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Drought Planning for Small Community Water Systems

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Prepared for the
Midwest Technology Assistance Center

February 2006

Illinois State Water Survey
Office of the Chief
Center for Atmospheric Science
Center for Groundwater Science
Center for Watershed Science
Champaign, Illinois

A Division of the Illinois Department of Natural Resources

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EXECUTIVE SUMMARY

The provision of adequate and secure supplies of clean water at reasonable cost is a cornerstone of social and economic development and national security. Major droughts have occurred in the past and will occur again in the future. Such droughts have two major impacts on small community water systems: water supply is reduced (surface waters and shallow groundwater) and water demand increases. The combination of these impacts can result in major stresses on the ability of water systems to meet demand. Many Western states have experienced widespread and severe economic and environmental impacts of “worst-case” droughts in recent years, and have recognized from these experiences the importance of improved water-supply planning and management, including drought preparedness. However, it is probable that many system managers in the Midwest Technology Assistance Center (MTAC) region have not evaluated their capability to meet water demand during major droughts, nor have in place adequate plans to deal with such emergencies. The MTAC region incorporates the 10 states of Illinois, Indiana, Iowa, Kansas, Michigan, Minnesota, Missouri, Nebraska, Ohio, and Wisconsin.

The goals of this project are:

1) to provide basic considerations for an initial assessment of drought preparedness for small community water systems serving less than 10,000 persons in the 10 states in the MTAC region; and

2) to produce recommendations for conducting drought-sensitivity studies by small community water systems in the MTAC region.

Although most small community water supply systems in the Midwest depend on groundwater supplies for drinking water, many systems also depend on surface water sources, particularly in areas where groundwater supplies are limited. Supplies dependent on surface water and shallow groundwater are highly vulnerable to shortages during major drought periods. Some of the surface water systems obtain water directly from rivers and streams, but, more commonly, reservoirs are constructed to store water from high flow periods for use during periods of flow less than demand.

To ascertain the current drought planning status at the state level and to evaluate how these state plans potentially impact small community water systems, state drought plans were acquired and additional information obtained where formal state drought plans are not available.

To define the extent of potential water shortages due to climate variability the small community water systems first are identified and characterized. Basic data are developed to evaluate the risk of systems experiencing potential water shortages. The evaluation framework is a water budget including reservoir volume, evaporation, reservoir levels, aquifer properties, well-field operations, water withdrawals, and appropriate models. Within the 10-state MTAC region those small systems dependent on surface water or groundwater are identified, as is the general availability of basic systems data necessary to evaluate water availability under various drought scenarios. On the basis of data availability, methods for evaluating water budgets and system adequacies under drought conditions are recommended.

The main contents of the report are as follows:

1. An inventory of contacts and data sources for characterizing small community water systems in the MTC region: e.g. location, water supply, water withdrawal, system capacity, water demand forecasts.

2. Identification and assessment of the availability of climate, surface water, and groundwater data and analytical tools within the MTAC region that can be used to conduct drought analyses.

3. A review of approaches for using real-time climate and hydrological data products to identify the thresholds for potential water supply impacts due to drought:

   a. Analysis of methods used to relate magnitude/duration thresholds of climatological drought to potential surface water and groundwater supply or demand impacts.

   b. Examination of schema used in states in the MTAC regional for relating climate thresholds to water supply impacts in drought watch and drought warning systems.

4. Recommendations for conducting drought-sensitivity studies for small community water systems in the MTAC region.

The report provides a framework for improving drought preparedness planning for small community water systems in the MTAC region. This plan also may be useful in drought-preparedness planning in other regions.

A major finding is that hydrologic droughts in the MTAC region were more frequent and severe in the first 60 years of the 20th century than in the last 40 years. It is recommended that small community water supply operators evaluate the capabilities of their systems to cope with severe and protracted droughts.

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1. INTRODUCTION

The U.S. Environmental Protection Agency (USEPA) defines a public water supply (PWS) system as any system which provides water to at least 15 service connections or 25 people for at least 60 days annually. These systems are further classified by the USEPA based on the population served, the water source, and whether or not the service is provided to the same customers year-round. One of these classifications is a community water system (CWS), defined as a system which provides water to at least 25 people throughout the year. This would include municipalities, nursing homes, and mobile home parks, but exclude systems serving only non-residential uses such as business, campgrounds, and schools. The Midwest Technology Assistance Center (MTAC) provides the resources to focus on community water systems in the Midwest serving populations less than 10,000, many of which have limited resources to respond to drought impacts and other water supply issues. Although the USEPA further classifies these systems as Very Small (25 - 500 people served), Small (501 - 3,300 people served), and Medium (3,301 - 10,000 people served), this report will lump these three classes into one general category, that being the "small" community water system. The MTAC region incorporates the 10 states of Illinois, Indiana, Iowa, Kansas, Michigan, Minnesota, Missouri, Nebraska, Ohio, and Wisconsin (Figure 1-1).

It is the intention of this document to provide useful information and insights about drought to managers and operators responsible for small community water systems. These managers and operators generally focus on issues and problems that are most commonly involved in providing clean drinking water to communities while fulfilling regulatory requirements. They often do not have the resources or time to examine low probability events, like the impact of severe drought on water supplies. However, drought is a force that is likely to impact water supplies at some point during the tenure of a community water system manager/operator in the MTAC region, and so should be given consideration for potential supply impacts. Drought can impact demand also, as water system customers often have increased domestic water requirements in response to a lack of natural rain on their gardens and lawns. Demand impacts are a function of local water system treatment and delivery capacities, and are beyond the scope of this document.

The goals of this project are: 1) to provide basic considerations for an initial assessment of drought preparedness for small community water systems serving less than 10,000 persons in the 10 states in the MTAC region, and 2) to produce recommendations for conducting drought-sensitivity studies by these small community systems. Information is provided about the nature of droughts, drought planning and water regulation resources in the MTAC states, characteristics of drought vulnerable water systems, and some tools and information to help guide drought preparedness planning.

Drought is most simply defined as "abnormal dryness", but, in fact, its accurate definition is more complex. In Section 2, the nature of drought is defined and discussed. The timing of this report coincides with the occurrence of severe drought in parts of the MTAC region. There are some signs that drought frequency in the MTAC region may be returning to a more active regime after a long quiescent period that was punctured only by the famous 1988-89 drought. Because of this long period of relatively benign conditions, most current water system managers/operators have only faced a single major drought or none at all. Therefore, an examination of droughts in the past century will reveal that drought used to be a far more common and severe test of water supply stability, and will provide context for potential future challenges. A specific focus will be given to descriptions of hydrological droughts that last long enough and are severe enough to directly impact the surface water and groundwater supplies used by small community water systems.

Many states in the MTAC region already have some form of statewide drought planning and water regulations that will be activated in times of drought. A general description of state drought plans is given in Section 3. Most of these plans are actually drought response documents, addressing mitigative measures that can be taken after the onset of drought conditions. Only a few state drought plans share insights into drought preparedness measures that can be taken in advance to lessen the vulnerability of systems to drought impacts. Links will be given to copies of drought plans for states that have them available electronically. Current contact information for state drought experts, and other Web links to state water supply regulators and regulations also are provided.

Most small community water systems are supplied from groundwater resources in the MTAC region, although a significant number depend on surface water supplies from lakes, reservoirs, and river. The characteristics of these surface water and groundwater systems will be examined in Section 4, including available information on these resources in the MTAC region that was gathered by contacting state water supply experts. In general, surface water supplies and their relationships to drought are better measured and understood, as they are easily accessible. Less is known about the nature and distribution of groundwater supplies and their vulnerability to drought. Some special case studies of Illinois groundwater supplies are discussed, but similar studies for much of the MTAC region are lacking. Therefore, some fundamental information that would aid in drought preparedness planning is not available, and limits the types of vulnerability analyses that can be performed.

Despite the limitations of information about groundwater systems, there are some general analyses that can be done that are highly relevant to drought preparedness planning, even for locations with limited knowledge of their groundwater supplies. In Section 5, climatological and hydrologic data that can be used to analyze drought are described. Many of these types of data can be accessed through various Web sites which are given, while some of the climate data described will be archived on the MTAC Web portal for later availability. Climate data and stream flow data can be used to assess the historical occurrence of drought in a region, and based on drought probabilities, thresholds of concern can be derived that would activate drought response initiatives as part of a local drought preparedness plan. With more complete geophysical data, the actual vulnerability of surface and groundwater supplies can be examined quantitatively, but the vast majority of small community water systems would not have this information. Instead, most would need to rely on correlating observable indicators of drought in the climatological and hydrologic data with information on responses of the water supply to similar conditions in the past. While this does not substitute for a full vulnerability assessment, it can be a useful part of a small community water system drought preparedness plan.

The document ends with the conclusion in Section 6 that steps can be taken by small community water system managers/operators to better prepare for drought. The establishment of a drought preparedness plan need not be complex, but could simply consist of compiling useful information about state drought plans, state water regulations relevant to drought, and local historical records of the water system supply behavior in previous dry periods and droughts. The compiled records could then be related to the climatological and hydrological information to gauge water supply responses to past dry periods and droughts. This information can be used to establish thresholds or triggers for drought responses, such as watering restrictions. More proactively, if a water system manager/operator finds that water supply was nearly or actually compromised by past droughts and dry periods, this information could be used to support making improvements to the water system infrastructure to reduce drought vulnerability. In this latter case, records of increasing water usage and water supply drawdown due to changes in household, commercial, energy, or agricultural use of water during times with normal water supplies may be juxtaposed with past limitations on supplies during historical droughts. While there might not have been water supply problems in the past during drought, trending water use factors could indicate a potential for water supply depletion during drought unless systems are improved. These issues are easier to raise and discuss with the background and information about drought and small community water systems provided in this report.

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Any opinions, findings, and conclusions or recommendations expressed in this publication are those of the authors and do not necessarily reflect the views of the ISWS, USEPA, or MTAC.

2. DROUGHT AND WATER IN THE MIDWEST - AN OVERVIEW

The climates of the member states of MTAC are quite varied, stretching from the dry steppe of the western Plains to the humid subtropical climate of southeastern Missouri, to the dry and snowy continental climate of northern Minnesota. Throughout the region, a distinctive seasonal cycle of temperature and humidity prevails, with maxima reached in summer, and minima during winter. Precipitation also reaches its seasonal peak in the warm season in most of the region, although there are some locations that shade this peak toward the spring or fall, and a distinct zone downwind from the Great Lakes that has a primary or secondary peak in late fall or early winter. On an annual basis, precipitation totals decline from south to north and east to west across the region. The 1971-2000 normals for precipitation vary from nearly 50 inches in the Missouri boot heel, to less the 20 inches in northwestern Minnesota, and less than 15 inches in western Nebraska. The majority of the MTAC region receives 30-40 inches of rain annually (Figure 2-1).

As part of the climate in the interior continental U.S., substantial variations from normal conditions can take place within and between seasons and years. In the MTAC region, distinctive features of the atmospheric circulation, such as the subtropical high during the warm season and the polar-front jet stream during the winter, are impacted by remote events in the climate system. For instance, oceanic sea surface temperatures in the Pacific and Atlantic Oceans can alter large scale atmospheric flow patterns over North America, and make portions of the region wetter or drier and warmer or cooler than normal. Most of these variations are not predictable ahead of time, and some are severe enough to test the resiliency of small community water systems through the occurrence of droughts. Droughts can be defined over many time scales and functional impacts, but generally refer to events when water availability is depressed and water demand is enhanced compared to normal conditions at a given place and time of year, leading to impacts on the environment and society. In the following section, the nature of drought in the MTAC region is examined, and the characteristics of drought that lead to impacts on small community water systems are assessed.

2a. Meteorological Drought

Drought Time Scales

Droughts often are defined through various combinations of time period and intensity of precipitation deficits that are found to be associated with some impact on nature or society. Therefore, the definition of drought can be quite varied, depending on the particular area of concern being addressed. The simplest way for a drought to start in the Midwest is for there to be an unusually long period without significant rain, or a dry spell. In most cases, though, even as a location accumulates a precipitation deficit compared to normal, there are embedded precipitation events, and it takes a period of months for a drought to develop. Processes of evaporation from surfaces and transpiration from plants, governed largely by temperature, also will affect the rate of drying of an environment. In fact, a variety of drought indices and soil-moisture models have been developed for use in agriculture and water management that incorporate both precipitation and temperature information in one value. The most famous of these are the series of Palmer drought indices developed by W.C. Palmer in the 1960s and based on water-balance considerations. A number of these more complex drought indices can be substituted for precipitation deficits in the discussion below.

Short-term droughts are defined as periods with significantly below-normal-precipitation amounts for periods of months. These short term droughts often are called meteorological droughts, because weather observations are used to define their start and end points, and their severity. A variety of precipitation-deficit thresholds can be defined, based on the statistics of precipitation for a location over its period of record for weather observations. Drought always is defined in the context of local history, as it is an anomaly from normal conditions. A desert is dry, but it is not "in drought" more often than the Midwest.

The most common and important impacts of short-term drought involve agriculture and domestic water use. During the growing season in regions like the Midwest with non-irrigated crops, agricultural and meteorological droughts often are synonymous terms. A shortage of precipitation (meteorological drought) leads to a shortage of plant available soil moisture (agricultural drought). Short-term droughts also impact natural environments, and, depending on the intensity of drought, also can be responsible for increased wildfire hazards. Economic dislocations can be felt in the tourism industry, if the meteorological drought takes place during winter in the northern Great Lakes winter outdoor-recreation belt. The most pressing concerns regarding short-term droughts for water managers are two fold: a) the short-term drought may mark the beginning of a long-term drought or the intensification of an existing long-term drought that may impact water supplies; or b) the short-term drought may increase demand for water usage from systems that may not be designed for extensive lawn-irrigation and pool-maintenance requirements. In the latter case, short-term drought is more important as it relates to water-system capacity as opposed to water resource capacity.

Long-term droughts are defined as extended periods of below normal precipitation lasting many months or even years. Long-term droughts often are referred to as hydrologic droughts, since long dry periods with significant precipitation deficits can lead to measurable reductions in lake, stream, and groundwater levels compared to seasonal normals. Hydrologic droughts, therefore, are capable of directly impacting the water supplies of small community water systems. Other noteworthy impacts cascade from hydrologic impacts, including energy production (cooling towers, ethanol production, coal cleaning, hydroelectric power generation), manufacturing (cooling, processing, waste disposal), barge transportation capacity and navigation, recreational use of water bodies, and many others. In the last 100 years in the Midwest, hydrologic droughts have lasted as long as 5 years at least twice, while in the past 1000 years, environmental indicators have revealed megadroughts that lasted for a decade or more (Stahle et al., 2000). The longest megadroughts are highly unusual but quite real possibilities that often are beyond the realm of planning for a small community water system. However, given the size of the 10-state MTAC region, the odds of a 1, 2, or even 5-year drought starting at some location in a given year are quite reasonable, and must be accounted for in water-supply planning. These long-term droughts will be the focus of this report.

Precipitation deficits often are referenced directly in native units such as inches at a particular location, but if one wants to examine drought over a large area like the MTAC region, these values must be given in terms that are comparable from place-to-place. The spread of annual climatological normals from 50 inches to 15 inches means that although a 10 inch annual deficit might be 20% of the expected total for southern Missouri, it would be more than 66% of the expected total in the environments of the western Plains. Therefore, ratios or percentages are often used in establishing thresholds of precipitation deficits corresponding to droughts of varying severity.

Another useful manner in which to describe a precipitation deficit is as a percentile, which is the chance of a certain level of precipitation occurring over a certain time interval. For example, a 12-month precipitation amount that is larger than 90% and smaller than 10% of all 12-month totals in history for a location is said to be at the 90th percentile, while a value at the 30th percentile is larger than 30% and smaller than 70% of the annual precipitation values over time. The primary advantage of percentiles is that they can be calculated for a variety of different drought indicator variables to facilitate their comparison in standard percentile units.

The U.S. Drought Monitor (USDM) map (http://www.drought.unl.edu/dm/monitor.html) is the principal method for disseminating the current status of drought in the United States, and utilizes percentiles to assist in determining drought classes. The 30th percentile is the beginning level for the abnormally dry class, D0, which runs from the 20th to 30th percentile. Moderate drought, D1, begins at the 20th percentile and covers the range from the 10th to 20th percentile. Severe drought, D2, covers the range of percentiles from the 5th to 10th percentile. Extreme drought, D3, is very rare, happening less than 5% of the time, and ranges from the 2nd to 5th percentile. Exceptional drought, D4, is the most rare of events, including those precipitation values that occur less than 2% of the time, or below the 2nd percentile level.

The USDM map attempts to represent a blend of both short-term and long-term drought conditions. For example, during much of the summer of 2005, northern and western Illinois were dominated by an extreme drought (D3) that at times extended into eastern Missouri, eastern Iowa, and southern Wisconsin. This was primarily an agricultural drought during the summer. However, as dryness continued during the fall (Figure 2-2), the Midwest drought was beginning to be of sufficient length and severity to have distinct impacts on lake, reservoir, stream, and groundwater levels, thus developing into a hydrologic drought. The USDM will be discussed below in the Tools and Information section of this report. Further exploration of the MTAC region precipitation deficit statistics will lead to useful definitions of hydrologic drought in the next section.

Precipitation Drought Frequency and Magnitude

One set of planning tools that water resource managers and others may find useful are maps and tables of the percent of normal precipitation expected during droughts at selected return periods and durations. The advantage of a return period, or frequency, analysis is that it assigns a degree of likelihood to the precipitation deficit. This allows users to choose the level of protection from drought in their planning and operations. There is one misconception about using return periods. A 100-year return period value is the amount of precipitation expected once every 100 years *on average*. The actual time interval between two droughts of such magnitude will vary because what is really expressed in a 100-year return period is the amount of precipitation with a 1 percent chance of occurring in any given year. Therefore, after a 100-year return period event, one does not have to wait a full 100 years for the next event. It has a small chance of occurring in any year.

The return period analysis was developed from 360 long-term, reliable stations in the ten-state MTAC region, supplemented by 53 stations in Kentucky, North Dakota, and South Dakota. These stations have more than 90% of data available for the 1900-2000 period. For each station, the ten driest 12-, 18-, 24-, 36-, 48-, and 60-month periods were separated on either side by a 6-month buffer to ensure that independent droughts were being sampled. Dryness for each duration was determined as a percent of normal precipitation, with normal defined as the 1971-2000 average. The resulting drought time series for each site was then fitted to a three-parameter Generalized Extreme Value distribution using the L-moments approach. By fitting an extreme-value statistical distribution through scattered data points, the expected precipitation amounts at specific return periods can be estimated reliably. Applying the typical limitation in frequency analysis of not assessing return periods more than double the period of record, the analysis stops at the 200-year return period because the record length was approximately 100 years.

The results of this analysis can be found in the set of tables by state (see tables in Appendix A) and maps spanning durations of 12, 18, 24, 36, 48, and 60 months and for return periods of 25, 50, 100, and 200 years (see figures in Appendix A). It is up to the user to determine the appropriate level of drought for planning purposes, both in terms of duration and frequency. This decision can be made on the basis of the frequency of past experiences with drought related water system inadequacies, or by selecting as the threshold the precipitation departure known to have caused water system difficulties in a past year. The differences across the region in this series of maps were minimal because the results are expressed as percent of normal, a number that is relative to the normal precipitation of a site. As a result, average values for each state were calculated and may be simpler to apply than selecting values from the maps. As expected, the percent of normal precipitation values are most severe for the shorter durations of drought. However, the less severe percent of normal precipitation values at the longer time scales may prove to be more taxing to the water supplies for water systems of a region due to their cumulative effect.

2b. Hydrological Drought

Other than precipitation, streamflow is the one hydrologic variable directly related to drought that has been measured using consistent methods across the Midwest over the past 70 years or more. There are few and incomplete records from state-to-state concerning how many and to what degree small community water supplies were impacted by any given drought (and these would be qualitative in nature, at best). Other significant measures of drought impact, such as groundwater levels and surface water levels at water-supply reservoirs are not available uniformly, are inconsistent, and typically have much shorter periods of record. There is no groundwater level observation network comparable to the streamgaging network of the U. S. Geological Survey (USGS). Most states operate their own observation well networks, for a multitude of purposes, measured across a wide range of frequencies, in a variety of aquifers and non-aquifers (including confined and unconfined systems), and few records extend beyond 50 years. Such water level data also may incorporate impacts not wholly a result of climatological conditions (e.g., impacts from reservoir operation strategies or groundwater withdrawals). Further, groundwater level declines are not always correlated directly to water supply, except for the shallowest of wells. Finally, stream base flow is closely related to groundwater levels. For these reasons, the analysis of streamflow records was considered to be an efficient manner to evaluate the impacts of historical droughts on the water resources of the 10-state MTAC region. Knowledge of the hydrological impacts of historical droughts can then be used to characterize and identify potential impacts of droughts on water supplies in the Midwest.

Available Data

Appendix B provides a list of 159 streamflow records from USGS stream gages that were selected for use in describing drought impacts on streamflows in the Midwest. These gaging station locations are shown in Figure 2-3. Two basic criteria were used in selecting these stations: 1) the streamflow record must be at least 50 years in length, which is needed to realistically estimate drought frequencies and record droughts; and 2) the streamflows at these gages must be considered to have relatively little impact from human activities and water-resource projects. To meet the second criterion, stations were selected from the Hydro-Climatic Data Network (Slack and Landwehr, 1992), a set of streamgaging stations with relatively low human impact that were developed by the USGS for potential analysis of climate impacts on streamflow. A few additional stream locations in North Dakota and South Dakota that otherwise meet the selection criteria were added to provide better spatial coverage of flow characteristics of streams in the westernmost fringes of the MTAC region.

Long-Term Mean Flow Characteristics in the Midwest

The long-term mean flow rate at any stream location is a function of the climate characteristics of the area (watershed) drained by the stream, with the average annual precipitation amount being the most important variable. For a given climate condition, the mean flow rate for a stream usually is directly proportional to the watershed size; i.e. the larger the drainage area, the greater the streamflow. In areas where there is significant lateral movement of groundwater, hydrogeologic factors may also impact the long-term mean flow rate, but few gaging locations selected for analysis in this study are affected significantly in this way. Streamflow rates at gaging locations in the United States usually are expressed in units of cubic feet per second (cfs). To assist in the comparison of flow characteristics between two streams of different watershed size, the long-term-mean flow rate also is expressed here in units of cfs per square mile of drainage area. Mean flow rates are determined using the entire period of record at each gaging station, and thus do not correspond to a particular 30-year climate average.

Figure 2-4 shows the geographic distribution of the long-term-average streamflow across the Midwest region. As can be seen, there is a consistent increase in the mean flow rate (per square mile) from the western edge of the region to the eastern edge, which reflects the general increase in average annual precipitation described earlier. For example, the mean flow rates for streams in Ohio typically are more than 3 times greater than for streams in Kansas. From the perspective of water-supply yield, this means that a much larger watershed area is needed in the western portion of the 10-state region (compared to the eastern portion) to produce a given amount of streamflow.

Historical Droughts of the Past Century

Water supplies in the Midwest have been impacted by numerous droughts over the past century; among these being the droughts of 1914-1915, 1931-1934, 1940-1941, 1953-1958, 1963-1964, 1976-1977, 1988-1989, and 2000-2001. Of these, the three droughts that have had the greatest overall impact to Midwest water resources have been the droughts of 1931-1934, 1953-1958, and 1963-1964. Figure 2-5 identifies the hydrologic drought of record across the 10-state Midwest region, as determined from streamflow records. Other droughts may have produced the lowest instantaneous or short-term flows at individual stations, but the three droughts shown in Figure 2-5 consistently provided the lowest average flows over drought periods extending for periods longer than 6 months.

The hydrologic drought of record for roughly two-thirds of the Midwest region was the 1953-58 drought, which for many locations was particularly severe and persistent. In the northern and eastern portions of the Midwest, the 1931-1934 drought or the 1963-1964 drought are the droughts of record. Although the 1963-1964 drought is considered to be the drought of record for much of Michigan, it is noted that there were very few stream gages operated in Michigan during the 1930s, such that the 1931-1934 drought could not be evaluated for much of this region.

From a climatological perspective, the 1930s drought period often is considered the drought of record for the Central U.S., and the summertime heat and short-term deficits in precipitation during the 1930s are well documented. Conditions during the famous Dust Bowl years were especially severe in the western portions of the MTAC region. However, the persistence and duration of the 1950s dry conditions clearly make it the dominant drought in terms of hydrologic impacts related to both streamflows and water supply in the central and eastern portions of the MTAC region.

Susceptibility of the Midwest Region to Short-Term Periods of Low Flow

There is a substantial variation across the Midwest in the response of streams to short-term drought conditions lasting 6 months or less. Some streams are very sensitive to dry conditions, falling relatively quickly to very low flow conditions, whereas the flow amounts in other streams never seem to vary much and are comparatively insensitive to drought. The sensitivity of surface-water supplies to drought is dependent not only on the frequency and severity of droughts, but also on possible connections between groundwater and surface waters that are controlled by surficial geology, topographic position, and other watershed characteristics. The ratios between the average flow during the 6-month drought of record (M6,R) and the long-term-mean flow (Qmean), shown for the 159 gaging stations in Figure 2-6, provide a good indication of the extent to which groundwater can provide sustainable low flows on a stream, even during cases of severe drought. For example, the 6-month record low flow for many stream locations in Michigan and Wisconsin is more than 35% of the long-term mean flow of the streams. These high values are indicative of streamflow regimes in which groundwater provides the predominant portion of flow in the stream. In contrast, the 6-month record low flow for most locations in the Midwest that lack a strong ground/surface-water connection typically is less than 5% of the long-term-mean flow.

Table 2-1 gives the average value of the M6,R to Qmean ratio for all gage locations in each state. This ratio is particularly high for Michigan and Wisconsin for the reasons noted above. Missouri has the third highest average ratio, primarily because there are a substantial number of streams in the Ozark Mountains region of southern Missouri fed by springs in the water-storing karst geology. The average ratio for all streams in Nebraska, South Dakota, and North Dakota is combined. Although the ratio for many locations in these states is low; there is a sizable area in central Nebraska and southern South Dakota, typified by the Nebraska Sand Hills region, where there is a strong connection between shallow groundwater and streams causing high levels of baseflow.

Streams that have a high groundwater contribution to low flows also have a high potential to act as a water-supply source, since they have sustainable flows during drought periods. However, such areas rarely use their streams for water supply, unless a particularly large quantity of water is needed, because they also have plentiful groundwater resources.

In contrast, streams that have a low amount of groundwater contribution typically also will lack sufficient shallow groundwater resources for use in water supply. Thus, unless there is a deeper aquifer from which to obtain potable water, water-supply systems in these regions historically have constructed reservoirs to store water for use during periods of extended low flow.

Susceptibility of the Midwest Region to Long Periods of Sustained Low Flows

All areas of the Midwest experience seasonal periods of below-normal precipitation that cause low flows in streams. But there is considerable variation in the susceptibility across the region to sustained low flows lasting a year or longer, which is related to the potential for long periods of sustained precipitation deficits. Figures 2-7 to 2-11 provide average flows during record drought periods of successively increasing duration. In all cases, the flow amounts are expressed as a ratio between the average flow during the drought period and the long-term mean flow for each gaging station. Table 2-2 gives statewide averages of the ratio of drought flow to long-term-mean flow for 8 different drought durations, lasting from 12 months to 54 months.

Twelve-month and 18-month record droughts. Note that in the eastern portion of the MTAC region, in Ohio and Indiana, the average flow during the record 12-month drought (Figure 2-7) is typically much higher than that for the record 6-month drought (Figure 2-6). This indicates that for the eastern portion of the MTAC region, water-supply planning typically may need to be concentrated on drought periods of less than one year. This suggests that streamflow amounts, reservoir levels, and groundwater levels that determine the base flow to streams in these regions can be expected to rebound during the wet (winter and spring) season, even in dry years.

In contrast, for southern Illinois and most of the regions west of the Mississippi River, the average flow for the record 12-month drought is still a relatively smaller amount, being less than 10% of the long-term-mean flow. For most locations, the flow value for the 18-month drought (Figure 2-8 and Table 2-2) is similar in magnitude to the 12-month value. For some stations the 18-month flow is actually less than the 12-month flow because it represents the average flow spanning two dry (summer and fall) periods. The key component to the occurrence of an 18-month hydrologic drought, or any multi-year drought, is having a dry winter and spring such that there is insufficient rebound in streamflow, reservoir, and groundwater levels from the previous summer and fall.

The states of Michigan and Wisconsin, in addition to having streams that commonly have sustained low flows from connections with groundwater, also are relatively unaffected by drought periods lasting 12 months or longer.

Record droughts longer than 24 months. With longer drought durations, there is increasing contrast in the hydrologic impacts between the western and eastern portions of the Midwest. Figures 2-9, 2-10, and 2-11 along with Table 2-2 show that Kansas and other states in the western portion of the Midwest typically can experience periods of low streamflows lasting many years, with average flows less than 10% of the long-term mean. Although the present analysis stops with drought durations of 54 months, it is apparent from the low-flow values in Table 2 that the record droughts of the 1950s across the Great Plains likely lasted longer than the 54 months shown in Figure 10. Thus, in the western part of the region, not only is the long-term-mean flow rate less than in the east, the duration of below-normal flows during drought is greater, and the surface storage capacity needed to provide reliable water supply during drought is increased by several magnitudes. Although there are also regions within Illinois, Iowa, Minnesota, and Missouri that have experienced extended periods of low streamflow lasting 30 to 54 months, average flows over these longer durations typically in the range of 20 to 40% of the long-term mean.

Another way of looking at the difference in the duration of drought impacts across the Midwest is to look at the maximum period in which the average flow remains below a certain threshold level. For example, Figure 2-12 shows the number of months in which the average flow was less than 20% of the long-term mean. Streamflows in Michigan and Wisconsin rarely are less than 20% of the long-term mean for much more than 6 months, if ever. Record droughts in Indiana and Ohio have average flows less than 20% of the long-term mean for only 12-18 months. In contrast, Illinois, Iowa, Minnesota, and Missouri can have extended low-flow periods of 24-48 months, and the Great Plains have extended low-flow periods of 54 months or longer. Therefore, Illinois, eastern Iowa, and eastern Minnesota represent areas where there is a significant east-west transition between short-term and extended period low-flow behavior.

Relationship of Drought Frequency to Hydrologic Impacts

In addition to the magnitude of previously observed record droughts or conceivable worst-case droughts, another factor in water-supply planning is the frequency with which droughts of various magnitudes impact water supplies. Figure 2-13 provides information on drought frequency for three gages representing a west-to-east transect across the MTAC region: Blackwater River at Blue Lick in western Missouri; the Little Wabash River below Clay City in southeastern Illinois; and Ohio Brush Creek near West Union in southwestern Ohio. All three streams have roughly similar low-flow characteristics for the short-duration, 7-day low flows in terms of their ratio to the long-term-mean flow.

For the drought-frequency plot for the Ohio Brush Creek, the 10- and 25-year droughts and the drought of record are roughly similar in magnitude. The drought-frequency plots for the Blackwater River and the Little Wabash River are fairly similar, but with two major differences. First, the ratios of the drought of record to the long-term-mean flow for Blackwater River are significantly less for durations greater than 36 months. Second, for the Little Wabash River there is a considerable gap between the 10- and 25-year droughts and the drought of record, particularly for the 12- and 18-month durations. In this case, even though the 25-year drought typically is considered a severe drought condition, the flows for the 25-year drought still are 4 to 5 times greater than the expected flows during the drought of record. For water-supply planning this is notable because streamflow records of moderate length, such as 30-years, could be woefully inadequate for describing conditions during a drought of record or worst-case-drought scenario. In addition, when the 10-year and 25-year droughts are not sufficiently severe to threaten water supplies, there may be an increased likelihood that there will be complacency in planning for the worst-case drought, leaving a community unprepared to handle the extreme drought condition.

3. STATE DROUGHT AND WATER PLANS

All 10 states in the MTAC region have some recognition of drought as a natural hazard that requires planning. Seven states have written drought or water-shortage plans: Illinois, Indiana, Kansas, Minnesota, Missouri, Nebraska, and Ohio. The remaining states of Iowa, Michigan, and Wisconsin have drought response as a component of a state water plan (IA) and a state all-hazard plans (MI, WI). The scope of these plans ranges from responding to drought impacts alone, to developing pro-active drought impact avoidance policies based on stakeholder inputs, economic surveys, and the analysis of previous droughts. Most states with written drought plans augment these with additional ad hoc activities at the time of crisis, as most written plans are not updated regularly. Finally, some drought-related emergency-action authorities also are found in state water law and regulations.

For the control of water resources and water systems, considerable amounts of legislation, regulations, and policy documents have been written by MTAC states. Most of these statutes and polices govern PWS systems in normal times, and only a few specifically address threats to water-system supplies or delivery capabilities in times of drought. Even if drought or other causes of water shortages are not mentioned explicitly, a review of these materials is useful to understand the juxtaposition of water laws and regulations with drought. Some state drought plans also reference water statutes and regulations directly, or have been authorized by legislation. In the following sections, state drought plans and water regulations will be discussed in the context of drought.

3a. State Drought Plans in the MTAC Region

Drought planning is an important aspect of general natural-hazard preparedness and water-supply planning in the Midwest. However, drought plans tend to be created or updated only in the shadow of a substantial drought, be it the 1980 drought (e.g., Illinois Drought Contingency Plan, 1983), the 1988-89 drought (Indiana's Water Shortage Plan, 1991), or the recent forays of the long-lasting Western drought (1999 to present) into the western MTAC region (Missouri, 2002; and Kansas, 2003). While Nebraska started revising its drought plan before the major 1999 drought, the impetus of that drought led to rapid completion of the new plan. The cluster of three plans in the early 2000s period was related to a strong drought situation, and to the release of the National Drought Policy Commission report on "Preparing for Drought in the 21st Century," which had the effect of encouraging drought-plan development (http://govinfo.library.unt.edu/drought/finalreport/accesstoreports.htm). Support also was provided by the National Drought Mitigation Center (NDMC) in Lincoln, Nebraska, which has become the major clearinghouse for expertise in drought-preparedness planning in the United States (http://drought.unl.edu/).

Drought-plan development requires adequate levels of time and resources, and is seemingly difficult both in states with extensive water laws and regulations (like in the West), and states with little legislative control on water supplies (like in the East). A typical approach involves an iterative process between government and stakeholders which leads to a clearly purposed document with public support. Donald A. Wilhite, Director of the NDMC, and his colleagues describe this process well in “Drought Preparedness Planning: Building Institutional Capacity” (Wilhite, et al., 2005; http://drought.unl.edu/plan/handbook/10step_rev.pdf). A thorough drought plan also is proactive, identifying vulnerabilities and correcting or mitigating them prior to a drought emergency. The American Water Works Association (AWWA) published an even more targeted Drought Management Handbook (AWWA, 2002) that provides step-by-step directions for preparing a drought plan for a community water system. Finally, the Great Lakes Commission produced a document that, even though containing some out-of-date contacts, provides very useful advice for community water planning in the northern part of the MTAC region (Great Lakes Commission, 1990). While it is important for managers of a small community water system to be aware of a state drought plan and follow state water regulations and laws, it would be beneficial for managers also to take proactive steps of their own to plan for drought on the local level.

Available state drought plans are listed in Appendix C. The documents available as of September 2005 have been archived in the MTAC Web site, and links are given in Appendix C that will enable small community water system managers to contact state drought personnel for future updates. While there are unique climatological, historical, and legislative backgrounds reflected in each drought plan, some common features arise.

Almost all state drought plans begin by specifying the reasons for drought planning, which usually relate to the improvement and normalization of procedures for mitigating drought impacts after a drought has started. A definition of drought usually follows, and in some cases a fairly specific set of climate indices are discussed. However, these climate indices often are not action “triggers” by themselves, but are used to track drought status over time. Usually, a drought requiring action is defined by the onset or predicted onset of actual impacts on economic, environmental, or social systems. Thus, the next step specified in a drought plan, convening a drought-response task force or committee, is usually an ad hoc decision of a few high ranking officials, as advised by their staff.

At this stage, most drought plans suggest the drought-response group shares information across state agencies and coordinates any responses that are required, including the dissemination of information to the public. It is at this time that any water-system impacts would be reported, as well as actions taken to aid water systems in distress. Many of these actions would have been performed unilaterally by a department of water resources following existing statutes and regulations, or emergency orders from the Governor, but the drought response group would allow for discussion and planning for future statutory steps. After activation of the drought response group, regularly scheduled meetings are held to gather information, inform the public, and coordinate actions until the drought impacts are over. The drought plan usually requires the establishment of drought stage or phase at each meeting, although some drought plans do not specify these stages. The public continues to be informed, and appropriate actions taken as a drought intensifies, and then ameliorates. A final and very important step that only some plans include would be for the committee members to meet at the end of the drought and review their performance under the existing plan. Recommend revisions and improvements to drought plans and procedures would be implemented, to be utilized in the future.

The role of the manager of a small community water system would be two-fold under a state drought plan: 1) following established reporting procedures to inform the state through the appropriate water agency of any problems and actions regarding water supplies or system capacity; 2) follow state advisories and orders regarding voluntary and or mandatory water-use restrictions and emergency procedures. Therefore, in addition to reviewing the drought plan relative to their state, a number of statutes and regulations directly related to water-shortage situations also are highly relevant in preparing for drought; these will be reviewed in the next section. State drought information sources and contacts are given in Appendix C, Table C-1; sets of drought and water regulatory Web links for each MTAC state are located in Tables C-2 through C-11; related links to the USEPA are in Table C-12.

3b. Public Water Supply (PWS) Regulation and Information

State Information Sources and Contacts

The state agencies involved in PWS system regulation and information are listed in Table 3-1. These agencies were contacted to request information on community water supplies, drought impact studies, and methods for evaluating adequacy of water supply systems during drought conditions.

The primary agency responsible for PWS regulation is not always the agency responsible for water resource investigations, specifically drought studies, within their state. For example, in Nebraska, the Department of Health & Human Services is responsible for the regulation of PWS systems, while the Nebraska Department of Environmental Quality is responsible for clean water (water quality) issues, and aquifer and other technical information would be available from the Nebraska Department of Natural Resources. In situations such as this, additional requests were made to these agencies and their web sites are listed in Appendix C.

Relevant State Regulations

The focus of the federal Safe Drinking Water Act (SDWA) is to protect drinking water and its sources. Individual states may have additional legislation defining the powers and duties of PWS agencies and describing the enforcement of the federal drinking water rules and regulations. Internet links for the relevant regulations for each state are provided in Table 3-2.

The 1996 Amendments to the SDWA require each State to develop a program to assist existing PWS systems in acquiring and maintaining technical, financial, and managerial (TFM) capacity. Source-water adequacy is clearly a component of technical capacity, but TFM capacity programs offer little to no guidance regarding drought analysis. Duration and intensity of water shortages to consider typically are not specified.

State Studies that have Examined PWS Adequacy

When contacted for information regarding adequacy studies, five of the ten states indicated they were not aware of any studies conducted to assess the adequacy of PWS systems in their state. During or shortly after periods of drought, three of the states conducted informational surveys of individual systems to gage their capacities. Within the MTAC region, Illinois and Missouri appear to have performed the most comprehensive drought analyses of surface-source PWS systems. The Illinois State Water Survey produced a series of reports in 1989 and 1990 investigating the adequacy of surface-source PWS systems in Illinois, including small community systems (McConkey-Broeren et al., 1989; McConkey-Broeren and Singh, 1989; Singh and Durgunoglu, 1990; and Singh and McConkey-Broeren, 1990).

In Missouri capacity studies were done as a result of the 1988 drought for systems with low reservoirs. The work was contracted by the Missouri Department of Natural Resources to the Natural Resources Conservation Service (NRCS) and USGS. Bathymetric surveys were conducted by the USGS for several water supply reservoirs. The NRCS reservoir operations computer program (RESOP) was then used to evaluate remaining storage in each reservoir.

Several of the remaining states reported that this type of analysis is typically the responsibility of the individual system and the engineering firm hired by that system, while the state agencies offer assistance as needed.

4. CHARACTERISTICS OF MIDWEST COMMUNITY WATER SUPPLIES AND DROUGHT IMPACTS

The USEPA defines a PWS as any system which provides water to at least 15 service connections or 25 people for at least 60 days annually. The systems are further classified by the USEPA based on the population served, the water source, and whether or not the service is provided to the same customers year-round. One of these classifications is a community water system, defined as a system which provides water to at least 25 people throughout the year.

Small water systems tend to have limited resources with which to respond to drought impacts and MTAC has provided the resources to focus this study on those systems serving populations less than 10,000. These systems include those in the USEPA classifications of Very Small (25 - 500 people served), Small (501 - 3,300 people served), and Medium (3,301 - 10,000 people served).

An overview of the types of community water systems located in the 10-state MTAC region are presented in Tables 4-1 and 4-2. This information for active systems serving populations less than 10,000, obtained from the USEPA Safe Drinking Water Information System (SDWIS) web site, clearly shows that small community water systems in the Midwest are predominantly supplied by groundwater, ranging from 60% of all systems in Kansas to 98% of all systems in Wisconsin.

While it is increasingly common for water systems to utilize both surface and groundwater sources, the water systems are classified by the source most vulnerable to contamination and requiring the most treatment. Surface water systems are most vulnerable to contamination, followed by groundwater systems under direct influence of surface water (GWUDI), while groundwater (GW) systems are considered the least vulnerable to contamination. If a system utilizes a surface water source, even for only 30% of its total water supply, the system would still be classified as a surface water (SW) system.

4a. Surface Water Supply Systems

Available Inventories/Data on Small Community Water Supply Systems by State

Requests were made to each of the agencies listed in Table 3-1 for inventories of their surface water systems. Data was extracted from these inventories for surface water systems serving populations less than 10,000. Those systems purchasing water were not included because they are typically purchasing from systems with greater capacities with a larger, more drought resistant source. The geographic distribution of surface water systems serving less than 10,000 persons in the Midwest is displayed in Figure 4-1, and the total number of these systems is summarized by state in Table 4-3.

Classification of Surface Water Supply Systems

Surface water systems were further classified according to their source water type, in part to better describe the potential vulnerability of these systems to drought. A small system withdrawing water from Lake Michigan will not be as drought susceptible as a small system whose only source is an aging reservoir with decreasing capacity.

The categories used for this classification were as follows: (1) major river (Mississippi, Missouri, or Ohio Rivers), (2) direct withdrawal from a river/stream , (3) river/stream with a low channel dam, (4) off-channel reservoir, (5) impounding reservoir, (6) quarry or borrow pit, (7) Great Lake or Great Lake connecting channel, (8) natural/glacial lake, and (9) a combination of sources. A system was placed in the last category only if the system's multiple sources were operated in such a way that no single source was the primary or predominant water source.

If a system did not specifically identify its water source but rather labeled the source as only "reservoir" or "stream", certain assumptions were made. A system identified as a reservoir, without indication whether it was in-channel or off-channel storage, was classified as an impounding reservoir. Systems identifying their source as a river, creek or stream were classified as direct withdrawals, unless the presence of a low channel dam was specifically mentioned.

The results of this classification, presented in Table 4-4, clearly indicate the type of surface water systems commonly used varies within the MTAC region. The three northernmost states (Michigan, Minnesota, and Wisconsin) utilize the Great Lakes and the Great Lake Connecting Channels, such as the St. Clair River and Lake St. Clair, to supply many of their surface water systems. To meet their surface water needs, Ohio uses a large number of up-ground reservoirs (off-channel storage), many of which were constructed as a result of a drought in the early 1960s. Indiana, Illinois and Missouri all utilize man-made reservoirs (both in-channel and off-channel) to supply the majority of their small surface water systems.

4b. Groundwater Supply Systems

Midwest Aquifers

Across the MTAC region, community groundwater supplies are derived from a wide variety of aquifer types. Heath (1984) broadly classified groundwater regions of the U.S.; detailed descriptions of the aquifer systems found across the U.S. were presented by Miller (2000). Across the Midwest, aquifer systems can be generally categorized as shallow and deep sand-and-gravel (unconsolidated) aquifers and shallow and deep bedrock (consolidated) aquifers. For purposes of this report, shallow aquifers are considered to be less than 100 feet deep.

Sand-and-gravel aquifers are the result of glacial deposition or are found as alluvial deposits within the valleys of modern river systems. Across the MTAC region, sand-and-gravel aquifers may be less than 10 to several hundred feet thick. They may occur at the land surface (surficial aquifers) or be buried beneath 100 feet or more of glacial overburden or fine-grained alluvium. Surficial aquifers typically are unconfined and water levels in wells completed in these aquifers reflect water table conditions. Because of their direct connection to land surface, recharge to these aquifers is dependent upon infiltrating precipitation, and, therefore, these aquifers are susceptible to drought. Deeper sand-and-gravel aquifers, confined beneath deposits of finer-grained materials, largely depend upon recharge as slow leakage from overlying deposits, and thus are less sensitive to drought as long as the overlying source beds can furnish water to the underlying aquifer systems.

Sand-and-gravel aquifers are encountered throughout the MTAC region. Yields of wells in sand-and-gravel aquifers are highly variable, from ten gallons per minute (gpm) or less to over 1000 gpm. Well yields are dependent upon the water- transmitting ability of the formation, which is largely a function of pore size and pore interconnectedness. Extremely large well yields (1000+ gpm) are common in thick, very coarse-sized, deposits. Where deposits are thin or composed of fine sands, well yields may not exceed 10 gpm. Well-known sand and gravel aquifers within the MTAC region include the High Plains aquifer of western Nebraska and Kansas, the Mahomet aquifer of east-central Illinois, and the Miami aquifer of southwestern Ohio. Sand-and-gravel aquifers probably provide the greatest proportion of water to small communities, principally because they can be tapped economically and are capable of supplying adequate amounts of water for the typically smaller demands of communities less than 10,000 population.

Bedrock aquifers also occur all across the Midwest, and like sand-and-gravel aquifers, are highly variable in their ability to yield water to wells. Yields of crystalline and carbonate bedrock aquifers depend on fracture density and secondary porosity developed along fractures. Bedrock aquifers range in type from fractured crystalline rocks (such as occur in northern Minnesota, Wisconsin, and Michigan), to carbonate rocks of limestone or dolomite (such as the Ozark Plateaus aquifers of Missouri and the Mississippian aquifers in Iowa, Michigan, and Ohio), to sandstones (such as the Cambrian-Ordovician aquifers of northeastern Illinois and southeastern Wisconsin). Surficial bedrock aquifers, just like their sand and gravel counterparts, are susceptible to drought.

MTAC Small Community Groundwater Supply Systems

A summary of the number of small community systems using groundwater and the number of wells used by those systems appears in Table 4-5. Blank entries in the table represent states that did not reply to inquiries or, in many cases, did not have well data readily available. In a couple of instances, different agencies are responsible for maintaining datasets that are not linked by a common identifier; for example, state drinking water regulatory agencies have summary data on community water systems (community name, population served, well number) but another agency may maintain specific data on community wells (such as well depth). However, without a common identifier linking the well data to its community, the joint use of the databases can be difficult. In some states, digital well data are not available or are kept only by the individual communities and not in a statewide database. Release of well-specific community water supply data has also been affected by Homeland Security concerns, making it more difficult for data sharing, especially to researchers external to the state agencies gathering the information.

Examination of Table 4-5 shows that the number of small community systems using groundwater far outweighs those using surface water. Further, the number of wells serving small communities in the MTAC region probably approaches 20,000. Based on the states for which shallow well numbers were readily available, about 20-30 percent of wells serving small community water systems are less than 100 feet deep. These wells are believed to be potentially most sensitive to drought, as discussed below.

Groundwater Recharge

Walton (1965) described the sources and process of groundwater recharge in Illinois. His description, however, generally is applicable to the whole Midwest:

> "The major sources of recharge to aquifers in Illinois are direct precipitation on intake areas and downward percolation of stream runoff (induced infiltration) … Recharge from direct precipitation and by induced infiltration of surface water involves the vertical movement of water under the influence of vertical head differentials. Thus, recharge is vertical leakage of water through deposits. The quantity of vertical leakage varies from place to place and it is controlled by the vertical permeability and thickness of the deposits through which leakage occurs, the head differential between sources of water and the aquifer, and the area through which leakage occurs."

Walton (1965) went on to describe the relation of groundwater storage, recharge, and drought on deep aquifers:

> "… water stored in thick deposits of glacial drift is available to deeply buried aquifers so that drought periods have little influence on water levels in these aquifers. Ground-water storage in deposits above aquifers and in aquifers permits pumping for short periods of time at rates greater than recharge."

Shallow, surficial aquifers (sand-and-gravel and bedrock) do not have water stored in overlying deposits from which they can draw during times of drought. Therefore, water levels in such aquifers are more sensitive to climate conditions and will decline in response to dry weather. Available drawdown in wells (the difference between the non-pumping water level and the allowable pumping level, such as the top of the well screen or the pump intake) will be correspondingly reduced. The situation can be exacerbated further by the effects of well interference; water demand often increases during drought, causing wells to be operated at higher pumping rates and/or for longer periods and increasing the drawdown at neighboring wells.

Alluvial valley aquifers often are in hydraulic communication with the streams occupying the valleys in which the aquifer is situated. In the Midwest, groundwater discharge to streams often is a large component of stream flow (Grannemann et al., 2000) and may be all of the flow in perennial streams during low flow periods, especially during drought. However, as described by Walton above, wells completed in these aquifers can induce infiltration of surface water through stream beds. If stream flow is significantly affected by drought, well yields also can be affected adversely. Conversely, pumping wells that are inducing recharge from nearby streams will reduce streamflow - an effect that may be unacceptable if ecological streamflow thresholds are crossed.

5. TOOLS AND INFORMATION FOR INDIVIDUAL WATER SUPPLY MANAGER ASSESSMENTS

5a. Climate Data

There are a variety of climate data sets and tools to aid drought planning available in this report and on the accompanying web site (see http://mtac.sws.uiuc.edu). This report contains information on normal annual precipitation across the MTAC region (see Figure 2-1) as well as the expected rainfall (expressed as a percent of normal) for droughts at selected durations and return periods (see Appendix A). More site-specific climate data is available on the web site including monthly precipitation data at 360 long-term sites. Links are provided to additional climate data available from the appropriate regional and state climate offices, including normal monthly precipitation values at a larger number of sites.

Here are two examples on how to use climate data for drought planning purposes. In the first example the 12-month 25-, 50-, and 100-year return period values are calculated for a specific site, in this case Peoria, Illinois. Using Table A-1 for Illinois, the 12-month 25-, 50-, and 100-year return period droughts are 56.4, 50.7, and 46.2 percent of normal precipitation respectively. Checking on the web site under the links to normal precipitation in Illinois, the normal annual precipitation for Peoria is 36.02 inches. Therefore, for the 12-month duration, the expected precipitation becomes 36.02 inches x 0.564 = 20.32 inches for a 25-year drought; 36.02 inches x 0.507 = 18.26 inches for a 50-year drought; and 36.02 inches x 0.462 = 16.64 inches for a 100-year drought.

In the second example, the monthly data for a site can be used to assess the relative standing of current or past droughts. While the calculations can be done by hand, it is best to use a spreadsheet to compute the rainfall of selected durations and sort them from driest to wettest. In Table 5-1 for Peoria, Illinois, 1988 and 1989 stand out as the driest calendar years on record. Let's say that a water supply system in the Peoria area had trouble meeting its water demand in 1994, the eighth driest year on record. While this was a dry year, there were seven more years in the historical record that were drier. Therefore, the manager or operator of this system should have a clear indication that the system may be vulnerable to shortages in more severe droughts, and that the system adequacy should be evaluated in greater detail.

Figure 5-1 shows the frequency of severe or extreme drought by decade across the 10-state MTAC region. Each month of each state that registers a Palmer Hydrological Drought Index value of -3 or less is counted once. Clearly, the decade of the 1930s dominates the record with nearly twice the number of months with severe droughts than any other decade and approximately 10 times more than was reported in the 1990s. In fact, the 1990s had the lowest frequency of drought on record. In both Table 5-1 and Figure 5-1, the last decade has been very benign in terms of drought, which may lead operators of community water supplies to underestimate their vulnerability to drought. Any problems that have occurred in the last 15 years, when drought activity was at its lowest, would be greatly amplified if drought conditions similar to the 1930s or 1950s return.

5b. Hydrologic Data

The USGS currently operates over 1400 streamgages within the 10-state MTAC region that have continuous flow records of the type needed for assessing hydrologic conditions and yield during periods of drought. Historical records also are available for thousands of discontinued USGS gages. These gages have periods of record lasting from only a year to over 100 years. Various state agencies also operate streamgaging stations; but typically the state gages either do not provide continuous discharge records, or are operated for a relatively short period of years such that they do not provide the long-term continuous flow information needed for drought frequency assessment. The length of the gaging record is particularly crucial in defining hydrologic conditions during the type of severe droughts that have the greatest potential to threaten water supply sources. As described earlier in this report, the most severe hydrologic droughts in the Midwest occurred in the period from 1900-1965, and a shorter, more recent hydrologic record may not reflect adequately the potential impacts of severe drought.

In many cases, streamflow gages are not located sufficiently close to a community water supply system to be used directly in estimating the expected amount of flow to that system during a severe drought. In other cases, a gage record may be available, but not of sufficiently length to include the occurrence of a severe drought. For this reason, analytical procedures often are needed to both extend short flow records and transfer the data from gaging stations for use in estimating streamflows at ungaged reservoir sites.

As noted earlier in this report, there is no groundwater level observation network comparable to the streamgaging network of the USGS. Most states operate their own observation well networks, for a multitude of purposes, measured across a wide range of frequencies, in a variety of aquifers and non-aquifers (including confined and unconfined systems), and few records extend beyond 50 years to some of the most severe historical droughts. However, low levels at observation wells may not necessarily reflect impacts resulting of drought.

5c. Methods and Analyses Used to Determine Source Water Adequacy

Identifying At-Risk Community Surface Water Supplies

For communities that withdraw water directly from a river or stream, and where there is little or no storage in reserve, the supply usually is considered adequate as long as the quantity of flow in the stream has always been greater than the community's current and projected uses. For many of the direct withdrawals in the Midwest, the record low flow in the river or stream is much greater than the amount of water used. The greatest concerns in evaluating adequacy of supply for direct withdrawals are: 1) the evaluation of low flow frequency if there are no streamflow records of sufficiently length and proximity to the withdrawal, and 2) determining that there is no upstream water use or other human modification that would cause the low flows to become diminished over time.

When the primary source of water supply is a reservoir, the process to identify adequacy of the supply becomes more complicated and involves a combined analysis of the storage capacity of the reservoir and the amount of flow coming into the reservoir (typically provided by a stream) over the course of a drought whose duration must also be determined. There can be various sources of uncertainty in the reservoir yield analysis, including estimation errors of: 1) the reservoir storage capacity, including possible losses in volume over time through sedimentation; 2) the inflow amount; 3) evaporation losses; 4) drought frequency or worst-case drought conditions. Of these, the uncertainties in the estimates of storage capacity and inflow amount generally have the greatest impact on water supply yield analysis. In the case of off-channel storage reservoirs, analysis of the inflow amount must jointly consider the availability of water in the initial source of supply (stream) and the portion of that water that the pumping system is capable of delivering.

The impact of these uncertainties on yield estimates can vary considerably for individual water supply systems, depending in part on the duration of the drought and the extent to which inflow can replenish the storage during the course of the drought. Many reservoirs in the Midwest are located on smaller watersheds where there is no streamgage data, and the limitations of regional hydrologic analysis to estimating inflow may provide the greatest source of uncertainty in yield analysis. For other systems, the inflow during the course of the drought may provide little additional water to the reservoir, and an accurate estimate of reservoir capacity could be the most important factor in determining yield. For many water supply reservoirs, there have been no bathymetric or sedimentation surveys to estimate reservoir capacity, and in most cases the original storage capacity of these lakes is uncertain, having been estimated using USGS topographic maps. Additional uncertainty is created with the loss of storage from the deposition of stream sediments into the reservoir. Most water supply reservoirs in the Midwest are over 30 years old, and, although the sediment loss in many reservoirs may be less than 10% of their original capacity, some reservoirs have lost more than 50% of their capacity.

Guidance documents typically are available from state agencies regarding general factors that must be addressed in evaluating surface water supply systems, but often provide little technical data from which to compute system yield or adequacy. In Indiana, the Drinking Water Branch prepared “Drinking Water Guidance Manual, Small and Medium Indiana Water Systems, 10,000 or fewer persons served: Community Systems”. This document acknowledges there are many factors to consider when determining the feasibility of a site for an impounding reservoir; however, the scope of the manual does not include guidance about who is responsible for that analysis or what methods are used. In Kansas, the document “Policies, General Considerations and Design Requirements for Public Water Supply Systems in Kansas” was prepared by Kansas Department of Health and Environment in 1995. This document has a chapter on source development with quantity requirements. It states that “Where water is drawn from a flowing stream, river or spring, DWR flow records should confirm its availability to meet the maximum daily demand for the design period during a 50 year drought with all prior water rights considered." There are similar restrictions for impoundments. This chapter also offers considerations when selecting potential sites. "Design Guide for Community Water Systems" was prepared by the Missouri Department of Natural Resources, Public Drinking Water Program. This document recommends using a reservoir operations model to determine the capacity of reservoirs, as well as performing a drought study using the drought of record. It offers additional suggestions for determining adequacy of stream sources.

Illinois State Water Survey Bulletins 66 and 67 (Knapp, 1982; Terstriep et al., 1982), provide hydrologic methods to estimate yields of off-channel and impounding reservoirs, respectively, which can be applied both to estimate yields of existing reservoirs in Illinois and to evaluate potential reservoirs. In these studies, historical series of low flows during drought periods are analyzed for selected USGS streamflow records, frequency analysis is conducted to estimate the recurrence frequency for various durations of low flow, and a non-sequential mass curve analysis is used to estimate the gross yield for selected values of reservoir capacity. Since the methods are typically applied to ungaged sites, guidance is provided for the user to select a streamgage that represents the flow values at a location of interest, and tables and graphs are presented so that the user may interpolate yield values for specific values of reservoir capacity. A similar hydrologic analysis, patterned after the method used in Illinois, was developed by the USGS (Koltun, 2001) for use in Ohio.

Identifying At-Risk Community Groundwater Supplies

Ultimately, the best way to assess community groundwater supply sensitivity to drought is through the use of groundwater flow models where the effects of reduced or no recharge can be examined. However, as evidenced in Table 4-5, there are hundreds of communities and thousands of wells within each state that would require modeling. Groundwater flow models are highly data-intensive (Table 5-2). Due to the data requirements and time needed to develop groundwater flow models, it is simply not practical to develop models for all of these supplies. In some cases, advantage can be taken of groundwater flow models already developed for many community recharge area delineations as part of regulatory drinking water protection programs, i.e., the source water assessment program (SWAP) administered through state/federal agencies charged with enforcing the Safe Drinking Water Act. Groundwater models, whether available or needing development, are most necessary for those community wells determined to be most potentially drought-sensitive. Therefore, a practical methodology to identify community wells potentially at-risk due to drought was devised. Once such communities are identified, models can be created, impacts assessed, and alternatives developed, for these drought-sensitive wells.

Due to the lack of completeness and data access across all of the MTAC states, Illinois community groundwater supply data were used to show how this might be done in other states. Digital databases for Illinois were used to provide input to a geographical information system (GIS) for display of selected well parameters that may suggest a community supply is drought sensitive. The power of GIS is evident and shows what can be done if appropriate digital datasets are developed. A summary of the approach is presented.

Well Depth. Illinois community (serving less than 10,000 persons) well data were segregated on the basis of well depth. As discussed in Section 4b, shallow wells are most likely affected by a lack of recharge resulting in lowered groundwater levels. Shallow wells also tend to have less available drawdown within which they can operate. Lower non-pumping water levels due to drought will further reduce available drawdown. Communities with wells less than 100 feet deep were deemed potentially sensitive, with wells less than 50 feet deep being most sensitive. Of 1,973 community wells serving less than 10,000 people, 158 wells are less than 50 feet deep and 433 are between 50 and 100 feet deep (Figures 5-2 and 5-3).

Proximity to Surface Waters. Shallow community (serving less than 10,000) wells were further identified on the basis of proximity to streams using a buffer of 1000 feet to highlight wells that receive potential recharge through streambed infiltration. These wells potentially could be affected by low streamflow during a drought or, conversely, could severely impact low streamflows during drought. Shallow wells less than 50 feet and between 50 and 100 feet deep in proximity to identified streams are highlighted in Figures 5-2 and 5-3, respectively. A total of 231 shallow wells were identified within 1000 feet of a recognized stream (80 wells less than 50 feet deep and 150 wells from 50 to 100 feet deep).

Well Density. Community (serving less than 10,000) wells were examined on the basis of well density, that is, the number of wells within a defined area. Typically, communities that use areally-limited aquifers will have several low-capacity wells in a very confined area. During drought, water demand typically increases, causing wells to operate for longer periods and at higher rates, increasing the effects of mutual interference. For this analysis, shallow community wells (≤100 feet deep) within 1,000 feet of one another were identified (420 wells), including those wells that are also within 1,000 feet of an identified stream (184 wells of which 59 are less than 50 feet deep), as shown in Figure 5-4.

From a list of nearly 2,000 community wells in over 1,100 small community systems, this methodology pared the list to less than 200 wells, representing 27 communities. These community wells are deemed potentially vulnerable to drought conditions on the basis of their shallow depth, proximity to other shallow community wells, and proximity to identified streams. Examination of the map with respect to Illinois' major sand and gravel aquifers shows that most of the potentially drought-sensitive community wells are located in southern east-central Illinois, south of the Mahomet aquifer and along minor river valleys, such as the upper reaches of the Kaskaskia, Embarras, and Little Wabash Rivers.

Uncertainties in Community Groundwater Supply Assessment

Once these community wells are identified, follow-up analyses can be conducted with the intent of developing alternatives for those communities to pursue to reduce their risk to drought. In some cases, community wells that are identified through the above process may not be drought-sensitive because the alluvial deposit in which those wells are completed is adjacent to a major river system (e.g., the Mississippi, Illinois, and Wabash River bottoms), or the aquifer is extensive and thick enough such that, even though shallow, is quite drought-resistant (e.g., western portions of the Mahomet aquifer).

Conversely, many drought-sensitive wells may not be identified by this methodology. Well depths of 100 feet and proximities of 1000 feet to other wells or streams were selected as methodological examples. Such an analysis ignores deeper wells that may have been completed in drought-sensitive aquifers and wells at greater distances from other wells that still could be affected by mutual interference. Nor does this analysis attempt to identify supplies that may be vulnerable due to system deficiencies. Water demand often increases during drought and system capability to meet increased demand often is a critical component of drought preparedness. Aquifer and well capabilities aside, a community also needs system capacity to meet the maximum daily demands that occur often during the hot, dry weather that droughts bring.

State Reports of Groundwater Source Adequacy in the MTAC Region

Several states in the MTAC region monitor water levels at individual systems as a method of data gathering in order to determine and study trend lines in the future. For example, Nebraska requires that static and pumping levels be monitored once per quarter from Oct 1 - Apr 30 and monthly from May 1 - Sept 30. This information is used to compute draw-down and to generate drought reports from June till the end of October. The Ohio EPA, Division of Drinking and Ground Waters recently completed its third edition of "Guidelines for Design of Small Public Ground Water Systems" as a guide for engineers and water supply planners involved in the design or development of small PWS systems.

5d. Potential Locations/Types of Systems in Need of Risk Assessment

In general, a much higher proportion of surface water systems are susceptible to problems during severe drought periods than groundwater systems (Hudson and Roberts, 1955). Water supply systems that depend on reservoirs also are generally more likely to be susceptible to shortages during drought, primarily because of the uncertainties in: 1) calculating the capacity of the reservoir in cases where there has not been a recent bathymetric or sedimentation survey, and 2) estimating the drought inflow to the reservoir, since reservoir systems are more likely to be located in smaller watersheds which typically do not have long-term streamgaging records. In contrast, direct withdrawals without storage are more likely to be on larger streams and rivers that have long-term streamgaging records.

With the above general tendencies noted, there is no available information to suggest a strong tendency for water supplies in a particular geographic region to be susceptible to drought impacts. Combinations of local factors such as the size of the reservoir, the hydrogeologic characteristics of the watershed and its streamflow, and the amount of water demand have considerable influence on the potential adequacy of each individual system. The presence or absence of drought preparedness and drought response planning are also critical factors influencing a system's potential vulnerability. Communities that over time have experienced growth in population and water use without corresponding increases in the size or number of their water supply sources also are more likely to be susceptible to future droughts, as are communities that have had only incremental increases in water supply capacity or other “stop-gap” measures implemented in response to past droughts.

Although the 1988-89 drought and other recent droughts have been the drought of record for some small regions within the Midwest, long-term streamgaging records indicate that for most of the Midwest there have been no droughts since the mid-1960s that rank within the top three on record. Records also indicate that streamflows during the worst droughts are not only the lowest in magnitude, but also have much longer durations than the low flow periods of less severe droughts, with the cumulative effect of causing a considerably greater reduction in reservoir storages. Surface water systems that have experienced even mild or moderate drought concerns since the 1960s should reexamine their possible vulnerability to shortages during severe droughts such as those droughts of the 1930s and 1950s.

6. CONCLUSIONS AND RECOMMENDATIONS

Long-term climate and hydrologic records indicate that hydrologic droughts in the MTAC region were more frequent and severe in the first 60 years of the 20th century than in the last 40 years. In recent decades the MTAC region has been through a period of relatively few and moderate droughts, possibly leading to a sense of false security about drought preparedness. There is the potential that intense and long-lived droughts will become more common as they were in the early 1900s and therefore provide a severe test of water supply adequacy.

There are general differences in drought characteristics across the MTAC region based on climate and hydrologic factors. For example, hydrologic droughts in the eastern portion of the MTAC region are comparatively short, often less than one year in duration, whereas major droughts in the western portion of the MTAC region may typically extend for up to five years. In addition, surface water and shallow groundwater systems can be considered more susceptible to problems during severe drought periods. However, there is otherwise no available information to suggest a strong tendency for water supplies in a particular geographic region to be more susceptible to drought impacts, as potential impacts can differ significantly from community to community.

State drought plans were acquired and reviewed to determine the level of drought planning for each state. Also provided is a list of state agencies involved in water supply regulation and information. Most state drought plans appear to be drought response plans rather than drought preparedness plans, and deal primarily in agency responses to ongoing drought conditions. The role of individual systems in these plans is to report problems and actions regarding drought impacts on supplies and to follow state advisories regarding voluntary or mandatory water use restrictions when applicable.

Although state agencies typically provide technical guidance to communities regarding other water supply matters, there is usually little information available to specifically evaluate the adequacy of water supply sources and potential drought impacts. This type of analysis is often considered the responsibility of individual water systems, and many small communities do not have the necessary data or resources to conduct such an evaluation. Analysis of the vulnerability of individual surface and groundwater supplies requires hydrologic and geophysical data that is often not available.

The information presented in this report is designed to provide basic considerations for an initial assessment of drought preparedness. Climate data is provided on an accompanying web site that can be used to compare the relative severity and duration of a current drought period with the most severe historical droughts. For groundwater systems, a practical method is presented in this report to identify community wells that are potentially drought-sensitive based on factors of well depth, well density, and proximity to surface waters. An application of this method to Illinois groundwater systems is provided as example.

The major recommendation of this report is that there is a need for drought preparedness at the state, regional, and local scales. The general status of drought preparedness planning for small communities in the Midwest is particularly limited at this time. This study has identified several national and state drought planning documents that provide general guidelines for small community water systems, but the technical information required to develop detailed drought plans are often not available. Although this study provides some basic resources for evaluating drought, comprehensive guidance documents and step-by-step methodologies for the assessment of source water adequacy need to be developed that can be used by individual communities, with emphasis on small communities that may otherwise lack the resources or knowledge to evaluate the drought susceptibility of their system. Consistent technical expertise and resources for assisting small communities may likely need to come from broader state or regional efforts.

Small community water supply managers and operators should take their own proactive steps to develop a drought plan that evaluates the capabilities of their systems to cope with severe and protracted droughts. The establishment of an initial drought preparedness plan by a community need not be complex. An awareness and compilation of material regarding 1) state drought plans, 2) state water regulations, 3) an idea of the historical droughts for the area, 4) system behavior in previous drought periods, and 5) an assessment of current and near-future supply and demand will go a long way towards a functional plan. The need for drought assessment is particularly great if a water supply system has experienced even mild or moderate drought concerns since the mid-1960s. Records of increasing water use, including those associated with population or commercial growth and outdoor and recreational uses, should be evaluated against limitations experienced in past drought situations and the potential for severe and extended such as those experienced in the 1930s and 1950s.

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Table 2-1. Statewide averages of the ratio between the record 6-month low flow (M6,R) and the long-term mean flow (Qmean).

State	M6,R to Qmean ratio
Illinois	0.052
Indiana	0.092
Iowa	0.037
Kansas	0.006
Michigan	0.368
Minnesota	0.042
Missouri	0.085
Nebraska-South Dakota-North Dakota	0.048
Ohio	0.042
Wisconsin	0.267

Table 2-2. Statewide averages of the ratio between the record low flows for extended drought periods (12- to 54-months) and the long-term mean flow (Qmean).

State	12-month ratio	18-month ratio	24-month ratio	30-month ratio
Illinois	0.115	0.141	0.236	0.245
Indiana	0.241	0.243	0.368	0.371
Iowa	0.089	0.111	0.162	0.190
Kansas	0.025	0.040	0.069	0.086
Michigan	0.526	0.531	0.618	0.628
Minnesota	0.104	0.142	0.190	0.209
Missouri	0.143	0.169	0.240	0.271
Nebraska-South Dakota-North Dakota	0.107	0.121	0.172	0.176
Ohio	0.201	0.231	0.368	0.361
Wisconsin	0.396	0.421	0.494	0.491

State	36-month ratio	42-month ratio	48-month ratio	54-month ratio
Illinois	0.333	0.351	0.425	0.421
Indiana	0.476	0.479	0.552	0.552
Iowa	0.216	0.223	0.259	0.269
Kansas	0.119	0.150	0.168	0.180
Michigan	0.689	0.691	0.735	0.738
Minnesota	0.256	0.257	0.298	0.304
Missouri	0.326	0.347	0.369	0.373
Nebraska-South Dakota-North Dakota	0.203	0.226	0.249	0.266
Ohio	0.483	0.470	0.566	0.547
Wisconsin	0.549	0.559	0.599	0.618

Table 3-1. State Agencies Involved in PWS Regulation in the MTAC 10-State Region.

State	**PWS Agency Name and Website**
Illinois	Illinois Environmental Protection Agency
	http://www.epa.state.il.us/water/index-pws.html
Indiana	Indiana Department of Environmental Management
	http://www.in.gov/idem/water/dwb/index.html
Iowa	Iowa Department of Natural Resources
	http://www.iowadnr.com/water/drinking/index.html
Kansas	Kansas Department of Health & Environment
	http://www.kdhe.state.ks.us/pws/
Michigan	Michigan Department of Environmental Quality
	http://www.michigan.gov/deq
Minnesota	Minnesota Department of Health
	http://www.health.state.mn.us/divs/eh/water/
Missouri	Missouri Department of Natural Resources
	http://www.dnr.state.mo.us/wpscd/wpcp/dw-index.htm
Nebraska	Nebraska Health & Human Services
	http://www.hhs.state.ne.us/enh/pwsindex.htm
Ohio	Ohio Environmental Protection Agency
	http://www.epa.state.oh.us/ddagw/
Wisconsin	Wisconsin Department of Natural Resources
	http://www.dnr.state.wi.us/org/water/dwg

Table 3-2. State Drinking Water Regulations in the MTAC 10-State Region.

State	Drinking Water Regulations Websites
Illinois	http://www.epa.state.il.us/water/rules-regulation.html
Indiana	Indiana Code http://www.in.gov/legislative/ic/code/title13/ar18/ Indiana Administrative Code http://www.in.gov/legislative/iac/title327.html Drinking Water Permit Guide http://www.in.gov/idem/water/dwb/guide/index.html
Iowa	Regulations not summarized online. Contact Iowa DNR for information
Kansas	http://www.kdhe.state.ks.us/pws/regs
Michigan	See 'Laws and Rules' http://www.michigan.gov/deq/0,1607,+7-135-3313_3675_3691---,00.html
Minnesota	http://www.health.state.mn.us/divs/eh/water/com/comrules.html
Missouri	http://dnr.missouri.gov/wpscd/wpcp/rules/index.html
Nebraska	http://www.hhs.state.ne.us/reg/t179.htm
Ohio	http://www.epa.state.oh.us/ddagw/oac.html
Wisconsin	http://dnr.wi.gov/org/water/dwg/code.htm

Table 4-1. Types of Community Water Systems Serving Populations Less than 10,000 within the MTAC 10-State Region.

	Illinois	Indiana	Iowa	Kansas	Michigan	Minnesota	Missouri	Nebraska	Ohio	Wisconsin
Number of Systems	1581	764	1103	879	1289	886	1401	592	1161	1011
Type of Systems (%)										
Surface Water	4%	3%	2%	9%	3%	2%	4%	1%	6%	<1%
Ground Water	63%	80%	78%	51%	83%	90%	77%	90%	74%	97%
Purchased Surface Water	23%	9%	9%	31%	11%	1%	10%	2%	12%	2%
Purchased Ground Water	10%	8%	10%	9%	3%	7%	9%	7%	7%	2%
Groundwater UDI Surface Water	<1%	0%	<1%	0%	0%	0%	<1%	1%	1%	0%
Purchased Groundwater UDI Surface Water	0%	0%	1%	0%	<1%	0%	<1%	0%	0%	0%

Table 4-2. Types of Community Water Systems Serving Populations Less than 10,000 within the MTAC 10-State Region.

	Illinois	Indiana	Iowa	Kansas	Michigan	Minnesota	Missouri	Nebraska	Ohio	Wisconsin
SW & SWP	27%	12%	11%	40%	14%	3%	14%	2%	18%	2%
GW & GWP	73%	88%	88%	60%	86%	97%	86%	97%	81%	98%
GWUDI & GWUDIP	0%	0%	1%	0%	0%	0%	0%	1%	1%	0%

SW = Surface Water
SWP = Purchased Surface Water
GW = Groundwater
GWP = Purchased Groundwater
GWUDI = Groundwater Under Direct Influence of Surface Water
GWUDIP = Purchased Groundwater Under Direct Influence of Surface Water

Table 4-3. Number of Surface Water Systems Serving Populations Less Than 10,000 in the MTAC 10-State Region.

	Total Systems
Illinois	57
Indiana	23
Iowa	18
Kansas	63
Michigan	31
Minnesota	14
Missouri	66
Nebraska	4
Ohio	61
Wisconsin	2

Table 4-4. Types of Surface Water Systems Serving Populations Less Than 10,000 in the MTAC 10-State Region.

	Major River	River / Stream	River / Stream with Low Channel Dam	Off-Channel Reservoir	Impounding Reservoir	Quarry / Borrow Pit	Great Lake or Great Lake Connecting Channel	Natural / Glacial Lake	Combination of Source Water Types
Illinois	6	5	2	11	26	1	3	0	3
Indiana	1	7	0	0	12	1	1	0	1
Iowa	0	3	1	0	5	0	0	4	5
Kansas	0	29	0	0	30	0	0	0	4
Michigan	0	3	0	0	1	0	27	0	0
Minnesota	0	0	3	0	0	4	4	3	0
Missouri	5	6	1	5	43	2	0	0	4
Nebraska	2	0	0	0	1	0	0	0	1
Ohio	2	5	0	27	11	1	7	0	8
Wisconsin	0	0	0	0	0	0	1	1	0

Table 4-5. Approximate Number of Community Supplies (CWS), Community Groundwater (GW) Supplies, and Shallow Wells in the MTAC 10-State Region.

	IL	IA	IN*	KS	MI	MN	MO	NE	OH	WI
Number of CWS using GW serving <10,000	1151	848	613	~794	~1080	880	1204	371	866	980
Number of Wells in CWS serving <10,000	1973	1771	2063	1913	~3633	~1767	1829	1864	**	**
Number of Wells <50' deep	158	443	~108	789	>111	107-131	268	58	**	**
Number of Wells 50-100' deep	433	280	~680	422	>587	295-319	92	401	**	**

* For data from Indiana, 477 wells were listed as 0 feet deep or had no depth information.
** Well data for Ohio and Wisconsin were not available at the time of report publication.

Table 5-1. Ten driest years in Peoria, Illinois.

Rank	Year	Amount	% of Normal
1	1988	22.16	61.5
2	1989	22.53	62.6
3	1910	23.18	64.4
4	1912	23.34	64.8
5	1930	24.03	66.7
6	1914	24.65	68.4
7	1962	24.82	68.9
8	1994	25.20	70.0
9	1956	25.62	71.1
10	1963	25.66	71.2

Table 5-2. Data Needs for Groundwater Flow Models.

Well locations and well construction details (e.g., depth and open or screened interval)
Pumping rates, historical and projected, especially as a result of drought-related increases
Non-pumping and pumping water levels, potentiometric surface maps
Aquifer physical characteristics - thickness, areal extent, boundary locations including connections to surface water bodies
Aquifer hydraulic properties, hydraulic conductivity, transmissivity, storativity
Recharge rates, leakage rates from overlying source beds, streambed infiltration rates
Confining bed characteristics – thickness, areal extent, leakance

Figure 1-1. The 10-state region supported by the Midwestern Technology Assistance Center, including Illinois, Indiana, Iowa, Kansas, Michigan, Minnesota, Missouri, Nebraska, Ohio, and Wisconsin.

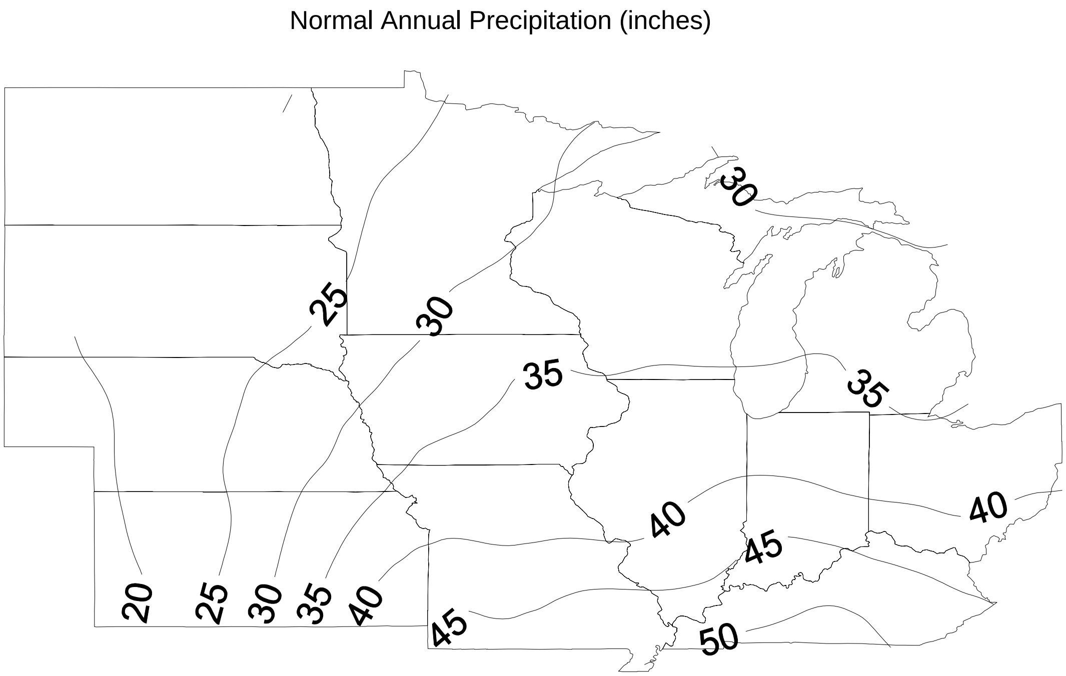


Figure 2-1. Normal annual precipitation (inches) based on the 1971-2000 average.

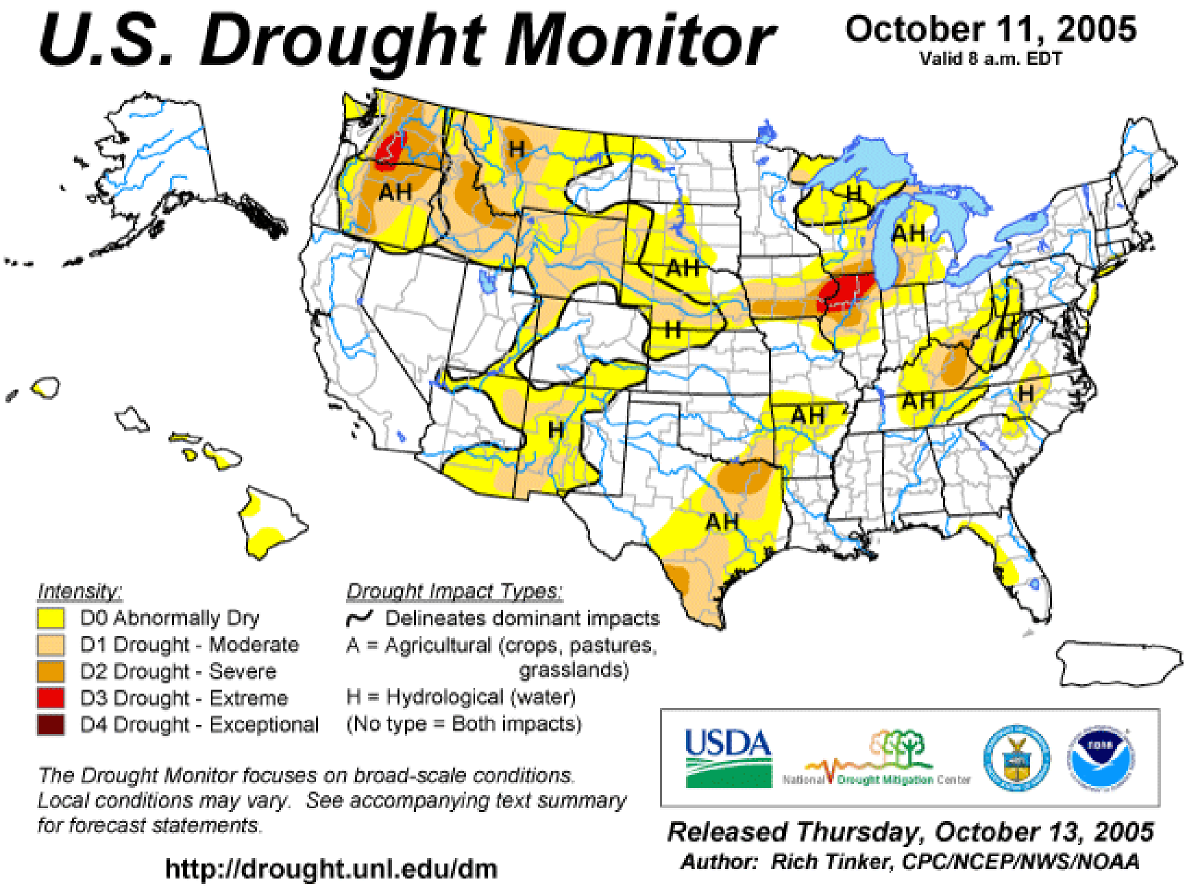


Figure 2-2. The U.S. Drought Monitor map for October 11, 2005. Note the extreme drought (red) in eastern Iowa and northern Illinois, which had been in place for more than 6 months at this point and was taking on hydrologic characteristics. The moderate drought in Nebraska (light tan) was also hydrologic in nature, especially along the Platte River, which had been suffering from low flows for several years.

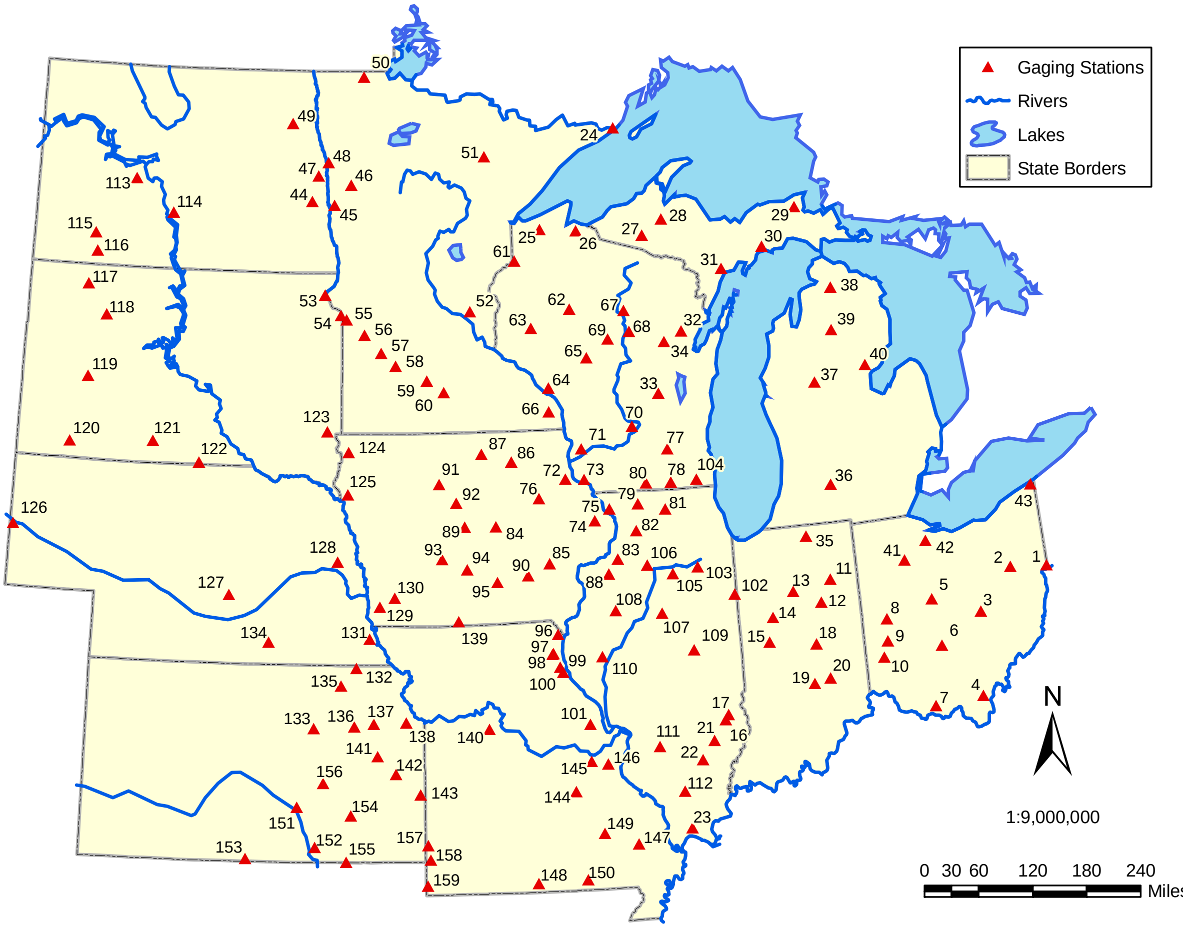


Figure 2-3. USGS Stream Gages.

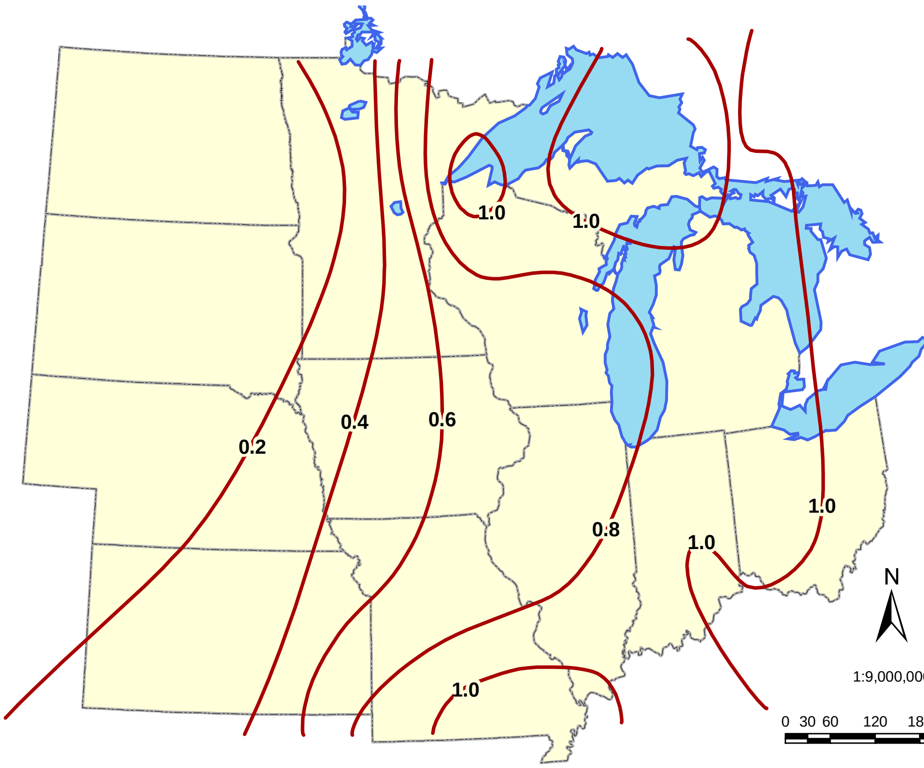


Figure 2-4. Long-term mean flow for streams in the Midwest, expressed in cfs per square mile.

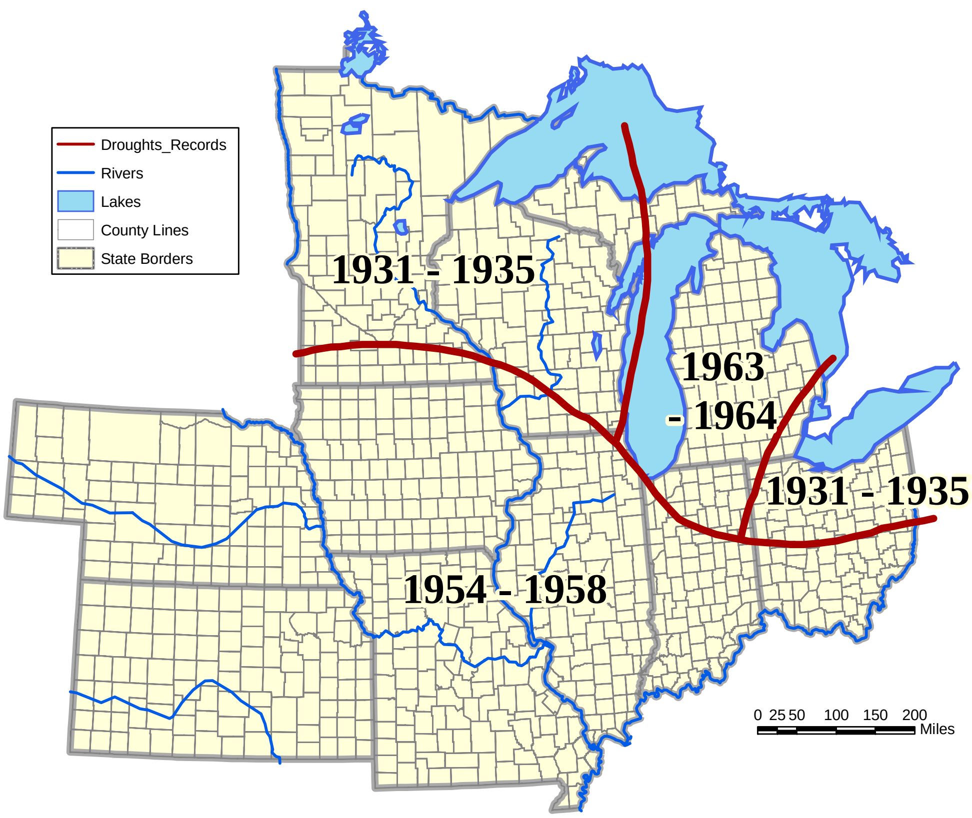


Figure 2-5. Hydrologic Droughts of Record in the Midwest.

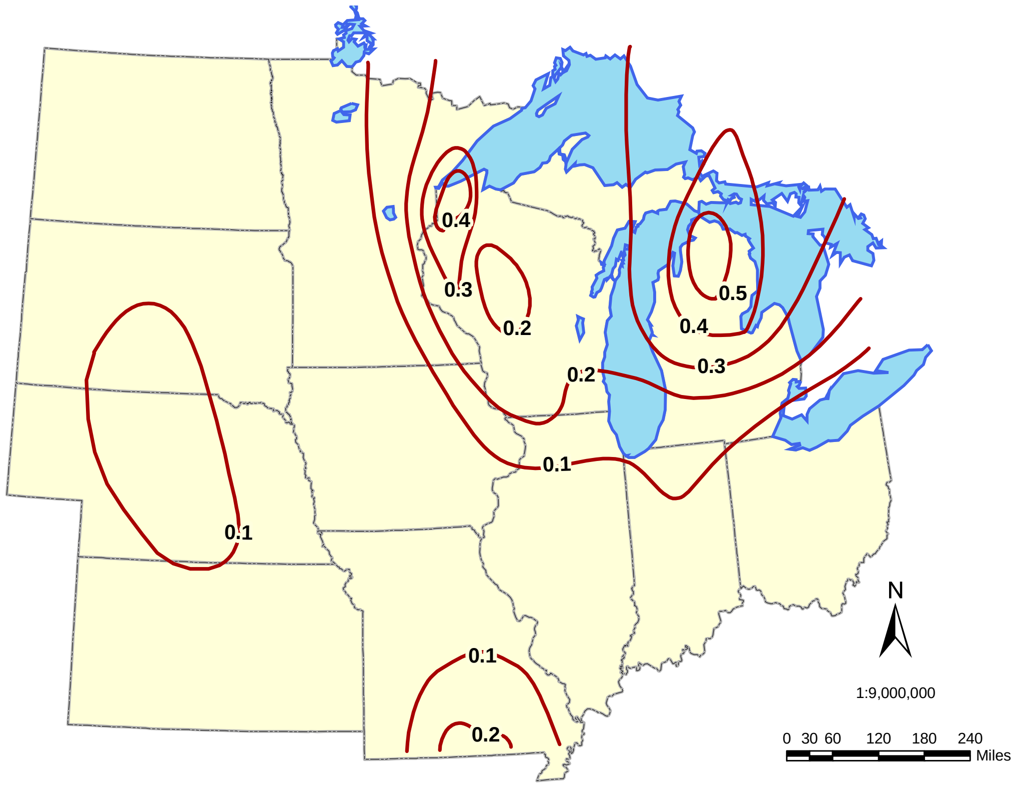


Figure 2-6. Ratios of average flow during 6-month drought of record to long-term mean flow.

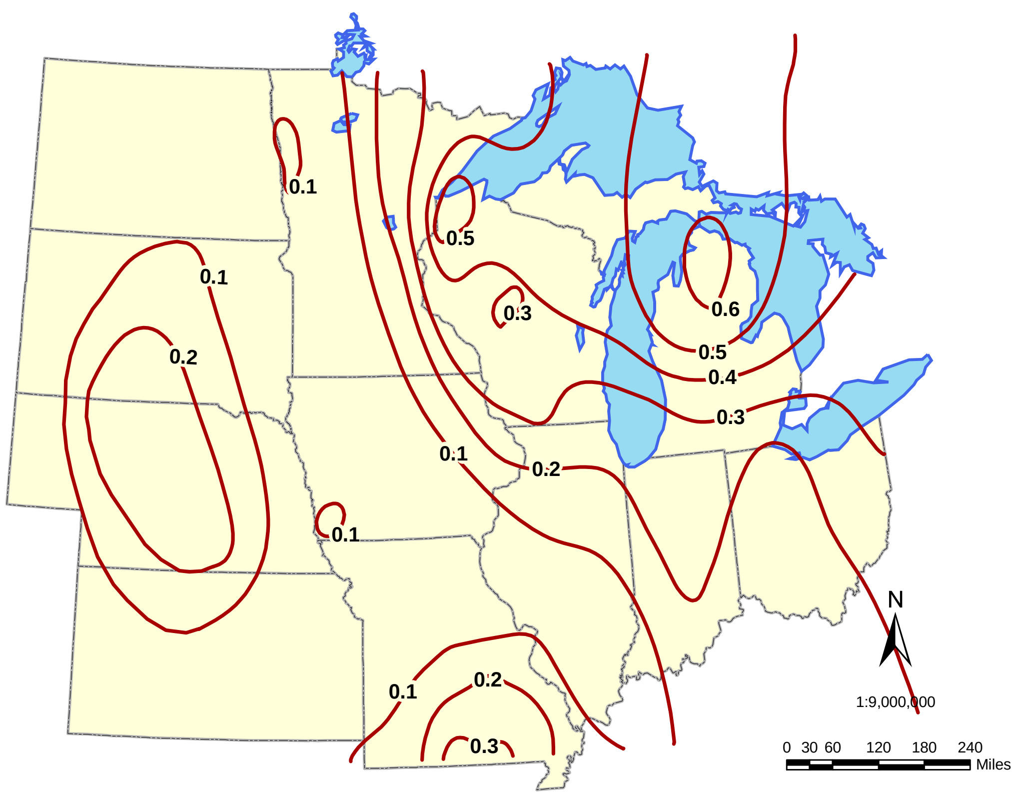


Figure 2-7. Ratios of average flow during 12-month drought of record to long-term mean flow.

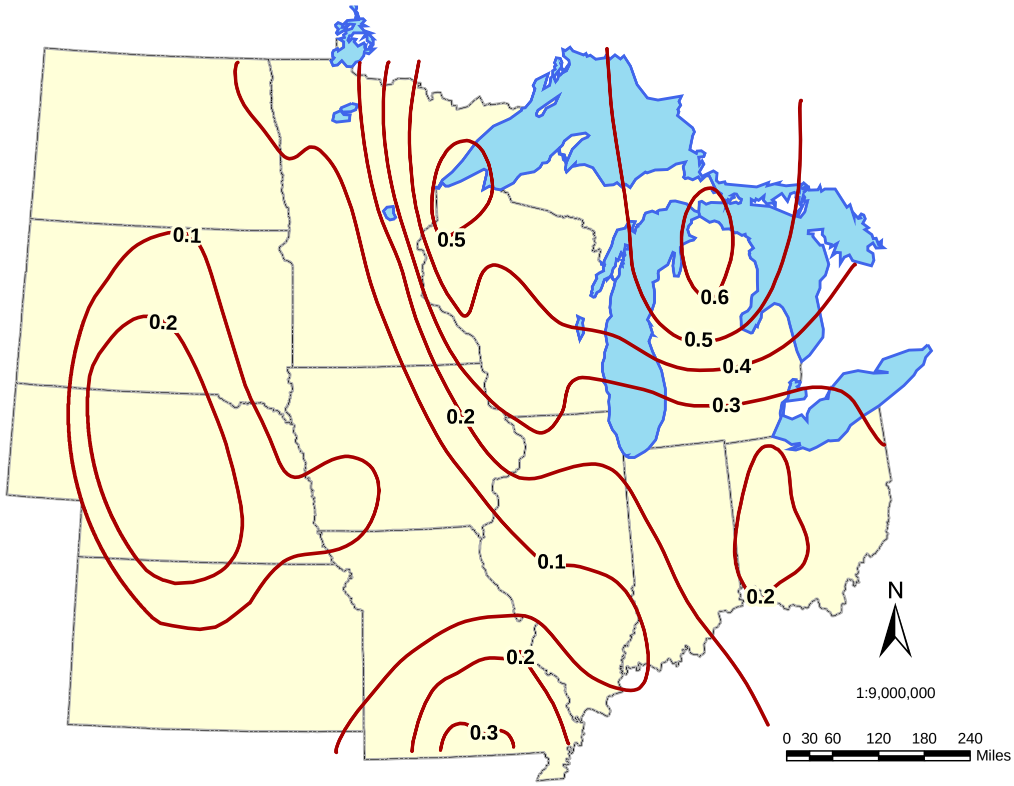


Figure 2-8. Ratios of average flow during 18-month drought of record to long-term mean flow.

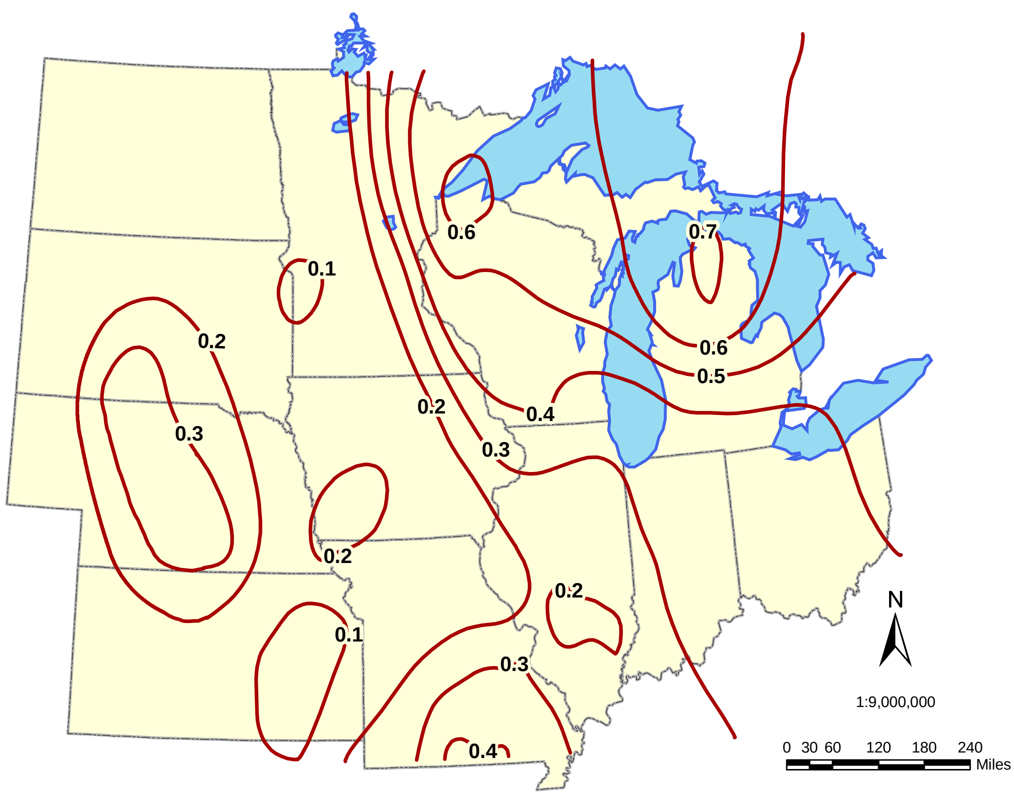


Figure 2-9. Ratios of average flow during 30-month drought of record to long-term mean flow.

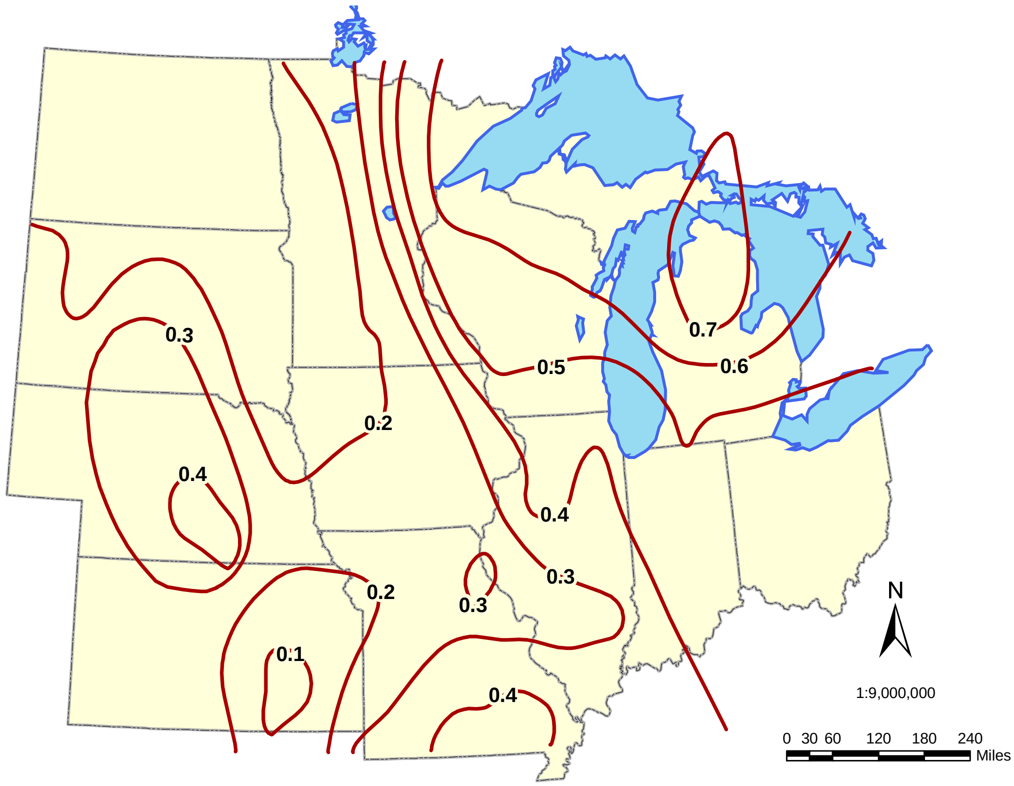


Figure 2-10. Ratios of average flow during 42-month drought of record to long-term mean flow.

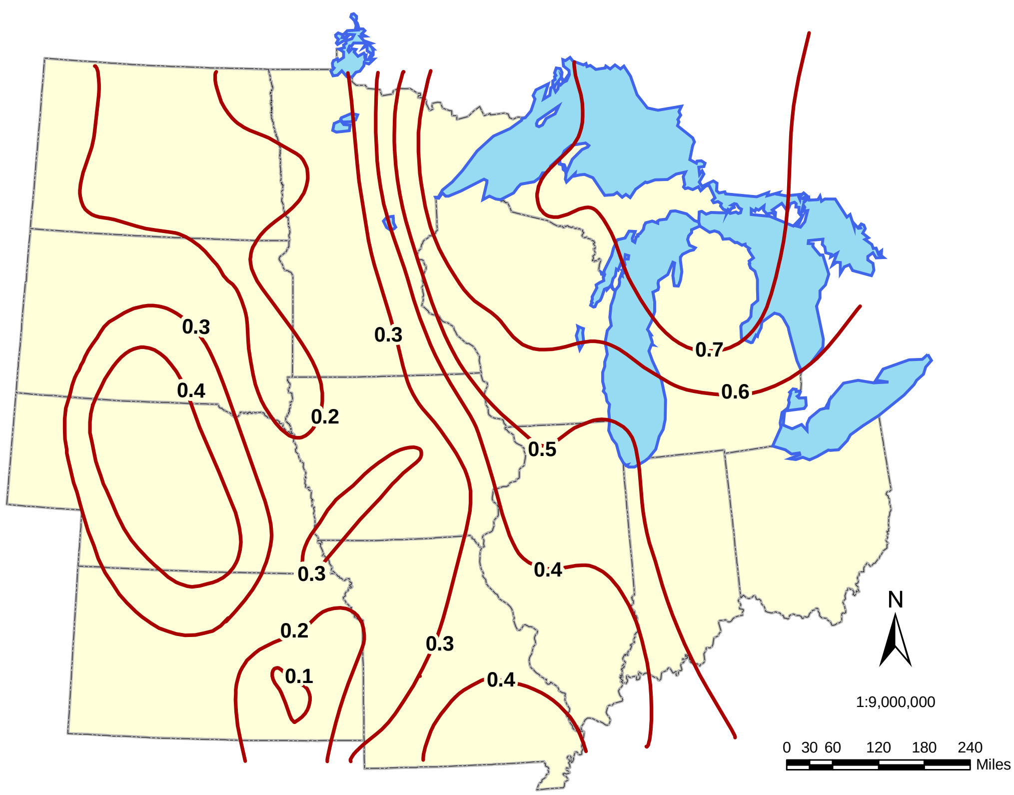


Figure 2-11. Ratios of average flow during 54-month drought of record to long-term mean flow.

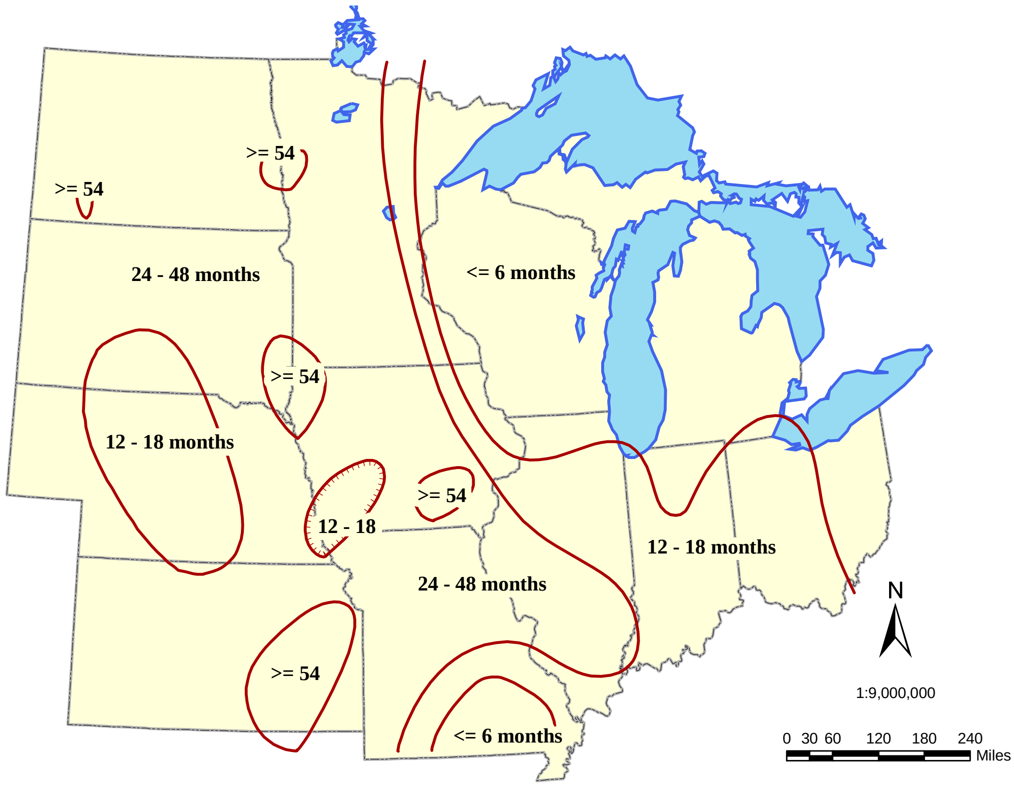


Figure 2-12. Duration of record drought with average flow less than 20% of the long-term mean flow.

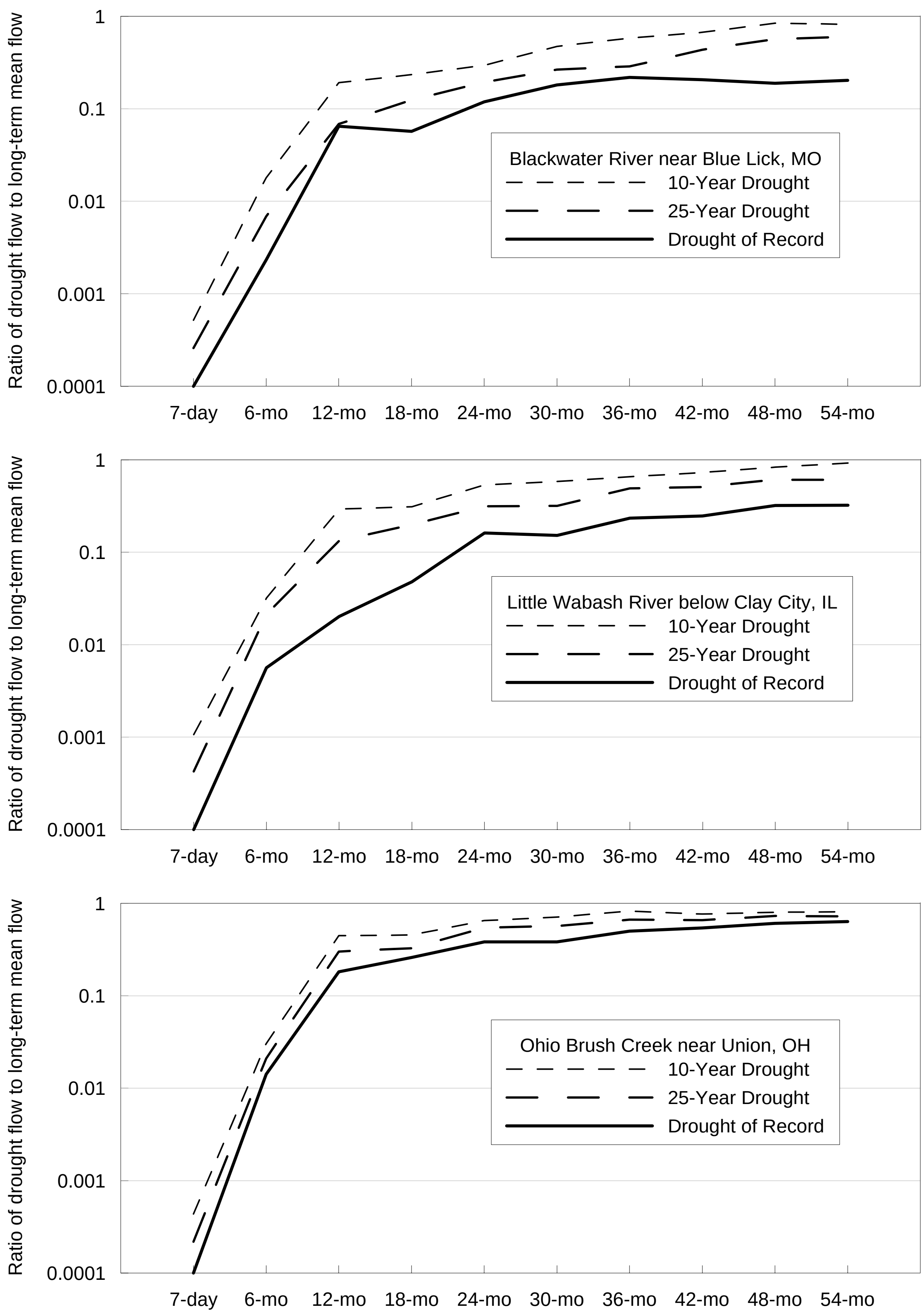


Figure 2-13. Comparison of Drought Frequencies at Three Midwest Locations.

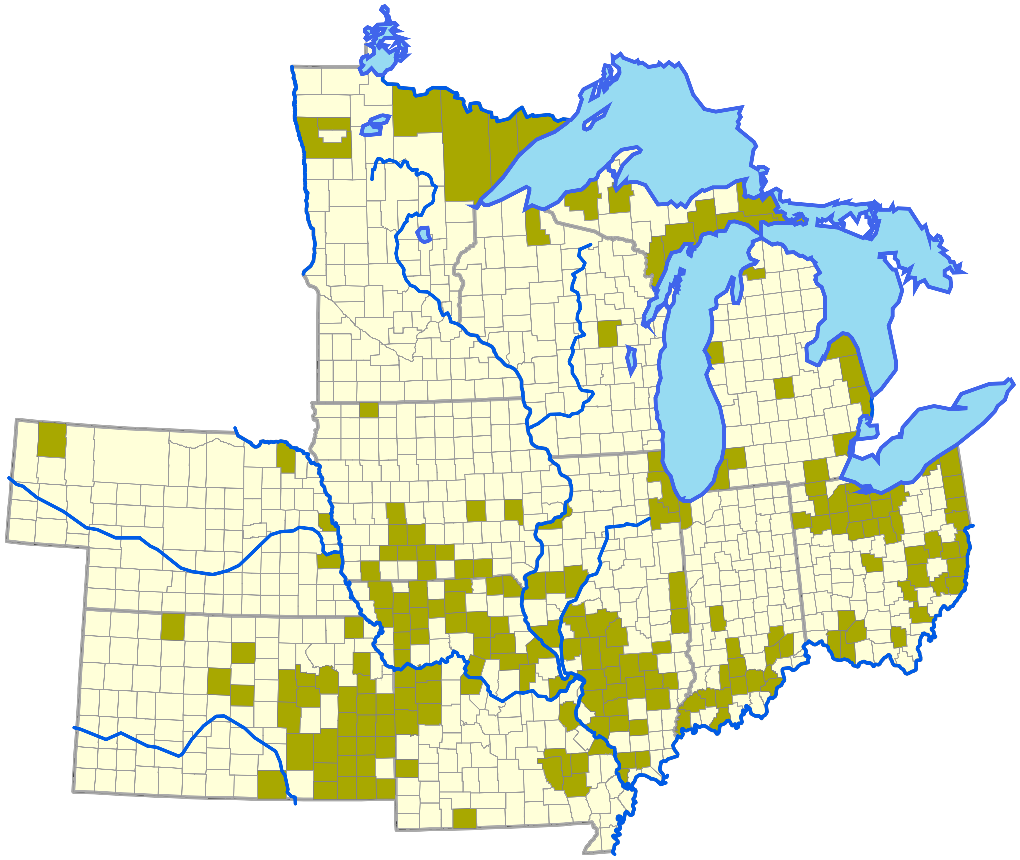


Figure 4-1. Location of Counties with Surface Water Systems Serving Populations less than 10,000 in the MTAC 10-State Region.

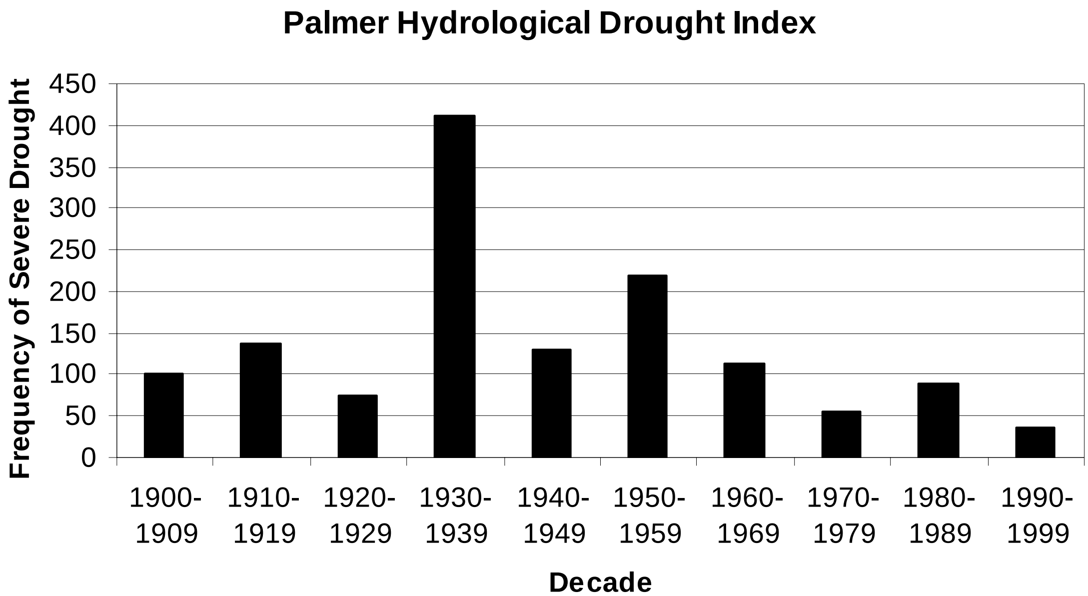


Figure 5-1. The frequency of severe to extreme drought by decade for the 10-state MTAC region based on the Palmer Hydrological Drought Index (PHDI) is shown. Each month of each state that registers a PHDI value -3 or less is counted once in the frequency.

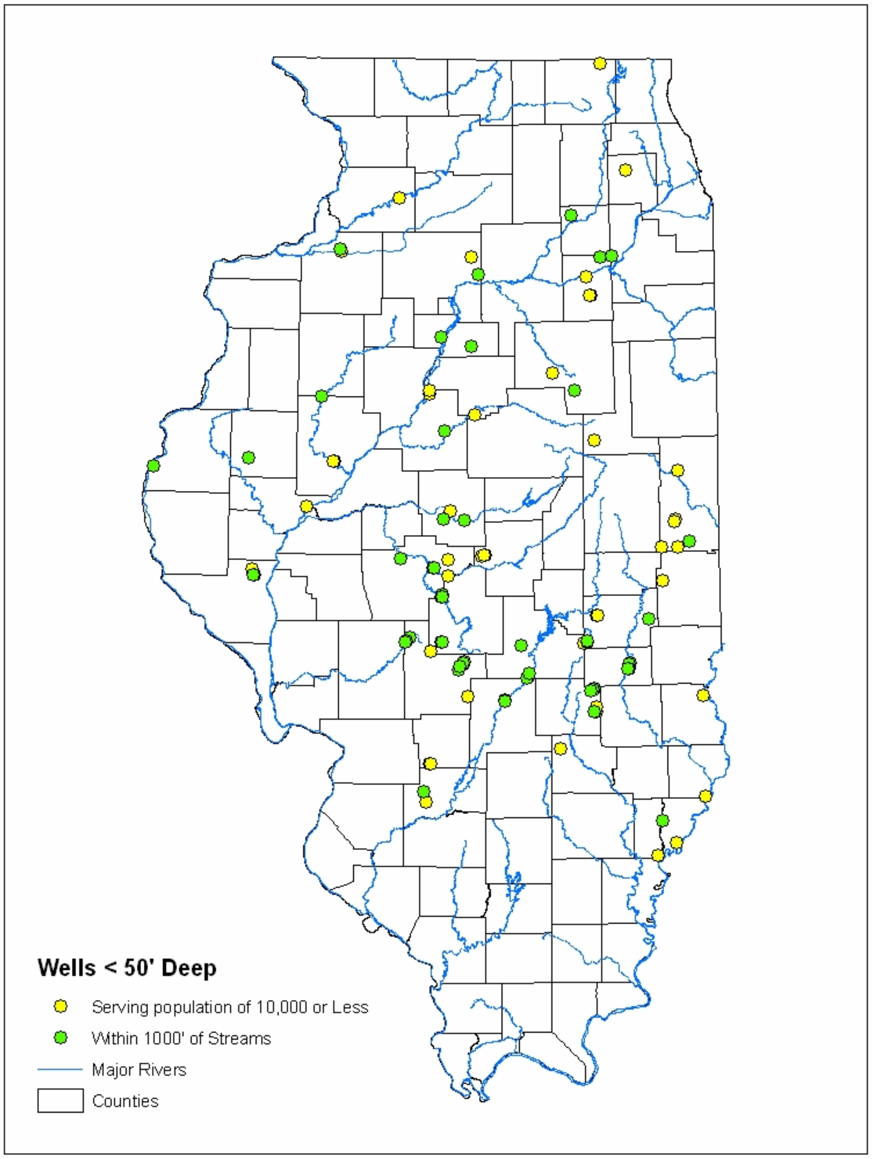


Figure 5-2. Location of Illinois community (<10,000 population) wells less than 50 feet deep including wells within 1,000 feet of a stream.

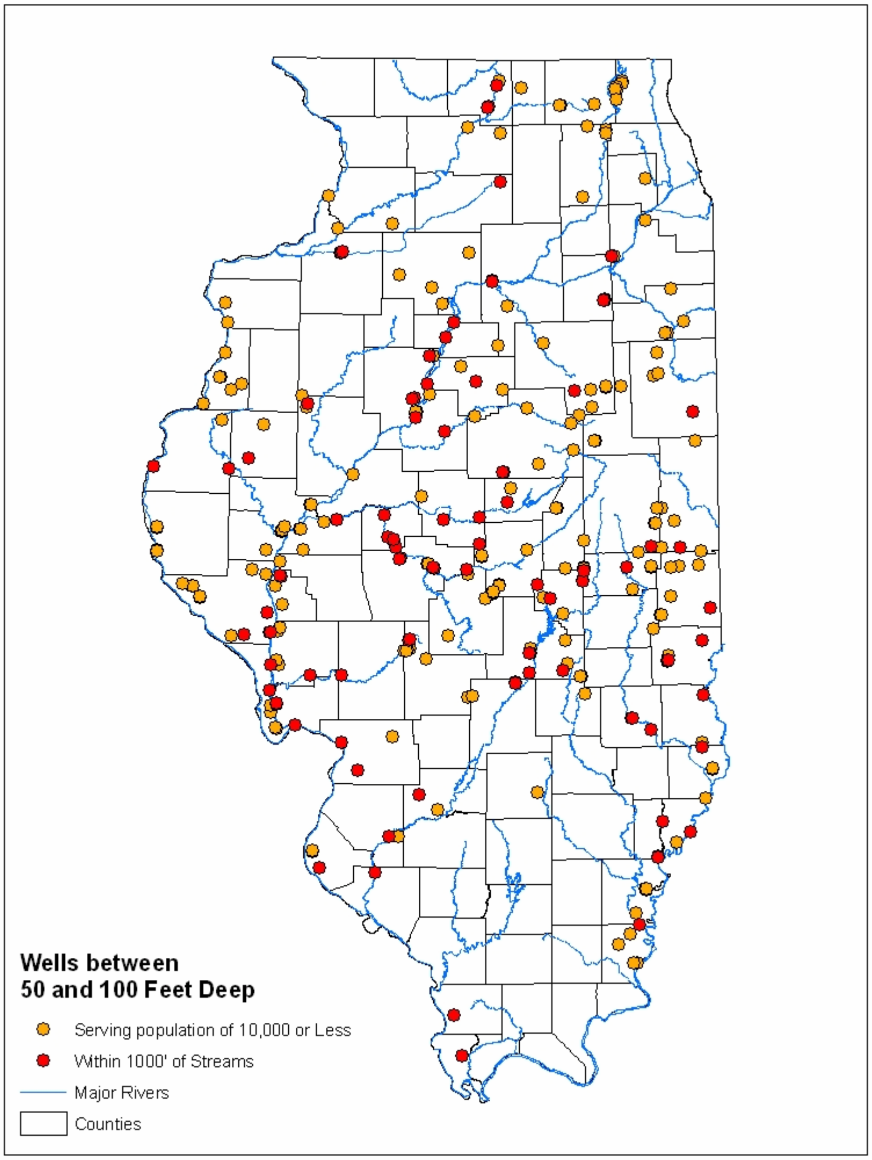


Figure 5-3. Location of Illinois community (<10,000 population) wells between 50 and 100 feet deep including wells within 1,000 feet of a stream.

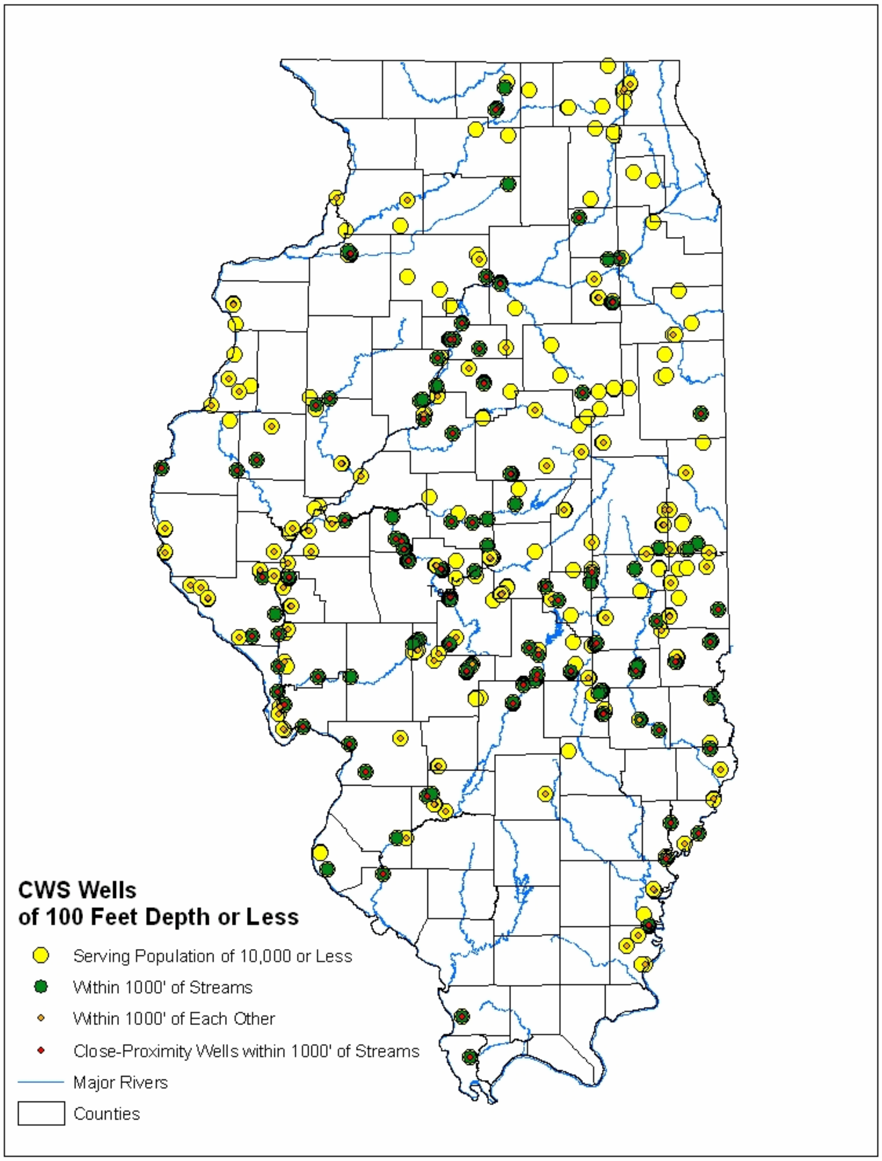


Figure 5-4. Location of Illinois community (<10,000 population) wells less than 100 feet deep within 1,000 feet of a stream and/or 1,000 feet of another shallow well.

Appendix A. Percentage of Normal Precipitation by Drought Length and Return Interval

Tables and maps of the percentage of normal precipitation for droughts of a given length and return interval. At any given location, a 25-year return event has a 1/25 = 0.04 = 4% chance of occurring during any given period, a 50-year event has a 2% chance, a 100-yr event has a 1% chance, and a 200-yr event has a 0.5% chance.

Table A-1. Expected average precipitation for all sites for Illinois, expressed as percent of normal (1971-2000), for selected drought durations and return periods.

Drought Duration	25-Year Return Period	50-Year Return Period	100-Year Return Period	200-Year Return Period
12-month	56.4	50.7	46.2	42.3
18-month	63.9	58.4	54.0	50.3
24-month	69.2	63.2	58.4	54.2
36-month	76.1	70.2	65.4	61.2
48-month	80.0	73.9	69.2	65.2
60-month	82.5	76.4	71.8	68.0

Table A-2. Expected average precipitation for all sites for Indiana, expressed as percent of normal (1971-2000), for selected drought durations and return periods.

Drought Duration	25-Year Return Period	50-Year Return Period	100-Year Return Period	200-Year Return Period
12-month	59.3	54.2	50.2	46.8
18-month	66.3	60.9	56.7	53.2
24-month	71.8	66.2	61.9	58.2
36-month	78.5	72.8	68.3	64.4
48-month	82.8	76.8	7.22	68.4
60-month	85.2	79.0	74.3	70.5

Table A-3. Expected average precipitation for all sites for Iowa, expressed as percent of normal (1971-2000), for selected drought durations and return periods.

Drought Duration	25-Year Return Period	50-Year Return Period	100-Year Return Period	200-Year Return Period
12-month	53.4	48.0	43.7	40.1
18-month	61.1	55.4	50.8	47.0
24-month	66.1	60.4	55.9	52.0
36-month	74.0	68.0	63.3	59.3
48-month	79.0	72.5	67.4	63.1
60-month	81.5	74.8	69.7	65.5

Table A-4. Expected average precipitation for all sites for Kansas, expressed as percent of normal (1971-2000), for selected drought durations and return periods.

Drought Duration	25-Year Return Period	50-Year Return Period	100-Year Return Period	200-Year Return Period
12-month	49.5	44.3	40.2	36.8
18-month	57.3	51.7	47.3	43.6
24-month	63.4	57.4	52.8	49.0
36-month	71.4	64.8	59.7	55.3
48-month	76.6	69.3	63.5	58.7
60-month	79.8	72.0	66.0	61.0

Table A-5. Expected average precipitation for all sites for Michigan, expressed as percent of normal (1971-2000), for selected drought durations and return periods.

Drought Duration	25-Year Return Period	50-Year Return Period	100-Year Return Period	200-Year Return Period
12-month	59.8	53.3	48.0	43.3
18-month	66.1	59.7	54.4	49.8
24-month	71.5	65.0	59.7	55.0
36-month	76.9	70.4	65.1	60.5
48-month	80.8	74.0	68.5	63.6
60-month	83.5	76.6	71.2	66.5

Table A-6. Expected average precipitation for all sites for Minnesota, expressed as percent of normal (1971-2000), for selected drought durations and return periods.

Drought Duration	25-Year Return Period	50-Year Return Period	100-Year Return Period	200-Year Return Period
12-month	53.7	47.8	43.0	38.9
18-month	60.7	54.8	50.1	46.1
24-month	67.4	61.0	55.8	51.3
36-month	74.0	67.4	62.2	57.8
48-month	77.8	70.7	65.2	60.6
60-month	80.8	73.5	67.9	63.3

Table A-7. Expected average precipitation for all sites for Missouri, expressed as percent of normal (1971-2000), for selected drought durations and return periods.				
Drought Duration	25-Year Return Period	50-Year Return Period	100-Year Return Period	200-Year Return Period
12-month	54.9	49.5	45.2	41.6
18-month	62.0	56.6	52.4	48.8
24-month	67.9	62.2	57.7	53.9
36-month	75.5	69.5	64.8	60.9
48-month	80.2	73.6	68.5	64.1
60-month	82.2	75.3	70.0	65.7

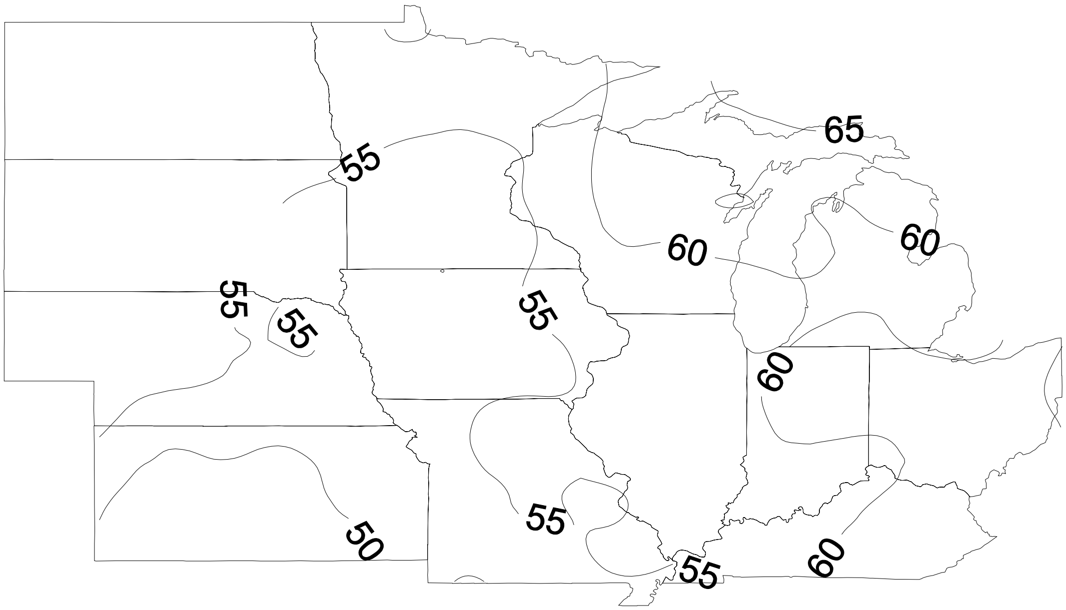
Table A-8. Expected average precipitation for all sites for Nebraska, expressed as percent of normal (1971-2000), for selected drought durations and return periods.				
Drought Duration	25-Year Return Period	50-Year Return Period	100-Year Return Period	200-Year Return Period
12-month	54.5	49.6	45.8	42.5
18-month	62.5	56.8	52.3	48.4
24-month	68.0	61.8	57.0	52.9
36-month	75.4	68.8	63.5	58.9
48-month	80.3	73.3	67.8	63.2
60-month	83.9	76.6	70.9	66.1

Table A-9. Expected average precipitation for all sites for Ohio, expressed as percent of normal (1971-2000), for selected drought durations and return periods.				
Drought Duration	25-Year Return Period	50-Year Return Period	100-Year Return Period	200-Year Return Period
12-month	62.2	56.4	51.9	48.1
18-month	69.0	63.6	59.3	55.8
24-month	74.6	68.9	64.3	60.3
36-month	80.6	74.9	70.3	66.5
48-month	84.5	78.5	73.7	69.6
60-month	86.6	80.4	75.7	71.9

Table A-10. Expected average precipitation for all sites for Wisconsin, expressed as percent of normal (1971-2000), for selected drought durations and return periods.

Drought Duration	25-Year Return Period	50-Year Return Period	100-Year Return Period	200-Year Return Period
12-month	59.2	53.6	49.0	45.0
18-month	66.8	60.7	55.7	51.4
24-month	71.3	65.2	60.4	56.2
36-month	77.8	71.6	66.7	62.5
48-month	81.6	75.4	70.7	66.7
60-month	84.4	78.0	73.2	69.1

12-Month, 25-Year Drought



12-Month, 50-Year Drought

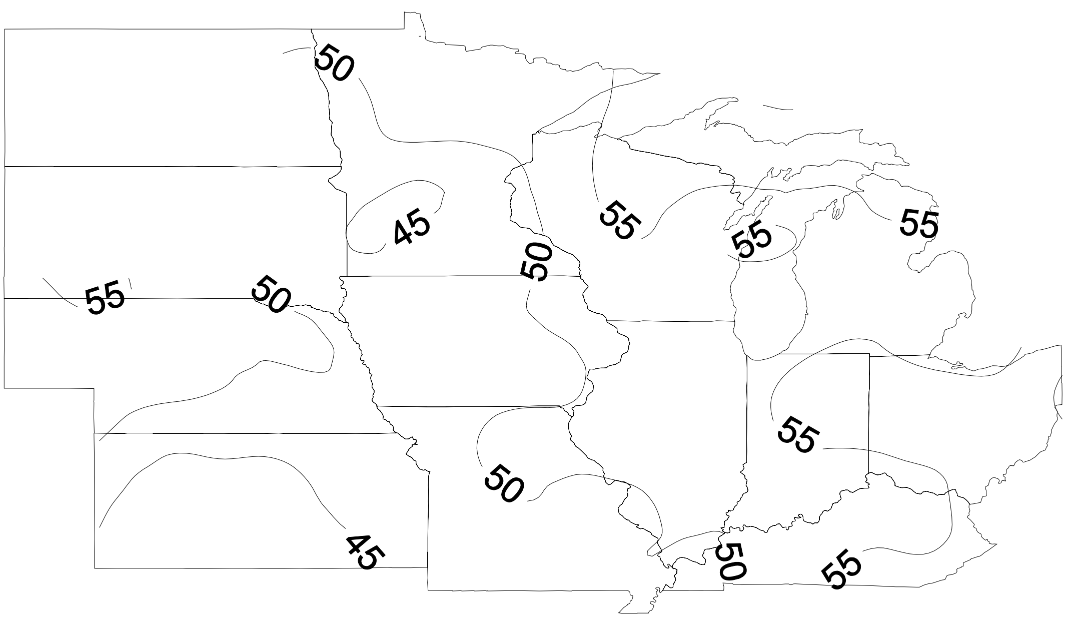
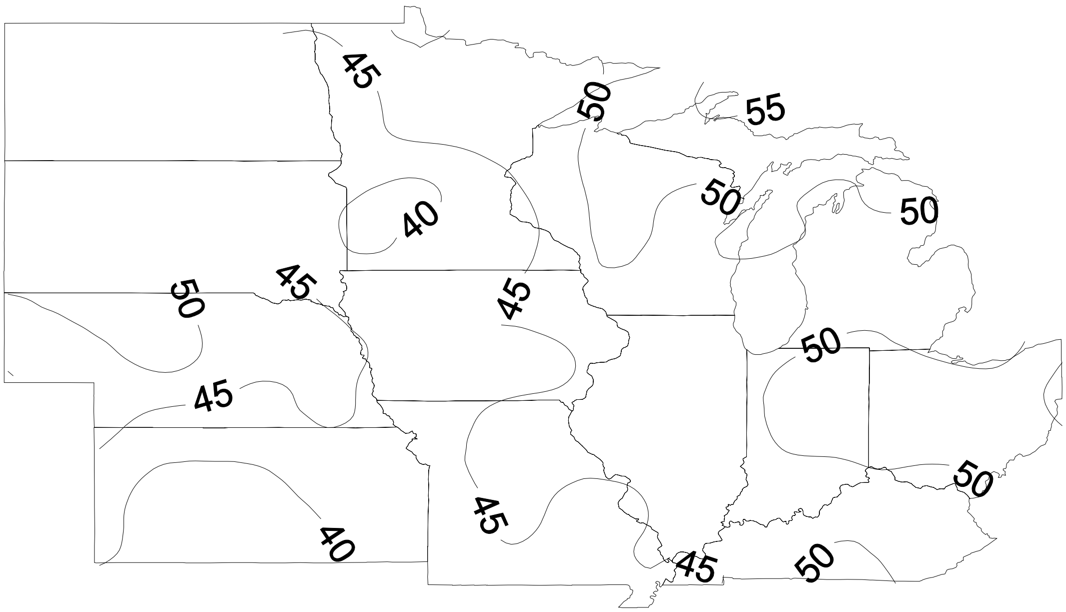


Figure A-1. 12-month drought at return periods of a) 25 years, b) 50 years, c) 100 years, and d) 200 years, expressed as percent of normal 1971-2000 precipitation.

12-Month, 100-Year Drought



12-Month, 200-Year Drought

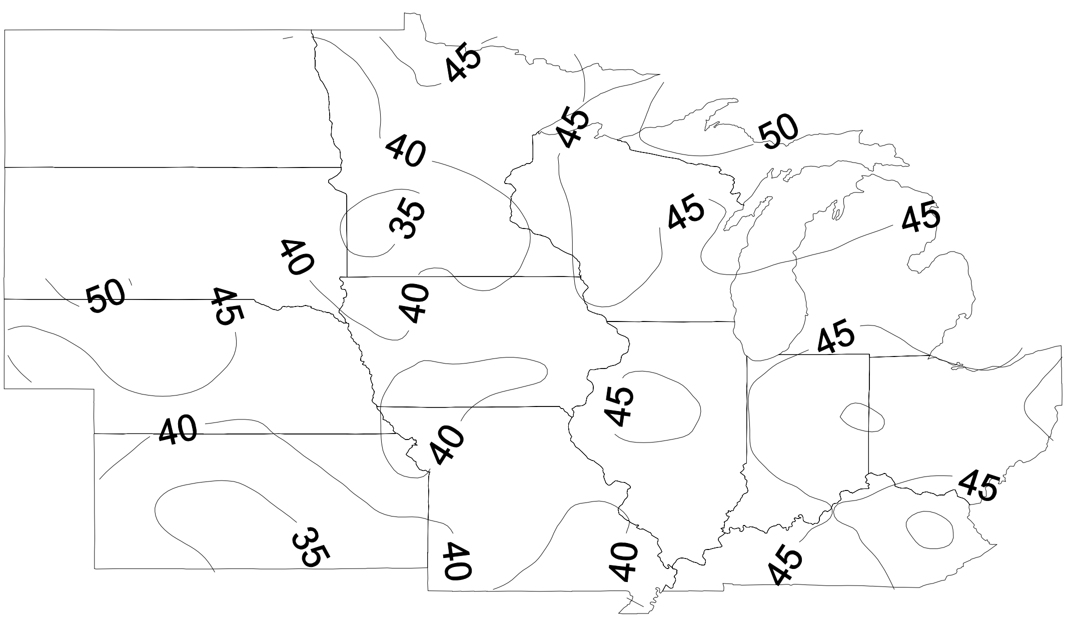
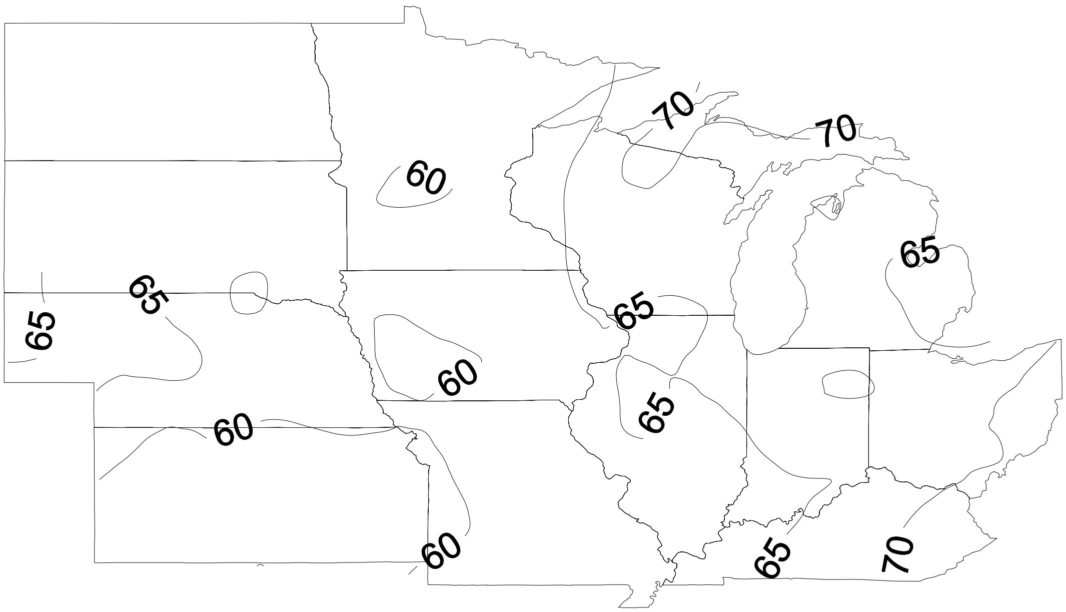


Figure A-1 *(cont.)*.

18-Month, 25-Year Drought



18-Month, 50-Year Drought

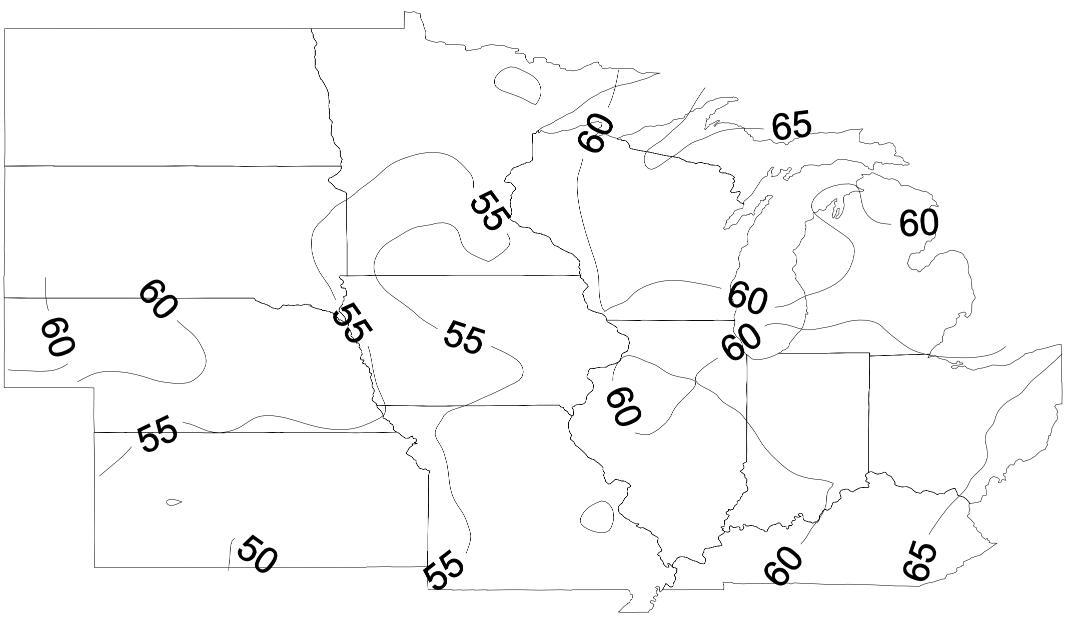
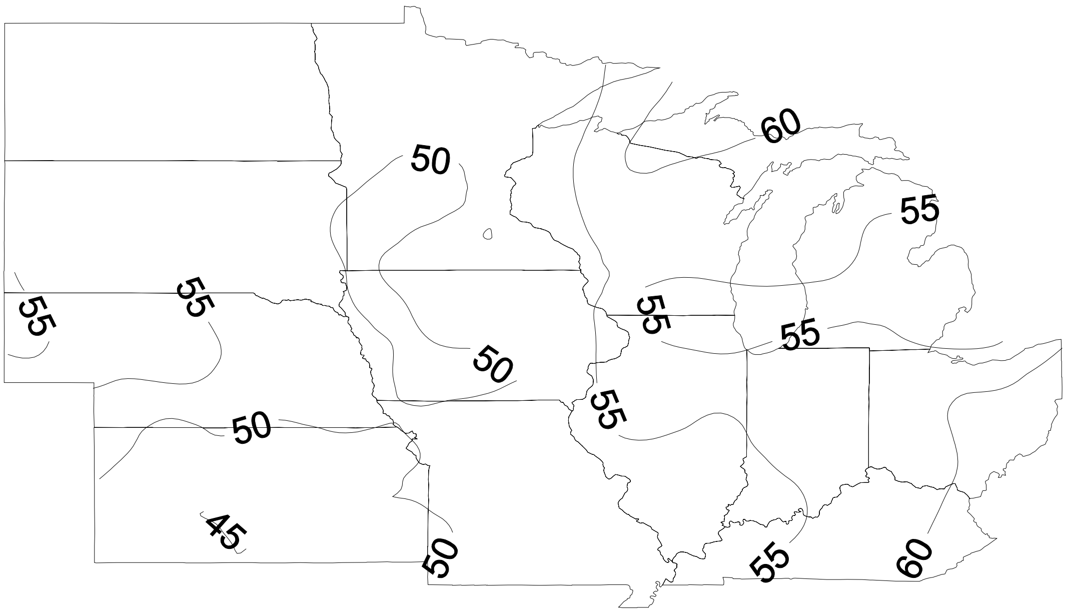


Figure A-2. 18-month drought at return periods of a) 25 years, b) 50 years, c) 100 years, and d) 200 years, expressed as percent of normal 1971-2000 precipitation.

18-Month, 100-Year Drought



18-Month, 200-Year Drought

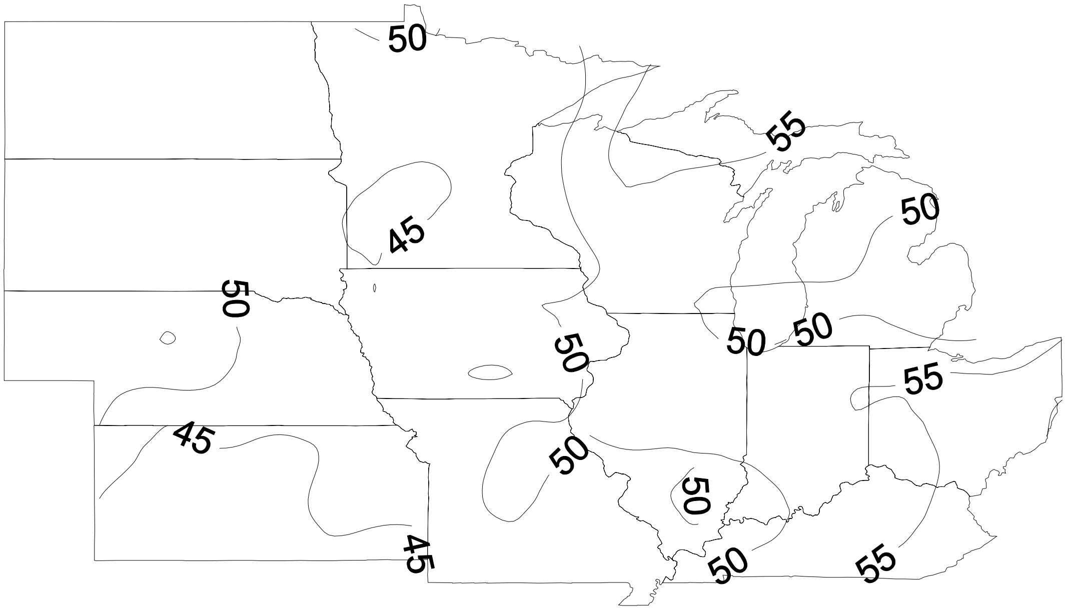
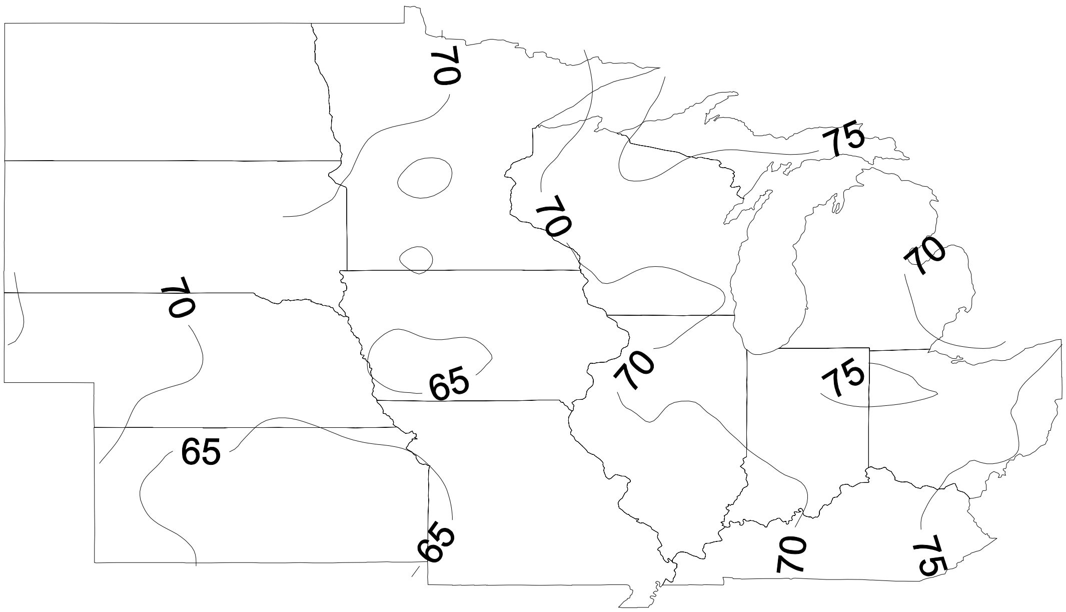


Figure A-2 *(cont.)*.

24-Month, 25-Year Drought



24-Month, 50-Year Drought

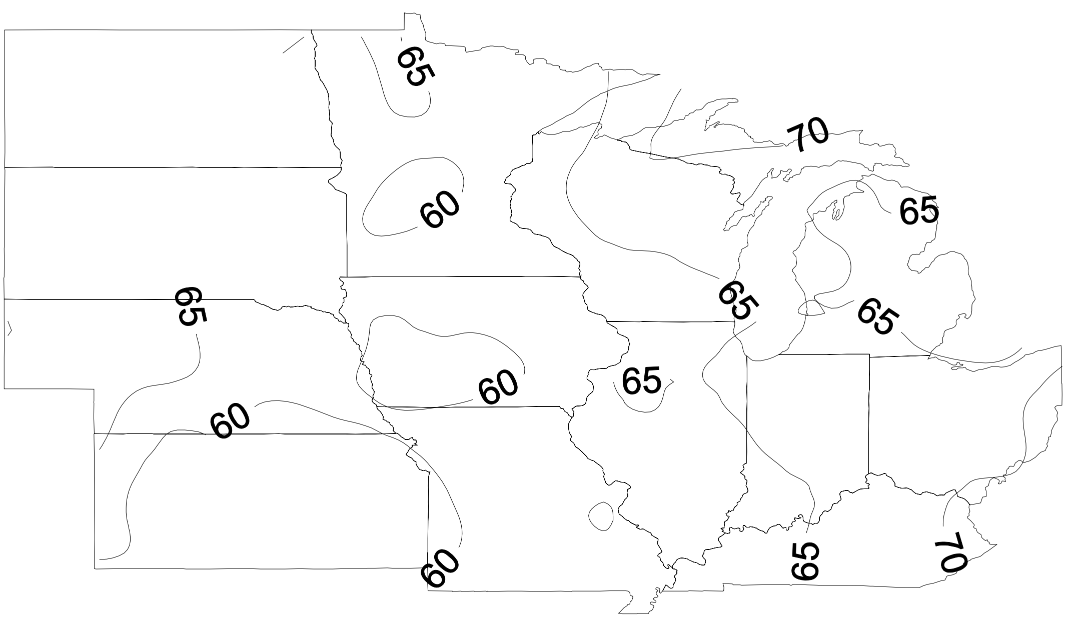
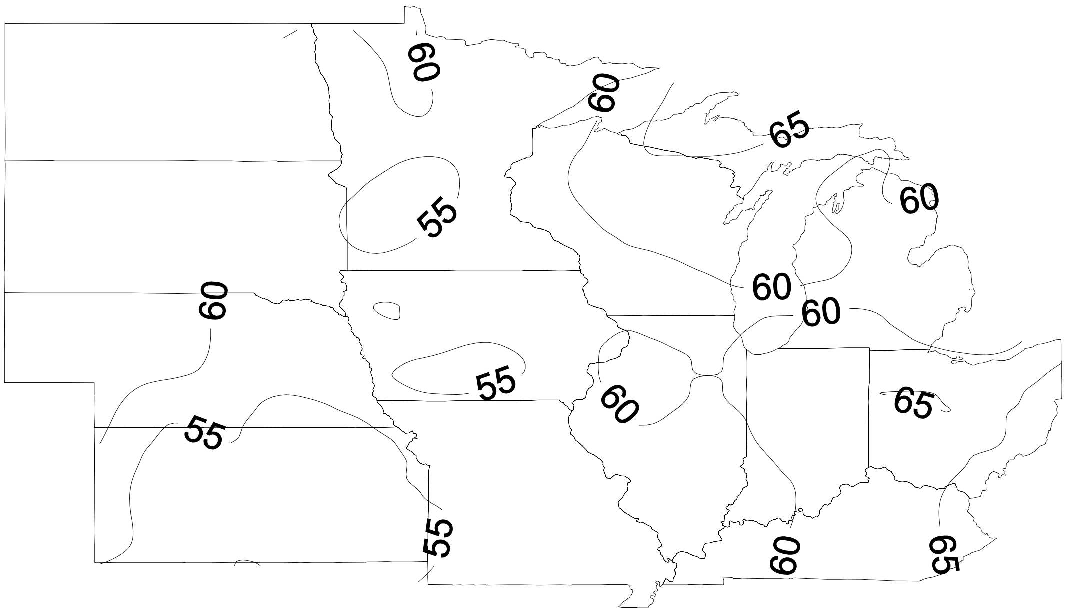


Figure A-3. 24-month drought at return periods of a) 25 years, b) 50 years, c) 100 years, and d) 200 years, expressed as percent of normal 1971-2000 precipitation.

24-Month, 100-Year Drought



24-Month, 200-Year Drought

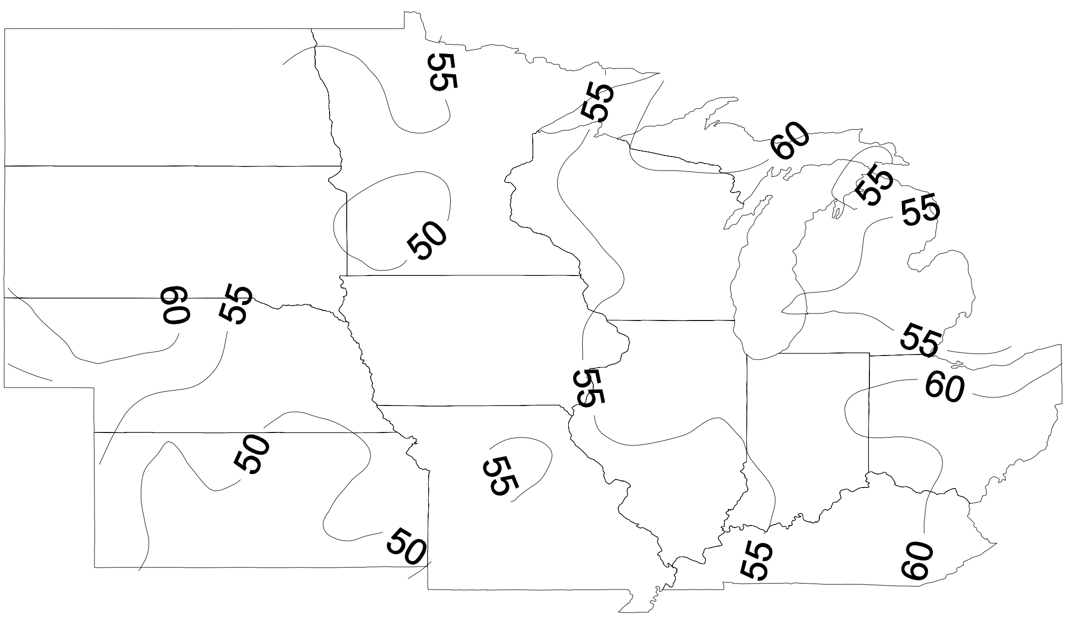
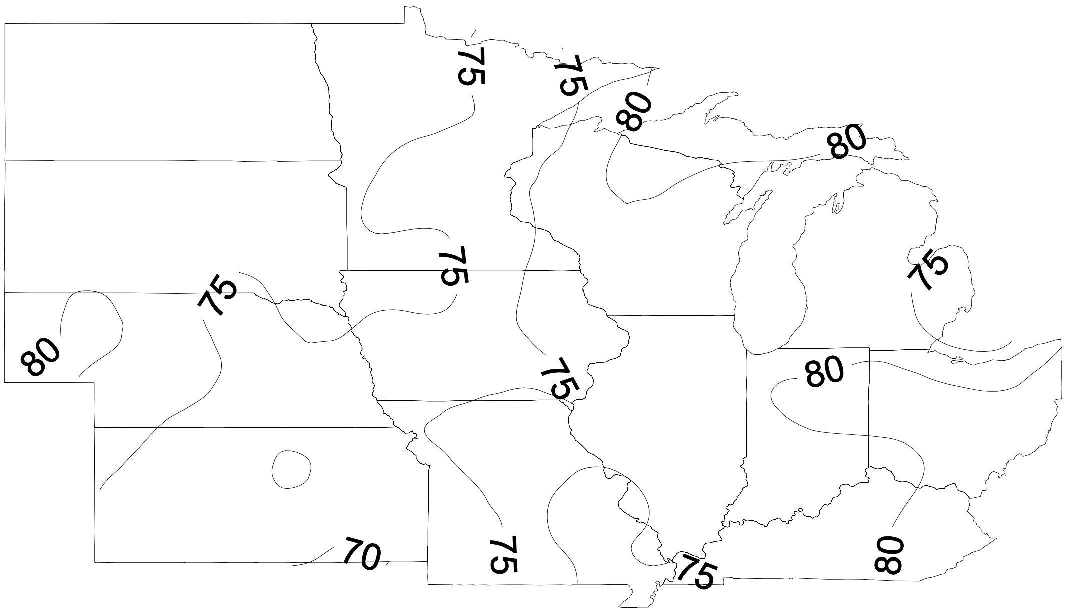


Figure A-3 *(cont.)*.

36-Month, 25-Year Drought



36-Month, 50-Year Drought

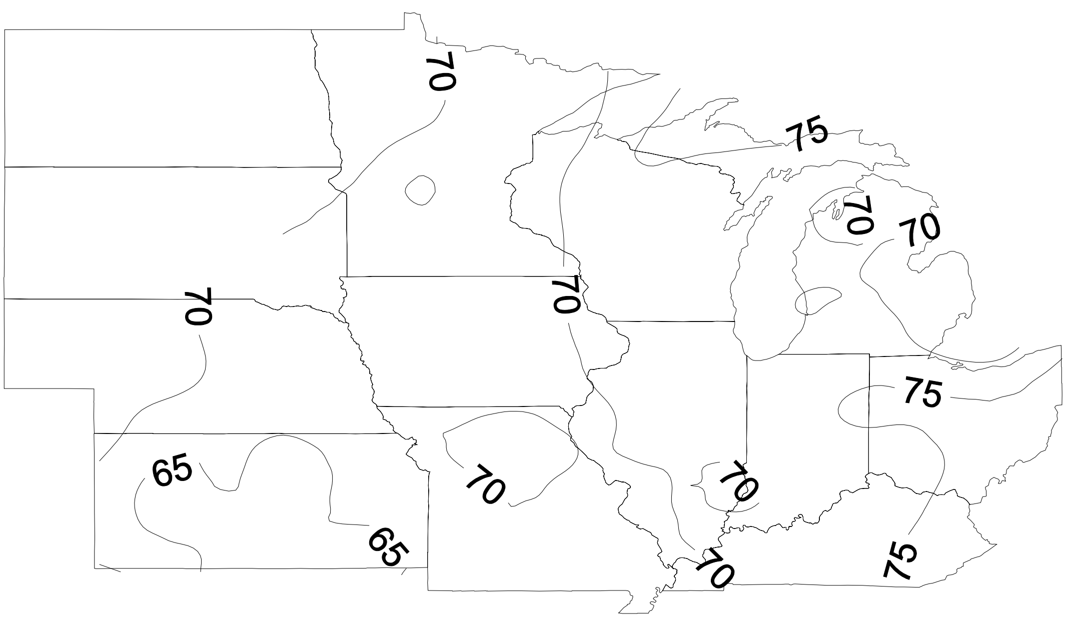
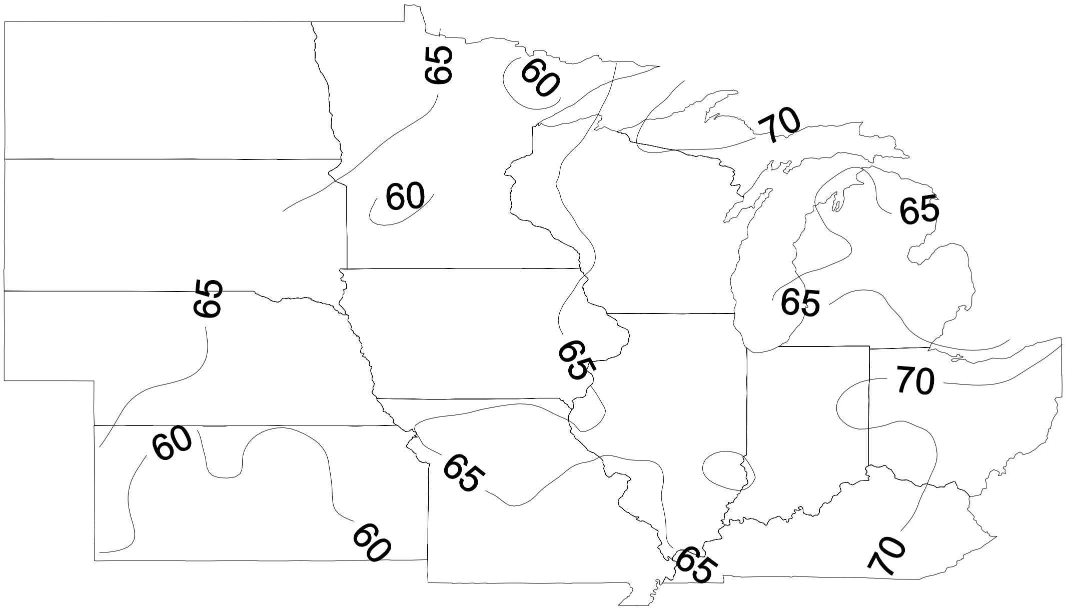


Figure A-4. 36-month drought at return periods of a) 25 years, b) 50 years, c) 100 years, and d) 200 years, expressed as percent of normal 1971-2000 precipitation.

36-Month, 100-Year Drought



36-Month, 200-Year Drought

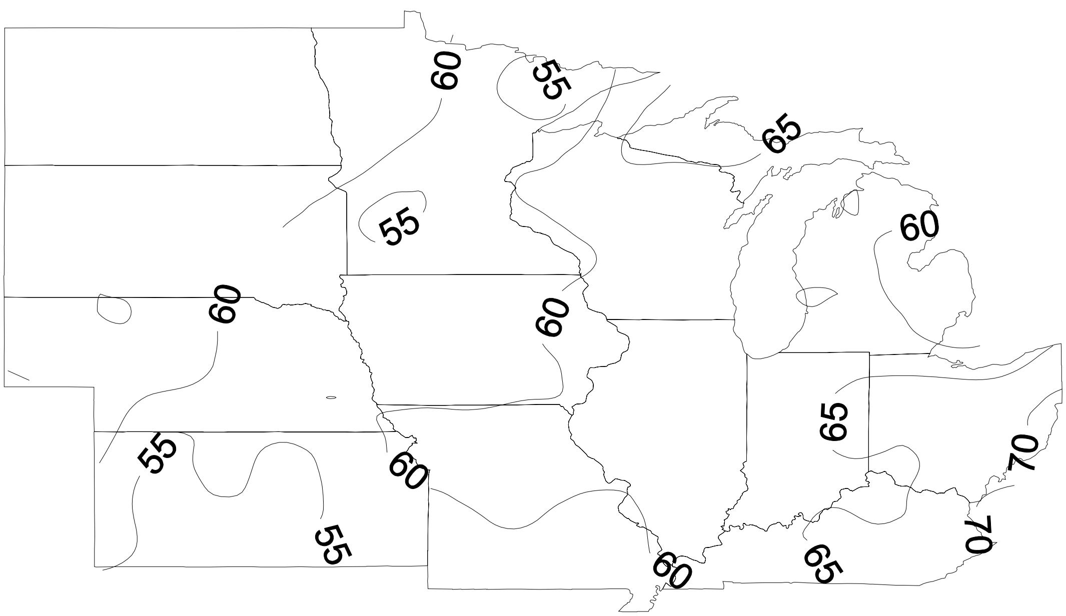
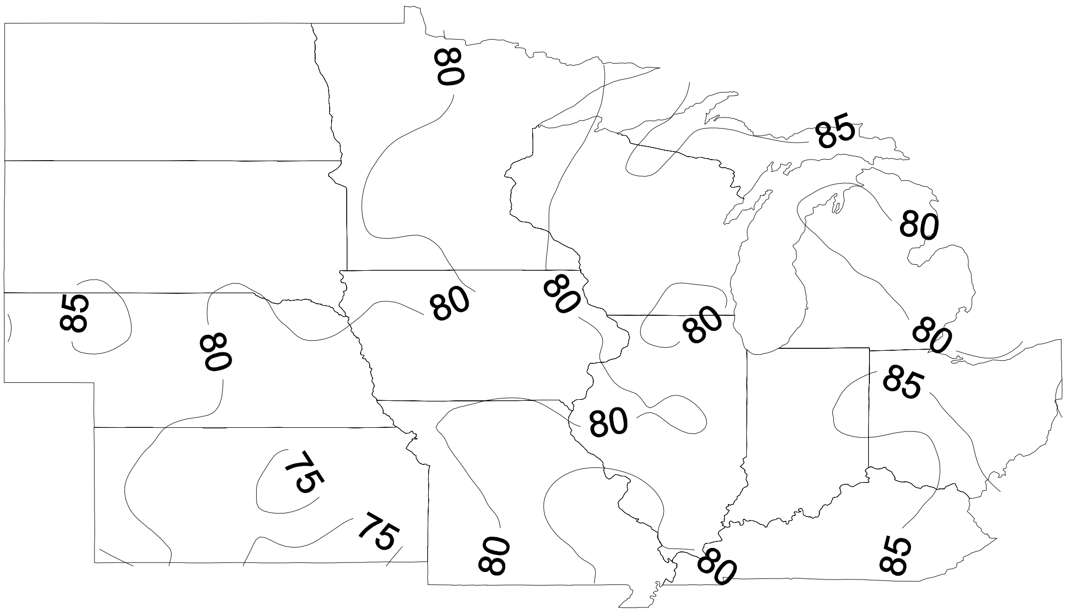


Figure A-4 *(cont.)*.

48-Month, 25-Year Drought



48-Month, 50-Year Drought

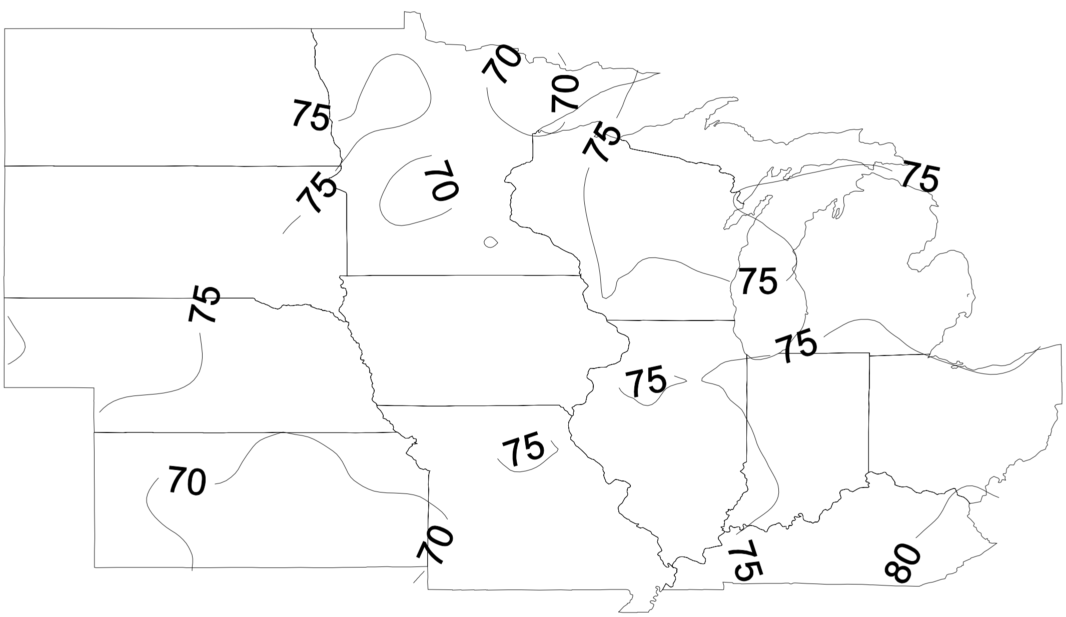
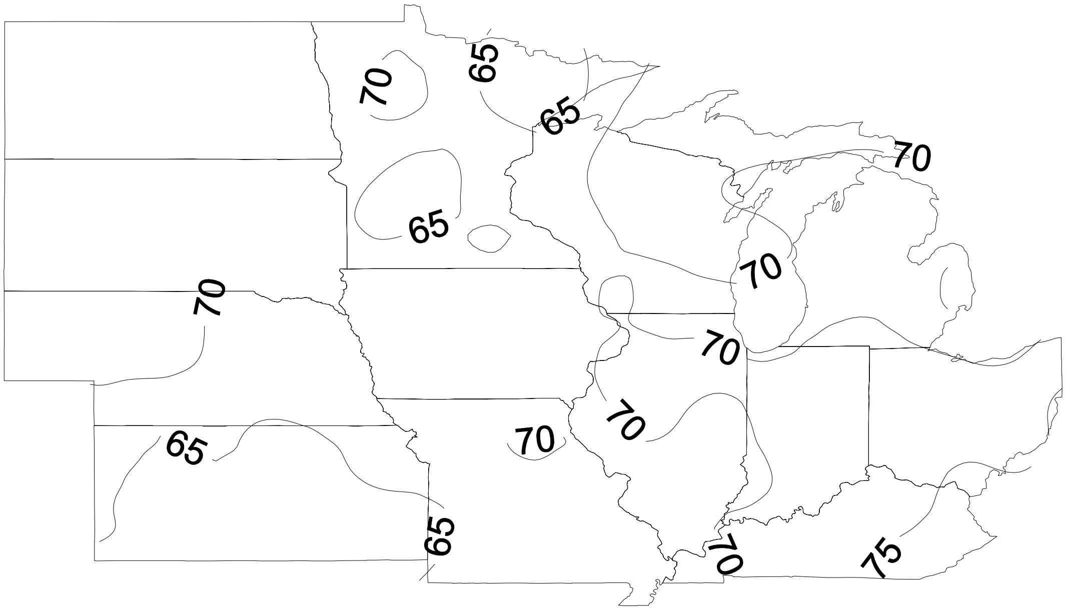


Figure A-5. 48-month drought at return periods of a) 25 years, b) 50 years, c) 100 years, and d) 200 years, expressed as percent of normal 1971-2000 precipitation.

48-Month, 100-Year Drought



48-Month, 200-Year Drought

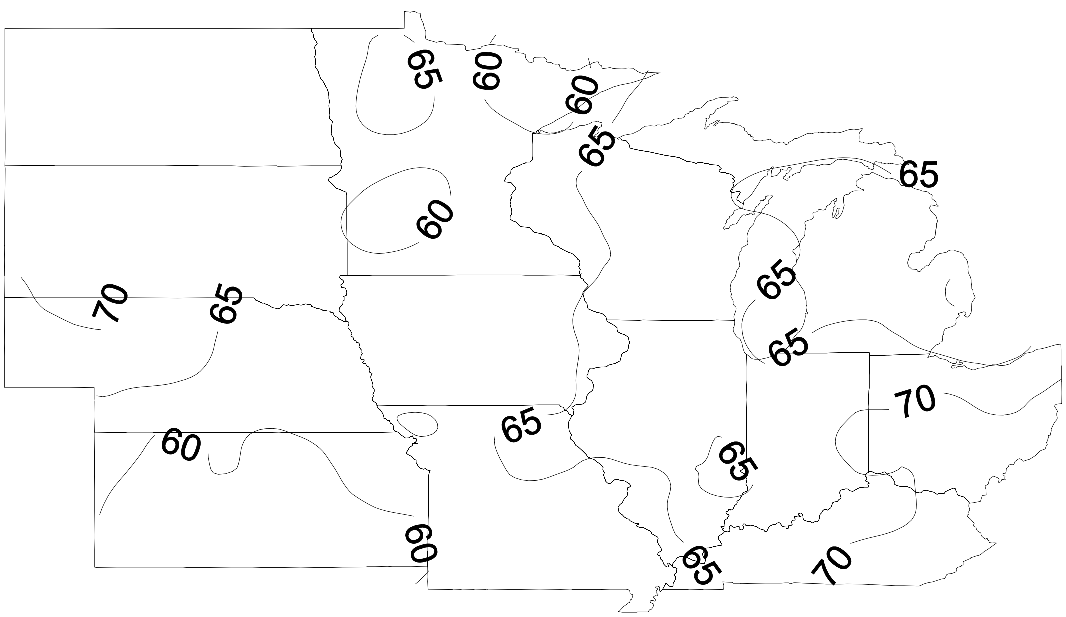
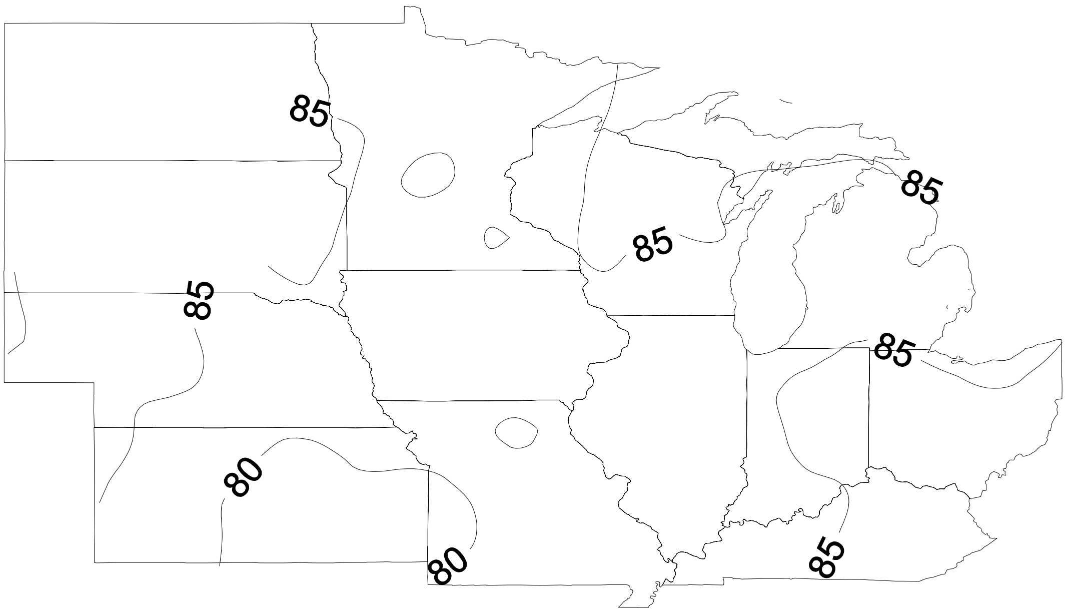


Figure A-5 *(cont.)*.

60-Month, 25-Year Drought



60-Month, 50-Year Drought

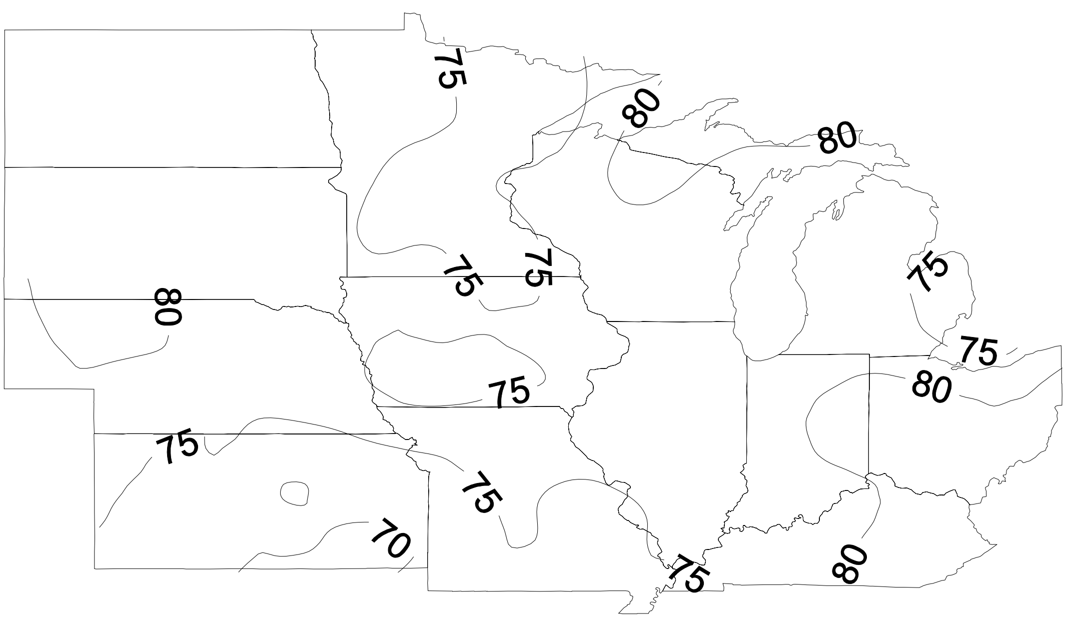
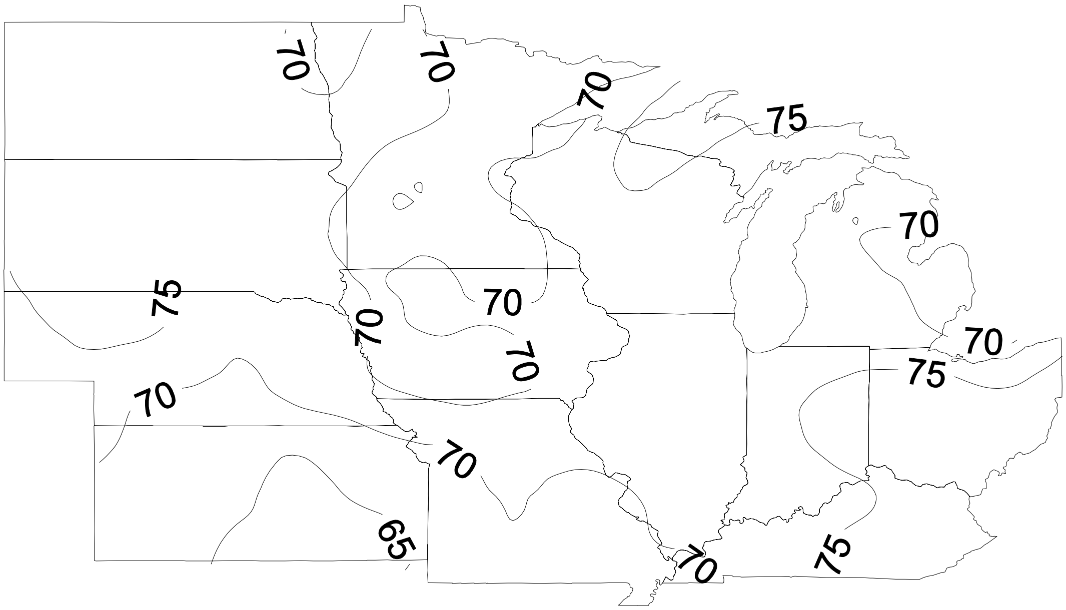


Figure A-6. 60-month drought at return periods of a) 25 years, b) 50 years, c) 100 years, and d) 200 years, expressed as percent of normal 1971-2000 precipitation.

60-Month, 100-Year Drought



60-Month, 200-Year Drought

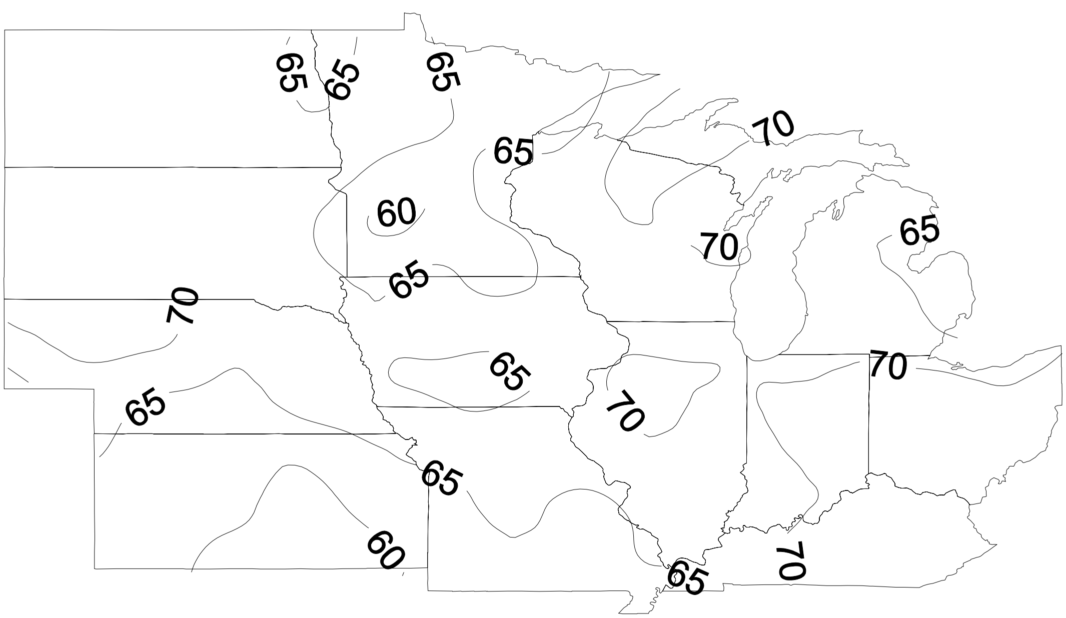


Figure A-6 *(cont.)*.

Appendix B. USGS stream gages used to describe drought impacts on streamflows in the Midwest

Figure ID	USGS Station Number	Station Name	State
1	03109500	LITTLE BEAVER CREEK NEAR EAST LIVERPOOL, OH	OH
2	03118500	NIMISHILLEN CREEK AT NORTH INDUSTRY, OH	OH
3	03144000	WAKATOMIKA CREEK NEAR FRAZEYSBURG, OH	OH
4	03202000	RACCOON CREEK AT ADAMSVILLE, OH	OH
5	03219500	SCIOTO RIVER NEAR PROSPECT, OH	OH
6	03230500	BIG DARBY CREEK AT DARBYVILLE, OH	OH
7	03237500	OHIO BRUSH CREEK NEAR WEST UNION, OH	OH
8	03262000	LORAMIE CREEK AT LOCKINGTON, OH	OH
9	03266000	STILLWATER RIVER AT ENGLEWOOD, OH	OH
10	03272000	TWIN CREEK NEAR GERMANTOWN, OH	OH
11	03324000	LITTLE RIVER NEAR HUNTINGTON, IN	IN
12	03326500	MISSISSINEWA RIVER AT MARION, IN	IN
13	03328500	EEL RIVER NEAR LOGANSPORT, IN	IN
14	03334500	SOUTH FORK WILDCAT CREEK NEAR LAFAYETTE, IN	IN
15	03339500	SUGAR CREEK AT CRAWFORDSVILLE, IN	IN
16	03345500	EMBARRAS RIVER AT STE. MARIE, IL	IL
17	03346000	NORTH FORK EMBARRAS RIVER NEAR OBLONG, IL	IL
18	03351500	FALL CREEK NEAR FORTVILLE, IN	IN
19	03362500	SUGAR CREEK NEAR EDINBURGH, IN	IN
20	03363500	FLATROCK RIVER AT ST. PAUL, IN	IN
21	03379500	LITTLE WABASH RIVER BELOW CLAY CITY, IL	IL
22	03380500	SKILLET FORK AT WAYNE CITY, IL	IL
23	03612000	CACHE RIVER AT FORMAN, IL	IL
24	04010500	PIGEON RIVER AT MIDDLE FALLS NR GRAND PORTAGE, MN	MN
25	04025500	BOIS BRULE RIVER AT BRULE, WI	WI
26	04027000	BAD RIVER NEAR ODANAH, WI	WI
27	04033000	MIDDLE BRANCH ONTONAGON RIVER NEAR PAULDING, MI	MI
28	04040500	STURGEON RIVER NEAR SIDNAW, MI	MI
29	04045500	TAHQUAMENON RIVER NEAR PARADISE, MI	MI
30	04056500	MANISTIQUE RIVER NEAR MANISTIQUE, MI	MI
31	04059500	FORD RIVER NEAR HYDE, MI	MI
32	04071000	OCONTO RIVER NEAR GILLETT, WI	WI
33	04073500	FOX RIVER AT BERLIN, WI	WI
34	04078500	EMBARRASS RIVER NEAR EMBARRASS, WI	WI
35	04100500	ELKHART RIVER AT GOSHEN, IN	IN
36	04105000	BATTLE CREEK AT BATTLE CREEK, MI	MI
37	04121500	MUSKEGON RIVER AT EVART, MI	MI
38	04128000	STURGEON RIVER NEAR WOLVERINE, MI	MI

Appendix B (continued)

Figure ID	USGS Station Number	Station Name	State
39	0413550	AU SABLE RIVER AT GRAYLING, MI	MI
40	0414200	RIFLE RIVER NEAR STERLING, MI	MI
41	0418900	BLANCHARD RIVER NEAR FINDLAY, OH	OH
42	0419800	SANDUSKY RIVER NEAR FREMONT, OH	OH
43	0421300	CONNEAUT CREEK AT CONNEAUT, OH	OH
44	0506050	RUSH RIVER AT AMENIA, ND	ND
45	0506200	BUFFALO RIVER NEAR DILWORTH, MN	MN
46	0506250	WILD RICE RIVER AT TWIN VALLEY, MN	MN
47	0506650	GOOSE RIVER AT HILLSBORO, ND	ND
48	0506900	SAND HILL RIVER AT CLIMAX, MN	MN
49	0508400	FOREST RIVER NR FORDVILLE, ND	ND
50	0510750	ROSEAU RIVER AT ROSS, MN	MN
51	0513050	STURGEON RIVER NEAR CHISHOLM, MN	MN
52	0528600	RUM RIVER NEAR ST. FRANCIS, MN	MN
53	0529000	LITTLE MINNESOTA RIVER NEAR PEEVER, SD	SD
54	0529100	WHETSTONE RIVER NEAR BIG STONE CITY, SD	SD
55	0529300	YELLOW BANK RIVER NEAR ODESSA, MN	MN
56	0530000	LAC QUI PARLE RIVER NEAR LAC QUI PARLE, MN	MN
57	0531350	YELLOW MEDICINE RIVER NEAR GRANITE FALLS, MN	MN
58	0531650	REDWOOD RIVER NEAR REDWOOD FALLS, MN	MN
59	0531700	COTTONWOOD RIVER NEAR NEW ULM, MN	MN
60	0532050	LE SUEUR RIVER NEAR RAPIDAN, MN	MN
61	0533350	ST. CROIX RIVER NEAR DANBURY, WI	WI
62	0536200	JUMP RIVER AT SHELDON, WI	WI
63	0536800	HAY RIVER AT WHEELER, WI	WI
64	0537950	TREMPEALEAU RIVER AT DODGE, WI	WI
65	0538100	BLACK RIVER AT NEILLSVILLE, WI	WI
66	0538500	ROOT RIVER NEAR HOUSTON, MN	MN
67	0539450	PRAIRIE RIVER NEAR MERRILL, WI	WI
68	0539750	EAU CLAIRE RIVER AT KELLY, WI	WI
69	0539950	BIG EAU PLEINE RIVER AT STRATFORD, WI	WI
70	0540500	BARABOO RIVER NEAR BARABOO, WI	WI
71	0541049	KICKAPOO RIVER AT STEUBEN, WI	WI
72	0541250	TURKEY RIVER AT GARBER, IA	IA
73	0541350	GRANT RIVER AT BURTON, WI	WI
74	0541850	MAQUOKETA RIVER NEAR MAQUOKETA, IA	IA
75	0541900	APPLE RIVER NEAR HANOVER, IL	IL
76	0542100	WAPSIPINICON RIVER AT INDEPENDENCE, IA	IA

Appendix B (continued)

Figure ID	USGS Station Number	Station Name	State
77	0542600	CRAWFISH RIVER AT MILFORD, WI	WI
78	0543148	TURTLE CREEK AT CARVERS ROCK ROAD NEAR CLINTON, WI	WI
79	0543550	PECATONICA RIVER AT FREEPORT, IL	IL
80	0543650	SUGAR RIVER NEAR BRODHEAD, WI	WI
81	0544000	KISHWAUKEE RIVER NEAR PERRYVILLE, IL	IL
82	0544400	ELKHORN CREEK NEAR PENROSE, IL	IL
83	0544750	GREEN RIVER NEAR GENESEO, IL	IL
84	0545150	IOWA RIVER AT MARSHALLTOWN, IA	IA
85	0545550	ENGLISH RIVER AT KALONA, IA	IA
86	0545800	LITTLE CEDAR RIVER NEAR IONIA, IA	IA
87	0545950	WINNEBAGO RIVER AT MASON CITY, IA	IA
88	0546600	EDWARDS RIVER NEAR ORION, IL	IL
89	0547000	SOUTH SKUNK RIVER NEAR AMES, IA	IA
90	0547250	NORTH SKUNK RIVER NEAR SIGOURNEY, IA	IA
91	0547900	EAST FORK DES MOINES RIVER AT DAKOTA CITY, IA	IA
92	0548100	BOONE RIVER NEAR WEBSTER CITY, IA	IA
93	0548400	SOUTH RACCOON RIVER AT REDFIELD, IA	IA
94	0548649	MIDDLE RIVER NEAR INDIANOLA, IA	IA
95	0548900	CEDAR CREEK NEAR BUSSEY, IA	IA
96	0549500	FOX RIVER AT WAYLAND, MO	MO
97	0549700	NORTH FABIUS RIVER AT MONTICELLO, MO	MO
98	0549800	MIDDLE FABIUS RIVER NEAR MONTICELLO, MO	MO
99	0550000	SOUTH FABIUS RIVER NEAR TAYLOR, MO	MO
100	0550100	NORTH RIVER AT PALMYRA, MO	MO
101	0551450	CUIVRE RIVER NEAR TROY, MO	MO
102	0552500	IROQUOIS RIVER AT IROQUOIS, IL	IL
103	0554200	MAZON RIVER NEAR COAL CITY, IL	IL
104	0554575	FOX RIVER NEAR NEW MUNSTER, WI	WI
105	0555530	VERMILION RIVER NEAR LEONORE, IL	IL
106	0555650	BIG BUREAU CREEK AT PRINCETON, IL	IL
107	0556750	MACKINAW RIVER NEAR CONGERVILLE, IL	IL
108	0556950	SPOON RIVER AT LONDON MILLS, IL	IL
109	0557200	SANGAMON RIVER AT MONTICELLO, IL	IL
110	0558500	LA MOINE RIVER AT RIPLEY, IL	IL
111	0559400	SHOAL CREEK NEAR BREESE, IL	IL
112	0559700	BIG MUDDY RIVER AT PLUMFIELD, IL	IL
113	0634050	KNIFE RIVER AT HAZEN, ND	ND
114	0634950	APPLE CREEK NR MENOKEN, ND	ND

Appendix B (continued)

Figure ID	USGS Station Number	Station Name	State
115	0635000	CANNONBALL RIVER AT REGENT, ND	ND
116	0635200	CEDAR CREEK NR HAYNES, ND	ND
117	0635650	SOUTH FORK GRAND R NEAR CASH, SD	SD
118	0635950	MOREAU R NEAR FAITH, SD	SD
119	0642550	ELK CR NEAR ELM SPRINGS, SD	SD
120	0644600	WHITE R NEAR OGLALA, SD	SD
121	0644950	LITTLE WHITE R NEAR ROSEBUD, SD	SD
122	0646450	KEYA PAHA R AT WEWELA, SD	SD
123	0648150	SKUNK CR AT SIOUX FALLS, SD	SD
124	0648350	ROCK RIVER NEAR ROCK VALLEY, IA	IA
125	0660050	FLOYD RIVER AT JAMES, IA	IA
126	0667750	HORSE CREEK NEAR LYMAN, NE	NE
127	0678350	MUD CREEK NEAR SWEETWATER, NE	NE
128	0680000	MAPLE CREEK NEAR NICKERSON, NE	NE
129	0680850	WEST NISHNABOTNA RIVER AT RANDOLPH, IA	IA
130	0680950	EAST NISHNABOTNA RIVER AT RED OAK, IA	IA
131	0681150	LITTLE NEMAHA RIVER AT AUBURN, NE	NE
132	0681400	TURKEY CREEK NEAR SENECA, KS	KS
133	0687800	CHAPMAN CREEK NEAR CHAPMAN, KS	KS
134	0688300	LITTLE BLUE RIVER NEAR DEWEESE, NE	NE
135	0688550	BLACK VERMILLION RIVER NEAR FRANKFORT, KS	KS
136	0688850	MILL CREEK NEAR PAXICO, KS	KS
137	0688950	SOLDIER CREEK NEAR TOPEKA, KS	KS
138	0689200	STRANGER CREEK NEAR TONGANOXIE, KS	KS
139	0689800	THOMPSON RIVER AT DAVIS CITY, IA	IA
140	0690800	BLACKWATER RIVER AT BLUE LICK, MO	MO
141	0691150	SALT CREEK NEAR LYNDON, KS	KS
142	0691400	POTTAWATOMIE CREEK NEAR GARNETT, KS	KS
143	0691700	LITTLE OSAGE RIVER AT FULTON, KS	KS
144	0701300	MERAMEC RIVER NEAR STEELVILLE, MO	MO
145	0701650	BOURBEUSE RIVER AT UNION, MO	MO
146	0701850	BIG RIVER AT BYRNESVILLE, MO	MO
147	0702100	CASTOR RIVER AT ZALMA, MO	MO
148	0705750	NORTH FORK RIVER NEAR TECUMSEH, MO	MO
149	0706150	BLACK RIVER NEAR ANNAPOLIS, MO	MO
150	0707150	ELEVEN POINT RIVER NEAR BARDLEY, MO	MO
151	0714420	LITTLE ARKANSAS RIVER AT VALLEY CENTER, KS	KS
152	0714780	WALNUT RIVER AT WINFIELD, KS	KS

Appendix B (concluded)

Figure ID	USGS Station Number	Station Name	State
153	0714900	MEDICINE LODGE RIVER NEAR KIOWA, KS	KS
154	0716750	OTTER CREEK AT CLIMAX, KS	KS
155	0717200	CANEY RIVER NEAR ELGIN, KS	KS
156	0718050	CEDAR CREEK NEAR CEDAR POINT, KS	KS
157	0718600	SPRING RIVER NEAR WACO, MO	MO
158	0718700	SHOAL CREEK ABOVE JOPLIN, MO	MO
159	0718900	ELK RIVER NEAR TIFF CITY, MO	MO

Appendix C - Drought Plan Information and Water System Web Accessible Resources

Table C-1. State drought plans and contacts as of October 2005, along with primary responsible agencies and the trigger of drought response actions, if known. Individual state information tables below contain Web links to current drought plans. Future updates of state drought plans and drought contact can be acquired from the National Drought Mitigation Center at http://drought.unl.edu/.

Illinois

Drought Plan: Drought Contingency Planning. Special Report No. 3 of the Illinois State Water Plan Task Force (June 1983).

Agencies: Primary agencies are the Illinois Environmental Protection Agency and the Illinois Department of Natural Resources.

Trigger: Declaration of drought by the Governor.

Contact: Gary Clark, Director, Office of Water Resources
Illinois Department of Natural Resources
3215 Executive Park Drive, Springfield, IL 62703
Phone: (217) 782-2152; Fax: (217) 785-5014
e-mail: gclark@dnrmail.state.il.us

Indiana

Drought Plan: Indiana's Water Shortage Plan (1991).

Agencies: Primary agency is the Indiana Department of Natural Resources.

Trigger: Drought watch status, and activation of the Water Shortage Task Force, occurs when either the Palmer Hydrologic Drought Index reaches -2, or stages on rivers in a drainage basin reach the 75% exceedance values for a month (25^{th} percentile).

Contact: James J. Hebenstreit, P.E., Assistant Director
Division of Water, Indiana Department of Natural Resources
402 W. Washington Street, Room W264
Indianapolis, IN 46204-2748
Phone: (317) 232-4160
e-mail: jhebenstreit@dnr.state.in.us

Iowa

Drought Plan: The 1985 State Water Plan (one of several documents, no definitive drought plan)

Agencies: Primary agency is the Iowa Department of Natural Resources.

Trigger: Declaration of drought by the Governor.

Contact: Michael K. Anderson, P.E.
Water Supply Section, Iowa Department of Natural Resources
401 S.W. 7th Street, Suite M
Des Moines, IA 50309
Phone: (515) 725-0336
e-mail: michael.anderson@dnr.state.ia.us

Kansas

Drought Plan: Operations Plan – Governor's Drought Response Team (2003).

Agencies: Primary agency is the Kansas Water Office.

Trigger: Drought Watch status, and activation of the Drought Response Team, is triggered when the U.S. Drought Monitor map displays moderate drought (D1) in Kansas.

Contact: Tom Lowe, Water Resource Planner
Kansas Water Office
901 S. Kansas Avenue
Topeka, KS 66612-1249
Phone: (785) 296-3185; Fax: (785) 296-0878
e-mail: tlowe@kwo.state.ks.us

Michigan

Drought Plan: A 1988 drought plan may exist, name unknown; currently, drought is a small segment of a multi-hazard plan called for in the Disaster Mitigation Act of 2000.

Agencies: Primary agency is the Michigan Department of Environmental Quality.

Trigger: Declaration of drought by the Governor.

Contact: Tom Segall
Office of Ground Water Planning and Special Services
P.O. Box 30473

Lansing, MI 48909
Phone: (517) 373-0014; Fax (517) 335-5420

Minnesota

Drought Plan: Minnesota Drought Response Plan (June 1993)

Agencies: Primary agency is the Minnesota Department of Natural Resources.

Trigger: Lower than normal precipitation, declining stream flows and groundwater levels.

Contact: Kent Lokkesmoe, Director
DNR Waters
500 Lafayette Road
St. Paul, MN 55155-4032
Phone: (651) 296-4810; Fax: (651) 296-0445
e-mail: kent.lokkesmoe@dnr.state.mn.us

Missouri

Drought Plan: Missouri Drought Plan (2002)

Agencies: Primary agency is the Missouri Department of Natural Resources.

Trigger: Drought Advisory Phase is determined using multiple drought indices, and a recommendation is made to the Director of the Department of Natural Resources, who may activate the Drought Assessment Committee.

Contact: Steve McIntosh, Director
Water Resources Program, Missouri Department of Natural Resources
Geological Survey and Resource Assessment Division
P.O. Box 176
Jefferson City, MO 65102
Phone: (573) 751-2867; Fax: (573) 751-8475
e-mail: nrmcins@mail.dnr.state.mo.us

Nebraska

Drought Plan: Nebraska's Climate Assessment Response Committee Drought Mitigation and Response Plan; also Nebraska State Hazard Mitigation Plan.

Agencies: Primary agency is the Nebraska Emergency Management Agency. Department of Agriculture and University of Nebraska active in drought situations.

Trigger: Declaration of drought by the Governor.

Contact: Merlyn Carlson, Director / Greg Ibach, Assistant Director
Nebraska Department of Agriculture
P.O. Box 94947
Lincoln, NE 68509-4947
Phone: (402) 471-2341
e-mail: gregai@agr.state.ne.us

Ohio

Drought Plan: Ohio Drought Response Plan (App. 1 to the Ohio Emergency Operations Plan)

Agencies: Primary agency is the Ohio Emergency Management Agency.

Trigger: Declaration of drought by the Governor, following a recommendation from the Drought Assessment Committee.

Contact: Dale W. Shipley, Executive Director
Division of Emergency Management Agency, State of Ohio
2855 West Dublin-Granville Road
Columbus, OH 43235-2206
Phone: (614) 889-7150; Fax: (614) 889-7183
e-mail: dshipley@dps.state.oh.us

Wisconsin

Drought Plan: No Drought Plan. State of Wisconsin Hazard Mitigation Plan

Agencies: Primary agency is the Wisconsin Department of Natural Resources.

Trigger: Declaration of drought by the Governor.

Contact: Diane Kleiboer
Disaster Resources Section, Wisconsin Emergency Management
P.O. Box 7865
Madison, WI 53707-7865
e-mail: KleibD@dma.state.wi.us

Table C-2. Description of Web-Accessible Resources for Illinois	
Primary PWS Agency	
	Illinois Environmental Protection Agency http://www.epa.state.il.us/water/index-pws.html
	Public Water Supply Information Search *Not available online*
	Drinking Water Annual Compliance Reports http://www.epa.state.il.us/water/compliance/drinking-water/compliance-report/index.html
Agencies Involved in Water Resource Investigations	
	Illinois State Water Survey http://www.sws.uiuc.edu/
	Illinois Drought Information http://www.sws.uiuc.edu/hilites/drought/
	Illinois Water Supply http://www.sws.uiuc.edu/docs/wsfaq/
Water Use / Water Allocation Program	
	Illinois Water Inventory Program http://www.sws.uiuc.edu/gws/iwip/
State Drought Plan	
	Drought Contingency Planning Special Report No. 3 of the Illinois State Water Plan Task Force (1983) http://www.drought.unl.edu/plan/state%20plans/Illinois.pdf

Table C-3. Description of Web-Accessible Resources for Indiana	
Primary PWS Agency	
	Indiana Department of Environmental Management Office of Water Quality Drinking Water Branch http://www.in.gov/idem/water/dwb/index.html
	Public Water Supply Information Search http://www.in.gov/apps/idem/sdwis_state/
	Drinking Water Annual Compliance Reports http://www.in.gov/idem/water/dwb/compliance/index.html
Agencies Involved in Water Resource Investigations	
	Indiana Department of Natural Resources Division of Water http://www.in.gov/dnr/water/
	Indiana Water Availability / Use / Rights http://www.state.in.us/dnr/water/water_availability/index.html
	Water Resource Availability Reports and Other Publications http://www.state.in.us/dnr/water/publications/index.html
Water Use / Water Allocation Program	
	Significant Water Withdrawal Facility Data http://www.state.in.us/dnr/water/water_availability/SWWF/index.html
State Drought Plan	
	Indiana Water Shortage Plan http://www.in.gov/dnr/water/water_availability/WaterResource/pdf/watshplan.pdf

Table C-4. Description of Web-Accessible Resources for Iowa	
Primary PWS Agency	
	Iowa Department of Natural Resources Water Supply Program http://www.iowadnr.com/water/drinking/index.html
	Active Public Water Supply Systems (*.pdf file) http://www.iowadnr.com/water/wso/files/aws.pdf
	Drinking Water Annual Compliance Reports http://www.iowadnr.com/water/drinking/reports.html
Agencies Involved in Water Resource Investigations	
	Iowa Department of Natural Resources Iowa Geological Survey http://www.igsb.uiowa.edu/
Water Use / Water Allocation Program	
	IowaDNR Water Allocation Program http://www.iowadnr.com/water/wse/allocation.html
State Drought Plan	
	Not available

Table C-5. Description of Web-Accessible Resources for Kansas	
Primary PWS Agency	
	Kansas Department of Health & Environment Public Water Supply Section http://www.kdhe.state.ks.us/pws/
	Public Water Supply Information Search *Not available online*
	Drinking Water Annual Compliance Reports http://www.kdhe.state.ks.us/pws/
Agencies Involved in Water Resource Investigations	
	Kansas Water Office http://www.kwo.org/
	Kansas Department of Agriculture Division of Water Resources http://www.ksda.gov/Default.aspx?tabid=173
	Kansas Geological Survey Geohydrology Section & Water Resources Information http://www.kgs.ku.edu/Hydro/hydroIndex.html
Water Use / Water Allocation Program	
	Division of Water Resources Water Appropriation Program: Water Use http://www.ksda.gov/Default.aspx?tabid=188
State Drought Plan	
	Operations Plan http://www.kwo.org/Reports%20&%20Publications/operations_plan.htm

Table C-6. Description of Web-Accessible Resources for Michigan	
Primary PWS Agency	
	Michigan Department of Environmental Quality Water Bureau, Drinking Water Unit http://www.michigan.gov/deq/0,1607,+7-135-3313_3675---,00.html
	Community Water Supply Listings http://www.michigan.gov/deq/0,1607,7-135-3313_3675_3691-9775--,00.html
	Drinking Water Annual Compliance Reports http://www.michigan.gov/deq/0,1607,+7-135-3313_3675_3691---,00.html
Agencies Involved in Water Resource Investigations	
	Michigan Department of Environmental Quality Land and Water Management Division Hydrologic Studies Unit http://www.michigan.gov/deq/0,1607,+7-135-3313_3684_3724---,00.html
	USGS, Michigan Water Science Center http://mi.water.usgs.gov/
Water Use / Water Allocation Program	
	Michigan Water Use Reporting Program http://www.michigan.gov/deq/0,1607,%207-135-3304-72931--,00.html
State Drought Plan	
	Not available

Table C-7. Description of Web-Accessible Resources for Minnesota	
Primary PWS Agency	
	Minnesota Department of Health Drinking Water Protection Program http://www.health.state.mn.us/divs/eh/water/
	Public Water Supply Information Search *Not available online*
	Drinking Water Annual Compliance Reports http://www.health.state.mn.us/divs/eh/water/com/dwar/index.html
Agencies Involved in Water Resource Investigations	
	Minnesota Department of Natural Resources Division of Waters http://www.dnr.state.mn.us/waters/index.html
Water Use / Water Allocation Program	
	Water Appropriations Permit Program http://www.dnr.state.mn.us/waters/watermgmt_section/appropriations/index.html
State Drought Plan	
	Drought Response Plan http://files.dnr.state.mn.us/natural_resources/climate/drought/droughtp.pdf

Table C-8. Description of Web-Accessible Resources for Missouri	
Primary PWS Agency	
	Missouri Department of Natural Resources Water Protection and Soil Conservation Division Public Drinking Water Branch http://www.dnr.state.mo.us/wpscd/wpcp/dw-index.htm
	Public Water Supply Information Search *Not available online*
	Drinking Water Annual Compliance Reports http://www.dnr.mo.gov/wpscd/wpcp/fyreports/index.html
Agencies Involved in Water Resource Investigations	
	Missouri Department of Natural Resources Geological Survey and Resource Assessment Division Water Resources Program http://dnr.missouri.gov/geology/wrp/wrphp.htm
	The Source Water Inventory Project http://drinkingwater.missouri.edu/swip/index.html
Water Use / Water Allocation Program	
	Major Water Users Registration http://dnr.missouri.gov/geology/wrp/waterusestatutes.htm
State Drought Plan	
	Missouri Drought Plan, 2002 http://dnr.missouri.gov/geology/wrp/WR69.pdf Missouri Drought Response Plan, 1995 http://www.dnr.state.mo.us/geology/wrp/WR44.pdf

Table C-9. Description of Web-Accessible Resources for Nebraska	
Primary PWS Agency	
	Nebraska Health & Human Services Public Water Supply Program http://www.hhs.state.ne.us/enh/pwsindex.htm
	Public Water Supply Information Search http://www3.hhs.state.ne.us/Sdwis_State/
	Drinking Water Annual Compliance Reports http://www.hhs.state.ne.us/enh/pws/2004rpt.pdf
Agencies Involved in Water Resource Investigations	
	Nebraska Department of Natural Resources http://www.dnr.state.ne.us/
Water Use / Water Allocation Program	
	Estimated Water Use in Nebraska (1995) http://www.dnr.state.ne.us/otherresources/waterreport95.html
State Drought Plan	
	Drought Mitigation and Response Plan http://carcunl.dnr.state.ne.us/docs/NebraskaDrought.pdf

Table C-10. Description of Web-Accessible Resources for Ohio	
Primary PWS Agency	
	Ohio Environmental Protection Agency Division of Drinking and Ground Water http://www.epa.state.oh.us/ddagw/
	Public Water Systems Listing http://www.epa.state.oh.us/ddagw/filedl.html
	Drinking Water Annual Compliance Reports http://www.epa.state.oh.us/ddagw/annualreports.html
Agencies Involved in Water Resource Investigations	
	Ohio Department of Natural Resources Division of Water http://www.dnr.state.oh.us/water/
	USGS Ohio Water Science Center http://oh.water.usgs.gov/
Water Use / Water Allocation Program	
	Water Withdrawal Facilities Registration Program http://www.dnr.state.oh.us/water/wwfr/ Water Inventory Program http://www.dnr.state.oh.us/water/waterinv/
State Drought Plan	
	Ohio Drought Response Plan Appendix 1 to the Ohio Emergency Operations Plan http://www.drought.unl.edu/plan/state%20plans/Ohio.pdf

Table C-11. Description of Web-Accessible Resources for Wisconsin	
Primary PWS Agency	
	Wisconsin Department of Natural Resources Drinking Water and Groundwater http://www.dnr.state.wi.us/org/water/dwg/
	Public Water Supply Information Search http://prodmtex00.dnr.state.wi.us/pls/inter1/pws2$.startup
	Drinking Water Annual Compliance Reports http://dnr.wi.gov/org/water/dwg/
Agencies Involved in Water Resource Investigations	
	Wisconsin Department of Natural Resources Bureau of Watershed Management http://dnr.wi.gov/org/water/wm/
	USGS Wisconsin Water Science Center http://wi.water.usgs.gov/
Water Use / Water Allocation Program	
	None
State Drought Plan	
	Not available

Table C-12. Description of USEPA Web-Accessible Resources

Safe Drinking Water Information System (SDWIS)
http://www.epa.gov/enviro/html/sdwis/

Small Systems Information and Guidance
http://www.epa.gov/safewater/smallsys/ssinfo.htm

Taking Stock of Your Water System: A Simple Asset Inventory for Very Small Drinking Water Systems
http://www.epa.gov/safewater/smallsys/pdfs/final_asset_inventory_for_small_systems.pdf

Glossary

Aquifer

A natural underground layer, either of sand and gravel or of shallow or deep bedrock, that contains water.

Baseflow

The sustained low flow of a stream, usually groundwater inflow to the stream channel. Also called *Groundwater Runoff.*

Community Water System (CWS)

A public water system which serves at least 15 service connections used by residents or regularly serves at least 25 residents for at least 60 days per year. An example of a community water system is one that serves a municipality.

Consecutive Public Water System

A public water system which receives water from another public water system(s) that is subject to regulation under the National Primary Drinking Water Regulations (NPDWRs).

Evapotranspiration

The process by which water is returned to the atmosphere by evaporation and transpiration caused by molecular activity at the liquid (water) surface where the liquid turns to vapor.

Finished Water

Water that has been treated and is ready to be delivered to customers. *Compare with Raw Water.*

Groundwater

The water that systems pump and treat from aquifers (natural reservoirs below the earth's surface).

Groundwater Runoff

See *Baseflow*.

Groundwater (GW) System

A community water supply system that pumps and treats water primarily consisting of water found beneath the Earth's surface, usually in aquifers.

Groundwater Under the Influence (GWUI) (also GWUDI)

Any water beneath the surface of the ground with significant and relatively rapid shifts in water characteristics which closely correlate to climatological or surface water conditions. Direct influence must be determined for individual sources in accordance with criteria established by the State. The State determination of direct influence may be based on site-specific measurements of water quality and/or documentation of well construction characteristics and geology with field evaluation.

Groundwater Under the Influence (GWUI) System (also GWUDI System)

A community water system in which the water primarily pumps and treats groundwater that is under the influence of surface water. See *Groundwater Under the Influence.*

Impounding Reservoir (also Impounded Reservoir)

An open body of water created by a dam or other barrier that obstructs the flow of water in a stream, and in which runoff from that stream typically provides the primary source of water entering the reservoir. Also called *In-Channel Reservoir* or *On-Channel Reservoir*.

In-Channel or On-Channel Reservoir

See *Impounding Reservoir*

Infiltration

The movement of water into soil, a portion of which is evaporated or transpired (evapotranspiration), a portion of which may move to surface streams (interflow), and a portion of which moves downward to the saturated zone (recharge).

Infiltration Gallery

A subsurface groundwater collection system, typically shallow in depth, constructed with open-jointed or perforated pipes that discharge collected water into a water-tight chamber. From this chamber the water is pumped to treatment facilities and into the distribution system. Infiltration galleries are usually located close to streams or ponds and may be under the direct influence (UDI) of surface water.

Interflow

That part of the precipitation which infiltrates the surface soil and moves laterally through the upper soil horizons above the water table toward surface waters. Also called subsurface runoff or groundwater runoff (see *Baseflow*).

Non-Community Water System

A public water system which is not a community water system, and has at least 15 service connections used by nonresidents, or regularly serves 25 or more nonresident individuals daily for at least 60 days per year.

Off-Channel Reservoir

An open body of water located apart from a water source, typically a stream or river, and into which water is diverted from that source and stored for later use. Also called *Off-Channel Storage*.

Overland Flow

The part of surface runoff that flows over the land surface toward stream channels.

Precipitation

Water vapor in the atmosphere that condenses, falls to, and reaches the earth in various forms (e.g., rain, snow, hail, sleet, etc.).

Primary Water Source

The source of water for a Community Water Supply System that requires the greatest amount of treatment to be rendered potable. Thus, a CWS may obtain the greater amount of raw water from wells but still be classified as SW because the surface water component requires more treatment.

Public Water System (PWS)

A system for the provision to the public of piped or otherwise conveyed water for human consumption, if such system has at least fifteen service connections or regularly serves an average of at least 25 individuals at least 60 days out of the year. A public water system is either a *community water system* or a *non-community water system.*

Raw Water

Water in its natural state, prior to any treatment for drinking. Compare with *Finished Water.*

Recharge

That part of precipitation which infiltrates and percolates downward to the *Zone of Saturation.*

Reservoir

A pond, lake, or basin, either natural or artificial, for the storage, regulation, and control of water.

Reservoir Gross Yield

The rate of water withdrawal that can be sustained for a given time period and drought duration including all uses and losses. The gross yield is typically a term that is used in the computation process for determining safe or net yield (i.e. the computed yield before losses and other abstractions are accounted for).

Reservoir Net Yield

See *Reservoir Yield.*

Reservoir Yield

The amount of water which can be supplied from a reservoir in a specified interval of time after accounting for losses to evaporation, seepage and leakage. Also called *Net Yield.* The safe or firm yield is the maximum quantity of water which can be guaranteed during a critical dry period.

Return Flow

The quantity of water that is released from the point of use and which becomes available for reuse.

Runoff

That part of precipitation which appears in surface waters of either perennial or intermittent form. Consists of Surface Runoff, Interflow (subsurface runoff), and baseflow (Groundwater Runoff).

Recharge

That part of precipitation which infiltrates and percolates downward to the saturated zone.

Side-Channel Reservoir

An off-channel reservoir, used to describe cases when the reservoir is located adjacent to the stream or river that serves as the water source.

Streamflow

The total discharge of water within a watercourse, including runoff, diversions, wastewater effluents, and other sources.

Surface Runoff

That portion of runoff which travels over the ground surface and through channels to reach the basin outlet. Surface runoff is composed of *Overland Flow* and *Streamflow.*

Surface Water

All water naturally open to the atmosphere, including rivers, lakes, reservoirs, streams, impoundments, seas, estuaries, and all springs, wells, or other collectors which are directly influenced by surface water.

Surface Water (SW) System

A community water supply in which the system pumps and treats water primarily from sources open to the atmosphere, such as rivers, lakes, and reservoirs.

Surface Water Purchased (SWP)

A community water supply in which the water consists primarily of surface water purchased from another community water supply.

Tile-drain Water

Infiltrated water that is captured by drain tiles and diverted to surface streams

Upground Reservoir

An upground reservoir is a man-made water basin that is separate from the stream or water source. This type of reservoir is filled with water being withdrawn from a river or stream. The stream flows are pumped from the river to the reservoir during periods of high flow. In comparison, an on-stream reservoir consists of a dam, which is constructed within the streambed. A length of the stream is converted into the reservoir.

Watercourse

A definite channel with bed and banks within which concentrated water flows continuously, frequently or infrequently.

Watershed

The land area that directly drains to a common stream, river or lake, often considered synonymous with a drainage basin or catchment. Watershed (drainage basin) boundaries follow topographic highs. The term *watershed* is also defined as the divide separating one drainage basin from another.

Water Table

The level of ground water. The upper surface of the zone of saturation of groundwater above an impermeable layer of soil or rock (through which water cannot move). This level can be very near the surface of the ground or far below it.

Zone of Saturation

The soil or rock located below the top of the groundwater table. By definition, the zone of saturation is saturated with water.

Term References

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