES) discharge temperature limits. Short-term site-specific thermal variances were granted by the Illinois Environmental Protection Agency, based on the showing of sufficient need by individual entities."

Chapter 10. Water Supply Case Study: The City of Decatur

Of all the community systems in Illinois that depend on a reservoir for their primary water supply, Decatur has the least amount of reservoir storage proportional to its overall water use, with Lake Decatur storing a six to seven-month supply for the city and its industries. Thus, despite the large quantity of water in the lake, it has a "short" supply in terms of the number of months the supply would last during a drought. Dredging in recent years has increased the lake's capacity, but the upper limit of capacity expansion through dredging, if the lake were to approach its original volume, would produce roughly an eight-month supply. Despite this relatively short supply, Decatur is not the most vulnerable of Illinois' community systems in terms of its likelihood of experiencing shortages, although it is clearly one of the most visible.

The Illinois State Water Survey (ISWS) classifies Decatur as an "at risk" water supply system, indicating that the current system has more than a 10 percent computed probability of experiencing shortages if a record drought were to occur. The lake's storage, combined with supplemental sources of supply, has been sufficient to survive extreme and extended droughts for nearly 100 years, primarily because the Sangamon River has dependably provided sufficient inflow in the spring following drought years to fully replenish the lake's storage. But the history of enduring past droughts is not a direct measure of the system's adequacy to face future droughts, in particular because the city's water use is substantially greater today than in the past. It is also possible that a drought worse than the historical droughts of the past 100 years could occur. If the river's flow in the spring following an extreme summer drought were 30 percent less than that of the previous driest spring on record, the river potentially would not fully replenish the lake (given the current level of water use and supplemental sources).

The relatively short amount of supply also puts Decatur in a unique water management situation when compared with other water supply systems in Illinois. During a severe drought, concerns about the water supply and water conservation initiatives typically begin when less than 20 percent of the available lake storage has been used, often no more than six weeks after reservoir drawdown first begins. This nearly guarantees that Decatur will be the first water system in central Illinois to be affected by a drought. Also, because of its prominent size and the large industries that share resources with the City of Decatur, its drought concerns may be expected to receive considerable regional attention. On the other hand, the Decatur system can also recover quickly from a drought. It would take only 0.25 inches of runoff from the Sangamon River watershed to provide enough inflow for Lake Decatur to refill. During the longest, most persistent droughts, it is expected that spring runoff events would refill the lake–removing immediate drought concerns for Decatur–while most other surface water supplies in the region would still be suffering from continuing impacts of drought.

The city's well field in DeWitt County, which pumps water from the Mahomet Aquifer, is the largest supplemental source of water available during a drought. Figure 10.1 shows the location of the well field and other locations along the Sangamon River from Lake Decatur upstream to Monticello, referenced later in this chapter. The DeWitt well field has been a particular source of interest because the Mahomet Aquifer in its vicinity has been determined to be hydrologically connected to the Sangamon River (Roadcap et al., 2011); thus some of the water taken from the aquifer could indirectly reduce the amount of water that the Sangamon River delivers to Lake Decatur. Conversely, flows in the Sangamon River in nearby Piatt County can potentially recharge the aquifer in that vicinity, particularly during high flow conditions. The low flow conditions experienced during the 2012 drought provided ISWS scientists with an opportunity to monitor the Sangamon River and nearby groundwater resources with the intent to characterize the interaction between the two resources. Findings of the ISWS efforts are presented later in this section.

Following the 2012 drought, Archer Daniels Midland Company (ADM)–Decatur's largest industry–constructed two new lateral wells into the shallow groundwater aquifer located underneath Lake Decatur and the Sangamon River. The interactions between this well and the reservoir's water during a drought period are unclear at this time, thus the well's effective yield is yet unknown and has been omitted from ISWS yield assessments. However, the well does provide a more certain supply for ADM when lake levels are low.

2012 Lake Level Conditions Compared to Major Historical Droughts

Figure 10.2 shows observed water levels in Lake Decatur during the 2012 drought. Lake Decatur first started experiencing a drop in water levels in early June. By late August, fewer than 90 days since drawdown began, the lake was drawn down 3.6 feet and had lost roughly half of the water that is considered usable for water supply. In late June and early July, before the drought was considered to pose a serious threat to its water supply, average water use by Decatur and its industries had risen to 43 million gallons per day (mgd)–roughly 20 percent higher than its normal rate of 35 to 36 mgd. On two days (June 28 and July 16) the water use exceeded 47 mgd. An increase in summer water use during the early stages of drought is common in many communities and is primarily related to outdoor uses such as lawn watering.

By August 2012, water levels on the lake were at a critical stage that required mandatory water restrictions, and ADM faced the possibility of curtailing production activities. After the city's stage II mandatory water restrictions were enacted earlier in August, the average water use was lowered to 34 mgd. This rate of use is essentially the amount that the city typically uses during winter

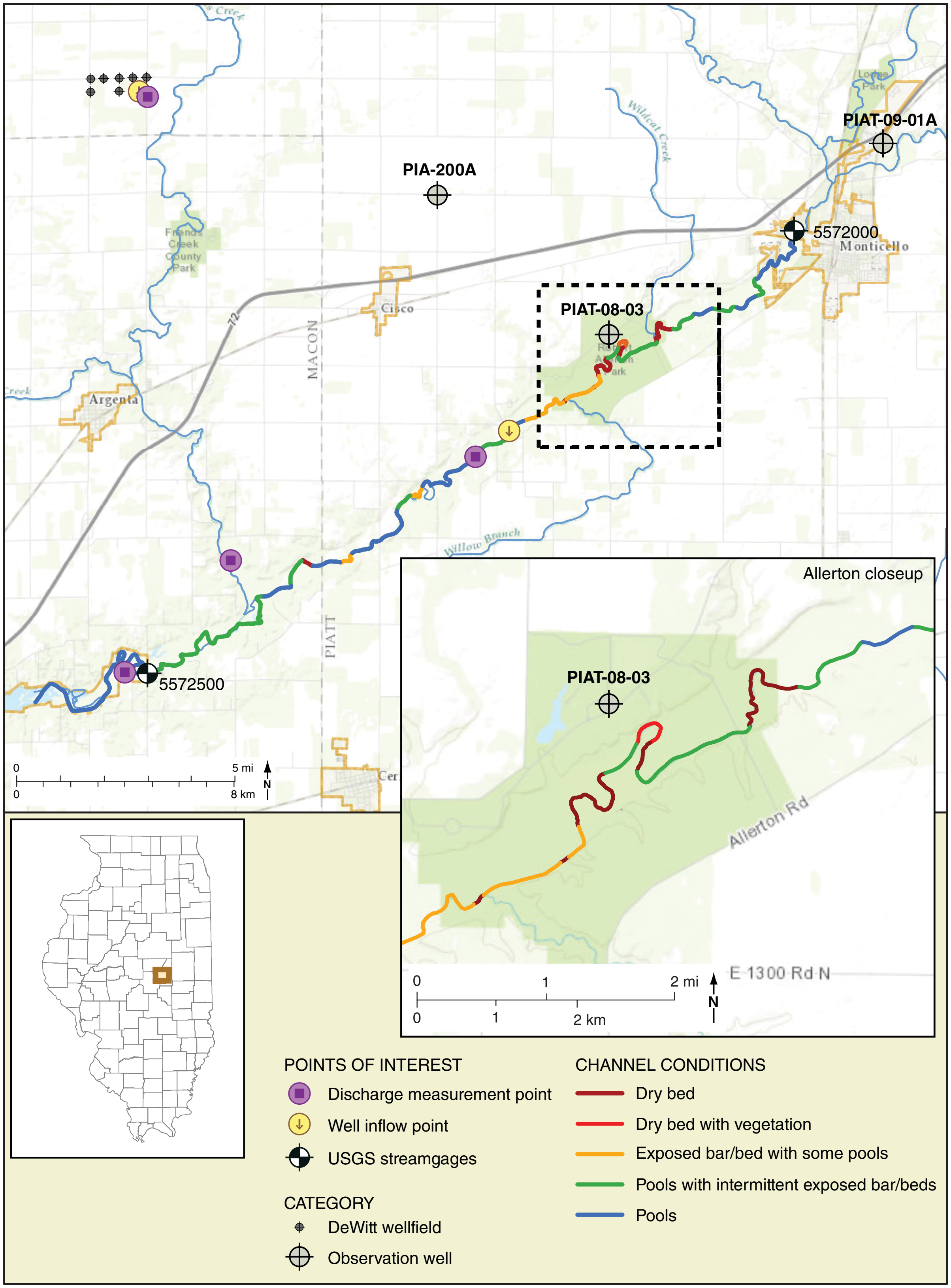


Figure 10.1 Locations of the Mahomet Aquifer, DeWitt well field, observation wells, and streamflow monitoring sites on the Sangamon River and Friends Creek

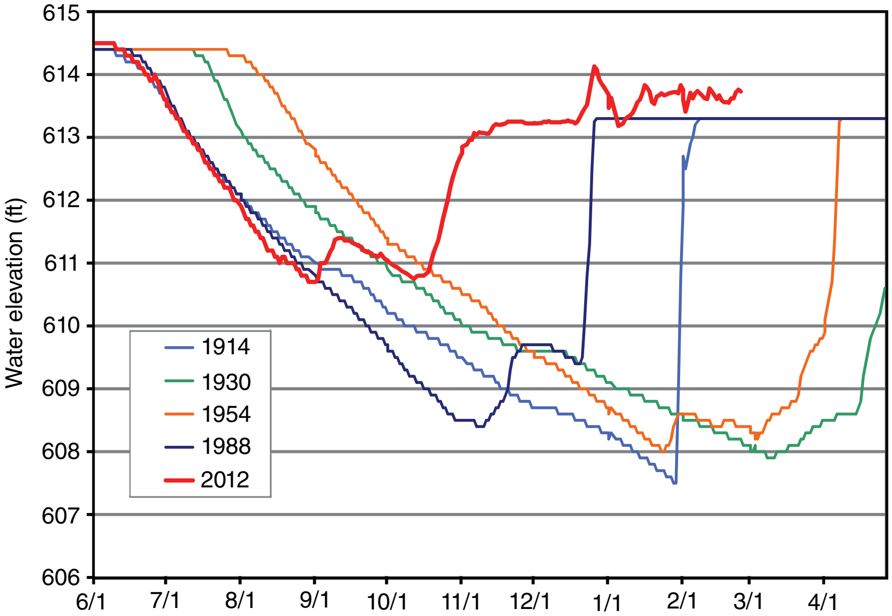


Figure 10.2 Comparison of observed Lake Decatur levels in the 2012 drought to simulate levels if weather conditions similar to four of the worst droughts on record were to occur with the present Decatur water supply system

months when outdoor uses of water are negligible. Rains in early September (the passage of Hurricane Isaac) substantially eased the situation, but water supply concerns continued into early October, after which additional rainfall allowed the lake level to recover.

Also shown in Figure 10.2 for comparison are model-generated lake levels for four of the worst historical drought sequences of the past 100 years, in which a water budget computer model was used to simulate the scenario in which the current water supply system is subjected to the identical hydrologic and climatic conditions that existed during significant drought periods of the past. In this manner, for example, the expected effect of the 1914–1915 drought on the present-day Decatur water supply can be estimated even though that particular drought preceded the construction of Lake Decatur.

An examination of the simulated lake levels for historical drought sequences indicates that there were three past droughts, in 1914–1915, 1930–1931, and 1953–1954, that, for the Decatur system: 1) had the longest durations; and 2) would produce the lowest lake levels (at or below an elevation of 608 feet). The conditions for the 1988 drought produced the fourth lowest simulated lake level in the past 100 years. The 1988 drought had a substantial recovery in November and December of that year and thus, although it was a very threatening drought, with all other factors being equal is not estimated to have had the same potential level of impact as the more severe, extended droughts of 1914–1915, 1930–1931, and 1953–1954.

When the observed 2012 lake levels are compared to simulated levels for historical droughts, two characteristics stand out: 1) the lake drawdown in 2012 began very early in the summer, similar to the onset of the two other early-season droughts of 1988 and 1914–1915; and 2) the lake level decline throughout summer 2012 was as rapid as that during any of the worst droughts on record. If the remnants of Hurricane Isaac had not passed over central Illinois, conceivably, the 2012 lake level decline would have continued to match that of the 1988 drought through the middle of October when other precipitation events would have initiated recovery in the lake level. By the end of August 2012 and before the arrival of Hurricane Isaac, the combination of the rapid decline in Lake Decatur levels and the possibility that dry conditions would persist into the fall and winter posed a genuine impending threat to the community's water supply.

Dry Conditions on the Sangamon River Upstream of Lake Decatur

One of the most notable hydrologic impacts of the drought was the no-flow conditions on the Sangamon River upstream of Lake Decatur, which extended for 26 consecutive days and for 34 of 36 days from July 21 to August 25, 2012, as recorded at the U.S. Geological Survey (USGS) streamgage at Monticello. Since the gaging station was installed in 1911, its flow record shows that the river at this location had experienced zero flow only during the 1988 drought for a total of eight days. At the Monticello gage, August 2012 was the third lowest average monthly flow ever recorded (1.57 cubic feet per second [cfs]) behind September and October 1988 at 0.48 and 1.32 cfs, respectively. The August 2012 total was not the driest because of some significant rainfall on August 16 and August 26. The Sangamon River downstream of Monticello near Allerton Park remained dry throughout the entire month of August 2012 and thus experienced its driest month on record. July 2012 was also very dry with the sixth lowest average monthly flow. Over a longer 12- or 18-month period, only 1930–1931, 1933–1934, and 1953–1954 were as dry or drier. The 2011–2012 period had the longest number of consecutive days with flow below 1000 cfs (604 days), which, as discussed in the next section, could have a significant impact on groundwater recharge. Figure 10.3 illustrates the dry river condition in August as it existed about 1 mile upstream of the USGS gage location.

On August 8, 2012, ISWS staff participated in a helicopter fly-over above the Sangamon River between Monticello and Lake Decatur to identify where the river was flowing and possible locations for flow measurements. Unexpectedly, there were no locations upstream of the lake that appeared to have any river flow. More remarkably, there was

Figure 10.3 Dry conditions on the Sangamon River as viewed from the Old Route 48 Bridge near Monticello

a 4-mile reach of the river near Allerton Park in Piatt County where the river bed was mostly dry, and in some cases completely dry. Figure 10.1 identifies the river bed conditions that existed at the time of the fly-over. In a short stretch in Allerton Park, the river appeared to have cut off a meander, and vegetation was growing in the portion of the channel that carries no flow when the river is low.

Like all natural river beds, this length of the Sangamon River is composed of a series of alternating deep spots (pools) and shallow spots (riffles). When a river initially experiences zero flow, only the riffles are exposed and dry. As dry conditions persist, the water level in the pools will typically slowly fall as the water evaporates or infiltrates into the river bed, thus exposing more of the bed. In this manner, small streams will often become completely dry during extended dry periods if the local groundwater table is below the water level in the stream. But in larger streams and rivers, the groundwater table typically remains close to or elevated above the deeper portions of the pools, in which case the pools usually do not dry up even when there is zero flow. In July and August 2012, however, the Sangamon River in the reach near Allerton Park was dry throughout the deepest pools of the river, not just the more shallow sections. For the pool levels to be this low, there would need to have been an exceptional amount of infiltration over the previous three-week period since the river's flow had fallen to a very low amount. Farther downstream near the Hog Chute Bridge, the river somewhat abruptly returned to a condition in which the pools were mostly wet. This suggests that there was a depression in the shallow groundwater table in the reach near Allerton Park where the stream was dry.

Operation of the DeWitt Well Field and Other Supplemental Sources

Due to the very dry conditions, Decatur turned on their emergency well fields in DeWitt and Piatt Counties on August 6. Water pumped from the DeWitt wells was discharged into Friends Creek, which then flowed into the Sangamon River and downstream to Lake Decatur. The well field was deactivated for five days as Hurricane Isaac passed over Illinois (August 31 to September 5), but then reactivated and operated until October 22 for a total pumping duration of 72 days in 2012. The withdrawal rate from the well field was generally maintained in the range of 10 to 14 mgd.

Decatur's Cisco well is an additional emergency well located next to the Sangamon River at Hog Chute Bridge, 3 miles downstream of Allerton Park and 3 miles southeast of Cisco, IL. The output of the Cisco well is roughly 3.2 mgd. The well is usually operated at approximately the same times as the DeWitt well field, but in 2012 was not activated until August 9 so as not to influence river conditions during the August 8 fly-over.

In late 2011, Decatur had also pumped supplemental water from the Vulcan gravel pit downstream of the Decatur dam, and by summer 2012 the pit was reportedly only about one-third full. Decatur was able to pump 3.5 mgd from the pit between July 31 and August 20, 2012.

Influence of Decatur's Pumping on Nearby Water Levels of the Mahomet Aquifer

Data from Guillou and Associates (Figure 10.4) shows the water levels at an observation well (OW-1) located at the edge of the DeWitt well field. When the well field was operated from August 6 to August 31, the level in the Mahomet Aquifer dropped 36 feet in elevation from 606 to 570 feet. After the well field was reactivated on September 6, the water level continued to fall several feet through the end of September 2012, reaching an elevation of 566 feet and a maximum drop of 40 feet.

Figure 10.4 also shows groundwater levels during the previous dry fall season of 2011. In 2011, the DeWitt well field was operated for a period of 113 days (September 6 to December 27, 2011) and during that time had fallen a maximum of 42 feet. As a result of the prior year's pumping, the static water level at OW-1 was already relatively low leading into the summer of 2012, being 9.15 feet lower than the static water level prior to the 2011 pumping period.

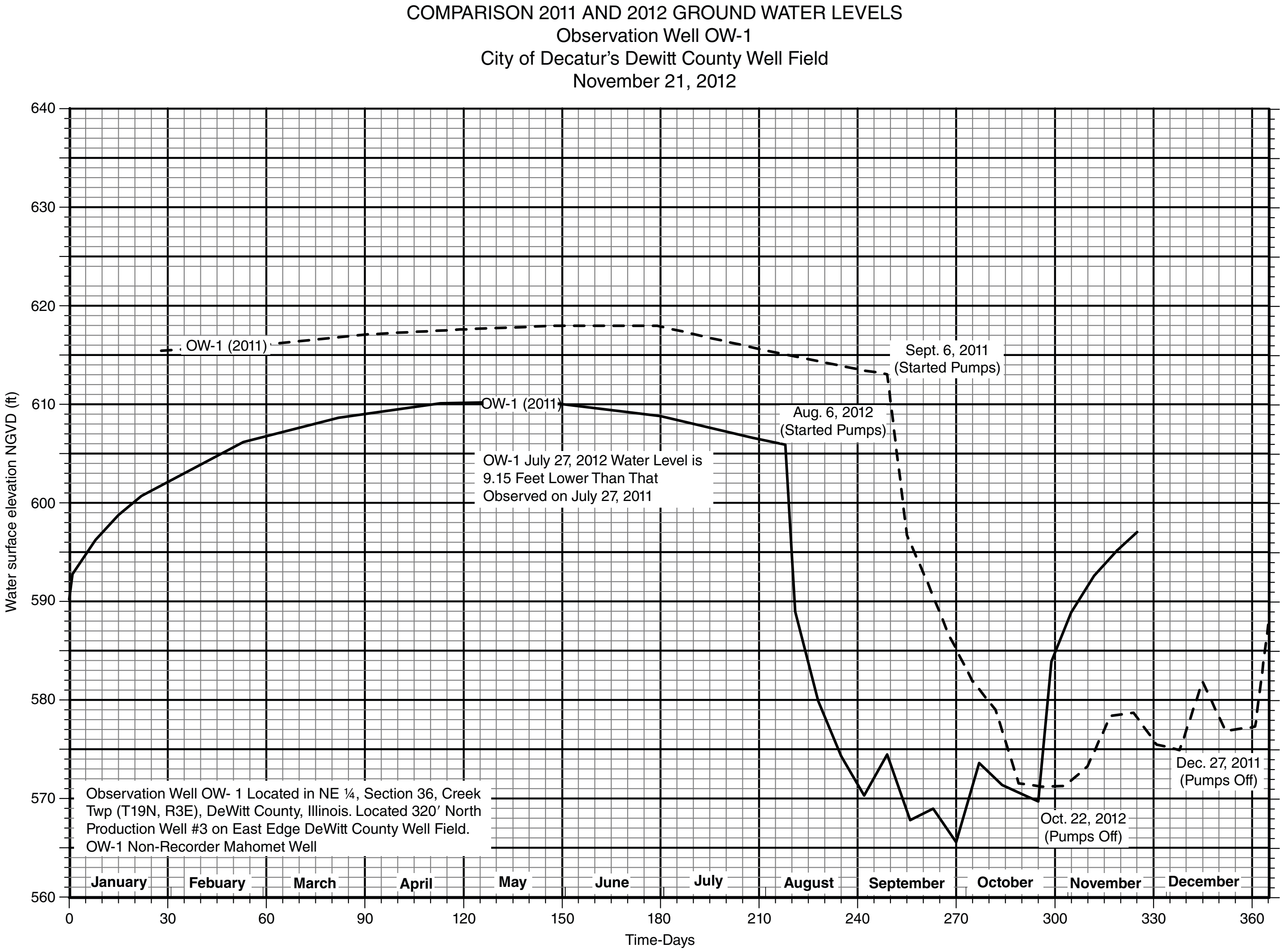


Figure 10.4 Water levels at the DeWitt Well field OW-1 observation well, 2012 (from Guillou and Associates)

The 2011 and 2012 drawdowns from the Decatur wells also extended eastward to observation wells in Piatt County (Figure 10.5). The locations of these observation wells are provided in Figure 10.1. Observation well PIA-2000A, located in the town of Cisco, is roughly 5 miles southeast of the DeWitt well field. Observation wells PIAT-08-03 and PIAT-09-01 are located in Allerton Park and at the railroad museum northeast of Monticello, respectively.

The water level in PIA-2000A fell roughly 17 and 18 feet during the 2011 and 2012 pumping periods, respectively. The PIAT-08-03 well near Allerton Park declined roughly 7 feet during each of the same pumping periods. In contrast, the PIAT-09-01 well northeast of Monticello declined only a few feet in each pumping period, an amount that is considered representative of normal seasonal decline and thus not specifically influenced by pumping from any of Decatur's wells. The hydrographs of all three observation wells (Figure 10.5) show a lack of recovery during winter 2012, indicating that the observed low water levels in spring 2012 were not restricted just to those locations influenced by the 2011 drawdown.

Regional Water Level Response in Summer 2012

The impact of the Decatur well field pumping in August and September 2012 created considerable regional drawdown in the Mahomet Aquifer (Figure 8.8), as estimated using an ISWS groundwater model of the aquifer. The drawdown amounts in Figure 8.8 are directly comparable to the maximum drawdown (40 feet) at OW-1 at the edge of the DeWitt well field (Figure 10.4). Figure 8.8 also shows some recovery in the aquifer levels in northern Champaign County, following the considerable amount of irrigation pumping occurring earlier in the summer in that region. Over the summer of 2012, the combined stress on the aquifer between the irrigation and DeWitt well field pumping was the greatest that the eastern half of the Mahomet Aquifer in Illinois has ever experienced.

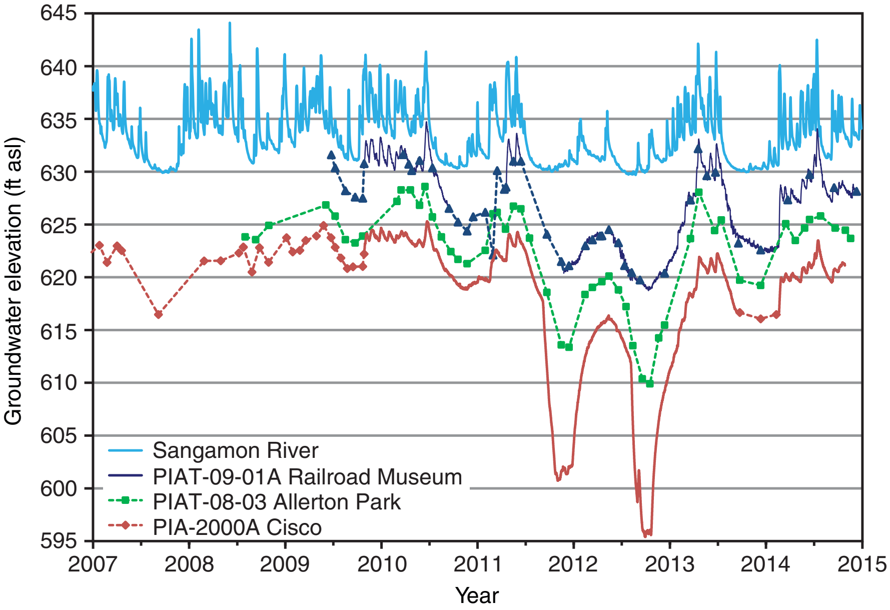


Figure 10.5 Hydrographs of PIA-2000A, PIAT-08-03, PIAT-09-01A, and the USGS gage on the Sangamon River at Monticello

Monitoring of Streamflow Downstream of the DeWitt Well Field

During previous pumping of the DeWitt well field in 2005 and 2007, observations suggested that a noticeable portion of the well water never reached Lake Decatur due to infiltration into the dry channel, thus reducing the overall effectiveness of the well field. The low flow conditions in August 2012 provided the perfect opportunity to examine and quantify the potential losses of water between the well field and the lake, leading ISWS to conduct a series of streamflow measurements. Table 10.1 lists flow measurements taken by ISWS during this period as well as the dates that the DeWitt well field and Cisco well were activated and deactivated. Locations of the ISWS low flow monitoring sites are shown in Figure 10.1. Flow measurements were taken at two locations on Friends Creek: 1) Cemetery Road immediately downstream of the wellfield discharge; and 2) 0.5 miles downstream of Jordan Road near Argenta (roughly 1 mile upstream of the Sangamon River confluence). Flows were also measured at two locations on the Sangamon River: 1) roughly 0.8 miles downstream of Hog Chute Bridge; and 2) roughly 0.4 miles downstream of the Oakley Bridge (3 miles north of Oakley), the latter of which was the most downstream site that could be measured before the river flows into Lake Decatur. Friends Creek flows into the Sangamon River 2.4 miles upstream of the Oakley Bridge. The primary monitoring period of interest occurred August 15–30, 2012. The Sangamon River in September, following the passage of Hurricane Isaac, never returned to the low levels needed to isolate the flow contribution from Decatur's wells. For this reason, the only ISWS flow measurements taken in September were on Friends Creek.

There was no flow in the river at the Hog Chute Bridge during the entire period of monitoring in August 2012. Thus, flow that occurred at the USGS gage in Monticello between August 16 and August 31 did not reach Hog Chute Bridge located 8 miles downstream, and instead was likely filling exposed pools in that reach. In a similar fashion, after the DeWitt well field was activated on August 6, it took roughly a week before its flow had filled the dry bed of Friends Creek and traveled the 15 miles to reach the Sangamon River.

Flow from the Cisco well discharges to the Sangamon River a short distance downstream of the Hog Chute Bridge. The well has a reported average pumping rate of 3.2 mgd or roughly 5 cfs. The two discharge measurements on the Sangamon River downstream of Hog Chute Bridge (on August 15 and 28) are assumed to directly reflect the flow coming from that well, as the river was observed to have no discharge immediately prior to the well being activated. However, the August 15 measurement (6.2 cfs) is 20 percent higher than the reported pumping capacity of the Cisco well.

A comparison of the flow amounts from the two Friends Creek locations indicates that there was little or no flow loss in Friends Creek. In contrast, flows measured on the Sangamon River downstream of the Oakley Bridge suggest that there was a considerable amount of flow loss along the river. If no flow loss had occurred, the flow downstream of the Oakley Bridge would have been expected to be the sum of the flow from the Cisco well (~5 cfs) and the flow from Friends Creek (18–20 cfs); however, the measured flows on August 23 and 29 were much less, 15.5 and 14 cfs, respectively. This indicates that 8–10 cfs, or roughly 40 percent of the water originating from the DeWitt and Cisco wells, was lost from the Sangamon River channel and never reached the Oakley Bridge. If it is assumed that the rate of loss is uniformly distributed along the river's reach between the Cisco well and the Oakley Bridge, this would imply that all of the Cisco well's output and around 30 percent of the DeWitt well's output are being lost in the Sangamon River between Friends Creek and the Oakley Bridge. It is possible that additional channel losses could be occurring downstream of the Oakley Bridge, and this should probably be expected in any conservative estimate of lake inflow; unfortunately, no viable measurement locations were found between the lake and the Oakley Bridge site.

The two August measurements on the mainstem of the Sangamon River represent only a snapshot of the channel's loss rates and the hydrologic interaction between the river and shallow groundwater. The observed characteristics could potentially change as: 1) sustained

Table 10.1 Date and Locations of ISWS Streamflow Measurements to Determine Contribution of Well Pumpage to Lake Decatur, cfs

			Friends Creek		Upstream → Sangamon River → Downstream				
Date	Lake Level (ft)	DeWitt Field Info	Inflow at Cemetery Rd.	Outflow 0.5 mi DS of Jordan Rd.	USGS Monticello station	Observations of Channel DS of HogChute Bridge	Cisco Well Info	Sangamon River 0.8 mi DS HogChute Bridge	Sangamon River 0.4 mi DS Oakley Bridge
8/1/2012	611.79	Off	Dry	No flow	No flow	No Flow	Off (Electrical problems until the 6th)	No Flow	No flow
8/3/2012	611.66				0.01 cfs				
8/6/2012	611.52	Activated 6 wells @ 1850rpm			No flow		Activated on August 9		
8/13/2012	611.18		15 cfs		0.01 cfs	No Flow			
8/15/2012	611.09				No flow			6.2 cfs	
8/20/2012	611.03		15.5 cfs		6 cfs	No Flow			
8/22/2012	610.97	6 wells @ 2050rpm			4.1 cfs				
8/23/2012	610.91			20 cfs	3.6 cfs	No Flow			15.5 cfs
8/28/2012	610.74				15 cfs	No Flow		4.3 cfs	
8/29/2012	610.73		17 cfs	18 cfs	15 cfs	No Flow			14 cfs
8/31/2012	610.62	Deactivated			9.8 cfs		Deactivated		
9/5/2012	611.0	Activated 6 wells @ 1850rmp			174 cfs		Activated		
9/17/2012	611.29		20.5 cfs		9.6 cfs				
10/19/2012	611.16		14.7 cfs		159 cfs				
10/22/2012	611.42	Deactivated							

▨ Primary monitoring period

pumping from the DeWitt well field causes continued water level declines in the Mahomet Aquifer near the river; 2) sustained pumping also results in nearby well interference, forcing a reduction in the pumping rates from the DeWitt field; and 3) cooler conditions occur during the late fall and winter of an extended drought. However, the passage of Hurricane Isaac at the beginning of September substantially diminished the dry streambed conditions, thus removing the feasibility for extended monitoring of low flows in 2012. For future drought events, it is recommended that such a sustained monitoring effort be undertaken.

Flow Losses on the Sangamon River in Previous Droughts

From 1951 to 1956, the USGS operated a second continuous-discharge gage on the Sangamon River at the Oakley Bridge upstream of Lake Decatur. Whereas flow at the Oakley Bridge during normal flow conditions is typically about 40 percent higher than at Monticello (because of the greater contributing watershed area), during the eight-month drought period from August 1953 to March 1954 the total flow amount at Oakley Bridge was only 12 percent higher than at Monticello. During the lowest flow conditions in October 1953, the flow at the Oakley Bridge was less than that at Monticello, essentially the same condition as observed in August 2012. It is possible, perhaps likely, that the flows at the Oakley Bridge would have been even lower in 1953–1954 if the Mahomet Aquifer in the DeWitt-Piatt County region had experienced a large amount of pumping as now occurs in drought periods. The flow losses observed in 2012 corroborate the 1953–1954 observations, and collectively verify that the Sangamon River downstream of Monticello indeed loses flow during extreme drought conditions. In contrast, the lower observed flows at the Oakley Bridge gage in 1953–1954 had been considered a discrepancy associated with measurement error in previous ISWS analyses.

Connection between the Mahomet Aquifer and the Sangamon River

The possible connection between groundwater and the cause and duration of the low flow (and no-flow) conditions on the Sangamon River is difficult to directly quantify. At this time, the interconnection of the river to the Mahomet Aquifer and shallower sands appears to be the most likely mechanism that caused the dry river beds. As shown in Figure 8.8, during the 2012 drought the water level in the Mahomet Aquifer was not significantly lowered west of Champaign where the large-capacity Illinois-American Water Company public water supply well fields are located. Therefore, increased seasonal demand from Champaign-Urbana was probably not an important factor in the river going dry. The new irrigation demands in northern Champaign County could have lessened the flow in the upstream portion of the watershed by inducing water out of the stream at rates that would not have occurred in previous droughts. It can also be speculated that other changes in agricultural practices that have occurred in the watershed since previous droughts may have resulted in lower water tables along riparian areas, including more widespread installation of intensive drainage tile networks, the conversion of many thousands of acres from pastureland to drained row crop fields, and the use of corn and soybean hybrids which use water earlier in the growing season. But none of these other potential influences explain how the pools dried up in the Sangamon River downstream of Monticello.

Roadcap et al. (2011) attributed the sharp rises in groundwater levels in well PIAT-09-01 to storm events on the Sangamon River, indicating a nearby hydraulic interconnection between the river and the aquifer. As hypothesized in that report, water stored in shallow sands near the river likely maintains baseflow in the river during dry periods. The complex geometry of the sands that connect the river to the underlying Mahomet Aquifer is unknown as is the amount of unconfined sand in the system that can store and release water. Leakage from the river through the shallow sands to the aquifer is variable, with a large portion of it appearing to occur during storm events when the downward gradients are the greatest. During dry conditions in the winter of 2011–2012, the water level in PIAT-09-01 (Figure 10.5) did not recover to its normal level following the dry fall season in 2011 (when there was emergency pumping from the DeWitt well field, as shown in Figure 10.4). There were only two small storms during the winter and another event in early May 2012, but none of these produced flows in the river of more than 800 cfs, and they only briefly raised the stream level at the Monticello gage above 640 feet (Figure 10.5). It is possible that these storms were neither big enough nor lasted long enough to refill the water removed from storage in the aquifer during 2011. Although more data are needed, water level data collected between 2011 and 2014 may indicate that the groundwater does not act in tandem until the river stage at Monticello exceeds approximately 635 feet in elevation or a corresponding flow of 600 cfs.

The lack of wintertime recovery in groundwater levels in 2011–2012 is evident throughout the watershed. It is likely that the reduced amount of stored groundwater throughout the watershed contributed to the low flow conditions in summer 2012. In particular, it is possible that the lack of recharge in the shallow sands and the underlying Mahomet Aquifer led directly to the no-flow conditions and dry streambeds downstream of Monticello. The winter-spring seasons of 1930–1931, 1933–1934, and 1953–1954 produced low flow conditions in the Sangamon River similar to that of 2011–2012, and it would be reasonable to expect in those years that there would have been little water replenishment in the aquifer and shallow sands as well. Thus, water supply planning for future droughts should consider such contingencies and the potential for not only flow losses in the Sangamon River but also the possibility of a limited recovery in the Mahomet Aquifer water levels in advance of the worst drought conditions.

Implications to the Yield of the Decatur Water Supply System

In June 2012, the ISWS calculated the yield of the Decatur water system to be 32.2 mgd (http://www.isws.illinois.edu/data/ilcws/addl/DecaturSupplementalMaterial.pdf) at the 90 percent confidence level. That yield was calculated using the climatic and hydrologic conditions measured during the 1914–1915 drought, which is computed to be the drought of record for Lake Decatur. The 90 percent level of confidence indicates that, during such a drought, there is roughly a 10 percent chance that the system could fail to deliver an average water supply rate equal to the computed yield. If a 95 percent level of confidence is used instead, the computed yield is reduced to 30.4 mgd. For these yield estimates, water withdrawn from Lake Decatur by ADM is considered to be a part of the Decatur water system, as the city and ADM share that water source. These yield estimates also assume that only 70 percent of the water that is pumped from the DeWitt well field reaches the lake.

For most historical drought periods, the streamflow measured at the USGS gage on the Sangamon River at Monticello provides the best available information on the amount of inflow into Lake Decatur. The size of the Sangamon River watershed where it flows into Lake Decatur is considerably larger than at Monticello. In past yield analyses, the river downstream of Monticello was previously considered to be a "gaining stream," and the observed flow amounts at Monticello were proportionally increased (scaled up) to represent the total inflow into the lake. However, from ISWS flow measurements taken during the 2012 drought and a renewed analysis of the 1953–1954 low flows at the Oakley Bridge gage, it can be observed that the river instead loses flow downstream of Monticello at certain times. Thus, whereas the collective flow into Lake Decatur is still expected to be higher than that measured at Monticello, the increase in flow amount should no longer be assumed to be directly proportional to the watershed area.

As indicated previously, the combined observed flows at Monticello and the Oakley Bridge gage in 1953–1954 provide data to describe flow losses between those two locations. For computing the water supply yield of Lake Decatur, it is reasonable to assume that similar flow losses occurred with many if not all other historical extreme droughts. In doing so, it can be estimated that the yield associated with the drought of record is reduced by 1.3 to 30.9 mgd (90 percent confidence level).

The assumptions used here in these adjusted yield estimates could be conservative in nature and underestimate flow losses (and overestimate yield) as they do not consider that:

- Additional flow losses may be occurring in the channel downstream of the Oakley Bridge. If channel losses cause an additional 10 percent of reduction in the flows coming from the DeWitt well field, for example, the yield of the system would roughly be reduced by an additional 0.7 mgd.
- External influences from increased regional pumping from the Mahomet Aquifer since the 1950s may have increased the inducement of flow from the river to the shallow sands along the river. The regional pumping effects are assumed to include both the Champaign-Urbana and the DeWitt well fields, the latter of which was first used in 1999.

Chapter 11. Navigation, Environmental, and Water Quality Impacts

Navigation Impacts

Low flow and low stage conditions on the Mississippi River created difficulties for commercial navigation throughout much of 2012 and into early 2013. The 9-foot-deep navigation channel of the Mississippi River, maintained by the U.S. Army Corps of Engineers (USACE), often contains scattered deposits of sediment and debris, particularly following flood conditions such as occurred the previous year in 2011. However, these deposits ordinarily do not affect the passage of tow boats and barges until water levels become low. When the groundings of tows become frequent, such as those which began to occur in summer 2012, the USACE clears and dredges the channel. Dredging on the river began in July 2012 and continued throughout most of the remainder of the drought.

River closures were occasionally needed for channel maintenance (surveying, dredging, and re-marking) or when grounded barges needed to be pulled away from sediment bars and river banks. Because of the low water conditions, the number of barges per tow was reduced, and barges were asked to lighten their loads in an effort to avoid scraping the bottom or sides of the channel. Barges loaded to their full capacity typically have an 11- to 12-foot draft; however, during the drought, drafts were progressively restricted to 9 feet, the specified minimum navigation channel depth. Closures, delays, and draft and tow restrictions can result in substantial economic losses and additional transportation costs. The USACE (2013) estimates that closures and low water conditions during the 2012 drought increased transportation costs by roughly $277 million.

Although much of the Mississippi River navigation system experienced navigation problems such as groundings in 2012, the 180-mile “middle” reach between St. Louis, MO, and Cairo, IL, located in Figure 11.1, was probably one of the most susceptible reaches on the Mississippi River. Lock and Dam 27 (LD27), located near St. Louis, is the last downstream dam on the Mississippi River. Upstream (north) of LD27, river stages and depths are to various degrees controlled by the lock and dam system; downstream of LD27, however, river stages are directly associated with the low flow quantity. Two of the most notable navigation impacts in 2012 occurred along this reach of the Mississippi River: 1) the five-day river closure at LD27 in September 2012 associated with a barge accident; and 2) the low water conditions and channel work needed in December 2012 through February 2013 at the “rock pinnacles” located near Thebes and Grand Tower in southern Illinois.

Lock and Dam 27

By late summer 2012, the low water level at LD27 had exposed a guide cell at the approach to a lock chamber, a structure which is almost always underwater. On September 15, a less-fortified section of the guide cell was struck and ruptured by a tow, causing tons of loose rock to fall into the flow of barge traffic into the lock. A five-day closure of the main lock and auxiliary lock was required to remove the rock and temporarily repair the cell.

Rock Pinnacles at Thebes and Grand Tower

Near both Thebes and Grand Tower, the Mississippi River cuts across thick limestone formations. At low water, the dissected limestone ledges become less submerged and in places can be exposed. The resulting rock outcroppings and pinnacles are a hazard to navigation, and at the lowest water levels, constrict the main channel. As a result, in fall 2012 barge drafts and tow sizes not only were restricted, but also the navigation through a 6-mile stretch near Thebes was limited to one-way traffic.

Throughout much of any drought year, the flows in this middle portion of the Mississippi River are partially sustained by the Missouri River’s navigation system. Flow releases from numerous reservoirs in the Missouri River basin are used to supplement flow and maintain navigation. However, at the end of November of every year, the Missouri navigation season comes to an end, and with it comes the scheduled termination of much of the flow supplementation that also benefits the middle Mississippi River. In accordance with the Missouri River Basin Master Manual, on December 1, 2012, the USACE reduced the Missouri reservoir releases from 37,000 to 12,000 cubic feet per second (cfs).

The navigation industry was greatly concerned that the subsequent flow reduction, beginning in December 2012 and lasting throughout the winter, might cause sufficiently low water levels at Thebes to force a navigation shut-down on the Mississippi River. To compound the concern, it was also expected that flows from the upper reaches of the Mississippi River might be sharply diminished by early January as winter weather caused that portion of the river to freeze. Although requests were made for the USACE to reopen the Missouri River reservoirs to help maintain navigation on the middle Mississippi River, such an action conflicts with the Missouri River Master Manual which binds the USACE’s operations.

Supplementing Mississippi River Flows Using Kaskaskia Reservoir Storage

The only USACE reservoir storage available to supplement the Mississippi River flow near Thebes was that in the Kaskaskia River basin in Illinois (Carlyle Lake and Lake Shelbyville). The maximum navigation release from those reservoirs, roughly 3700 to 4000 cfs, is sufficient to increase the water level at Thebes by roughly 6 inches.

Although navigation is one of the primary functions of the joint-use storage in Carlyle Lake and Lake Shelbyville, in over 40 years of operation there has yet to be a designated navigation release from these reservoirs. But in the fall of 2012 the USACE was fully prepared to use the storages of these reservoirs for this purpose. As it turned out, the remnants of Hurricane Isaac passed over the Carlyle Lake region earlier in

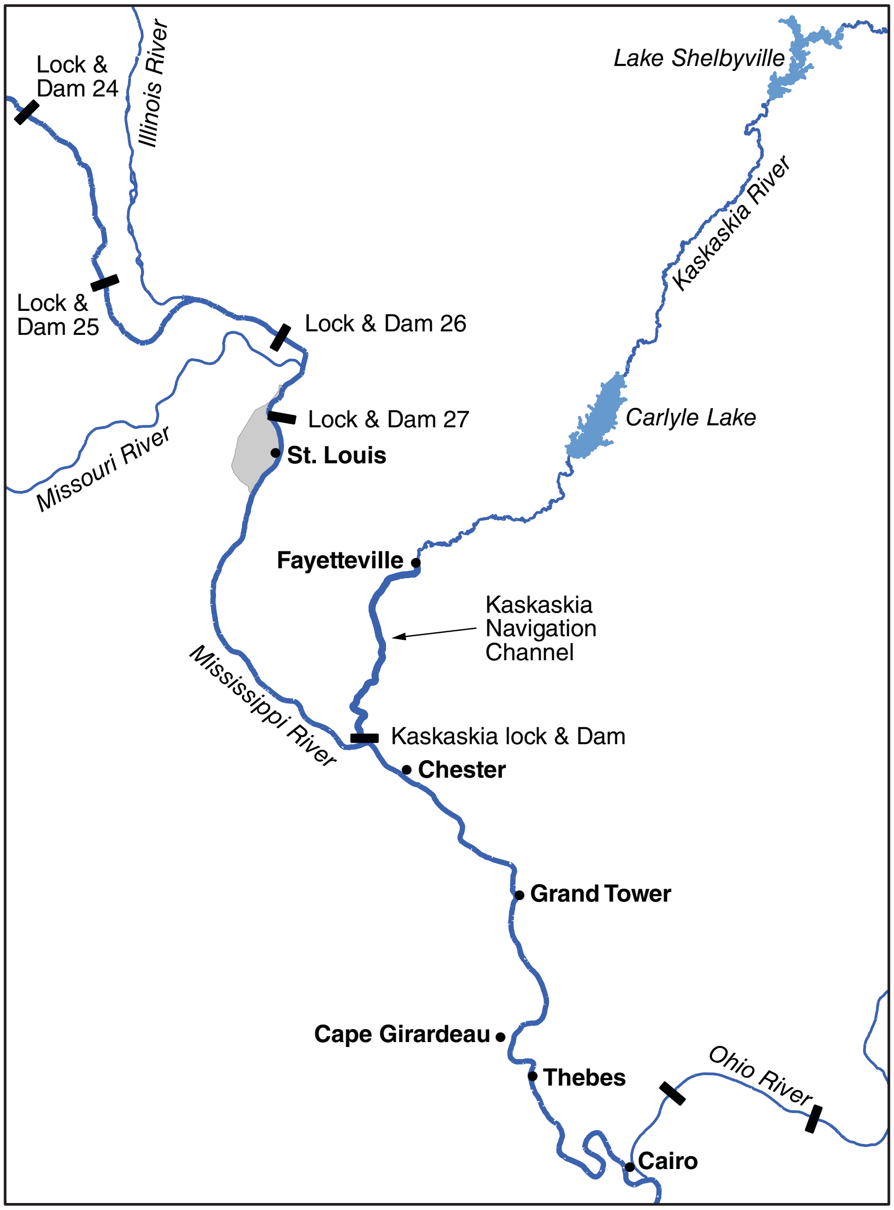


Figure 11.1 Location of the Middle Mississippi River and Kaskaskia River navigation systems

the fall, such that the storage of Carlyle Lake had not merely recovered from the drought, but was in the flood control pool as much as 3 feet above the normal pool level (Table 6.4). The USACE began releasing water from Carlyle Lake on December 15, 2012 to supplement flows on the Mississippi River. But with wet conditions in January 2013, the water level in Carlyle Lake never fell back to its normal winter pool level. Because the joint-use storage in Carlyle Lake was not accessed during this time, its December–January flow releases were never officially designated as a navigation release. By late January 2013, flow levels in the Mississippi River had recovered sufficiently that navigation restrictions were no longer a concern.

In December 2012, contractors for the USACE began blasting and removing rock near Thebes to maintain the 9-foot navigation channel during low water periods. In late January, that work moved from Thebes to Grand Tower, and by the end of February the rock removal effort had been completed.

Environmental and Water Quality Impacts

Surface Water Quality

Although there is no known specific analysis of water quality conditions during the 2012 drought, certain general impacts can be inferred. During droughts, streams and rivers typically have low flows, with the majority of the flow in natural settings coming from shallow groundwater. Thus, for many constituents, surface water quality can become atypical and more similar to groundwater quality, with lower concentrations of nutrients such as nitrate and phosphate, and higher levels of iron, manganese, and other constituents. On the other hand, the water quality of streams that receive substantial amounts of wastewater (for example, portions of the Fox and Illinois Rivers) may be more likely to take on characteristics of that wastewater if the shallow groundwater contribution is limited.

As flows and water levels in the streams and rivers of Illinois decreased during the drought, water temperatures rose and dissolved oxygen levels fell. Low dissolved oxygen conditions result from the accumulation of oxygen-consuming substances under prolonged low flow stagnant conditions and because warmer waters hold less dissolved oxygen. High temperatures and less water also mean an increase in evaporation, which increases the concentrations of many solutes. Some of these solutes, such as ammonia and nitrite, can be toxic at certain levels.

Algal blooms can also increase during droughts, further robbing the water of oxygen and possibly producing cyanotoxins such as microcystin, which is toxic to humans. In response to several reports of harmful algal blooms, the Illinois Environmental Protection Agency (IEPA) and the U.S. Geological Survey (USGS) sampled 13 lake and stream sites during August–October 2012. Three sites contained high to very high levels of microcystin, with a highest recorded value of 4,800 micrograms per liter (μg/L) (IDNR, 2013). The World Health Organization standard for microcystin is 20 μg/L.

Fish Kills and Other Environmental Damages

Low dissolved oxygen levels and increased water temperatures in streams, lakes, and ponds stressed fish, as well as other aquatic organisms and biota, sometimes leading to fish kills. Fish kills have various causes, but during droughts a primary cause is low dissolved oxygen levels. The Illinois Department of Natural Resources (IDNR) Division of Fisheries reported more than 80 fish kills in rivers, streams, lakes, and ponds in Illinois between July and September 2012 (tabulated in IDNR, 2013). Twelve of the kills were described as "major," most of those with a loss of life numbering in the thousands. The greatest frequency of reported fish kills occurred during the week of July 9–15, 2012. High losses were specifically reported on the Illinois River and one of its tributaries, the Vermilion River; however, fish kills were observed on almost all the major rivers in the state.

Some of the largest fish kills occurred in lakes used for cooling purposes. Some power plants were permitted under an IEPA variance to discharge water at temperatures in excess of 120 degrees into their cooling lakes. Heated water discharges have multiple adverse effects on fish and other aquatic organisms including direct lethality, increased metabolism and oxygen consumption, and increased toxicity of certain chemicals (Madden et al., 2013).

Additionally, several mussel beds dried up, leaving the mussels exposed to high temperatures and predators. Mussel die-off was reported along the Embarras, Fox, and Kankakee Rivers in 2012. Although wildlife are ordinarily stressed during drought, the dry conditions also indirectly caused the death of roughly 700 deer in the state when they contracted Hemorrhagic Disease. The spread of the disease is worse during droughts because deer are forced to seek limited water sources that harbor the insects carrying the disease. The number of deer lost, however, was not enough to noticeably affect either the overall population or the hunting season. The drought had both positive and negative effects on Illinois birds. Wetland vegetation flourished on the banks of the receded Illinois River, creating a dense cover of vegetation on any bare ground. On one hand, this has made life for shorebirds very difficult, as there is no exposed mud for them to probe for food. On the other hand, however, ducks and other water birds will have a huge amount of food to feast on when water returns to the area.

Groundwater Quality

Illinois currently does not have sufficient ongoing groundwater quality monitoring that might pick up variations in quality during a drought. Recently, McHenry County, with the assistance of the USGS, has installed specific conductance probes into a few of their monitoring wells, which might indicate water quality variations during a drought. However, these probes were not installed until after the 2012 drought. The relatively short duration of the 2012 drought means that there are insufficient data from monitoring programs, such as the IEPA's ambient water quality programs for public supply wells, to statistically validate possible drought-induced water quality changes.

Groundwater quality is generally a function of several processes, including 1) the quality of surface recharge entering aquifers; 2) the quality of recharge from subsurface sources entering aquifers, such as bedrock discharge entering the Mahomet Aquifer (Panno et al., 1994); 3) water-rock-microbial interactions within an aquifer, such as the dissolution of minerals and ion exchange reactions; 4) the effects of high-capacity well pumping which may draw waters of differing qualities into the aquifer or well bore; and 5) groundwater-surface water interactions.

The effects of drought on groundwater quality are difficult to quantify. Probably the primary mechanism for altering water quality in an aquifer is a reduction of natural recharge. Reduction in recharge can either improve or degrade groundwater quality, depending on the quality of the recharge water. Recharge water can either bring in surface-derived contaminants, dilute contaminants already in the aquifer, or both. An example of decreased recharge degrading groundwater quality would be if septic system discharge becomes a greater percentage of recharge water due to less dilution. This kind of relative increase in a contamination source during drought is often observed in surface waters. For example, during the 2005 drought, the water quality of the Illinois River was altered when there was a significant decrease in natural groundwater discharge, but the amount of wastewater effluent discharged to the river, especially in the Chicago region, did not decrease (Kelly et al., 2010). Thus chemical markers of wastewater from Chicago were observed hundreds of miles downstream of the city.

Whittemore et al. (1989) found a relationship between groundwater quality variations in public supply wells in Kansas and the Palmer Drought Index. The predominant effect they observed was that total dissolved solid (TDS) concentrations, primarily sulfate, chloride, calcium, and sodium, slowly increased during droughts due to a lack of diluting recharge. This correlation between drought and groundwater quality was significant only for aquifers with relatively shallow water tables (< 10 meters). Kampbell et al. (2003) reported increased levels of several dissolved constituents, including nitrate, chloride, sulfate, and orthophosphate, in shallow wells surrounding Lake Texoma (on the Red River border between Texas and Oklahoma) during a short-term drought in 2000.

Another potential mechanism that can affect groundwater quality during drought is if lowered water tables expose reducing zones to atmospheric oxygen, leading to the oxidation of reduced minerals or aqueous species. For example, if a pyritic zone is exposed, the oxidation of pyrite can lead to decreases in pH, increases in sulfate, and increases in arsenic (Appleyard et al., 2006). Exposing a reduced zone that had not previously been exposed to oxygen would generally require a significant decrease in the water table and would probably be due to increased groundwater extraction as is typical during droughts.

It should be noted that these potential groundwater quality effects are reported only for unconfined, i.e., water table, aquifers. One would not expect deep aquifers, such as the deep sandstone aquifers in northeastern Illinois, to exhibit any direct effects from drought. Groundwater travel times in these aquifers are measured in decades to hundreds of years, thus the relatively short-term duration of droughts is too short to materially affect them.

Chapter 12. Conclusions

On June 19, 2012, the Illinois Drought Response Task Force (DRTF) was activated with Governor Quinn's approval in response to emerging drought conditions and drought impacts in Illinois. With this action, Illinois became the first Midwestern state to officially designate drought conditions in 2012, with most nearby states following suit in late June and July. Official drought proclamations such as this are expected to occur in Illinois on average once in seven to eight years. They are based on identification of impending drought impacts, or threat thereof, that necessitate a concerted response from relevant state agencies. As with past droughts, the Illinois State Water Survey (ISWS) played a key role for the state in identifying emerging impacts in the early stages of drought development and recommending, by way of the State Water Plan Task Force, a suitable threshold for convening the DRTF.

On July 16, 2012, the National Climatic Data Center prepared a national drought overview indicating that a greater percentage of the conterminous United States was in moderate to exceptional drought (using the Palmer Z short-term index) than in any time since 1956. A substantial portion of the affected United States was located in the Mountain West, Southwest, and High Great Plains, a large region that was geographically separate from the pocket of drought that was affecting Illinois and nearby states. Nevertheless, the "largest drought" soon was translated by many to be the "worst drought since the 1950s," a label that stuck throughout the course of the 2012 drought, regardless of locations affected and extent of impacts. Whereas the "worst drought since the 1950s" classification eventually turned out to be accurate for the epicenter of the western drought (Colorado, Nebraska, and Kansas), where precipitation deficits continued into summer 2013, such a designation was not applicable to Illinois and neighboring states.

Agricultural Impacts

The 2012 drought in Illinois will be primarily identified by its agricultural losses. As reported in Chapter 8, the average corn yield in Illinois was roughly 40 percent below the expected normal, the lowest relative yield since the 1988 drought and the second lowest in the past 50 years. The corn crop was also tainted with high levels of aflatoxins, often requiring blending of the harvest with corn from other regions to dilute concentrations to acceptable levels. The soybean crop fared better, with average yields roughly 10 percent below the expected normal. Although the soybean crop was in poor shape in early August, sufficient precipitation in late August and early September, including that from Hurricane Isaac, provided for substantial recovery of the soybean crop.

Water Resource Condition

The severity of the 2012 drought's impact to Illinois' surface water and groundwater resources varied substantially by location. Central Illinois was most greatly affected, on average representative of a 10-year drought but with several streams and shallow observation wells experiencing their lowest levels on record, most often referring to the past 30 to 50 years. The lowest 2012 water level in Lake Decatur, one of the water supplies most significantly affected by the drought, is representative of a drought event with a 10- to 12-year recurrence. The southern and western Illinois regions also had a few hydrologic observations that were at or near their historical minimums, but on average the regions experienced drought measurements suggestive of a 7- to 10-year event. Water resources in the remaining northern regions of Illinois were generally lightly affected, with a less than 5-year event. All of these observations taken in hindsight, however, belie the seriousness of the drought threat posed to water resources and related impacts (water supplies, environment, and navigation) during the summer of 2012.

Gravity of the Drought During Summer 2012

Through July and August 2012, streams and water supply reservoirs across substantial portions of central and southern Illinois were experiencing conditions that were comparable, at the same stage of development, to the worst water resource droughts of the past 100 years. It is reasonable to assume that historical minimum streamflows, typically associated with the fall season, may have occurred in a widespread manner across Illinois in September or October 2012 had precipitation continued to remain below normal. Lake Decatur, in particular, was on pace and would have been expected to reach low levels similar to what was experienced in 1988. Most reservoir and shallow groundwater levels, on the other hand, would generally not have been expected to reach noteworthy minimum levels unless and until conditions remained relatively dry well into 2013. There are important exceptions, as noted in this report, particularly regarding the reservoir supplies for Decatur, La Harpe, and the Vienna Correctional Center.

The Role of Hurricane Isaac in Truncating the Drought

November turned out to be the driest month of 2012 in Illinois. Furthermore, from September 1 to December 31, 2012, the average observed precipitation in Illinois (12.4 inches) was only 0.2 inches above normal. Without the 3 to 5 inches of precipitation that occurred in central and southern Illinois during the first four days of September, when the remnants of Hurricane Isaac passed over the region, much of those regions would have continued to suffer through a cumulative increase in precipitation deficits through the remainder of the year. Thus, it is contended herein that Hurricane Isaac effectively truncated the drought, singularly bringing about a drought recovery from a water resource condition in which streams, reservoirs, and shallow groundwater would likely have continued to decline through the fall or early winter. Under such a hypothetical scenario (assuming that all continuing climate events were unaffected), the drought would instead likely not have ended until April–June 2013. Given the rarity of tropical storms in Illinois, Hurricane Isaac provided a unique ending to a potentially severe and threatening drought situation.

Detecting Future Droughts and Usefulness of Available Drought Indexes

The U.S. Drought Monitor (USDM) is a highly visible drought index that many agencies and the public access for information to track drought conditions, and the USDM will likely continue to provide a primary information resource for future drought episodes. The Palmer Drought Severity Index (PDSI) is a second drought index, most typically used by climatologists, that is particularly useful for providing historical perspectives regarding drought severity. The two indexes use similar qualitative adjectives in describing drought severity, those being moderate, severe, and extreme drought. The USDM also has a more severe category, that being exceptional drought. Although the two indexes are developed in noticeably different ways, their categorizations are roughly similar; that is to say the USDM "severe drought" and PDSI "severe drought" categories roughly represent events of similar severity and frequencies of occurrence.

In the authors' judgement regarding applications to Illinois drought events, the USDM qualitative categories often appear to convey a shifted perception regarding drought impacts and the associated need for response. For example, one might expect that a USDM "severe drought" would be causing tangible water resource or agricultural impacts to an extent that would demand attention from state authorities. However, in the first chapter of this report it is shown that a USDM "severe drought" instead represents roughly a once in four year event with, at most, isolated impacts; furthermore, at least one region of Illinois has been classified in the USDM "severe drought" category in 10 out of the past 16 years. Instead, events classified by the USDM (or PDSI) within the "extreme drought" category are more closely associated with perceptible impacts and official drought designations in Illinois. Although the USDM "extreme drought" classification could in concept be used as an indicator of official drought in Illinois, its use as such in most cases would result in delayed identification of emerging drought conditions.

The ISWS and Illinois' State Water Plan Task Force have established a reliable record regarding identification of emerging drought conditions in the state leading to official drought designation. Droughts are identified by their specific impacts, not by any given climatic measure or index. Whenever drought conditions begin to emerge in Illinois, the ISWS assesses the potential for tangible impacts to agriculture and water supplies. Such assessments: 1) use near-future projections of hydrologic and agricultural conditions based on the 14-day weather forecast; 2) anticipate drought impacts and specific concerns based on knowledge from prior drought episodes; and 3) incorporate an understanding of seasonal patterns regarding hydrologic response and agricultural growth into longer range projections of associated impacts.

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