YIELD ANALYSES FOR THE DECATUR WATER SUPPLY SYSTEM: SUPPLEMENTAL MATERIAL

H. Vernon Knapp, Senior Hydrologist
Illinois State Water Survey
June 2012

A summary of the drought vulnerability of the City of Decatur's water supply system was published in ISWS Contract Report 2011-08 – *Meeting East-Central Illinois Water Needs to 2050: Potential Impacts on the Mahomet Aquifer and Surface Reservoirs*. The following links point to pertinent sections of that report.

Use of Uncertainty and Confidence Limits in Estimating Drought Yields
Categories of Drought Vulnerability
Yield Estimates for the Decatur System

This supplemental document provides additional and more comprehensive background information and analytical results that were used in preparing the summary in the above report.

The analyses examined the hydrologic and climatic records from the past 95 years for the purpose of identifying and simulating the conditions that the Decatur water supply system would experience if any of the worst droughts on record were to recur under present-day conditions. The analyses thus provide a juxtaposition of the historical drought periods with the current water supply facilities and resources. This is accomplished by creating a water budget model of Lake Decatur that simulates the expected inflows to and losses and withdrawals from the lake during those historical drought periods. Both Decatur and ADM share the use of Lake Decatur as a water supply source. For this reason, the estimated system yield is the total yield for both users. The yield estimates do not include water that ADM may obtain from its own wells.

SYNOPSIS

Based on its analysis, the ISWS has classified the drought vulnerability of the Decatur water supply system as ***at-risk***. Such a classification indicates that there is between a 10% and 50% estimated probability that the system would suffer a water shortage during drought conditions similar to the worst historical drought on record. More specifically, during either of the two worst water-supply droughts on record (for Decatur these are estimated to be the 1914-1915 and 1930-1931 droughts) there appears to be roughly a 20% probability that the system would experience a shortage of supply. In the ISWS assessment, a supply shortage is considered to occur if the lake's usable storage is exhausted (at an elevation below 605.0); but this also assumes that there are no extreme curtailments in water use to an extent where it can be reasonably concluded that the water supply failed to meet expected demands.

The ISWS recognizes that if the lake level gets very low in the later stages of a drought (for example, when there is only a 30- or 60-day supply of usable storage remaining in the reservoir) and there is no foreseeable end to drought conditions, decisions will be made by the

City that could have substantial socio-economic impacts to the community. To help visualize conditions during the course of extreme droughts, the results presented below also include simulated daily lake elevation during four of the worst historical droughts, assuming such droughts were to occur under present-day circumstances. The plots of daily elevation may be useful in deciding, for example, whether the 605' minimum elevation used to determine yield is an acceptable minimum based on the associated potential socioeconomic impacts.

BACKGROUND INFORMATION

Use of Confidence Limits in Determining Available Water and Potential Water Shortages

All hydrologic and climatic data input for the water budget simulation of a reservoir is subject to some uncertainty. This uncertainty typically comes in one of two forms: 1) normal measurement error, and 2) variation in hydrologic and climatic properties between the measurement location and the reservoir.

Bathymetric measurements of a reservoir's capacity fall into the first category of uncertainties. Such measurements typically are expected to have a standard measurement error of around 10 percent. Thus, if a reservoir's capacity was measured to be 10,000 acre-feet, the true capacity could easily (with 68 % probability) be anywhere between 9,000 to 11,000 acre-feet; and the possibility also exists (with 32% probability) that the true capacity could fall outside that range. If the yield of that reservoir's water supply system were calculated using only the measured value of 10,000 acre-feet, disregarding the measurement error, there would be roughly a 50% chance that the yield amount would be overestimated (and a 50% chance the yield amount would be underestimated). That process of using only the measured capacity value produces the traditional "best" estimate of the yield amount (often referred to as the "safe yield" or "firm yield"); however, that best yield estimate provides only a 50% level of confidence – meaning that there is a corresponding 50% probability that the reservoir could not supply that amount of water during the drought being used for design. To have a higher level of confidence in the yield result, it is necessary to assume that the capacity measurement was overestimated, and that the true capacity is a lower volume of water (such as 9,000 acre-feet or even less).

In a similar fashion, other data inputs (such as streamflow into the reservoir and evaporation from the reservoir surface) also can have substantial error and uncertainty. The reader is referred to ISWS Contract Report 2007-08 for more details about these uncertainties. But the concept regarding the need for confidence in the resulting yield estimate is unchanged. If we use these data at face value and disregard their uncertainties, we end up with a "best" estimate of the yield, for which, by its nature, there is roughly a 50% chance of overestimation.

It is up to each community to decide the level of confidence and associate risk that they willing to face during a severe drought. A small community might be willing to face greater uncertainty than a larger community because the overall socioeconomic impact of experiencing a water shortage may be small compared to their related costs for developing additional water sources. We expect, however, that larger communities, particularly those that have limited sources of supplemental during an emergency, would desire a comparatively low risk of water shortage, thus wanting a high level of confidence in their estimate of available yield.

For purposes in identifying community drought vulnerability, the ISWS calculates yield estimates that have a 90% level of confidence in addition to the traditional (50% confidence) yield estimate. The resulting "90% confidence yield" value infers that, once all the major data uncertainties in data have been considered, there is less than a 10% probability that the community would not be able to provide the designated yield throughout the course of a drought condition similar to the designated "drought of record." The drought of record is the worst historical drought for which hydrologic records are available.

The primary hydrologic data input for Lake Decatur is the inflow from the Sangamon River, as estimated using the USGS stream gage on the Sangamon River at Monticello, which has a continuous record of daily flows from 1914 to the present. Other supplemental sources of inflow are pumpages from the DeWitt well field and a former gravel pit owned by the City (formerly referred to as the Vulcan gravel pit), which are only accessed during drought conditions. Lake Tokorozawa, which was used as an emergency supply source during the 1988 drought, is not considered in the analysis because there is no standing agreement between its owners and the City that would assure its availability during an extreme drought. The potential quantities of supply from other minor sources are also discussed.

In its analysis, the ISWS has determined that an approximate 90% level of confidence is obtained for the Decatur water supply system when the following adjustments are made to data used in the Lake Decatur water budget model:

- The assumed capacity of Lake Decatur is reduced to 19,666 acre-feet
- Estimated streamflow into Lake Decatur during drought period is reduced by 19.2%
- The estimated water quantities from supplemental sources (the DeWitt well field and the City-owned gravel pit) are reduced by 25.6%
- Evaporation from Lake Decatur during drought periods is increased by 17.9%

The ISWS also understands that the City of Decatur has entered into a dredging contract that is expected to increase the capacity of the lake in upcoming years by 3000 acre-feet, which would effectively increase the yield of the system by roughly 3 million gallons per day (mgd). The ISWS has not considered the projected capacity increase in its estimate of drought vulnerability. Also, a new bathymetric survey should be undertaken to verify any future change in capacity.

Assumptions concerning Supplemental Water Sources

<u>Usable Storage within Lake Decatur</u>

Water stored at the very bottom of a reservoir is typically considered unusable for water supply. In most cases there are water quality concerns with this bottom water (undesirable taste and odor problems), but there can also be physical limitations in accessing and pumping the water when the reservoir's water becomes shallow. For its water supply studies, the ISWS typically considers the bottom 10% of storage in a lake to be unusable; for Lake Decatur this corresponds to a lake elevation of 604.5 feet. In its own assessment, the City currently considers water below 605.0 feet as unusable, corresponding to the bottom 12% of the lake's storage.

Using the higher elevation of 605.0 would result in a reduction in yield of approximately 0.7 mgd less than that presented in the results below.

Supplemental Water Sources

There are three known supplemental water sources that were not used in the simulations: Lake Tokorozawa, the Cisco well #2 operated by the City, and water discharged into the lake from wells operated by ADM. As stated earlier, Lake Tokorozawa was not assumed to be available as an emergency supply source because there is no standing agreement between its owners and the City that would assure its availability during an extreme drought. If available, the City estimates that Lake Tokorozawa could provide from 2000 to 2750 acre-feet (650 to 900 million gallons). Over the course of a 281-day drought, these volume estimates would equate to an effective yield of between 2.3 and 3.2 mgd. Any potential pumping from Lake Tokorozawa (as well as the City-owned gravel pit) would feed directly to the water treatment plant; thus, it is assumed that there would be no losses in transmission (as with other supplemental sources).

The Cisco well #2, has a reported yield of 2255 gallons per minute (3.2 mgd). Pumping from the well is released into the Sangamon River, presumably increasing the amount of river inflow into Lake Decatur. During the drought of 1988, 635 million gallons was pumped from this well. However, with its proximity to the Sangamon River, the ISWS at this time believes that over an extended drought much of the groundwater pumped from the Cisco well would be induced from the river (Personal communication with Dr. George Roadcap, hydrogeologist at the ISWS). Thus, use of the well might have little net effect on the volume of water reaching the lake, and there is enough uncertainty about the effective yield for the ISWS to not include this in the its analysis.

In addition to the water pumped from Lake Decatur at their treatment plant near Reas bridge, ADM also purchases a substantial amount of water from the City and pumps water from its own wells. In most years, the ADM wells are pumped at an average rate of between 1.2 and 1.5 mgd. In 2011, the City requested that ADM release well water into the lake during a dry period to supplement lake storage; the total amount of that release was nearly 63 million gallons. The ADM wells are located near Lake Decatur and have a depth of around 100 feet; as with the Cisco well #2, this opens up the possibility that, over the course of a sustained drought, much of this water might be induced from the lake which if true would result in little net overall increase in available water to the lake.

Operating the DeWitt field to avoid well interference

As specified in the City's Drought Action Plan, the decision to pump from the DeWitt well field is triggered by the occurrence of low water levels in Lake Decatur (at or below an elevation of 613.0 feet). During most severe droughts, such low water levels would typically not be reached until 4 to 5 weeks after the lake begins to fall below its full pool (614.4 feet).

The DeWitt well field has been operated during several short drought episodes since the field was installed. These experiences have shown that drawdown in the groundwater levels surrounding the field will begin to interfere with other wells after a certain interval of pumping; that interval being dependent in part on the rate of pumpage from the field. During the moderate drought of 2005, interference began to occur roughly 65 days after pumping at an average rate of

9.7 mgd, at which time pumping from the field was discontinued. During the moderate drought of 2007, the wells were pumped for 39 days at a rate of 12 mgd. A study by Black and Veatch has indicated that the field should be able to yield 7 mgd on a continuous basis.

Based on these experiences, the ISWS's yield simulations assumed that, once activated, the field could be pumped for 65 days at a rate of 9 mgd, after which the pumping amount would be decreased to 7 mgd and continued through the duration of the drought. For the simulations of the 1930-1931 drought of record, this assumption results in a total pumpage of 1915 mgd over the 281-day duration of that drought. After loss rates are factored in (discussed below) this results in a net yield of the DeWitt field of 4.8 mgd over the course of the drought.

Since then, the City has identified a different operation scheme for using the well field, in which the field would be: 1) pumped at a rate of approximately 13 mgd until interference begins to occur, 2) turned off until the groundwater levels have partially recovered, and then 3) resumed at 13 mgd until interference problems again appear. If pumping is estimated to occur roughly 50% of the time using such an alternating on/off pumping scheme, the total pumpage during the 1930-1931 drought of record would be roughly 1658 million gallons. It is reasonable to assume that the transmission loss percentage rate (as the water is released to Friends Creek and flows to the lake) could be less when pumping at a higher capacity. We also note that until the well field is operated during an extended severe drought, it will be unclear how often pumping can occur using any operation scheme.

<u>Transmission Loss from the DeWitt field</u>

The analysis assumes that 30% of the water pumped from the DeWitt well field would be lost in transmission to the lake, mostly through bank seepage but also evaporation. What has not been considered is the possibility that long-term pumpage from the Mahomet Aquifer by the DeWitt field could be inducing flow from the Sangamon River in Piatt County. Dr. George Roadcap, hydrogeologist at the ISWS, has suggested that the effective loss rate of water pumped from the DeWitt field could be as high as 55% considering impacts to the river and other users. If true, the assumed loss rate of 30% could noticeably overestimate the net effective yield of the well field. Although an uncertainty factor has been added in producing our estimates of the 90% confidence yield, that factor does not fully reflect the potential loss rate from the field as estimated by Dr. Roadcap.

Assumptions Concerning Water Use and Restrictions During Drought

Most dry summers, including 2005, never develop into a severe drought condition. During those summer conditions, it is essentially impossible to predict if the weather is going to stay dry and eventually develop into a water-supply drought condition. For this reason, there is usually no real mechanism to restrict water use in the early stages of a water-supply drought – unless water use was also restricted during any dry summer period (such as might occur once every three years).

For all historical drought sequences, the simulated water level of Lake Decatur first starts to drop below full pool during the summer. Because the weather will have been very dry at the start of a drought, the city's outdoor water use at that time will likely be very high (45 mgd or more). For example, in the summer of 2005, Decatur's water use was roughly 45 mgd, nearly 20% above the average annual use and approximately 6% higher than most summer periods. [Note: The ratio of drought summer use to normal conditions would be expected to be much greater in communities that do not have a large stable commercial/industrial water-use sector.]

Using the lake water budget simulation model, for most droughts it is estimated that voluntary restrictions during the worst drought periods, implemented at a lake level of about 612.7-613.0 feet, would occur roughly a month following the onset of lake drawdown. Mandatory restrictions, implemented at a lake level of about 611.7-612.0 feet, would typically occur another three weeks later during the worst droughts. During an early-occurring drought, such as the 1988 or 1914 droughts, mandatory restriction might be implemented as early as the second week in August; but for most drought periods such restriction would typically not be implemented until September.

We note that during the mandatory restriction period of 2007 (starting in November 2007), combined city restrictions and water conservation from major commercial/industrial users were able to reduce withdrawals from Lake Decatur to about 32 mgd, or 5 mgd below the normal (annual average) use. If this same level of reduction in industrial water use can also expected during future droughts, it is likely that the average water use during a major drought (lasting 7-9 months) might actually be lower than the City's average annual use rate – even when adding in the very high water use rates expected to occur during the first 1-2 months of the drought. For a 7-month drought, this may mean an average use for Decatur of 36 mgd. For a 9-month drought (such as the 1930 drought), the average use could be slightly lower than 35 mgd. Such a reduction in water use during drought is unusual for most Illinois cities, because drought water use is normally expected to be higher than the normal use for cities that lack a large industrial base or lack the ability to substantially reduce the commercial/industrial use during a drought.

As the capacity in Lake Decatur continues to fall in the later stages of a drought, the City will most likely be expected to seek additional restrictions in water use that will reduce the total municipal and industrial water demand below 32 mgd. In particular, as the lake level falls below an elevation of 610 feet (at roughly 50% of the lake's capacity), the ability of the ADM water plant near Reas Bridge to pump water will also become physically limited; the pumping capacity for their self-supplied water would progressively decline and a greater percentage of ADM's total use would need to come from the City's treatment plant as total water use is also reduced. For the purposes of its simulations, the ISWS has chosen to keep the minimum demand rate at 32 mgd, which it has arbitrarily set as a demand at which there might be relatively minimal impact to the City and its industries. It is acknowledged that, in planning for and developing its water supply, the City will effectively determine the level of water restrictions it is willing to impose and, thus, the associated impacts it is prepared to accept during a severe drought condition. As discussed in the results section, additional restrictions in water use in the later stages of the drought of record could reduce the percent chance that the lake would fall to its minimum usable level, but cannot totally eliminate that potential of supply shortage. If the capacity of the lake were to fall below its minimum usable level, the hydrologic records suggest that the combined amount of water entering the lake from the Sangamon River and pumping from the Dewitt well field would likely be sufficient to maintain a base level of water use in the range of 13-15 mgd.

Summary of Uncertainties and Caveats

As previously described, the estimate of the 90% confidence yield considers errors in the data used to estimate yield, which are expected to be the primary sources of uncertainty in the analysis. But the analysis does not include errors associated with certain assumptions and conditions that cannot be quantified with available data, including the possibility that the effective loss from the DeWitt field could be different than 30%. To a certain extent the identified ranges of data uncertainties are also subjective; and in hindsight, for example, the 5% loss associated assigned to the reservoir volume might be too low. Other minor data uncertainties, such as that associated with precipitation over the lake, have been neglected. Potential seepage from the dam and groundwater seepage into the lake has also been neglected because there is no available data on these abstractions, although data available from most Illinois reservoirs suggest it is also a minor factor.

To focus on these individual elements disregards the major premise of using a probabilistic-based yield assessment; that being, there are no exact or firm yield amounts that can be predicted using the available hydrologic data and methods. Adding or subtracting a few mgd from the yield estimate does not greatly change the underlying error distribution or its intended message. Engineers and hydrologists may often be required to provide their best traditional estimate of water availability during a drought, and in many cases uncertainties are difficult to quantify, but the term "firm yield" or "safe yield" is a misnomer unless it were to refer to a legal allocation of water supply. The probabilistic yield estimates presented in this methodology are intended to provide a reasonable and scientifically sound representation of the uncertainty in each system's yield, even if by necessity it is an inexact estimation. The ISWS believes that the confidence-based yields and estimated probabilities of shortages can be much more useful than traditional "safe yield" estimates in identifying a community's drought vulnerability and evaluating its various implications.

YIELD AND LAKE-LEVEL SIMULATION RESULTS

Yield of the Current System under Historical Drought Sequences

Yields (at 50% and 90% confidence levels) were determined for each of the individual historic drought sequences using the water budget analysis. The computed yields for each drought are the maximum amounts of water that could be withdrawn from the lake during each particular drought without the lake running out of available storage. For Decatur, the worst 7 drought sequences, ranked in order from most severe (lowest yield) to moderate (highest yield), occurred in 1930-31, 1914-15, 1953-54, 1963, 1988, 1940-1941, and 1999-2000.

		50% Yield	*90% Yield*
Worst Drought:	July 14, 1930 – April 20, 1931 (281 days)	37.9 mgd	32.3 mgd
Second worst:	June 4, 1914 – January 31, 1915 (242 days)	38.8	32.2
Third worst:	July 30, 1953 – March 12, 1954 (226 days)	43.1	35.9
Fourth:	June 14, 1963 – January 19, 1964 (220 days)	45.0	37.1
Fifth:	June 12, 1988 – November 11, 1988 (153 days)	48.4	40.1

Sixth:	July 3, 1940 – February 2, 1941 (215 days)	50.0	---
Seventh:	August 17, 1999 – February 12, 2000 (180 days)	52.9	---

Note: These newer yield values are slightly lower than those published in ISWS Contract Report 2011-08 (Table 13, Page 141).

The listed durations of these drought periods are the periods from the simulated onset of lake drawdown to the simulated date of the minimum pool level. The onset of lake drawdown is typically preceded by 2 months or more of very dry weather.

It is noted that the worst droughts listed here have not necessarily been the most intense droughts, but instead tend to be the longest in duration such as needed to exhaust the available storage in the lake. For example, the 1988 drought was probably the most intense of the seven drought periods, but was not long in duration and started to recover by November of that year; as a result it is only the 5^{th}-worst on record as far as impact on yield. The worst 4 droughts listed above all have durations in excess of 7 months, with the worst (1930-31) drought lasting 9 months. Three of the 7 most severe droughts (1914, 1963, and 1988) started very early, causing lake drawdown to begin before the middle of June. Droughts that start early in the summer typically pose the greatest threat to the Decatur system because: 1) the highest rates of water use would typically occur in mid-summer before restrictions are applied; and 2) an early start potentially provides the longest window (duration) of drawdown before lake levels ultimately recover by the following spring.

As computed, there is excess yield (above the current rate of water use) for the less severe drought periods; however, this does not imply that the City should ever try to extract higher levels of water use during lesser drought periods. To the contrary, this would be very ill-advised. As opposed to the historical simulations presented here, in which we have perfect hindsight, during a real-time drought situation there is rarely an indication that its drought's recovery is just around the corner. For example, in 1988 there was considerable fear that conditions would continue to get worse until (and beyond) mid-November when the lake levels started to recover. As embodied by the City's Low Lake Level/Drought Action Plan, drought response should always assume the possibility that dry conditions will persist.

Lake Level Simulations Assuming Variable Water Use During Drought

The water budget model for Lake Decatur provides the ability to simulate lake levels over the course of a drought sequence. Figures 1-4 show the simulated lake levels associated with scenarios in which the 1930-1931, 1914-1915, 1953-1954, and 1988 droughts were to recur under present-day conditions. Results are presented for calculations using the observed data (50% yield estimate) as well as reduced inflow/storage amounts that account for data uncertainties (80% and 90% confidence limits). Only the 50% scenario was simulated for the 1988 drought; and although changes in water use and supplemental sources have occurred since the 1988 drought, the simulated lake levels track reasonably closely to the historical levels.
In the water budget simulations, we are also able to allow water use to vary in a manner similar to what might be expected during a real drought condition as discussed in the previous section on variable water use. During a severe drought, Lake Decatur will first start to drop below full pool

during the summer, and at that time there is an expectation that withdrawals from the lake will be very high (45 mgd or more). Voluntary and mandatory restrictions in water use will be enacted and result in lower use rates in the later stages of drought. For its simulations, the ISWS has assumed a minimum water use rate of 32 mgd (a rate which was achieved by the City and its industries in the fall of 2007 following mandatory restrictions), although more severe restrictions and related their impacts would be expected to occur as water levels become very low. More information on ISWS assumptions regarding water use is presented in the previous section "Assumptions Concerning Water Use and Restrictions During Drought."

The following water use rates were used in simulating the 1930-31 drought-of-record scenario (Figure 1).

July to mid-August 1930 – average water use is 45 mgd
Late August 1930 – 41 mgd
September 1930 – 38 mgd
October 1930 through April 1931 – 32 mgd

Water use rates for other historical drought sequences were slightly different as based on how early in the season the drought started and the expected date at which the lake was expected to reach specified trigger levels (as defined by the City's Low Lake Level/Drought Action Plan, April 24, 2007 Revision).

The times at which supplemental resources are accessed during drought conditions are also based on the City's Drought Action Plan. Minor adjustments were made based on the examination of the City's water use and actual drought response during the late summer and fall in 2005 and 2007. Under the 1930-1931 drought sequence, the following sequence of events are identified:

Date	Lake Level	Event/Action
July 14	614.4	Lake level drops below full pool
July 29	613.3	Start pumping from Vulcan Pit
August 8	612.8	Start pumping from DeWitt field at 9mgd Implement voluntary restrictions
September 1	611.8	Implement mandatory restrictions
October 12	610.6	DeWitt field reduced to 7mgd; Vulcan pit runs out
March 17	607.4	Minimum lake level
April 20	607.7	Secondary minimum level*
May 26	614.3	Lake returns to full pool level

Note: * April 20 would become the minimum lake level at slightly higher water use rates

The simulated sequence of events for each historical drought period will be different as triggered by lake drawdown. For example, the timing of voluntary and mandatory restrictions in water use are projected to occur much earlier during the 1914-15, 1963-64, and 1988 droughts simulations, when lake drawdown is estimated to begin in early June.

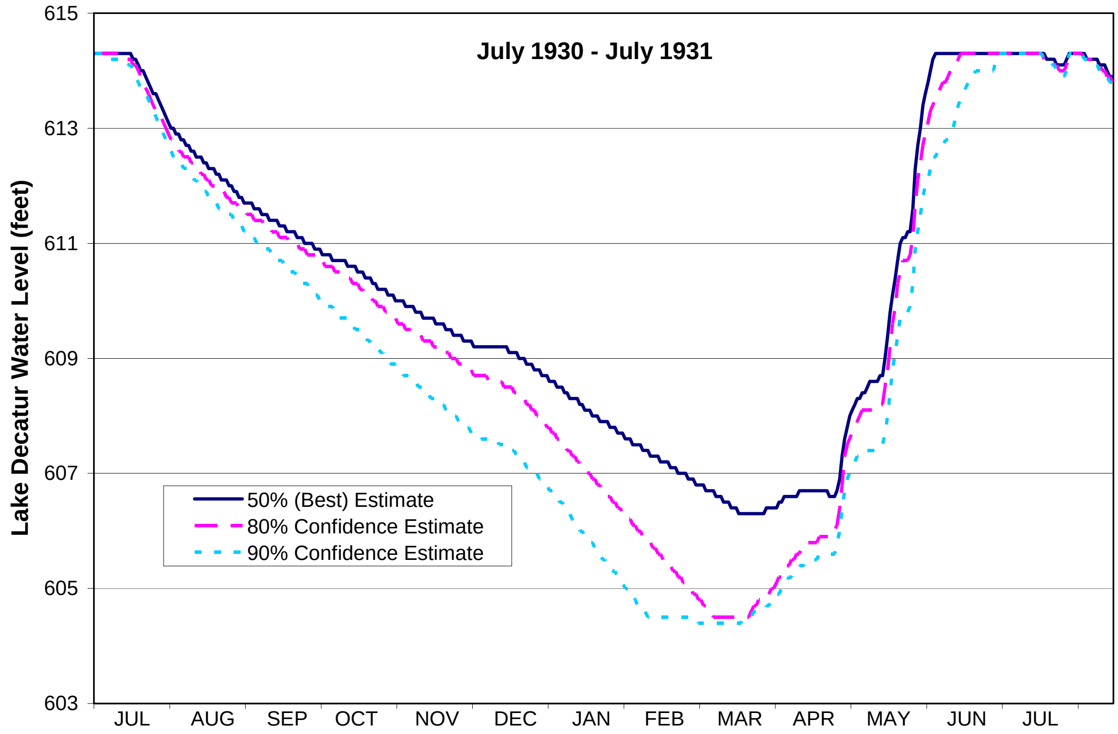

Figure 1: Simulated Lake Levels if the 1930-1931 Drought Were to Recur

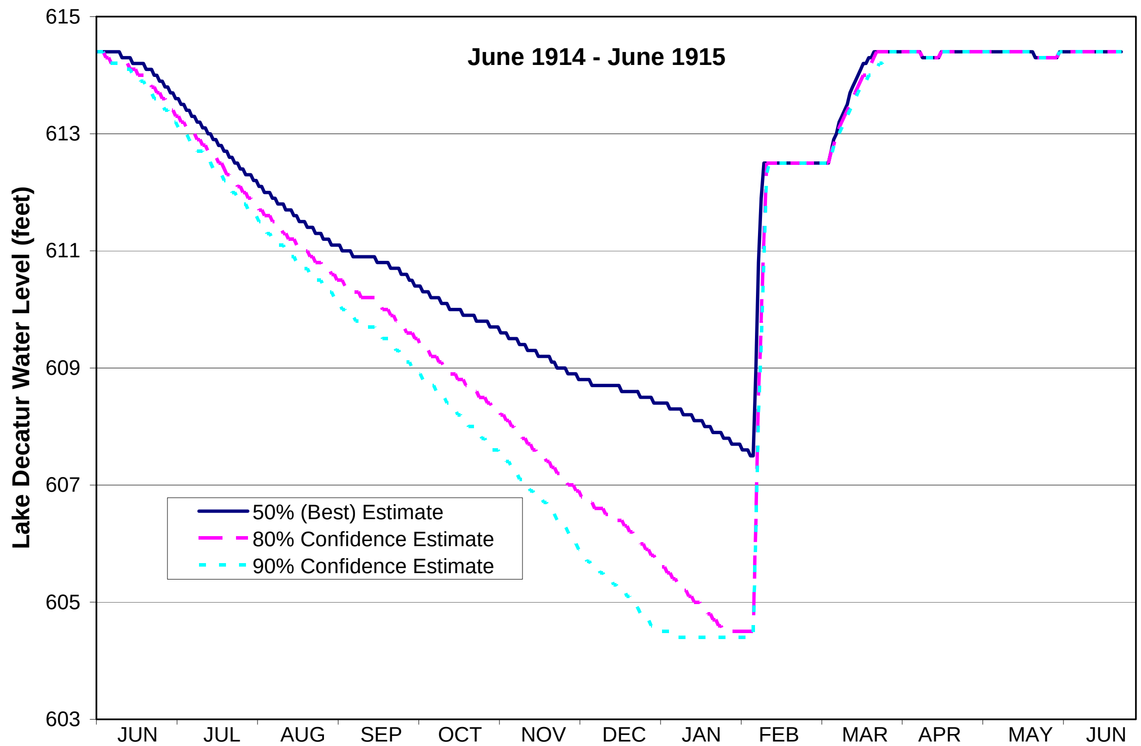

Figure 2: Simulated Lake Levels if the 1914-1915 Drought Were to Recur

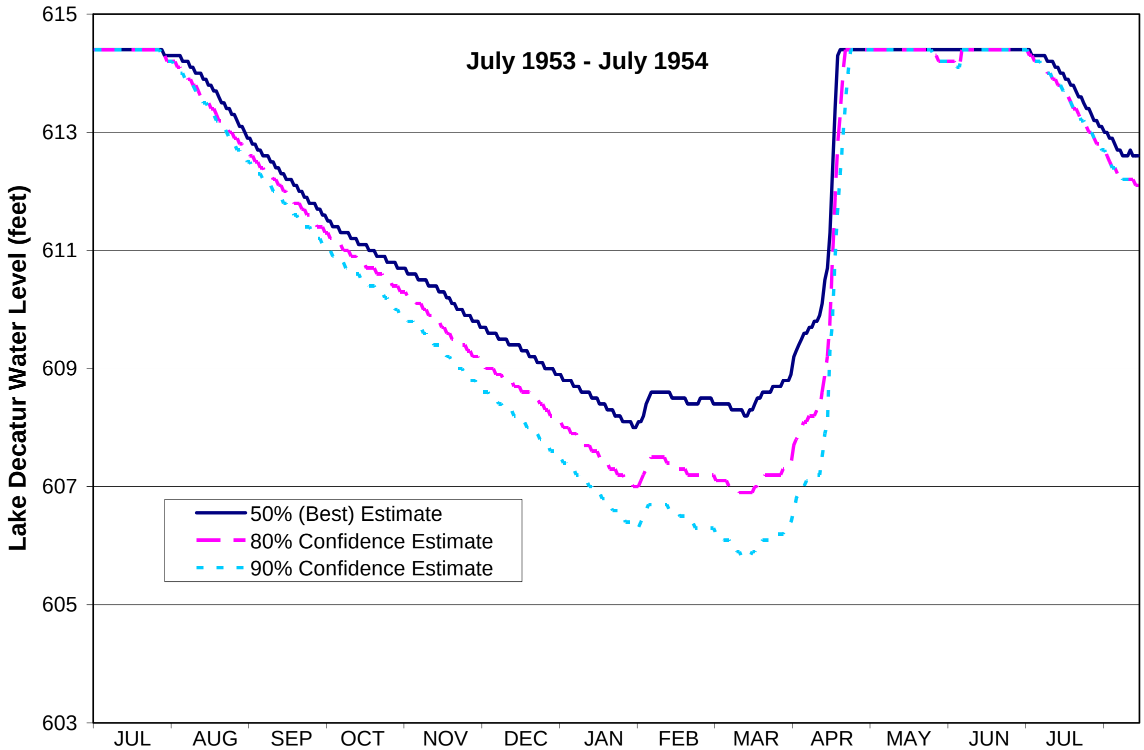

Figure 3: Simulated Lake Levels if the 1953-1954 Drought Were to Recur

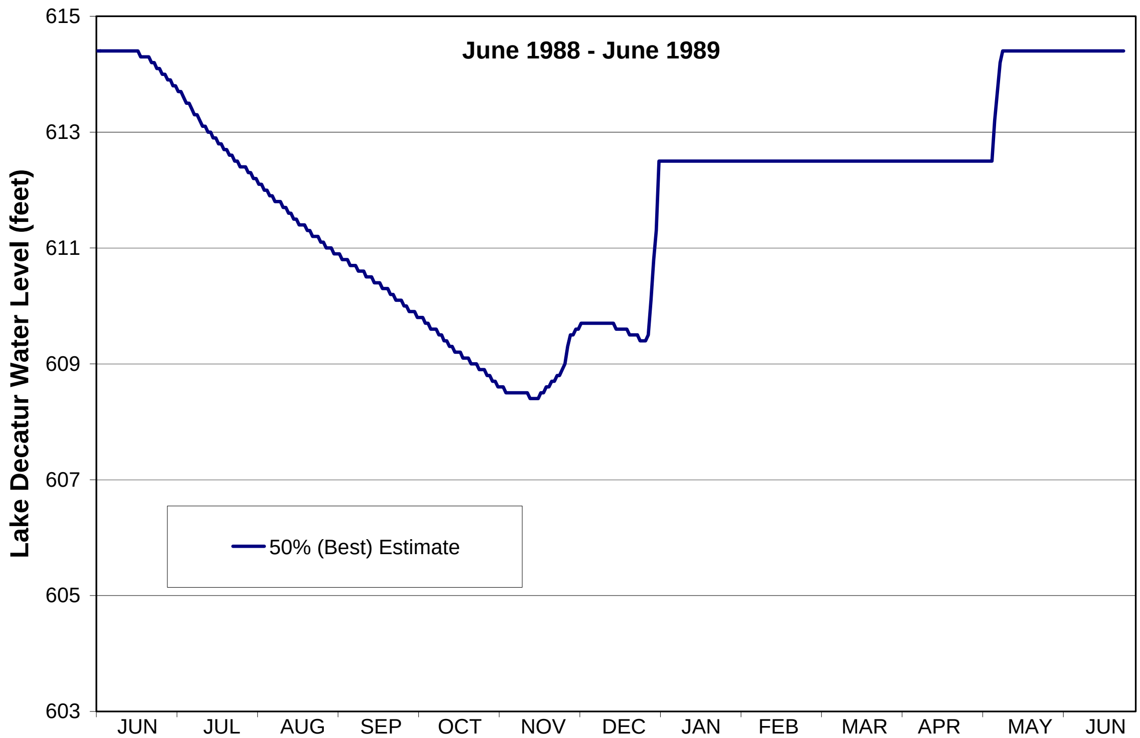

Figure 4: Simulated Lake Levels if the 1988 Drought Were to Recur

Discussion of Figures 1-4

[Note: Figure 1 is slightly different than the version (Figure 85) shown in ISWS Contract Report 2011-08. That version in the report assumed that Lake Toko was available as an emergency water supply source, and with the additional water thus shows higher lake levels during the later stages of the 1930-1931 drought.]

The simulated lake levels for the 1930-31 and 1914-15 droughts (Figures 1 and 2) both indicate that there would be slightly greater than 20% chance of the lake falling to a minimum level of 604.5 feet if water use was to be maintained at 32 mgd (i.e., a water use scenario that tries to maintain minimal impact to the City and its industries). Since these are the two worst droughts in the past 100 years, similar droughts might be expected to recur on average once in 50 years. For the 1953-54 drought (Figure 3), although the lake level would not be expected to fall to its minimum level, water levels would be sufficiently low to cause significant concerns of shortage and associated responses.

The 1988 drought (Figure 4) is shown because, although it did not last as long as the more significant drought periods, it was the most intense drought on record in terms of lake level decline through the early portion of the drought, with lake levels falling to below 609 feet before the end of October. Thus, until that drought started to recover in November of that year, it provided as much of a threat of shortage as any of the other (longer) drought periods shown here.

Along with the four drought periods shown here, simulated water levels fall below an elevation of 610 feet for both the 1963-64 and 1940-41 droughts (using the best 50% estimate). Since lake levels below 610 feet were simulated for 6 historical drought periods over the past 100 years, it can be concluded that such a low level might be expected to occur on average once in 16-17 years given the present system and its water demand. Conditions similar to the two worst drought periods, 1930-31 and 1914-15, might be expected to occur roughly once in 50 years. It is noted that it has already been 80 years since the occurrence of the last of these two worst droughts; however, this does not necessarily mean that another drought of such severity is either more likely or less likely to occur in the near future.

The water level simulations for the 90%-confidence estimates shown in Figures 1 and 2 assume that water withdrawals are reduced to 15 mgd once the usable storage in Lake Decatur is exhausted. The 15 mgd amount is roughly equal to the amount of water supplied by: 1) natural inflow from the Sangamon River (8 mgd), and 2) supplemented flow coming from the DeWitt well field at a pumping rate of 7 mgd. Of additional significance, particularly for the 1930-31 drought, is the duration at which the City's use could be reduced to this 15 mgd amount under the 90%-confidence scenario. As shown in Figure 1, there is a 10% chance that the water level could remain below an elevation of 605.0 for more than 60 consecutive days and below an elevation of 607.0 for more than 120 consecutive days.

Potential Effect of Severe Water Restrictions on Simulated Lake Levels

When Lake Decatur falls to a water level of 610 feet, it has roughly half of its capacity remaining. In addition, at this water level there begin to be limitations in the amount of water that can be withdrawn from the ADM intake near Reas Bridge, assuming the City's water restrictions by that time have not otherwise already limited water withdrawals by that industry. Figure 5 examines a scenario in which severe water restrictions, reducing the lake's withdrawals to 26 mgd, are implemented once the lake falls below 610 feet. This figure is directly comparable to Figure 1, in which the simulated water levels are identical for the first half of the 1930-31 drought period, but for which water use remains at 32 mgd for the latter half of the drought. As shown in Figure 5, the effect of diminished water use over the last half of the drought slows down the drawdown in the lake, such that the line associated with 90% confidence remains above the minimum usable pool elevation by the end of the drought period (March-April 1931). Note that the diminished water use does not eliminate the probability that the lake's usable storage is exhausted, but it does reduce that probability from 20% to less than 10%. If this scenario were adopted by the City during periods of severe drought, the ISWS would still consider Decatur to have a marginal water supply system because of the anticipated economic impact associated with the diminished water use and the potential threat of greater losses.

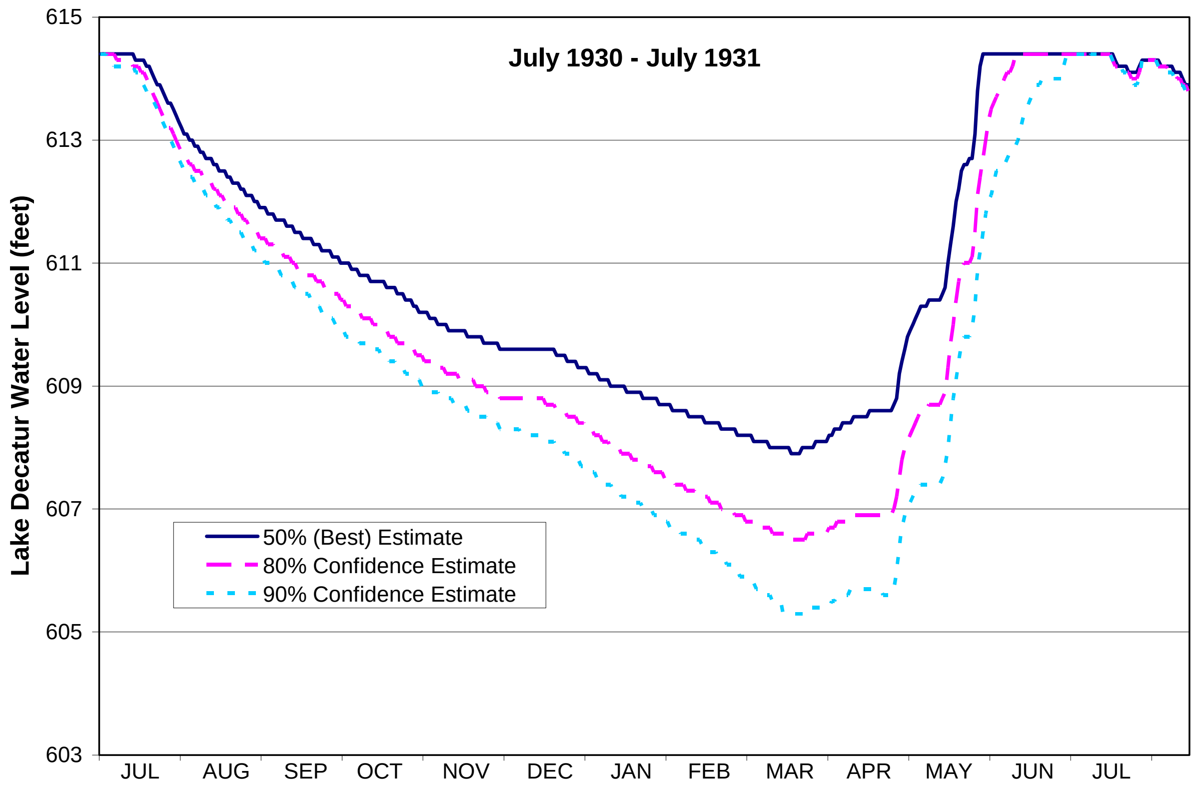

Figure 5: Simulated Lake Levels of the 1930-1931 Drought with an Assumed Reduction in Water Use to 26 mgd once the Lake Level Drops to 610 feet

What Would a Potentially Worse Drought Look Like for Decatur?

ISWS Contract Report 2011-08 discusses the potential that Illinois could at any time experience a drought that is worse than any of the historical droughts analyzed here, much like how southeastern United States experienced its worst drought in 2007-2008. The characteristics of a "worse case" drought might not be substantially different than other major droughts of the past. One scenario that we present here includes a combination of characteristics from selected historical droughts, specifically: "What would happen if one of the early-season droughts (such as occurred in 1914, 1963, and 1988) were to linger and not recover until April of the following year (such as with the 1930 drought) – thus becoming a 10-month drought as compared to the 9-month 1930 drought of record?"

Figure 6 shows the simulated lake levels associated with the worse-case scenario, again assuming present-day water use conditions and sources. Results are presented for the 50%, 80% and 90% confidence calculations. As with the previous simulations, we varied water use in a manner that possibly might be expected during a real drought condition following implementation of voluntary/mandatory restrictions, but kept the water use at 32 mgd through the latter stages of the drought. The simulation shows that, under these conditions, there would be roughly a 50% probability that the lake would fall to the specified minimum level of 604.5 feet. Both the 80% and 90% confidence simulations indicate that Lake Decatur could stay at or

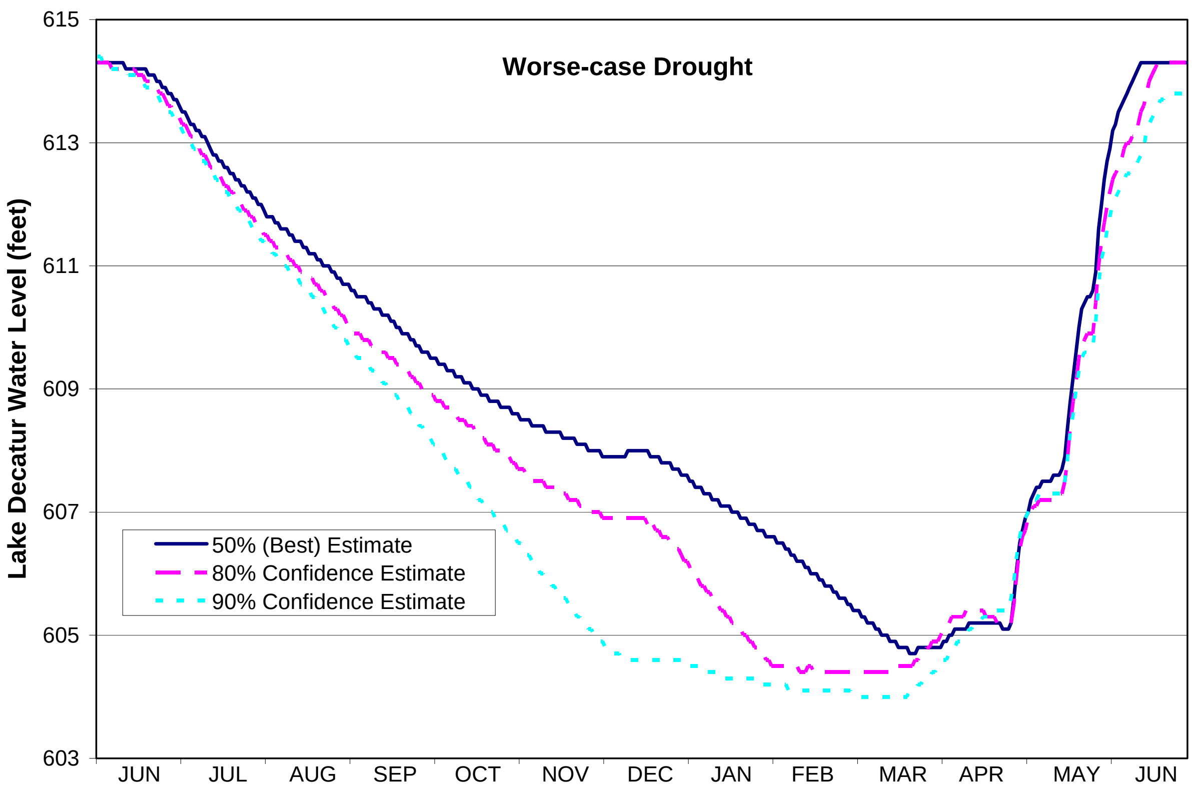

Figure 6. Simulated Lake Levels During a 10-Month Worse-Case Drought

below its minimum usable storage for several consecutive months. We cannot estimate the probability of this type of worse-case drought occurring, and are not necessarily recommending that this scenario be a benchmark for planning purposes; but the important point is that the Decatur system would be highly vulnerable if the region suffers a drought that is worse than any currently on record (in the past 100 years).

OTHER FACTORS TO CONSIDER IN DETERMINING SUPPLY ADEQUACY

In determining yield and adequacy of supply, there are two additional issues that we have not yet addressed:

- What minimum lake level is the community prepared to deal with?
- For what drought severity/frequency should a community be prepared?

Both essentially ask: "What are the acceptable impacts of a drought?" – something that each community must assess on its own. The answer will vary depending on factors such as the size of the community and availability of emergency sources of water if shortages were to occur. For example, very small communities may be willing to accept a complete shortage of water during a severe drought as long as they are able to haul water from a nearby community and such an event occurs very infrequently. On the opposite end of the spectrum, the consequences of a large community experiencing a complete shortage could be staggering; and, as such, large communities may seek to plan for the most severe droughts – perhaps even the potential for a new drought of record – to know that water would be available, if even at a reduced level of use.

What minimum lake level is the community prepared to deal with?

Although there are physical dimensions that may limit the minimum usable storage during a drought, perhaps a more serious limitation is the socioeconomic impact to the City as its reservoir approaches its minimum storage level. It is important to keep in mind that, in the midst of a major drought, we have very limited ability to forecast the end of that drought and there is no assurance that the drought will end in a similar time frame as other historical drought conditions. It is one thing to look back on a past historical drought and have hindsight on when the drought recovery happens; but, it is quite another thing to actually experience the same drought, have your lake be at very low levels, and need to make decisions not knowing when the recovery is coming.

According to ISWS records, the minimum water level experienced at Lake Decatur was at 605.3 feet in 1954. Within two years of this event, the City responded by adding the current Bascule gates at the dam, allowing the normal pool level in the lake to be raised above the previous normal pool level of 610.0 feet. The yield estimates presented here are based on an unusable storage of 10%, with a corresponding lake level of roughly 604.5 feet. At 604.5 feet, the lake is estimate to have a remaining of roughly 680 million gallons (MG), or roughly 21 days of storage (assuming a water use rate of 32 mgd). Is this a safe-enough buffer, or should the City want to use a higher minimum lake level for determining adequacy of supply?

For what drought severity/frequency should a community be prepared?

There are no State guidelines as to what type of a drought communities should plan for. Yield assessments are usually developed by the ISWS for either the worst historical drought (drought of record) or for estimated 50- or 100-year drought frequencies. The primary concern with Decatur, compared to other major surface water supplies in the region, is its short critical drought duration. If a drought were to occur that is worse than the current drought-of-record, there may be relatively little time available to obtain alternative supplies once there is a clear indication that the drought's impacts may extend beyond the capacity of existing sources.

Again, it is important to realize that there is always the possibility that a worse drought may occur – even without considering the additional potential of climate change impacts. New droughts of record happen in regions of the United States virtually every decade. For example, the drought of 2007-2008 affecting Atlanta and northeastern Georgia is the worst drought to hit that region since hydrologic records began almost 100 years ago. Parts of California experienced their worst drought in 1988-1992, and the Colorado River experienced its lowest flow totals ever during the drought of 2000-2002. Paleoclimatic records (such as tree rings) indicate the occurrence of many severe droughts in previous centuries. If we assumed that the drought conditions of the last 100 years are as equally likely to occur over the next 40 years (disregarding the potential for climate change impacts), then there would be roughly a 33% chance that a new record drought will occur before 2050.

CONCLUSION

The most important aspect of the analysis presented herein is the introduction of uncertainty and confidence in the estimate of yield and drought vulnerability of Decatur's water supply system. Whereas many of the individual estimates of data uncertainty are approximations, the composite analysis and resulting confidence limits provide a very sound picture of the range in yield estimates and implications regarding the drought vulnerability of the community's water supply. The bottom line is that accumulated uncertainties in the data and yield analysis can vary the estimate of total yield by 15-20%, and given these uncertainties the Decatur system is considered at risk of experiencing water shortages during extreme droughts.

Planners and managers must determine the appropriate level of drought severity for which they should be prepared based on the potential consequences of water shortages and how quickly alternative supplies could be obtained in the event of a water shortage. If the 1930-31 drought of record is used as the benchmark, Decatur must plan for a water budget deficit lasting as many as 281 days. However, just as Georgia and northern Alabama recently experienced their worst in over 100 years, it is entirely possible that central Illinois at some future time will experience a drought that lasts even longer than the 1930-31 drought. With this potential scenario, Decatur might want to plan for a period of deficit that is as much as 10 months in duration. Without additional sources of supply – beyond those considered in this analysis – the system will be vulnerable to water shortages if either a more severe drought were to occur or the community's water use were to grow above the current use.