Contract Report 626

Operation Alternatives for the Springfield Water Supply System and Impacts on Drought Yield

by

H. Vernon Knapp

Prepared for the
City of Springfield, Illinois

April 1998

Illinois State Water Survey
Hydrology Division
Champaign, Illinois

A Division of the Illinois Department of Natural Resources

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CONTENTS

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INTRODUCTION

Since 1936, Lake Springfield has been the primary source of water supply for the city of Springfield. A pumping facility was developed in 1955 to supplement the storage in Lake Springfield during dry periods with water from the South Fork Sangamon River. Over the last 42 years, there have been no additional sources of supply developed for the city. Periodic studies have been conducted to reevaluate the yield of the Springfield water supply system and alternative water sources, however. Selected studies include those by Crawford, Murphy, and Tilly, Inc. (1965, 1980), Makowski et al. (1986), and Fitzpatrick and Knapp (1991). Most of the alternative water supply sources currently under consideration were initially identified in these or other previous studies.

When a water supply system employs more than one water resource, as is the case with the Springfield system, the various combinations of sources and operating schemes associated with them will often alter the total yield of the system. This is especially true for surface water supply systems, such as a reservoir where the available storage is finite, or a stream where the water available for pumping is variable. Many issues associated with developing a combined water supply system can only be fully understood by examining: 1) how the operation of one water supply source can impact the yield of another source, and 2) how all sources can be used in a system to produce the most desirable results. Several alternative objectives can be considered in the operation of a water supply system. Often the primary objective is to increase the combined yield of the various sources. But other objectives, such as minimization of water quality problems, system operation flexibility, and other uses of water such as recreation, can also be important considerations.

To analyze the joint operation of a number of water supply sources, it is necessary to describe how these resources would be used in a sequential manner, starting from the onset of drought conditions to drought recovery. Since the temporal characteristics of each drought are different, it is useful to analyze a number of drought sequences to evaluate the potential range of impacts associated with a particular system operation scheme.

This study specifically examines the impact of different operation scenarios on the water levels and overall yield of the Springfield water supply system. Limitations on the system, such as minimum lake levels and target drawdown levels, which may be needed for environmental concerns and operation of the city's utilities, are included as options within the simulated operation schemes. The purpose of this study was to develop yield estimates for the water supply system under a wide range of possible operating conditions, so that the city may select a drought operation policy that best meets its own objectives.

EXISTING AND POTENTIAL COMPONENTS OF THE SPRINGFIELD WATER SUPPLY SYSTEM

Existing Components

As described earlier, the city of Springfield currently gets its water from two sources: Lake Springfield and the South Fork Sangamon River. These two sources, and their current operation, are described as follows.

Lake Springfield

Lake Springfield was constructed in 1934 by the impoundment of Sugar Creek, located southeast of the city (see figure 1). The lake had an original storage capacity of approximately 59,900 acre-feet. Sedimentation has reduced the storage capacity of the lake over the years by roughly 9,400 acre-feet, with average annual loss of 154 acre-feet as estimated by Fitzpatrick and Knapp (1991). The city of Springfield dredged the upper portion of the lake over the period 1985-1989, restoring nearly 2,000 acre-feet of storage. The present (1997) capacity of the lake is estimated to be 52,500 acre-feet. Fitzpatrick and Knapp (1991) provide the stage-storage relationship for Lake Springfield. The lake has a surface area of approximately 4,000 acres, and a drainage area of approximately 265 square miles, which includes the surface area of the lake.

The spillway crest elevation of Lake Springfield is 559.35 feet above mean sea level (msl). However, the datum used for lake-level records is based on the original estimate of the spillway elevation, that being 560 feet msl. All references to lake level in this study will refer to this original datum. On average, about half of the time the lake experiences drawdown during which there is no outflow from the lake. The remainder of the time, the water level in the lake is maintained at or near an elevation of 560 feet msl, or "full pool," by adjusting the five steel drum gates that control the reservoir outflow. During winter operations, which typically last from mid-December to the beginning of March, the gates are adjusted to maintain the water level at an elevation of approximately 559 feet msl.

The designation of the "average pool" is different from the full pool and is defined by historical average conditions, which include periods of drawdown during drought. Figure 2 shows the average pool in Lake Springfield based on 62 years (1936-1997) of lake-level records, as provided by Springfield City Water, Light, and Power (CWLP).

The lake provides water for both the city's public water supply and circulation (cooling) water for the coal-fired electricity-generating units located alongside the lake. These utilities are physically able to operate at full capacity when the lake level is maintained above an approximate elevation of 547 feet msl. A significant drawdown below 547 feet msl would require a reduction in capacity or shutdown of the generating units.

South Fork Pumping Facility

A low-channel dam, located just downstream of the confluence of Horse Creek with the South Fork Sangamon River (see figure 1), was constructed in 1955 to provide a supplemental source of water for the Springfield water supply system. When the water level behind the dam is sufficiently high, water is backed up along the Horse Creek channel to a pumping facility located adjacent to Lake Springfield, which is used to transfer water into the lake. Pumping usually

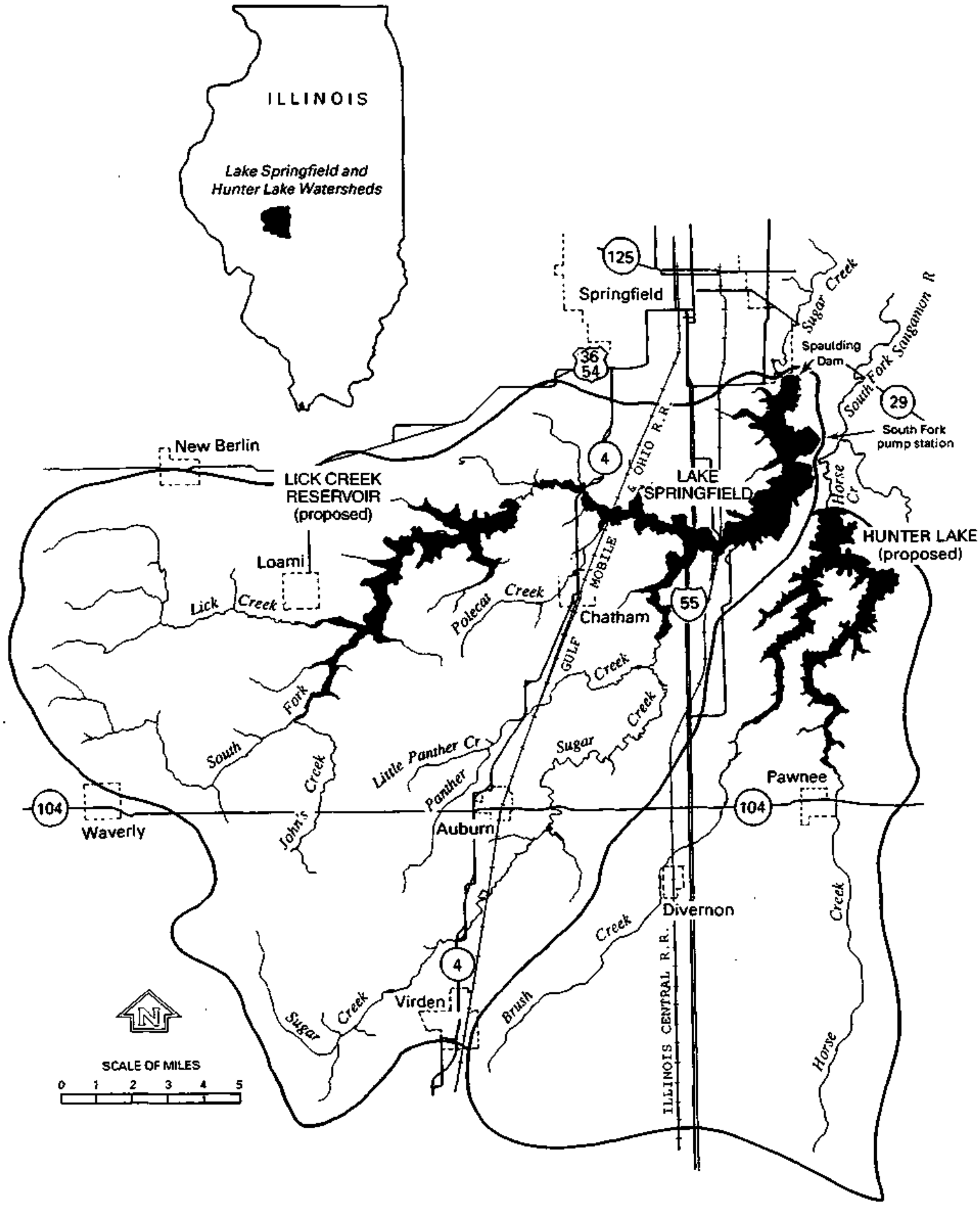

Figure 1. Location of existing and potential surface water sources for the Springfield water supply system

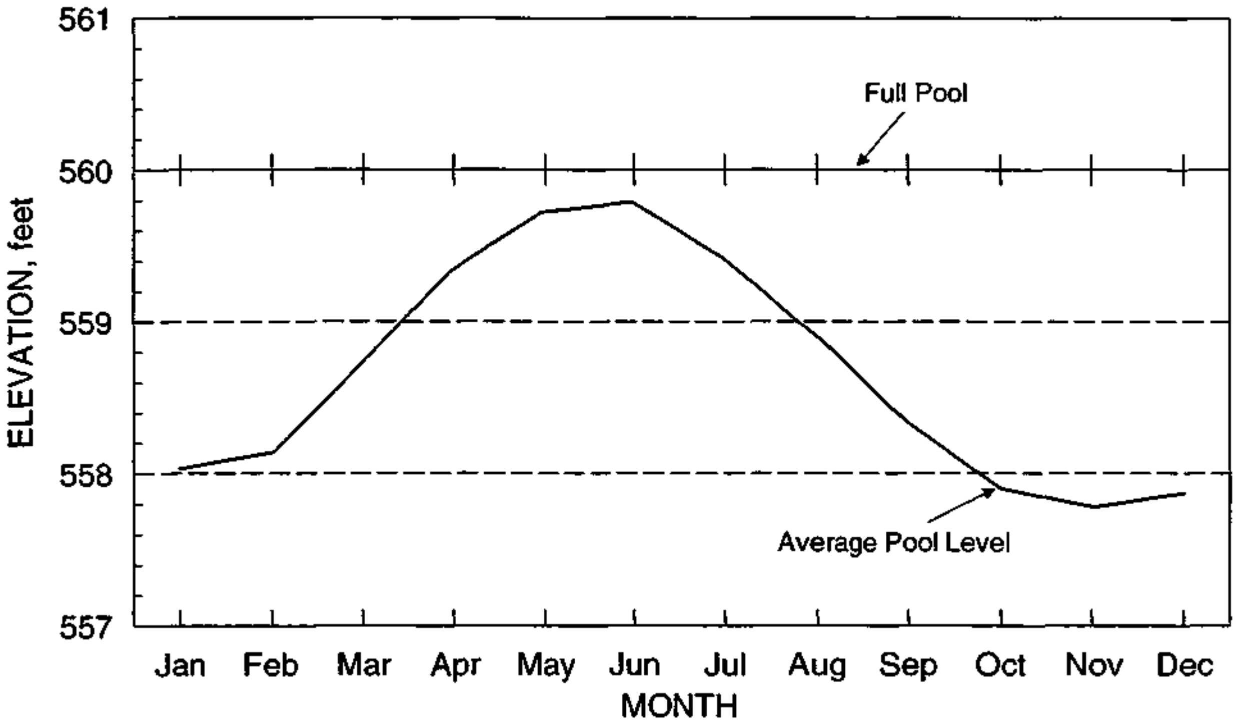

Figure 2. Average pool levels for Lake Springfield, 1936-1997

begins only after the water level in Lake Springfield has dropped one to two feet below "average" pool, as defined for each month in figure 2.

The two pumps at the facility are each rated at a pumping capacity of 35 million gallons per day (mgd). Historical records indicate that in normal operation their average pumping rate has been closer to 31.5 mgd, with a combined pumping capacity of 63 mgd or roughly 98 cubic feet per second (cfs). However, recent tests indicate that these records may be in error, and now claim that the maximum pumping capacity of the facility is approximately 78 mgd, or about 122 cfs. The original estimate of the pumping capacity, 63 mgd, was used for most of the analyses in this report. However, a section of the report, "Impact of Increasing the Pumping Rate at the South Fork Facility," addresses the increases in estimated yield that can be expected with a maximum pumping capacity of 78 mgd.

Any streamflow amounts above the maximum pumping capacity will not be retained by the channel dam. When flows in the South Fork are below the maximum pumping capacity, then one or both pumps must remain idle for portions of each day, each time allowing the storage behind the channel dam to be replenished. When the total amount of flow in the river falls below 10 cfs, pumping can occur for only a short amount of time, and the water behind the channel dam will tend to stagnate, which can cause anaerobic conditions. At these times, the channel dam is normally lowered and pumping activities are ceased.

The water available for pumping from the South Fork during major droughts was evaluated in Fitzpatrick and Knapp (1991), and estimated as a portion of the total amount of flow occurring during the duration of a drought. In the present study, the amount of pumping was simulated based on daily streamflow estimates for the South Fork using the operation guidelines as outlined above.

Potential Components

Over the years, there have been numerous alternative water supply sources identified to provide supplemental water to the Springfield system. This report considers the following six potential sources, which are regarded as the most viable at this time:

- Hunter Lake
- Lick Creek Reservoir
- groundwater from the Sangamon River valley and pumping from sand and gravel pits, located north and east of Springfield
- groundwater from the Illinois River valley west of Jacksonville
- groundwater obtained from the Havana Lowlands in Mason County
- reclaimed water from ash sluicing and replacement water from the Springfield Sanitary District or other outside source

Each of these water supply sources is described below.

Hunter Lake

The proposed Hunter Lake would impound Horse Creek, located immediately to the east of Lake Springfield approximately four stream miles above Horse Creek's confluence with the South Fork Sangamon River (see figure 1). The drainage area of Horse Creek at this location is approximately 128 square miles. The proposed full pool elevation of the lake is 571 feet msl, with an estimated storage capacity of 46,600 acre-feet and surface area of 3,010 acres. Fitzpatrick and Knapp (1991) provide the stage-storage relationship of Hunter Lake.

As proposed, water from Hunter Lake would be used to supplement the storage in Lake Springfield during dry periods when the water level in Lake Springfield has been drawn down to a specified depth below average pool. At that time, water would be transferred from Hunter Lake into Horse Creek and would flow approximately four miles downstream, where it would retained by the low-channel dam on the South Fork. This water would then be pumped into Lake Springfield by the present pumping system. Using this operation scheme, the total amount of water that could be transferred from Hunter Lake to Lake Springfield would be limited by: 1) the pumping capacity at the South Fork, and 2) the amount of time the South Fork pumping facility would already be used for transferring South Fork flows to Lake Springfield. An alternative method of water transfer from Hunter Lake could involve either gravity flow by way of a direct conduit to Lake Springfield or a direct pumping facility between the two lakes.

Lick Creek Reservoir

The impoundment of Lick Creek immediately upstream of Lake Springfield has also been proposed as an alternative source for supplying additional yield to the Springfield water supply system. The proposed reservoir would be located at river mile 6.8 on Lick Creek, in Section 26 of Curran Township. The full pool elevation of the proposed reservoir is expected to be between 585 and 595 feet msl, depending in part on the desired yield. The drainage area of Lick Creek at the proposed location is approximately 110 square miles and represents roughly 41 percent of the total drainage area in the Lake Springfield watershed.

The estimated capacity of the proposed lake at full pool elevations of 585, 590, and 595 feet msl are 13,140, 21,470, and 32,910 acre-feet, respectively. The surface areas at these three elevations are approximately 1385, 1946, and 2631 acres, respectively.

During normal conditions, it is anticipated that outflow from the Lick Creek Reservoir would occur as simple spillway overflow. As Lake Springfield water levels are drawn down during drought conditions, the outlet structures in the Lick Creek Reservoir would be used to transfer water to supplement the storage in Lake Springfield. The amount and timing of these transfers may impact the total system yield, and these potential options were examined in the simulation analysis.

Groundwater Sources

Three potential groundwater resource development alternatives are being considered for the Springfield water supply system. The first alternative involves redeveloping the groundwater supplies along the Sangamon River flood plain, generally located north and east of the city within a 16-mile radius from Lake Springfield. The shallow sand-and-gravel aquifers associated with the Sangamon River supplied a major portion of the city's water supply prior to the construction of Lake Springfield in the 1930s. Since the yield of this source may be somewhat limited, consideration is also being given to two distant sand-and-gravel aquifer systems: the Illinois River bottom lands west of Jacksonville and the Havana Lowlands area in Mason County. Both these aquifer systems are an extensive groundwater resource that have the potential to supply much or all of the additional yield needed by the city, albeit from a considerable distance. Illinois River bottom lands are located approximately 50 miles west of Springfield, and the Havana Lowlands are located 30 to 35 miles northwest of the city. Potential supplies for as much as 18 mgd are considered in this study. In the analysis of drought yield and reservoir operation, all groundwater contributions are assumed to be sustainable throughout the drought period.

Reclaimed Water

Approximately 8 mgd of the raw water demand from Lake Springfield is used for sluicing coal ash from the power plant to settling lagoons downstream of the lake. About 3 mgd of this amount is lost in the settling lagoons to evaporation and seepage to groundwater. There is the potential that the remaining 5 mgd could be returned to the power plant where it can be reused for ash sluicing. Water from other outside sources could also be used to replace the 3 mgd of water lost to evaporation and groundwater. Among the potential sources of this replacement water are filter backwash and/or treated effluents from the Springfield Sanitary District. By reclaiming water from ash sluicing and other sources, the overall demand on water from the lake system could be reduced by as much as 8 mgd. The amount of reclaimed/reused water is assumed to be constant throughout drought periods.

ANALYTICAL METHODS

Comparison of Methods Used in Yield Analysis

The *yield* of a surface-water-supply system is the maximum amount of water that can be supplied from that system during a specific period of time, typically over the duration of a particular drought. The *safe yield* of the system is the yield that occurs over a critical period, normally defined by either the drought of record or by a hypothetical drought having a specific interval of expected recurrence. For example, the 100-year drought is a hypothetical drought that is expected to be surpassed in severity on average only once every 100 years. The yield of the 100-year drought is normally defined through a frequency analysis of historical droughts, as applied either directly to the yield estimates for the historical droughts or to the hydrologic inputs used to estimate the yields. The primary hydrologic inputs used in reservoir yield analysis are streamflow, precipitation and evaporation over the lake, and other water transferred into or out of the lake. Other potential inputs into the analysis, which are typically minor and most often neglected, are groundwater seepages to and from the lake, and dam seepages.

There are two basic types of methods commonly used for the estimation of reservoir yield: 1) a nonsequential mass analysis, and 2) a sequential simulation analysis, sometimes called an operations study. As discussed below, each method has certain strengths and limitations.

Nonsequential Mass Analysis

The reservoir yield estimates given in most studies in the past 30 years have employed the nonsequential mass (NSM) analysis developed by the Illinois State Water Survey (Stall, 1964; Terstriep et al., 1982). The NSM analysis examines the total amount or "mass" of inflows and outflows from a reservoir during a hypothetical drought of a specific duration and frequency. The yield of the reservoir is computed as the sum of the reservoir storage and total inflows during the duration of the hypothetical drought, minus the total outflows or *losses* from the reservoir. Under ordinary reservoir yield analysis, the only inflows and outflows examined are the stream inflows and the net evaporative loss (evaporation minus streamflow).

Drought duration is defined as the time period between when the reservoir level first starts to fall below normal pool to the time of maximum drawdown. The NSM analysis is conducted for numerous possible drought durations, leading to the *critical drought duration* that provides the minimum reservoir yield. The critical drought duration for a particular reservoir can vary depending on the demand rate and other factors that affect the water budget of the lake.

The significant advantage of the NSM analysis is that it can be used to process the streamflow data into a matrix of nondimensional reservoir capacities, demand rates, and recurrence intervals. These demand-storage-recurrence data are highly transferable for use at ungaged sites, providing a mechanism to evaluate the yield of existing and potential reservoir sites throughout a region or the State.

A key characteristic of the NSM analysis is that it neglects the occurrence and sequence of inflows and losses. For example, the NSM analysis will compute the minimum 9-month flow and the minimum 18-month flow within a 50-year streamflow record for use in estimating drought yield. It is of no concern whether the 9- and 18-month minimum flows occurred during the same historical drought, and there is a reasonable chance that they did not. It is also possible that the 50-year minimum inflow and the 50-year maximum net evaporation occurred during different droughts.

The loss of sequential information generally has no impact on reservoir yield estimates when the impounding reservoir is the sole source of water supply. But when other components or sources are brought into a water supply system, the sequencing differences between various water supply sources is a concern that needs to be addressed. Ordinarily, the assumption of coincident minimum inflows and maximum net evaporation is considered part of a conservative design approach through which the safe yield of the reservoir may be slightly underestimated.

Simulation Analysis

Simulation analysis mathematically describes (or models) the physical dimensions of reservoir levels and operation for a specific sequence of flow conditions, such as during a historical drought, using a selected set of experimental constraints or policies (scenarios). Simulations are normally conducted using either daily or monthly time intervals. Of these, monthly simulations are most common and are usually performed only for those months where there is zero outflow from the reservoir. In contrast, daily simulations can be used to evaluate lake levels and yields for the entire period for which flow estimates are available. The daily simulation analysis requires considerably more time and resources in its development, and a complex analysis usually requires computer programming.

The main strengths of a simulation model are that: 1) it provides a mechanism to evaluate the joint use of various water supply sources, and 2) it provides for experimentation of various operation scenarios, which lets the model user draw inferences about the system performance during drought. Simulations also provide examples of the temporal changes in reservoir levels throughout a drought, which may influence decisions when choosing an operation scheme. In all these aspects, it is most useful that the simulation analysis be used on multiple drought events, since differences in the temporal qualities of droughts may have a significant impact on yields and operation policies.

When simulating a long period of record, there are essentially no choices in defining initial drought conditions (such as the date and reservoir level at the onset of a drought) as these are continuously computed by the model. The designation of a critical drought duration is also a moot issue, since this does not directly influence the evaluation of system yield. Each drought will have its own unique duration, which impacts the yield characteristics for that drought only.

The yield results of the NSM and simulation analyses can be expected to provide different but roughly similar results when: 1) the streamflow inputs to the two methods are equivalent, and 2) the yield for a single reservoir is analyzed. The results of the NSM analysis may be lower, especially for short duration droughts, which is attributable to the assumption of coinciding minimum inflows and maximum net evaporation.

Differences in the Type of Data Used by the Two Methods

Yield estimates of both the nonsequential analysis and the simulation modeling are provided in this report, and are thus available for comparison. Besides the basic differences in the two methodologies, there are also differences in the data used in each approach. For the nonsequential analysis given in Fitzpatrick and Knapp (1991), the estimate of low flow frequency is based on a regional analysis of flow records for the period 1949-1988, as originally developed in Knapp (1990). Net evaporation data given in Terstriep et al. (1982) were also used. These data are based on a frequency analysis of monthly evaporation using climatic records from 1911 to 1978. In this study's simulation analysis, both streamflows and net evaporation are simulated using climatic records for the period 1891-1995. (Observed flows are used for the South Fork Sangamon River for the period 1949-1995.) The simulation approach also uses a different method to estimate lake evaporation, as described later. The simulation approach does not apply frequency analysis to either streamflows or evaporation, only to the resulting drought yields.

Streamflow Estimation

Useful information in defining the drought inflow into a reservoir includes but is not limited to: 1) discharge records on streams that flow directly into the reservoir, and 2) discharge records on other nearby streams, which can be employed in estimating flows for the ungaged streams that enter the reservoir. Another factor in the usefulness of streamflow data is its period of record. Unless a streamflow record includes data on at least one major drought, the record may have limited use for estimating flows during critical droughts.

Available Streamflow Records

The simulation analysis requires estimates of streamflow at four stream locations: 1) Lick Creek at the proposed Lick Creek Reservoir, 2) Sugar Creek at Lake Springfield, 3) Horse Creek at Hunter Lake, and 4) the South Fork Sangamon River at the location of the pumping facility. Table 1 lists the continuous streamflow records that are used in this study for the estimation of flows at these four locations. Four of the five streamgages listed in table 1 were operated by the U.S. Geological Survey. Discharge records for a fifth gage, on Sugar Creek near Auburn, were developed by the Illinois Department of Natural Resources, Office of Water Resources (DNR-OWR) for the period 1951-1978, and by the Illinois State Water Survey for 1985-1987. These flow records for the Sugar Creek gage are fragmentary for most years.

Need for Synthetic Flow Records

Two basic choices exist for estimating streamflow records for use in the simulation analysis. One option is to use an observed flow record from a nearby streamgage and modify that flow record, usually by applying a scaling factor, to account for the difference in the drainage areas between the gaged site and the stream of interest. A second option is to synthesize the flow record using a continuous simulation rainfall-runoff model and observed precipitation record.

There are two concerns with choosing the first option. First, the only major drought that occurred during the period of streamgaging is the drought of 1953-1955. Second, only two gages in the vicinity of Lake Springfield provide continuous flow records through that major drought. Both factors severely limit the range of possible drought conditions that could be represented by the estimated streamflow records. This conflicts with the primary purpose for conducting a simulation analysis, that being to be able to evaluate the system operation under a broad range of conditions.

It is important to extend the analysis beyond just the 45-year period for which nearby streamgage records are available, so that the maximum range of potential conditions can be used in evaluating system operations and in developing the estimate of the 100-year drought. Use of the 105-year records of precipitation for synthesizing streamflows provides such an opportunity to examine a much greater number and range of drought conditions.

Table 1. Streamgaging Records Used in the Analysis

Gage number	*Location*	*Drainage area (sq. mi.)*	*Years of record*
05575800	Horse Creek near Pawnee	52.2	1967-1985
05575830	Brush Creek near Divernon	32.4	1973-1982
05576000	South Fork Sangamon River near Rochester	867.	1949-1995
05577500	Spring Creek at Springfield	107.	1947-1995
________	Sugar Creek near Auburn	49.1	1951-1978; 1985-1987

Note: All streamgage records listed in this table were collected and developed by the U.S. Geological Survey (USGS), with the exception of the record for Sugar Creek near Auburn, which was collected and developed by the Illinois Department of Natural Resources.

Ra infall/Runoff Modeling

A continuous simulation rainfall/runoff model was developed to estimate inflows for Lake Springfield, Hunter Lake, and the Lick Creek Reservoir, and streamflows for the South Fork Sangamon River. The model used is an adaptation of PACE Hydrologic Model (Durgunoglu et al., 1987), which was developed at the Illinois State Water Survey and has been applied during several hydrologic modeling projects. A brief description of the model is supplied below. The reader is referred to Durgunoglu et al. (1987) or Knapp et al. (1991) for additional details.

Figure 3 shows a schematic of the three basic modules or components within the PACE model. Components 1 and 2 of the PACE model were used in this study, but not Component 3, which conducts the routing of flows in the stream. In its place, a simple unit hydrograph was employed to estimate the flows in the stream resulting from the watershed runoff response. Use of the unit hydrograph approach instead of routing reduces the accuracy of the daily streamflows estimated by the model, but also greatly decreases the amount of modeling effort and does not modify the overall volume of flow that reaches the stream. The overall volume of flow is the most important information in evaluating inflows into the reservoir for estimating drought yield.

Component 1 estimates runoff, infiltration, soil moisture, evapotranspiration, and shallow groundwater recharge for selected types of soil and land use, using daily precipitation and temperature records, and average monthly estimates of relative humidity, wind, and percent sunshine as input. The amount of infiltration and runoff resulting from a precipitation event is estimated using a modification of the standard runoff curve number (RCN) approach, originally developed by the U.S. Department of Agriculture-Soil Conservation Service (SCS). The RCN is recalculated on a daily basis to account for changes in the soil moisture, so that as the amount of moisture in the soil column decreases, the RCN and the amount of runoff resulting from a rainfall amount are reduced. As the soil moisture column reaches its field capacity, water drains out of the soil column, where it can either flow directly toward the stream following a rain event (interflow), or goes into shallow groundwater storage, from which it is slowly released to the stream.

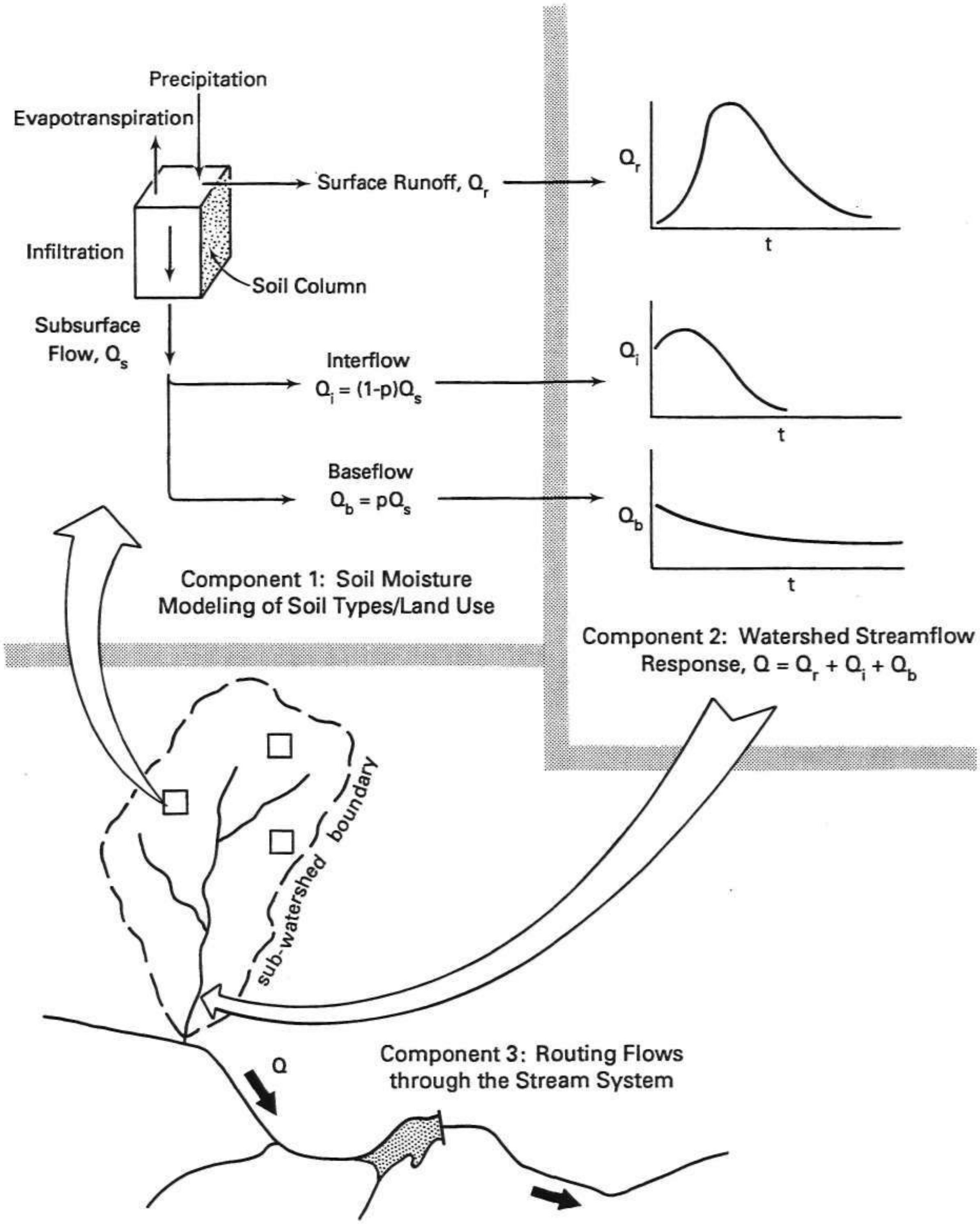

Figure 3. Components of the PACE Watershed Model used for simulating streamflows

Table 2. Precipitation Records Used in the Analysis

Gage location	*Years of record*
Springfield	1880-1995
Pana	1890-1894,1898-1995
Carlinville	1893-1995
Morrisonville	1895-1995
Jacksonville	1896-1995
Virden	1948-1995

Note: Data from various nearby stations were used to fill in some missing records. Data from two additional stations, at Griggsville and Hillsboro, were used in this process for replacing missing records at Jacksonville and Carlinville, respectively.

Component 2 estimates the rates of interflow and baseflow to the stream by way of groundwater storage separated into upper and lower levels. The daily release rate of water into the stream from each level is computed as a function of the water stored in that level; however, the release rate is considerably more rapid for the upper level than the lower level, the latter of which provides sustained flow through dry periods.

Model Calibration. Table 2 lists the precipitation records that were used for calibration and application of the rainfall-runoff modeling. Daily streamflows were modeled for the period of record at the five gaging locations listed in table 1. Average monthly streamflows observed at the five gaging stations were used for calibration. The primary model variables used in calibration include the base value of the runoff curve number, and recession constants used for determining the rate of groundwater flow to the streams. Calibration was alternately performed for dry conditions to determine the groundwater recession constants and then for wet (direct runoff) conditions. No attempt was made to calibrate to daily streamflows, a process that would have required considerably greater resources, since flows calibrated on a monthly basis are sufficiently accurate for examination of reservoir yield. Figure 4 shows selected comparisons of the observed and simulated monthly flows, as used in model calibration.

In the calibration process, particular attention was given to flows during drought periods, and an attempt was made to duplicate the 18-month and 30-month average flows for the historical droughts. Table 3 compares the modeled and observed average drought flows for the two locations with longer gage records, the South Fork Sangamon River near Rochester and Spring Creek at Springfield. The five droughts listed in table 3 are the worst during the period 1949-1995 and, arguably, the only hydrologic droughts during that period.

As is the case with all continuous streamflow modeling, both underestimation and overestimation of drought flows occur for specific time periods. As shown in table 3, the 18-month and 30-month flows are accurately estimated for the 1953-1955 drought, and are of variable accuracy for other droughts. Areal precipitation estimates used in the modeling had a great effect on the accuracy of the flow estimation. The general accuracy for the South Fork flow estimates is somewhat lower because only two precipitation gages, Pana and Morrisonville, are in or near the 867 square miles of this watershed. Both of these gages are on the southern fringes of the watershed and may not always accurately represent average rainfall over the watershed.

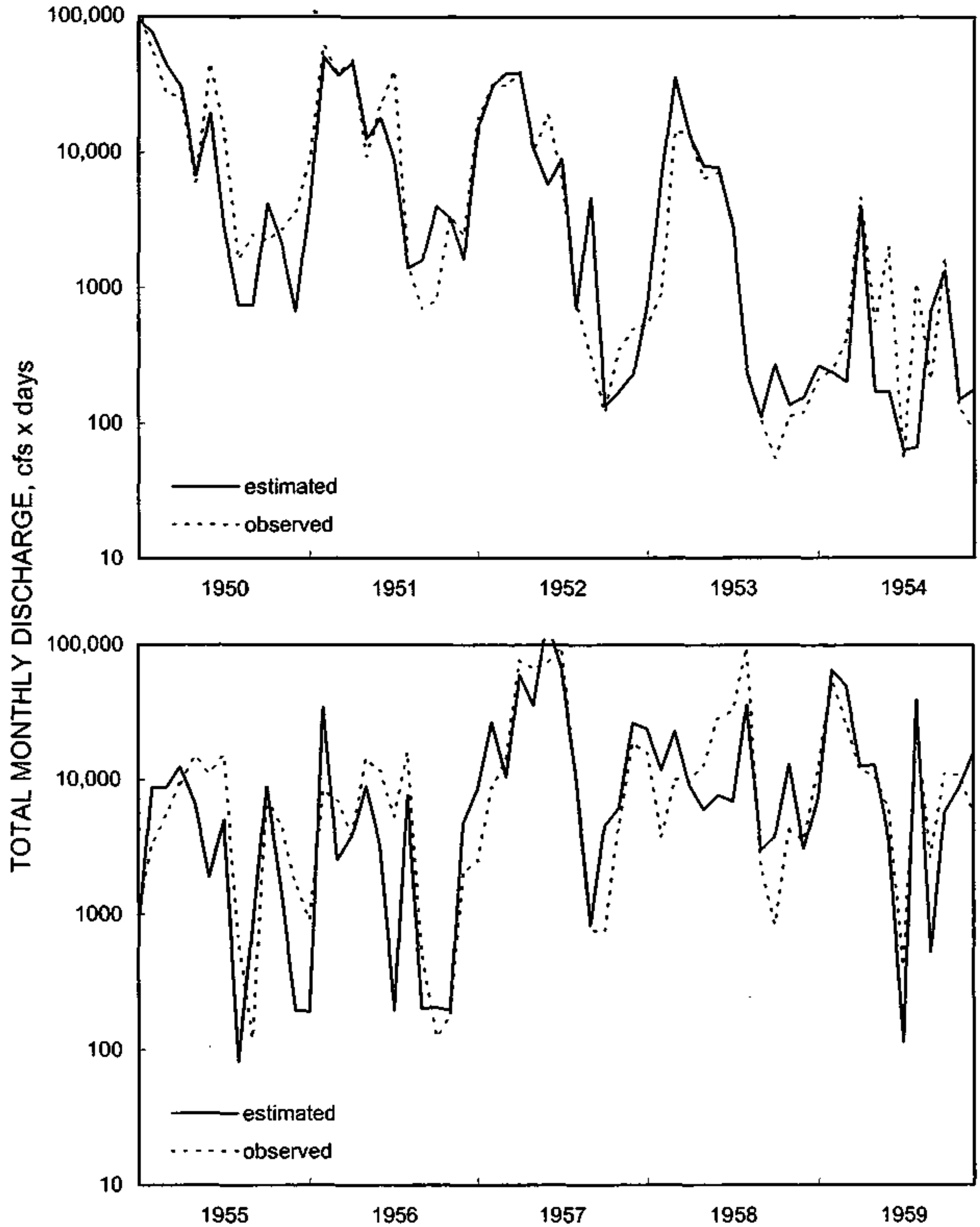

Figure 4. Examples of observed and simulated monthly flows for the South Fork Sangamon River near Rochester

Table 3. Comparison of Simulated and Observed Drought Flows (cfs) for the Five Worst Droughts in 1949-1995, South Fork near Rochester and Spring Creek at Springfield

	South Fork		*Spring Creek*	
Droughtflows	*Observed*	*Simulated*	*Observed*	*Simulated*
18-month				
1953-1955	24.7	16.5	1.6	2.1
1963-1965	147.8	208.3	24.3	7.8
1976-1977	184.2	236.1	26.5	37.5
1980-1981	197.1	189.7	28.2	19.5
1988-1989	142.4	267.2	12.4	16.7
30-month				
1953-1955	72.9	73.2	6.5	7.8
1963-1965	191.1	290.3	33.0	23.1
1976-1977	241.1	305.5	39.1	45.2
1980-1981	352.8	308.6	45.7	35.6
1988-1989	222.5	373.7	29.1	29.7

Weighting of Precipitation Gages in the Calibration and Simulation Process. When multiple precipitation gages are used for rainfall-runoff modeling, each precipitation record will produce a unique runoff response. Under these circumstances it is necessary to define, or weight, the portion of the watershed associated with each runoff response. The Theissen polygon method, commonly used to define the weights, assumes that each portion of the watershed will experience the same rainfall as measured at the nearest precipitation gage. However, a different method was employed in this study, that being to define the weights through the model calibration process. For example, if, when using two precipitation gages, a 60-40 weighting ratio produced lower model error than a 65-35 ratio, then the former weights would be adopted for modeling, regardless of the respective gages' locations in or near the watershed. Model error was defined as the sum of the squares of the differences between the observed and simulated monthly flows, using the logarithm of the flow values. Using this approach, the calibration process calculated the weights given in table 4. Use of the Virden precipitation record provided the best calibration results for many watersheds. However, the Virden gage record begins in 1948. For earlier years the precipitation record from Springfield was used as a substitute, except for the southern half of the Sugar Creek watershed, for which the Carlinville precipitation record was used.

Simulation of Lake Inflows and South Fork Flows, 1891-1995. Daily streamflows at each of the gage sites listed in table 1 were simulated for 1891-1995 using the calibrated model. Inflows into the Lick Creek Reservoir were estimated to be the same as that observed and modeled for Spring Creek at Springfield. (The Lick Creek and Spring Creek watersheds are almost identical in size, and roughly similar in location and orientation.) Inflows into Hunter Lake were estimated to be equal to the sum of the flows at the Horse Creek and Brush Creek gages, and multiplied by a factor of 1.5. Inflows into Lake Springfield were estimated to be equal to the sum of the inflow into the Lick Creek Reservoir and three times the flow modeled

Table 4. Weighting of Precipitation Gages Used in Runoff Modeling

Stream	*Gage location and weight (percent)*	
Horse Creek	Virden (82)	Morrisonville (18)
Brush Creek	Virden(lOO)	
South Fork Sangamon River	Morrisonville (56)	Pana (44)
Spring Creek	Jacksonville (53)	Virden (47)
Sugar Creek	Virden (100)	

for the Sugar Creek gage at Auburn. Observed flows on the South Fork Sangamon River were used in the analysis for the period 1949-1995. Simulated South Fork flows were used for the period 1891-1949.

Table 5 ranks the major droughts during the period 1891-1995 using the 18-month drought flows at four sites, which were estimated from the simulated and observed flows described above. The great droughts of 1953-1955 (listed as 1954) and 1893-1895 (1895) consistently display the two lowest average flows. But there is a greater variability in the ranking of all other major droughts. This variability is dependent on the precipitation record used in the modeling process, and therefore on the general geographic location. The drought of 1931 is clearly the third worst drought on record. Four other droughts consistently have a high ranking in terms of their low flow magnitudes, those being the droughts of 1934, 1941, 1901, and 1914. The recent drought of 1988-1989 is the only other drought that is ranked for all stream sites given in table 5.

It is noted that the ranking of drought yields will not always match the ranking of drought flows, such as that given in table 5, primarily because varying drought durations must be considered in the estimate of yield. However, for all yield estimates, the droughts of 1954 and 1895 stand apart from the other droughts in terms of severity, with 1931 being the third worst drought.

Simulation of Lake Evaporation

Lake evaporation is not a directly measurable amount, but can be estimated using a number of methods, most of which employ climatic measurements such as air temperature, relative humidity, wind speed, and solar radiation. For this study, daily lake evaporation was estimated using the Blaney-Criddle equation (Doorenbos and Pruitt, 1977) as modified by Frevert et al. (1983). This equation was originally developed to.estimate reference (potential) evapotranspiration for use in analyzing agricultural water needs, but also gives suitable estimates of free-surface evaporation as applied to Illinois lakes. The PACE model uses the Blaney-Criddle equation to estimate the reference evapotranspiration used in soil moisture simulation.

Table 5. Average Flow Amount (cfs) and Drought Occurrence during Top Ten Simulated Drought Conditions

Rank	*Lick Creek flows*	*Lake Springfield inflows (minus Lick Creek flows)*	*Hunter Lake inflows*	*South Fork flows*
1	2.1 (1954)	3.2 (1954)	2.7 (1954)	24.7(1954)
2	2.9 (1895)	7.5 (1895)	5.9 (1895)	25.5 (1895)
3	7.6(1941)	17.9(1931)	12.7(1931)	84.0(1934)
4	7.6(1901)	31.0(1914)	15.9(1934)	87.7(1931)
5	8.3(1931)	35.3 (1988)	16.3 (1901)	113.5(1914)
6	9.2 (1905)	36.7 (1934)	16.5(1941)	126.6(1941)
7	10.0 (1923)	40.0 (1901)	21.7(1907)	142.4(1988)
8	12.5 (1914)	42.9(1981)	21.9(1914)	147.8 (1964)
9	14.1 (1934)	48.1 (1941)	30.1 (1981)	154.6(1901)
10	16.7 (1988)	50.6 (1964)	30.6 (1988)	184.2 (1977)

The Blaney-Criddle estimate is defined by the following equation:

$$EVAP = a + b * PDAY * TF/100 \qquad (1)$$

where

EVAP = lake evaporation (inches/day)
PDAY = total length of possible sunshine per day (minutes)
TF = average daily air temperature (degrees Fahrenheit)
a = (0.0043 RH - 0.01 PSUM - 1.41)/ 25.4
b = 0.81917 - 0.0040922 RH + 0.010705 PSUN + 0.0338 WIND - 0.00005968 RH * PSUN - 0.0003072 RH * WIND
RH = minimum afternoon relative humidity
PSUN = percent of possible daily sunshine
WIND = wind speed at the time of minimum humidity (miles per hour)

Measurements of relative humidity, wind speed, and percent sunshine are not available for the early part of the 20th century. For this reason, instead of using daily estimates of these parameters, average monthly values for these parameters were estimated and applied to the entire 105-year period of simulation (1891-1995). These monthly averages were computed using data from the 15-year period, 1973-1987. In this manner, a 105-year series of daily evaporation was computed using equation 1. A series of daily values for *net evaporation* was computed by subtracting the daily precipitation, observed at the Springfield climatic station, from the daily evaporation estimate.

Table 6 shows drought frequency estimates of net evaporation, as estimated using the Blaney-Criddle method. Also shown is the estimate of net lake evaporation as presented in Terstriep et al. (1982), hereafter referred to as Bulletin 67. The Blaney-Criddle method generally estimates greater lake evaporation, but the two sets of evaporation amounts are comparable and in most cases are within 10 percent of each other. However, there is a considerable difference, of more than 25 percent, in the estimates for long-duration droughts and high recurrence intervals. The two major factors that cause this difference are: 1) the period of record for which the evaporation was estimated, and 2) the method used to estimate drought frequency in Bulletin 67. Two of the top five estimates of 18- and 30-month net evaporation are for droughts of 1893-1895 and 1900-1902, neither of which was evaluated in the Bulletin 67 estimates. An examination of the data used in Bulletin 67 also suggests that the evaporation frequency analysis for that report should be revisited.

The Blaney-Criddle estimates used in this study provide a more accurate representation of net evaporation during droughts having long durations and a recurrence of 25 years or greater. Use of the Blaney-Criddle estimates results in a relative decrease in the 100-year yield of Lake Springfield, because the estimated evaporation rate is approximately 1.1 mgd more than when the Bulletin 67 data are used. The yields of Hunter Lake and the Lick Creek Reservoir will also decrease, by an amount roughly proportional to the surface area of these lakes at full pool.

Table 6. Net Lake Evaporation at Springfield, in inches, during Droughts of Various Durations

	Blaney-Criddle Estimate of Reference Evapotranspiration				
Recurrence	*3-month*	*6-month*	*12-month*	*18-month*	*30-month*
10-year	14.9	20.4	14.9	24.5	28.2
25-year	15.9	22.2	18.4	33.1	36.9
50-year	16.4	23.3	20.1	34.8	43.2
100-year	16.7	23.9	21.1	38.5	49.1

		Bulletin 67 Lake Evaporation			
Recurrence	*3-month*	*6-month*	*12-month*	*18-month*	*30-month*
10-year	13.52	18.75	16.41	23.57	24.68
25-year	14.25	20.29	18.78	26.99	30.55
50-year	14.72	21.21	20.57	29.51	34.97
100-year	14.91	21.52	21.63	30.85	38.63

Simulation of Drought Yield for the Springfield Water Supply System

A computer program, coded in FORTRAN, was created to simulate the daily water budget for the Springfield water supply system, including Lake Springfield and two potential lakes, Hunter Lake and the Lick Creek Reservoir. The water budget of each lake includes a daily accounting of the reservoir storage, inflows into the lake, net evaporation, withdrawals for water use, transfers from/to the lake, and outflow over the spillway. Pool elevations and lake surface areas were computed from the daily reservoir storage amounts.

Specific water transfers included as available options in the water budget model of the system are: 1) the pumping of water from the South Fork Sangamon River into Lake Springfield whenever the flow in the South Fork exceeds 10 cfs, with a maximum pumping rate of 98 cfs; 2) release of water from Hunter Lake into Horse Creek and the coincident pumping of that water from the South Fork to Lake Springfield, available for use only when the South Fork pumping facility is not already being used at its capacity; 3) release of water from the Lick Creek Reservoir into Lake Springfield; and 4) pumping of groundwater. Potential reclaimed water from ash sluicing and filter backwash is analyzed in conjunction with groundwater pumping, since both essentially provide a constant net addition to the water supply system during the period when they are in use. Each of the available transfers is assumed to occur only after the pool in Lake Springfield falls below a threshold level, which can be the average pool level, a specified depth below the average pool, or a set pool elevation.

Reservoir outflows for both Hunter Lake and the Lick Creek Reservoir are determined using a level-pool routing with the standard free weir flow equation:

$$Q = c\ w\ h^{1.5} \qquad (2)$$

where Q = outflow in cfs,
c = spillway coefficient, taken as 3.6,
w = width of the spillway, taken as 325 feet, and
h = depth of water above the crest of the spillway, estimated by the relationship between reservoir storage and pool elevation.

The proposed width for the Hunter Lake spillway was provided by CWLP, and the Hunter Lake spillway coefficient was assumed to be the same as that for Lake Springfield, as estimated from data in the dam safety inspection report for Lake Springfield (U.S. Army Corps of Engineers, 1980). Values of the Hunter Lake spillway width and coefficient were also used for simulating outflows from the Lick Creek Reservoir.

The outflow from Lake Springfield, which occurs over five steel drum gates, each of which are 45 feet wide, was also estimated using Equation 2. However, the outflow is increased during periods of high flows to generally keep water levels below an elevation of 560.5 feet msl, as is part of the normal operating procedure of the lake. Outflows from Lake Springfield are increased by opening (lowering) the steel drum gates over which the water flows. Computation of reservoir outflows has very little impact on the estimation of yield, since the outflow during drought periods is zero, but it is essential for continuous daily simulation of the lake water budgets during normal and wet periods.

The water budget model also includes an algorithm to change the amount of available storage in each reservoir, as expected to occur from future sedimentation. The impact of sedimentation on future reservoir capacities and yields are examined in the chapter "Results of the Simulation Analysis for Future Conditions."

System Operation Variables

Eight model variables were developed that allow the model user to define a wide range of potential operating conditions, such as when to begin pumping from the South Fork and the transfer rates from the two potential reservoirs. The most complicated of these variables is *TransOpt,* which defines options for transferring water from the potential second reservoir to

Lake Springfield including the sequence that two reservoirs will be drawn down. The major options available with TransOpt are described below:

TransOpt

1 Water is transferred from the second reservoir (Hunter Lake or the Lick Creek Reservoir) to keep a high pool level in Lake Springfield. Transfers are discontinued when the pool level in the second reservoir is drawn down a total of 6 meters (19.8 feet) and do not resume until either: a) the pool in the second reservoir rises above the 6-meter level, or b) Lake Springfield is drawn down below an elevation of 550 feet msl. The 6-meter maximum drawdown is used to protect aquatic life in the second lake, as recommended in the Hunter Lake Habitat Evaluation Procedures (HLHEP, 1992).

2 Lake Springfield and the second reservoir are drawn down in an alternating sequence. Water is transferred from the second reservoir until its level is drawn down a total of 2 meters (6.6 feet). Transfers are then discontinued until either: a) the pool in the second reservoir rises above the 2-meter level, or b) the level in Lake Springfield is drawn down below 555 feet msl. The transfers are then resumed until the second lake is drawn down to 6 meters below full pool. As when TransOpt is 1, the storage below the 6 meter depth is not used until after Lake Springfield is drawn down below a pool level of 550 feet msl. The 2-meter and 6-meter drawdown levels for the second reservoir were adopted based on aquatic habitat considerations given in HLHEP (1992).

3 The two reservoirs are drawn down together, proportional to the amount of available storage remaining in the lake.

4 Transfers from the second lake begin only when Lake Springfield is drawn down below a level of 555 feet msl. Transfers continue until either: a) the second lake is drawn down 2 meters, or b) the pool level in Lake Springfield rises above 555 feet msl. Transfers resume only after Lake Springfield is drawn down below a level of 550 feet msl.

5 Same as when TransOpt is 1, but water is transferred water from Lake Springfield back to the second lake when Lake Springfield is at or above its average pool level.

6 Same as when TransOpt is 1, but pumping from the South Fork occurs whenever Lake Springfield is below full pool during the months of April, May, and June.

As is discussed later, yield estimates tend to be greatest when TransOpt is 4 and least when TransOpt is 1. For this reason, these two options are the ones most frequently simulated. Yield estimates when TransOpt is 2 are almost identical to those when TransOpt is 3.

Seven other variables, listed below, provide additional options for the water supply system operation:

Variable

MinElev — the minimum pool elevation of Lake Springfield, in feet msl, below which water is considered unavailable for water supply.

PumpOpt — the depth below average pool on Lake Springfield, in feet, used to trigger pumping from the South Fork pumping facility. Average pool is as defined earlier in this report.

GWOpt — the depth below average pool on Lake Springfield, in feet, used to trigger pumping from groundwater and reclaimed water.

Qgw	the total pumping rate from groundwater and reclaimed water, in mgd.
LCR Pool	the full pool elevation of the Lick Creek Reservoir, in feet msl.
QHunt	the transfer rate from Hunter Lake to Lake Springfield, in cfs.
QLick	the transfer rate from the Lick Creek Reservoir to Lake Springfield, in cfs.

Variables QHunt and QLick are varied to examine the impact of the transfer rate on the system yield. Transfer rates in the range of 40 to 60 cfs are normally considered for Hunter Lake, while the Lick Creek Reservoir transfers are normally modeled in the range of 15 to 30 cfs. However, in all cases, the transfer rate is doubled once Lake Springfield has been drawn down to a level near 550 feet.

The water budget model is normally operated using one selected operation scenario and a large number of different water use demand rates, producing multiple sets of daily lake levels for the period of simulation, 1891-1995. The simulated daily lake levels are then examined, and the occurrence of extremely low lake levels are used to identify each drought. The yield for each drought is determined as the maximum demand rate that does not cause the reservoir pool level to fall below a specified minimum level. The minimum level for Lake Springfield is generally given as either 540 feet, using almost all of the available capacity, or 547 feet, which is taken as the minimum lake level that will fully support the city's utilities. The minimum levels for Hunter Lake and the Lick Creek Reservoir are taken as 541 and 570 feet, respectively, using roughly 95 percent of the total volume of these lakes.

Once the yields are estimated for all historical droughts and a selected operation scenario, a frequency analysis is conducted to estimate the yields for the 10-, 25-, 50-, and 100-year droughts. This frequency analysis is described in the next section.

Drought Yield Frequency Estimation

Terminology

Four indexes are used to describe the frequency of a drought: 1) the drought rank, 2) the recurrence interval, 3) the drought probability, and 4) the Z probability value, described below. Table 7 provides the basic numerical relationships between these values, when applied to drought results from the 105-year period of simulation and the computation of the 10-, 25-, 50-, and 100-year droughts.

<u>Drought Rank</u>. The drought rank is used to compare the relative severity of the droughts that occurred within a specified period of years, in which severity is normally defined by the water supply yield during that drought. The specified period of years is normally considered to be the period of record during which streamflow or lake-level records are available, but for this study is considered to be the total number of years of simulation. The most severe drought, or drought of rank 1, is the drought that has the lowest yield during the period of years. The drought of rank 2 has the second lowest yield during the period, and so forth.

<u>Recurrence Interval</u>. The average expected recurrence interval of a drought, or simply the recurrence interval, is the average number of years expected to occur between droughts that have

Table 7. Relationships between Drought Rank, Recurrence Interval, Drought Probability, and the Z Variate

Rank	*Recurrence interval (years)*	*Probability*	Z
1	105.00	.00952	2.346
2	52.50	.01905	2.075
3	35.00	.02857	1.902
4	26.25	.03810	1.773
5	21.00	.04762	1.669
6	17.50	.05714	1.580
7	15.00	.06667	1.501
8	13.12	.07619	1.431
9	11.67	.08571	1.367
10	10.50	.09524	1.309
11	9.55	.10476	1.255
–	100.00	.01000	2.327
–	50.00	.02000	2.054
–	25.00	.04000	1.751
–	10.00	.10000	1.282

a similar or lower yield. A drought with a recurrence interval of 25 years, also called a 25-year drought, will occur on average once every 25 years. Within a 100-year period of record, it is expected that the 25-year drought will have a drought rank of 4. Thus, it is expected that three droughts of greater severity will also occur during this 100-year period.

Drought Frequency. Under most situations, hydrologic frequency is defined as the probability that an event will occur in any given year. But droughts can be multiple-year events, for example, the 25-year drought can be occurring over two or three consecutive years. Thus in practice, the drought frequency is redefined as the probability that the maximum water supply impacts of a drought will be attained in a given year. The drought frequency is estimated as the inverse fraction of the recurrence interval. For example, the frequency for the 25-year drought is 1 divided by 25, equal to 0.04 or 4 percent. Thus, there is a 4 percent probability that the 25-year drought will be attained in a given year.

Z Variate. For a given drought frequency, there is a corresponding Z variate, which is defined for a normal probability distribution function as the number of standard deviations of that frequency from the mean of the distribution. The drought that has a 50 percent frequency, or 2-year recurrence interval, is at the mean of the probability distribution and has a Z value of zero. The drought event that has a 10 percent frequency, or 10-year recurrence interval, is roughly 1.282 standard deviations from the mean. The use of the Z variate assumes that drought yield values are an annual series with a normal probability distribution. Though this assumption is an incorrect one, the assignment of Z values are very useful for plotting and developing the drought yield frequency distribution.

Drought Yield Frequency Distribution

Figure 5 shows a typical relationship between the estimated yield and the recurrence of the drought as simulated in this study. The plot uses a log versus a normal probability scale. A normal probability scale is linear with respect to the Z probability variate. The plotting position for each drought is determined by computing its approximate recurrence interval (RI):

$$RI = N/m \qquad (3)$$

where: N = the total number of years of simulation, equal to 105, and
m = the drought rank.

In all cases examined, there is a consistent "S" shape to the frequency relationship when plotted at this scale using droughts having a recurrence of eight years or greater.

None of the frequency distributions normally used in hydrologic studies for estimating either flood or drought frequency have a distribution shape similar to that shown in figure 5. In an ordinary frequency analysis of reservoir yield, it is often sufficient to estimate the yield for a particular recurrence interval using a hand-plotted graphical fit of the data points. However in this study, because there are direct comparisons between yield estimates for various operation scenarios, it is essential to remove subjective inconsistencies and use an objective mathematical technique to estimate yield-frequency.

A tangent function was found to provide a good fit to the data when using the log-probability scale and, as shown by the solid line in figure 5, provides the S-shape needed to define the yield frequency distribution. The tangent relationship between the log of the yield (log Y) and the Z value used to plot probability, is given by the following equation:

$$TAN\,[\,c_1\,(\log Y - Y_{mean})] = c_2\,(Z - Z_{mean}) \qquad (4)$$

The values of c_2 and Z_{mean} were set constant to 5.268 and 1.804, respectively. In essence, this means that the tangent function will be centered (or have its break point) at a recurrence interval of roughly 30 years, and maintain the same curvature characteristic as that shown in figure 5, though the amplitude of the curve (in mgd) may be varied. The Y_{mean} defines the log of the system yield at the center of the tangent function, at a recurrence interval of 30 years. The value of c_1 defines the amplitude of the curve.

For each different operation scenario, the values of c_1 and Y_{mean} were calibrated using the simulated yield amounts for the 11 worst droughts. A least squares analysis was employed in the calibration process, but greater weight was assigned to the squared error for the three worst droughts.

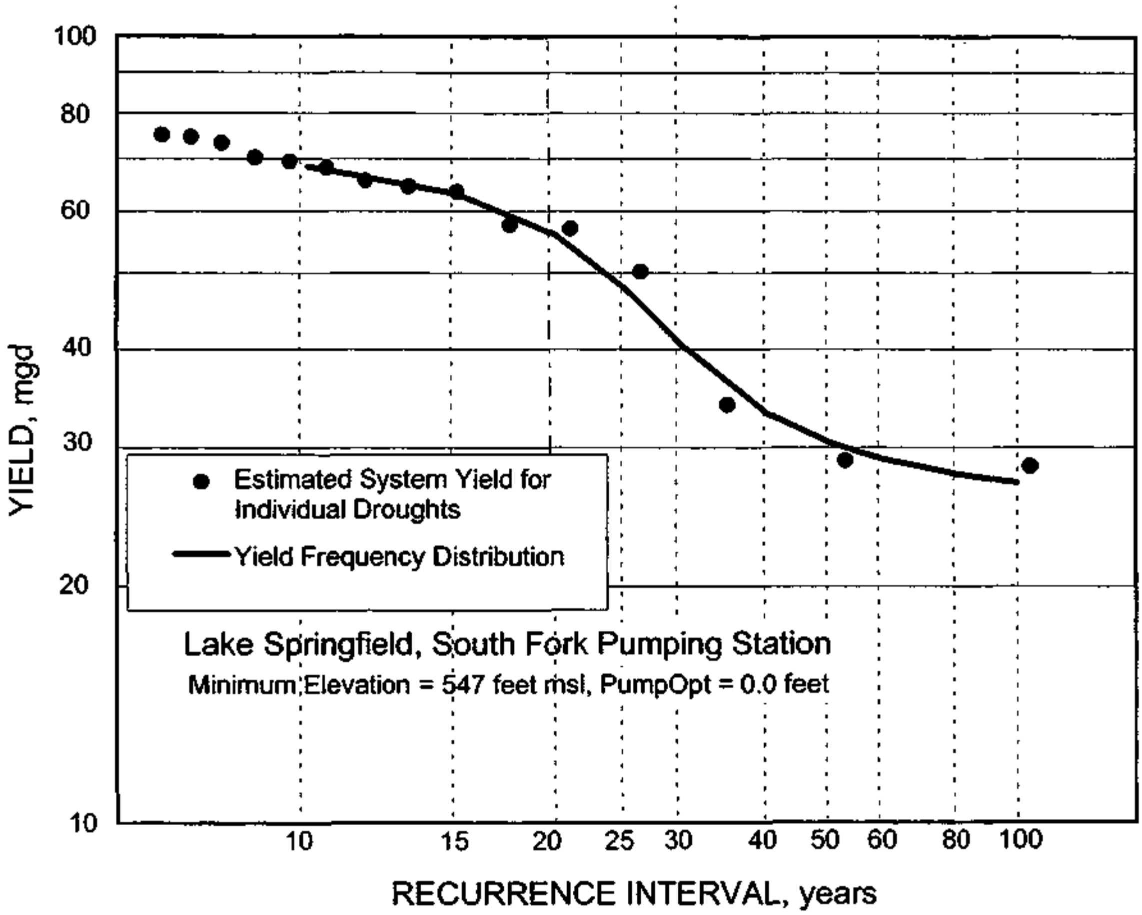

Figure 5. Example of the Drought Frequency Relationship

RESULTS OF THE NONSEQUENTIAL MASS ANALYSIS

The nonsequential mass (NSM) analyses of yields for Lake Springfield, Hunter Lake, and the Lick Creek Reservoir are presented herein as a point of reference. These yield amounts are not used in comparing the impacts of operation on the overall yield of the Springfield water supply system.

Terminology

Three basic terms are used to describe the yield of the water supply system or its individual components using the NSM analysis. The *gross yield* is the maximum amount of water that can be supplied from only one selected component in the system. The *combined yield* is that supplied from all components in the system. The *net yield* for a selected component is the difference between the combined yield when using that component and the combined yield without that component.

Description of Yield Estimates

Yield estimates for Lake Springfield and Hunter Lake, presented in table 8, are essentially the same as those developed using the worksheets in Fitzpatrick and Knapp (1991). However, the yield estimates for Lake Springfield have been updated to reflect conditions in the year 2000, as impacted by additional reservoir sedimentation in the years 1990-2000. The impact of sedimentation on the yield of Lake Springfield over this period is dependent on the drought duration. The yields of the 6-, 9-, 18-, and 30-month droughts are reduced by 2.7, 1.8, 0.9, and 0.5 mgd, respectively. Yield estimates are given only for the critical drought durations. The yield of the South Fork pumping facility, as estimated using Fitzpatrick and Knapp (1991), is also presented. Bulletin 67 evaporation rates were used in all reservoir yield computations.

Table 8 presents the gross yield and net yield estimates for the Lick Creek Reservoir for three potential design pool elevations: 595, 590, and 585 feet msl. The net yield can be either greater or less than the gross yield, depending on the pool elevation and drought recurrence.

In general, the Lick Creek Reservoir will affect the water-supply yield of Lake Springfield by reducing the amount of inflow to Lake Springfield during droughts. This reduces the net yield of the system, as reflected when the net yield of the Lick Creek Reservoir is less than its gross yield. But it is possible for the net yield to exceed the gross yield as a result of differences in the critical drought duration of the system components. For some drought frequencies, the critical drought duration of the Lick Creek Reservoir is 30 months, while the critical duration for the present water supply system combined with the Lick Creek Reservoir is 18 months. In such cases, the yield provided by the Lick Creek Reservoir over the shorter 18-month drought period is greater than the gross yield that was computed for a 30-month period.

Table 8. Previous Yield Estimates (mgd) for the Springfield Water Supply System's Components, Primarily Developed with the Nonsequential Mass Analysis

	Yields (mgd) for different recurrence intervals			
System Component(s)	*100-yr*	*50-yr*	*25-yr*	*10-yr*
Lake Springfield, full storage	24.1	30.6	38.4	56.4
Lake Springfield, MinElev = 547	18.2	24.8	30.9	46.8
Hunter Lake	18.6	22.6	27.2	39.4
South Fork Pumping Station				
Combined yield with Lake Springfield, MinElev = 547	28.5	36.7	49.6	67.5
Net yield when added to Lake Springfield	10.3	11.9	18.7	20.7
Lick Creek Reservoir at 595 feet msl				
Gross Yield	13.5	16.6	20.9	29.7
Net yield when added to present system, MinElev = 547	12.8	17.7	17.9	31.2
Lick Creek Reservoir at 590 feet msl				
Gross Yield	9.4	12.5	16.8	22.9
Net yield when added to present system, MinElev = 547	8.8	10.9	11.1	24.4
Lick Creek Reservoir at 585 feet msl				
Gross Yield	6.5	9.2	11.9	18.0
Net yield when added to present system, MinElev = 547	5.8	5.9	6.1	16.9

Notes: The estimated yield of the present water supply system is the combined yield of the South Fork pumping facility and Lake Springfield.
MinElev is the minimum pool elevation of Lake Springfield, in feet msl, below which water is considered unavailable for water supply.

RESULTS OF THE SIMULATION ANALYSIS FOR CURRENT (YEAR 2000) CONDITIONS

Table 9 presents the drought yields for a variety of operation scenarios, estimated using the water budget model and drought frequency analysis. The large number of scenarios was developed in an attempt to both: 1) define a broad usable range of potential operating conditions, and 2) provide examples of the variation in yield that could be expected from changes in system operation. A general discussion of the sensitivity of yields to potential operations, and interpretation of the results is provided below.

Terminology

Two basic terms are used to describe the yield of the water supply system or its individual components using the simulation analysis. The *system yield* is the maximum amount of water that can be supplied through joint operation of all components in the water supply system, as simulated on a daily basis. The system yield is different than the combined yield given in the NSM analysis. The *net yield* for a selected component is the difference between the system yield when using that component and the system yield without that component.

Lake Springfield Alone

Yields were estimated for Lake Springfield using four different minimum lake levels, below which water is considered unavailable for use (variable MinElev). The reservoir storage at an elevation of 540 feet msl is approximately 5 percent of the total capacity of the lake, and for the remainder of this study is considered the practical minimum elevation from which water can be withdrawn.

A comparison of yield estimates between the NSM and simulation analyses indicates that simulation analysis produces higher yield estimates for all drought frequencies except that for the 50-year drought. One reason why the 50-year yield is comparatively lower for the simulation analysis is that within the 105-year period of simulation there are two droughts of similar intensity (1894-1895 and 1953-1955). Thus, the frequency analysis estimates that the second-ranked drought will have a recurrence interval of approximately 50 years, as shown in table 7.

Lake Springfield and South Fork Pumping Facility (Present System)

The term "present system" is used herein to define the Springfield water supply system with the two existing components: Lake Springfield and the South Fork pumping facility. It is not intended to refer to the manner in which those two components are presently used. Scenario B5, presented in table 9, most closely identifies the current operation, in which pumping from the South Fork is not initiated until the lake level is approximately 2 feet below the long-term average level.

Three variables were used in the simulation analysis to determine a range of possible system yields for the present system. These variables are: 1) the minimum elevation of storage in Lake Springfield available for water supply (MinElev), 2) the depth below average pool, in feet, at which pumping from the South Fork commences (PumpOpt), and 3) the option (when

Table 9. Springfield System Yields: Present Day Conditions (Year 2000)

Note: Descriptions, of the variables that define the operation scenarios are provided in more detail in the section "System Operation Variables" or1 pages 19-20.

Operation scenario	*Yields (msd) for different recurrence intervals* *100-yr*	*50-yr*	*25-yr*	*10-yr*
A) Lake Springfield Alone Variable: minimum pool elevation of Lake Springfield (MinElev), in feet msl				
Al) No Minimum Elevation	27.1	30.1	45.8	64.0
A2) MinElev = 540	26.1	29.1	44.7	62,7
A3) MinElev = 547	21.4	24.0	37.8	54.3
A4) MinElev = 550	18.1	20.4	32.9	48.1
B) Lake Springfield and South Fork Pumping Facility Variables: minimum pool elevation of Lake Springfield (MinElev), in feet msl depth below average pool, in feet, used to trigger pumping (PumpOpt) option to pump in April-June whenever Lake Springfield is below full pool (when TransOpt is 6)				
B1) No Minimum Elevation, PumpOpt=0.0	34.1	38.1	59.7	85.3
B2) MinElev = 540, PumpOpt=0.0	33.1	37.1	58.2	83.2
B3) MinElev = 540, PumpOpt=4.0	31.8	35.3	53.2	73.7
B4) MinElev = 547, PumpOpt=0.0	27.2	30.5	47.8	68.4
B5) MinElev = 547, PumpOpt=2.0	26.8	29.8	45.4	63.5
B6) MinElev = 547, PumpOpt=4.0	26.0	28.9	44.1	61.7
B7) MinElev = 547, PumpOpt=6.0	24.4	27.3	42.6	60.6
B8) MinElev = 547, PumpOpt=0.0, TransOpt=6	27.2	30.5	48.2	69.2
B9) MinElev = 547, PumpOpt=2.0, TransOpt=6	27.2	30.4	47.2	67.0

Table 9. Continued

C) Hunter Lake Alternatives

Variables: minimum pool elevation of Lake Springfield (MinElev), in feet msl
depth below average pool, in feet, used to trigger South Fork pumping (PumpOpt)
options describing when to transfer water from Hunter Lake (TransOpt)
transfer rate from Hunter Lake to Lake Springfield, in cfs (QHunt)

Operation scenario	*Yields (mgd) for different recurrence intervals*			
	100-yr	*50-yr*	*25-yr*	*10-yr*
C1) Hunter Lake as the sole water supply source	19.7	21.4	29.9	38.9
C2) MinElev = 540, PumpOpt=0.0, TransOpt=l QHunt=40	55.3	60.3	85.5	112.8
C3) MinElev = 540, PumpOpt=0.0, TransOpt=l QHunt=60	53.4	59.0	87.4	119.5
C4) MinElev = 540, PumpOpt=0.0, TransOpt=4 QHunt=40	55.9	60.8	84.7	110.3
C5) MinElev = 540, PumpOpt=0.0, TransOpt=4 QHunt=60	55.3	60.6	87.3	116.8
C6) MinElev = 547, PumpOpt=0.0, TransOpt=1 QHunt=34	49.3	53.3	73.1	93.9
C7) MinElev = 547, PumpOpt=0.0, TransOpt=l QHunt=40	49.5	53.9	75.1	97.7
C8) MinElev = 547, PumpOpt=0.0, TransOpt=l QHunt=50	48.4	53.2	77.6	104.7
C9) MinElev = 547, PumpOpt=0.0, TransOpt=l QHunt=60	48.0	52.9	78.1	106.4
C10) MinElev = 547, PumpOpt=0.0, TransOpt=l QHunt=80	47.5	52.6	78.9	108.9
C11) MinElev = 547, PumpOpt=0.0, TransOpt=4 QHunt=40	50.1	54.2	73.8	94.4
C12) MinElev = 547, PumpOpt=0.0, TransOpt=4 QHunt=60	50.1	54.6	77.0	101.2

Table 9. Continued

Operation scenario	*Yields (mgd) for different recurrence intervals* 100-yr	50-yr	25-yr	10-yr
C13) MinElev = 547, PumpOpt=0.0, TransOpt=6 QHunt=40	50.0	54.4	76.1	99.3
C14) MinElev = 547, PumpOpt=2.0, TransOpt=l QHunt=40	48.3	52.5	72.9	94.6
C15) MinElev = 547, PumpOpt=2.0, TransOpt=l QHunt=60	46.5	51.4	75.8	103.3
C16) MinElev = 547, PumpOpt=2.0, TransOpt=4 QHunt=40	48.4	52.4	71.6	91.8
C17) MinElev = 547, PumpOpt=2.0, TransOpt=4 QHunt=60	48.1	52.5	74.4	98.2
C18) MinElev = 547, PumpOpt=2.0, TransOpt=6 QHunt=40	50.1	54.3	74.5	95.9
D) Lick Creek Reservoir Alternatives				
Variables: minimum pool elevation of Lake Springfield (MinElev), in feet msl; depth below average pool, in feet, used to trigger South Fork pumping (PumpOpt); full pool level for Lick Creek Reservoir (LCR Pool), in feet msl; options describing when to transfer water from the Lick Creek Reservoir (TransOpt); transfer rate from Lick Creek Reservoir to Lake Springfield, in cfs (QLick)				
D1) Lick Creek Reservoir as the sole water supply source, LCR pool = 595	12.6	13.5	17.9	22.4
D2) Lick Creek Reservoir and Lake Springfield without the South Fork Pumping Facility MinElev = 547, TransOpt=l LCR Pool = 595, QLick=30	31.6	34.9	51.8	70.8
D3) Lick Creek Reservoir and Lake Springfield without the South Fork Pumping Facility MinElev = 547, TransOpt=4 LCR Pool = 595, QLick=30	31.6	34.8	51.0	69.2
Lick Creek Reservoir (LCR) Pool = 595 feet msl				
D4) MinElev = 540, PumpOpt=0.0, TransOpt=l LCR Pool = 595, QLick=30	46.2	51.1	75.7	103.5
D5) MinElev = 540, PumpOpt=0.0, TransOpt=4 LCR Pool = 595, QLick=30	47.0	51.7	75.4	101.7

Table 9. Continued

Operation scenario	Yields (mgd) for different recurrence intervals 100-yr	50-yr	25-yr	10-yr
D6) MinElev = 540, PumpOpt=0.0, TransOpt=5 LCR Pool = 595, QLick=30	46.2	51.1	75.7	103.5
D7) MinElev = 540, PumpOpt=0.0, TransOpt=6 LCR Pool = 595, QLick=30	46.5	51.4	76.1	104.1
D8) MinElev = 540, PumpOpt=2.0, TransOpt=4 LCR Pool = 595, QLick=30	44.4	49.0	72.7	99.4
D9) MinElev = 547, PumpOpt=0.0, TransOpt=l LCR Pool = 595, QLick=30	40.5	44.8	67.2	92.8
D10) MinElev = 547, PumpOpt=0.0, TransOpt=l LCR Pool = 595, Qlick=15	36.9	40.6	59.0	79.6
Dl 1) MinElev = 547, PumpOpt=0.0, TransOpt=l LCR Pool = 595, QLick=20	40.7	44.8	65.8	89.3
D12) MinElev = 547, PumpOpt=0.0, TransOpt=l LCR Pool = 595, QLick=40	39.4	43.7	66.3	92.3
D13) MinElev = 547, PumpOpt=0.0, TransOpt=4 LCR Pool = 595, QLick=30	41.7	45.7	65.9	88.1
D14) MinElev = 547, PumpOpt=0.0, TransOpt=3 LCR Pool = 595, QLick=30	40.0	44.4	66.9	92.8
D15) MinElev = 547, PumpOpt=0.0, TransOpt=4 LCR Pool = 595, QLick=50	40.9	45.6	70.3	99.1
D16) MinElev = 547, PumpOpt=0.0, TransOpt=4 LCR Pool = 595, QLick=60	40.6	45.4	70.4	99.8
D17) MinElev = 547, PumpOpt=2.0, TransOpt=l LCR Pool = 595, QLick=20	38.8	42.3	59.2	77.4
D18) MinElev = 547, PumpOpt=2.0, TransOpt=l LCR Pool = 595, QLick=40	38.5	42.8	65.7	92.3
D19) MinElev = 547, PumpOpt=2.0, TransOpt=4 LCR Pool = 595, QLick=30	39.6	43.5	63.0	84.6
D20) MinElev = 547, PumpOpt=2.0, TransOpt=6 LCR Pool = 595, QLick=20	39.8	43.3	60.9	79.8

Table 9. Continued

Operation scenario	*Yields (msd) for different recurrence intervals* 100-yr	*50-yr*	*25-yr*	*10-yr*
Lick Creek Reservoir (LCR) Pool = 590 feet msl				
D21) MinElev = 540, PumpOpt=0.0, TransOpt=4 LCR Pool = 590, QLick=30	41.4	46.2	70.8	99.4
D22) MinElev = 547, PumpOpt=0.0, TransOpt=l LCR Pool = 590, QLick=30	35.1	39.2	60.9	86.8
D23) MinElev = 547, PumpOpt=0.0, TransOpt=l LCR Pool = 590, QLick=15	36.3	40.2	60.5	84.0
D24) MinElev = 547, PumpOpt=0.0, TransOpt=4 LCR Pool = 590, QLick=15	36.2	39.7	57.4	77.1
D25) MinElev = 547, PumpOpt=0.0, TransOpt=4 LCR Pool = 590, QLick=30	36.2	40.3	61.9	87.3
D26) MinElev = 547, PumpOpt=2.0, TransOpt=4 LCR Pool = 590, QLick=30	34.0	38.0	59.1	83.9
D27) MinElev = 547, PumpOpt=2.0, TransOpt=1 LCR Pool = 590, QLick=20	34.7	38.3	57.1	78.3
D28) MinElev = 547, PumpOpt=2.0, TransOpt=6 LCR Pool = 590, QLick=20	36.1	39.9	59.0	80.6
Lick Creek Reservoir (LCR) Pool = 585 feet msl				
D29) MinElev = 540, PumpOpt=0.0, TransOpt=4 LCR Pool = 585, QLick=15	38.0	42.3	64.9	91.2
D30) MinElev = 540, PumpOpt=0.0, TransOpt=1 LCR Pool = 585, QLick=30	37.4	41.8	65.2	92.8
D31) MinElev = 547, PumpOpt=0.0, TransOpt=1 LCR Pool = 585, QLick=30	31.4	35.3	56.4	82.2
D32) MinElev = 547, PumpOpt=0.0, TransOpt=1 LCR Pool = 585, QLick=15	31.9	35.8	56.4	81.8
D33) MinElev = 547, PumpOpt=0.0, TransOpt=4 LCR Pool = 585, QLick=15	32.3	36.0	55.3	77.9
D34) MinElev = 547, PumpOpt=0.0, TransOpt=4 LCR Pool = 585, QLick=20	32.4	36.2	56.4	80.4

Table 9. Continued

Operation scenario	Yields (mgd) for different recurrence intervals 100-yr	50-yr	25-yr	10-yr
D35) MinElev = 547, PumpOpt=0.0, TransOpt=4 LCR Pool = 585, QLick=30	32.2	36.1	57.3	83.0
D36) MinElev = 547, PumpOpt=2.0, TransOpt=4 LCR Pool = 585, QLick=30	31.0	34.8	54.5	78.0
D37) MinElev = 547, PumpOpt=2.0, TransOpt=l LCR Pool = 585, QLick=20	31.4	35.2	55.5	79.6
D38) MinElev = 547, PumpOpt=2.0, TransOpt=6 LCR Pool = 585, QLick=20	32.2	36.0	56.1	79.8
E) Use of Groundwater and Reclaimed Water				
Variables: minimum pool elevation of Lake Springfield (MinElev), in feet msl; depth below average pool, in feet, used to trigger South Fork pumping (PumpOpt); depth below average pool, in feet, used to trigger groundwater pumping (GWOpt); full pool level for Lick Creek Reservoir (LCR Pool), in feet msl; options describing when to transfer water from the Lick Creek Reservoir (TransOpt); transfer rate from Lick Creek Reservoir to Lake Springfield (QLick) is 30 cfs for all cases				
With Lake Springfield and South Fork Pump Facility				
E1) MinElev = 547, PumpOpt=0.0, GWOpt=0.0 Qgw=12 mgd	38.5	42.0	59.8	79.4
E2) MinElev = 547, PumpOpt=0.0, GWOpt=2.0 Qgw=12 mgd	36.9	40.4	58.0	77.2
E3) MinElev = 547, PumpOpt=0.0, GWOpt=4.0 Qgw=12 mgd	35.5	38.9	56.1	75.0
E4) MinElev = 547, PumpOpt=0.0, GWOpt=6.0 Qgw=12 mgd	33.1	36.5	53.8	73.3
E5) MinElev = 547, PumpOpt=0.0, GWOpt=0.0 Qgw=6 mgd	32.7	36.2	54.0	74.1
E6) MinElev = 547, PumpOpt=2.0, GWOpt=2.0 Qgw=6 mgd	31.5	34.6	50.5	68.2
E7) MinElev = 547, PumpOpt=2.0, GWOpt=2.0 Qgw=12 mgd	36.5	39.7	55.8	73.1

Table 9. Concluded

Operation scenario	Yields (mgd) for different recurrence intervals 100-yr	50-yr	25-yr	10-yr
E8) MinElev = 547, PumpOpt=2.0, GWOpt=2.0 Qgw=15 mgd	39.0	42.3	58.5	75.7
E9) MinElev = 547, PumpOpt=0.0, GWOpt=0.0 Qgw=18 mgd	44.3	48.0	66.2	85.5
E10) MinElev = 547, PumpOpt=2.0, GWOpt=2.0 Qgw=18 mgd	41.6	45.0	61.3	78.5
E11) MinElev = 547, PumpOpt=2.0, GWOpt=0.0 Qgw=18 mgd	43.6	47.0	63.3	80.2
With Lake Springfield, South Fork Pump Station, and Lick Creek Reservoir				
E12) MinElev = 540, PumpOpt=0.0, GWOpt=0.0 Qgw=6 mgd, LCR Pool = 590, Trans0pt=4	47.3	52.2	76.9	104.7
E13) MinElev = 540, PumpOpt=0.0, GWOpt=0.0 Qgw=6 mgd, LCR Pool = 585, TransOpt=4	43.9	48.5	72.4	99.4
E14) MinElev = 540, PumpOpt=0.0, GWOpt=4.0 Qgw=6 mgd, LCR Pool = 585, TransOpt=l	40.7	45.3	69.1	96.6
E15) MinElev = 547, PumpOpt=2.0, GWOpt=2.0 Qgw=6 mgd, LCR Pool = 595, TransOpt=l	44.3	47.8	64.9	82.8
E16) MinElev = 547, PumpOpt=2.0, GWOpt=2.0 Qgw=12 mgd, LCR Pool = 595, TransOpt=l	49.8	53.4	70.6	88.1
E17) MinElev = 547, PumpOpt=0.0, GWOpt=0.0 Qgw=6 mgd, LCR Pool = 590, TransOpt=4	41.4	45.8	67.8	92.8
E18) MinElev = 547, PumpOpt=0.0, GWOpt=4.0 Qgw=6 mgd, LCR Pool = 590, TransOpt=1	37.6	42.0	65.5	93.3
E19) MinElev = 547, PumpOpt=2.0, GWOpt=2.0 Qgw=6 mgd, LCR Pool = 590, TransOpt=l	40.6	44.4	62.9	83.0
E20) MinElev = 547, PumpOpt=2.0, GWOpt=2.0 Qgw=12 mgd, LCR Pool = 590, TransOpt=1	45.5	48.9	68.0	88.5
E21) MinElev = 547, PumpOpt=0.0, GWOpt=0.0 Qgw=6 mgd, LCR Pool = 585, TransOpt=4	37.6	41.8	63.7	89.1
E22) MinElev = 547, PumpOpt=2.0, GWOpt=2.0 Qgw=6 mgd, LCR Pool = 585, TransOpt=1	35.8	39.7	59.6	82.4
E23) MinElev = 547, PumpOpt=2.0, GWOpt=2.0 Qgw=6 mgd, LCR Pool = 585, TransOpt=1	40.8	44.9	65,2	87.7

TransOpt is 6) to continue pumping from the South Fork in the late spring, April through June, until Lake Springfield is at full pool. The variables are defined in more detail in pages 19-20. In all scenarios the maximum pumping capacity from the South Fork facility is assumed to be 63 mgd. Increases in the estimated yield that can be expected with a maximum pumping capacity of 78 mgd are addressed in the section "Impact of Increasing the Pumping Rate at the South Fork Facility."

With current operations, pumping does not ordinarily begin until the lake level is approximately 2 feet below average pool. The 100-year yield of the system following this present policy and a minimum lake level of 547 feet msl (scenario B5 in Table 9) is estimated to be 26.8 mgd (for the year 2000).

Lake Springfield water levels were simulated using the water budget model and the following parameter options: 1) scenario B5 was used for operations, 2) storage capacity of the lake was set equal to year 2000 conditions, 3) the demand rate was equal to the 100-year yield of 26.8 mgd, and 4) climatic conditions during the 1893-1895 and 1953-1955 droughts were used. The results of these simulations are shown in figures 6 and 7. These simulations give some indication of the sequence of water levels that could be expected if droughts of similar magnitude were to occur in present times. Realistically, the drought demand rate under present conditions would likely be greater than the 100-year yield used in these simulations.

Figure 8 shows the simulated levels in Lake Springfield during the drought of 1988-1989 using scenario B5 and the estimated demand rate during that drought, including the demand for public water supply, ash sluicing, and forced evaporation. The simulated drawdown levels are similar to, but not quite as low as those experienced in 1988. The recovery of water levels during the spring is typical of all but the most severe drought periods. A severe drought is considered to be a drought having a recurrence interval greater than or equal to 20 years.

A change in PumpOpt from 2.0 to 0.0 feet causes a 0.4 mgd increase in the 100-year drought yield, as shown by scenarios B5 and B4. Thus, it is somewhat beneficial to pump water from the South Fork early during a drought when the lake level is still close to the average pool. However, if the pumping facility system is used every time the lake level falls below the average pool, the facility will also be operating frequently during nondrought years. By waiting, and not pumping until the lake falls at least 2 feet below average pool, the total amount of pumped water during nondrought years can be significantly reduced, thereby reducing overall pumping costs. Table 10 shows the differences in the average volume of pumping that would be generated using scenarios B2-B8.

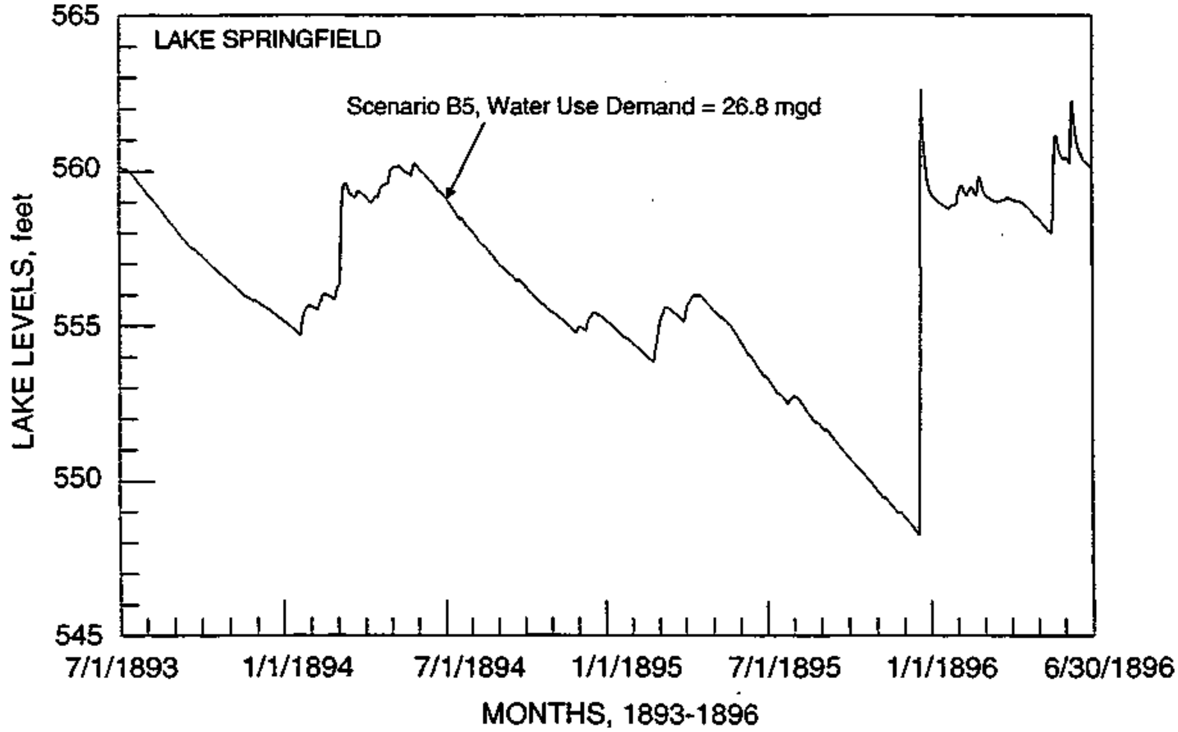

Figure 6. Simulated levels in Lake Springfield during the 1894-1895 drought: scenario B5

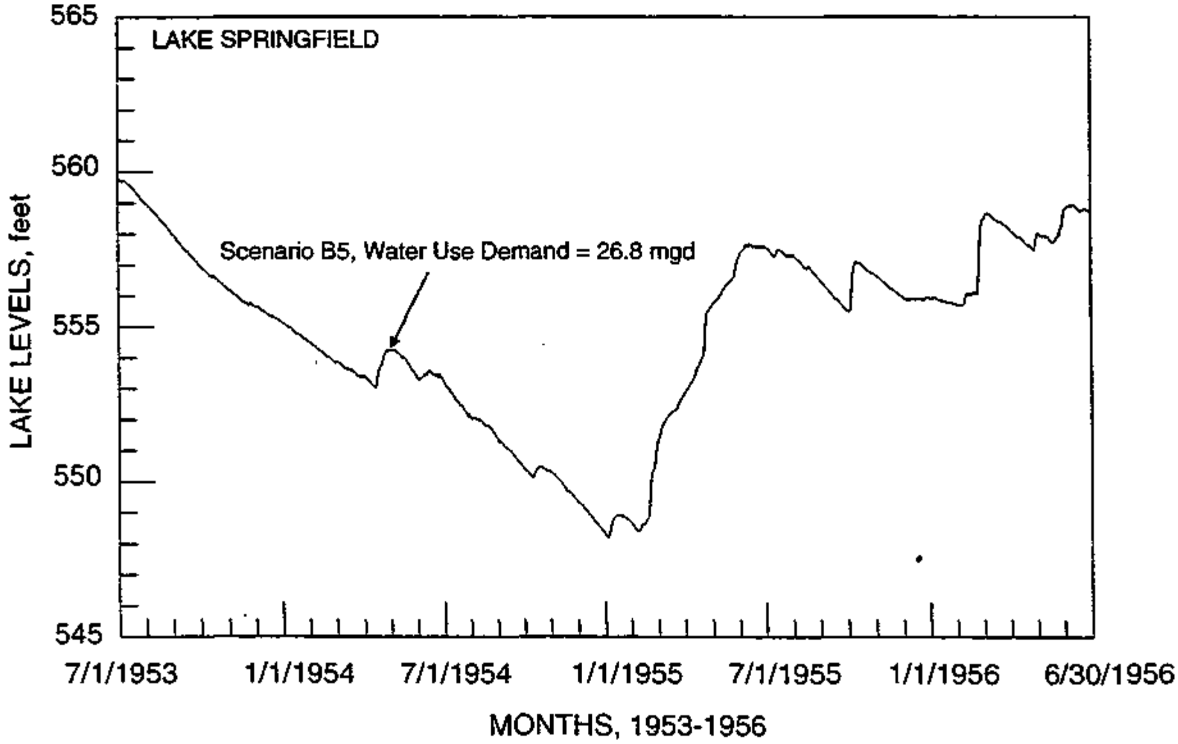

Figure 7. Simulated levels in Lake Springfield during the 1953-1955 drought: scenario B5

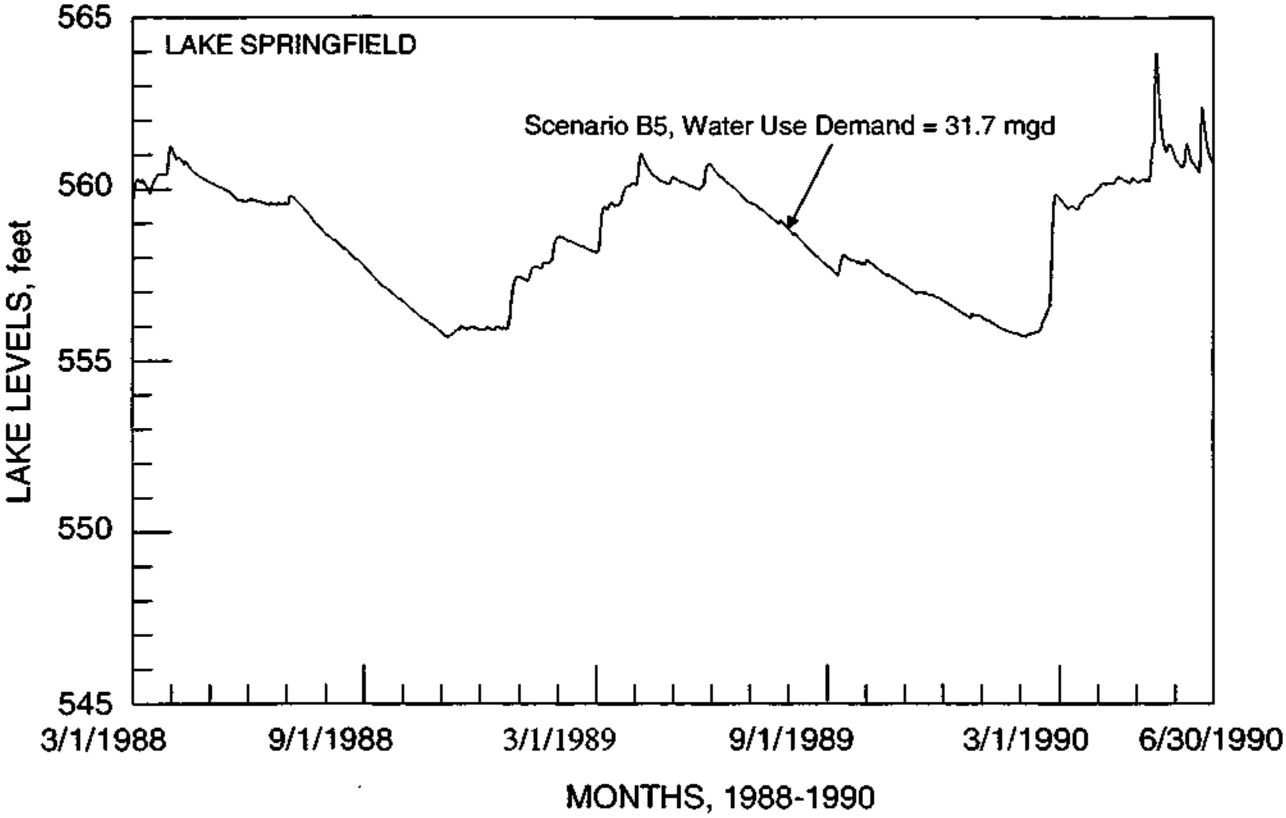

Figure 8. Simulated levels in Lake Springfield during the 1988-1989 drought: scenario B5

When TransOpt is 6, as in scenarios B8 and B9, pumping will occur during the months of April, May, and June whenever lake levels are below full pool. The initial purpose for including this option in reservoir operation was for lake-level recovery when Lake Springfield is below normal levels in early spring. But while this option may be effective in reservoir recovery during minor droughts, it is ineffective during severe droughts for two major reasons: 1) in general, water levels during severe droughts are already well below normal, thus pumping would also be occurring using most other operation scenarios, and 2) amid most severe droughts there is relatively little flow in the South Fork Sangamon River available for pumping. The circumstance when TransOpt is 6 may be effective in increasing drought yield when the onset of the drought occurs in June. Pumping in June can be used to maintain water levels near full pool, when they otherwise may drop up to 1.0 below full pool. This accounts for the relatively small, 0.4 mgd improvement in the 100-year yield for scenario B9 when compared to scenario B5. However, to achieve this yield improvement, pumping would have to occur during any June when lake levels were below full pool, a situation expected to occur on average once in four years.

Net Yield of the South Fork Pumping Facility

Table 11 presents the net yield of the South Fork pumping facility, computed as the difference in yields with and without the use of the facility. The net yield for all drought frequencies is considerably lower than that estimated in Fitzpatrick and Knapp (1991) and shown in table 8. There are three basic factors that are believed to contribute to this difference in the net yield.

The first factor is that the critical durations of the simulated droughts are generally shorter than those estimated in Fitzpatrick and Knapp (1991). As shown in table 12, with the exception of the two worst droughts in 1894-1895 and 1953-1955, all other major droughts have a duration of 15 months or less. The drought duration is estimated as the time period between when the lake level first starts falling below full pool to the time of maximum drawdown at an elevation of 547 feet, and does not account for the time required for the lake to recover to full pool.

A second factor is that the droughts of 1894-1895 and 1930-1931 experienced comparatively long periods during which the flow in the South Fork was low and no pumping would occur. The flows that did occur during these droughts were more concentrated in high flow events. In comparison, the 1953-1955 drought had more sustained flows, providing an average supply of 8 mgd.

A third factor that potentially could contribute to the smaller net yield of the South Fork pumping is that the simulated flows for the South Fork, used for the period 1891-1949, were not calibrated on a daily basis. As stated previously, the estimated number of days for which pumping could occur is less for some of the earlier drought periods. If the number of pumping days are underestimated for these droughts, then the yields of the pumping facility are also underestimated. If this is the case, the total impact of this potential simulation error is not expected to be greater than about 1 mgd, but may be as much as 2 mgd.

Table 10. Average Annual Volume of Pumping from the South Fork over the Period of Simulation, 1891-1995, in million gallons (mg)

Scenario	*Average annual pumping (mg)*
B2	1156
B3	238
B4	808
B5	301
B6	130
B7	89
B8	836

Table 11. Net Increase in Yield Provided with the South Fork Pumping Facility

Minimum elevation for Lake Springfield	*Yield (mgd)*			
540 ft msl (Difference between scenarios B2 and A2)	7.0	8.0	13.5	20.5
547 ft msl (Difference between scenarios B4 and A3)	5.8	6.5	10.0	14.1

Table 12. Impact of South Fork Pumping on Drought Yield Rank and the Critical Drought Duration

	Lake Springfield alone		*Present system (scenario B5)*	
Drought	*Rank*	*Duration (months)*	*Rank*	*Duration (months)*
1953-1955	1	32	2	18
1894-1895	2	19	1	19
1930-1931	3	17	3	15
1933-1934	4	16	4	15
1914-1915	5	9	5	7
1901-1902	6	15	12	15
1922-1923	7	8	10	8
1988-1989	8	19	15	8
1944-1945	9	8	6	8
1980-1981	10	10	14	8
1976-1977	11	8	7	8
1964-1965	12	8	8	8

Hunter Lake

The first simulation for Hunter Lake (scenario C1) assumes that the lake is the only component in the water supply system. The estimated yield of this scenario can be directly compared to that for the NSM analysis. The Hunter Lake yields as estimated by the two methods are very similar. All other simulations assume that Hunter Lake is operated jointly with Lake Springfield and the South Fork pumping facility. In all cases, water from Hunter Lake is transferred into Horse Creek, and pumped from the South Fork facility into Lake Springfield. The variables used in the simulations are: 1) the minimum elevation for Lake Springfield (MinElev), 2) the choice of when to transfer water from Hunter Lake (TransOpt), 3) the depth below the average pool at which pumping from the South Fork commences (PumpOpt), and 4) the transfer rate from Hunter Lake (QHunt).

The release of a minimum or protected flow from Hunter Lake for in-stream use was not considered in this analysis. If a constant protected flow were released from Hunter Lake and allowed to flow past the South Fork pumping facility, then the water supply system yield would be reduced by an amount equivalent to the release rate. If the protected flow rate were to have a significant seasonal variation, then its impact on the system yield should be simulated after revising the water budget simulation model.

Comparison of System Yields

When Hunter Lake is added to the present water supply system, the 100-year system yield increases by almost 23 mgd (the difference between scenarios C4 and B2). This is 3 mgd greater than the yield of Hunter Lake alone. The apparent "synergy" in the system yield occurs because for many droughts the critical duration for the combined system is shorter than the critical duration for Hunter Lake alone.

A comparison of the scenarios shows that the yield of the 50- and 100-year droughts is slightly greater when no water is transferred until Lake Springfield has been drawn down by 5 feet (TransOpt is 4). If too much water is transferred from Hunter Lake to Lake Springfield early within a drought period, which is most possible when TransOpt is 1, there is a chance that water will be overflowing from Lake Springfield later in the drought while the storage levels in Hunter Lake remain well below full pool.

Drought yield is also impacted by the transfer rate from Hunter Lake (QHunt), and its impact is greater when there is an earlier transfer of water (TransOpt is 1). Maximum yields for the 50- and 100-year droughts are obtained with a transfer rate of approximately 40 cfs. With a higher transfer rate, it is possible that "too much" water could be transferred to Lake Springfield during the early stages of a drought. In such a case, there is a chance that spring runoff could cause Lake Springfield to refill and start spilling water at the same time that Hunter Lake remained well below normal pool. An example of this situation is shown in ensuing paragraphs.

When the normal transfer rate is kept lower (at 40 cfs), to maximize drought yields during the 50- and 100-year droughts, then the yields of less severe droughts will not be maximized. The reason this occurs is that the less severe droughts have a shorter duration (8 months) than the 50- and 100-year droughts (18 months). With a lower transfer rate, more water would be retained in Hunter Lake with the anticipation that the drought in question could develop into a longer, more severe drought. The fact that a higher transfer rate could produce greater yields for a less severe drought is irrelevant, since it would not make sense to operate the system to maximize the yield of the 10-year drought.

The impact of the Hunter Lake transfer on the water supply system is illustrated in Figures 9 and 10, which compare lake levels for the drought of 1894-1895 using scenarios C7, C10, and C11. In scenario C10 (TransOpt is 1, QHunt=80 cfs), a large amount of water is transferred from Hunter Lake in the summer and fall of 1894, which helps maintain a high water level in Lake Springfield. However, in March 1895, there is sufficient inflow into Lake Springfield to cause overflow, in effect spilling water that could have been retained if less water had been transferred from Hunter Lake. The impact of this spillage is experienced in the fall of 1895, when the water level of Lake Springfield falls below 547 feet msl. The same experience occurs with scenario C7 (TransOpt is 1, QHunt=40 cfs), albeit to a lesser degree. Scenario C11 (TransOpt is 4, QHunt=40 cfs) produces the lowest average levels in Lake Springfield, but is the only scenario where there is sufficient storage in the water supply system to prevent the minimum level from falling below 547 feet. Thus, it is the only one of the three scenarios shown in Figures 9 and 10 that has a system yield equal to or greater than the demand rate of 49.5 mgd. The respective yields of scenarios C7 and C10 during the 1894-1895 drought are 0.9 and 4.2 mgd less than that for scenario C11.

Maximum yield is obtained from Hunter Lake if water is pumped from the South Fork station whenever Lake Springfield falls below the average pool (PumpOpt=0.0 feet). If pumping does not begin until the Lake Springfield drawdown is 2 feet below the average pool (PumpOpt=2.0 feet), there is a reduction in the system yield of roughly 2 mgd. This impact of PumpOpt on system yield is noticeably greater than that for just the present system.

Scenarios C13 and C18 show the impact of when TransOpt is 6, which involves pumping from the South Fork and transfers from Hunter Lake in April-June whenever lake levels are below full pool. The increase of the 100-year yield associated with this option is 0.5 mgd when PumpOpt=0.0 feet and 1.8 mgd when PumpOpt=2.0 feet.

Lick Creek Reservoir

The first simulation for the Lick Creek Reservoir (scenario D1) assumes that the lake is the only component in the water supply system. Scenarios D2 and D3 simulate joint operation of the Lick Creek Reservoir with Lake Springfield, but without the South Fork pumping facility. These scenarios are presented for evaluation and comparison purposes only. The yield for scenario Dl is noticeably lower than the gross yield estimated using the NSM analysis for all drought recurrences except the 100-year drought.

All other simulations assume that the Lick Creek Reservoir is operated jointly with Lake Springfield and the South Fork pumping facility. The variables used in the simulations are: 1) the minimum elevation for Lake Springfield (MinElev), 2) the choice of when to transfer water from the Lick Creek Reservoir (TransOpt), 3) the depth below the average pool at which pumping from the South Fork commences (PumpOpt), and 4) the transfer rate from the Lick Creek Reservoir (QLick). Yields are evaluated for three potential pool elevations for the Lick Creek Reservoir: 585, 590, and 595 feet msl.

Comparison of System Yields

The combined system yield for the Lick Creek Reservoir and Lake Springfield (scenario D2) is less than the addition of their individual yields (scenarios A2 and D1). This occurs because the Lick Creek Reservoir will reduce the amount of inflow to Lake Springfield during droughts. Thus, the 100-year net yield of the Lick Creek Reservoir, at a pool elevation of 595 feet msl, is 10.2 mgd, or the difference between scenarios D5 and A2. However, this net yield changes when the South Fork pumping facility is included in the system.

When the Lick Creek Reservoir (at 595 feet msl) is added to the present water supply system, the 100-year system yield increases by almost 14 mgd (the difference between scenarios D5 and B2). This is almost 4 mgd greater than the net yield of the Lick Creek Reservoir, as described in the previous paragraph. The apparent increase in the system yield occurs because the use of the South Fork pumping facility creates a decrease in the critical drought duration, as shown earlier in Table 12. If the Lick Creek Reservoir is designed to have its pool elevation at 590 or 585 feet msl, the 100-year net yield is reduced to 8 and 5 mgd, respectively. These yields are roughly proportional to the reservoir's design capacity. Net yields are additionally greater by 0.5 to 1.0 mgd when the minimum elevation for Lake Springfield is taken as 547 feet msl.

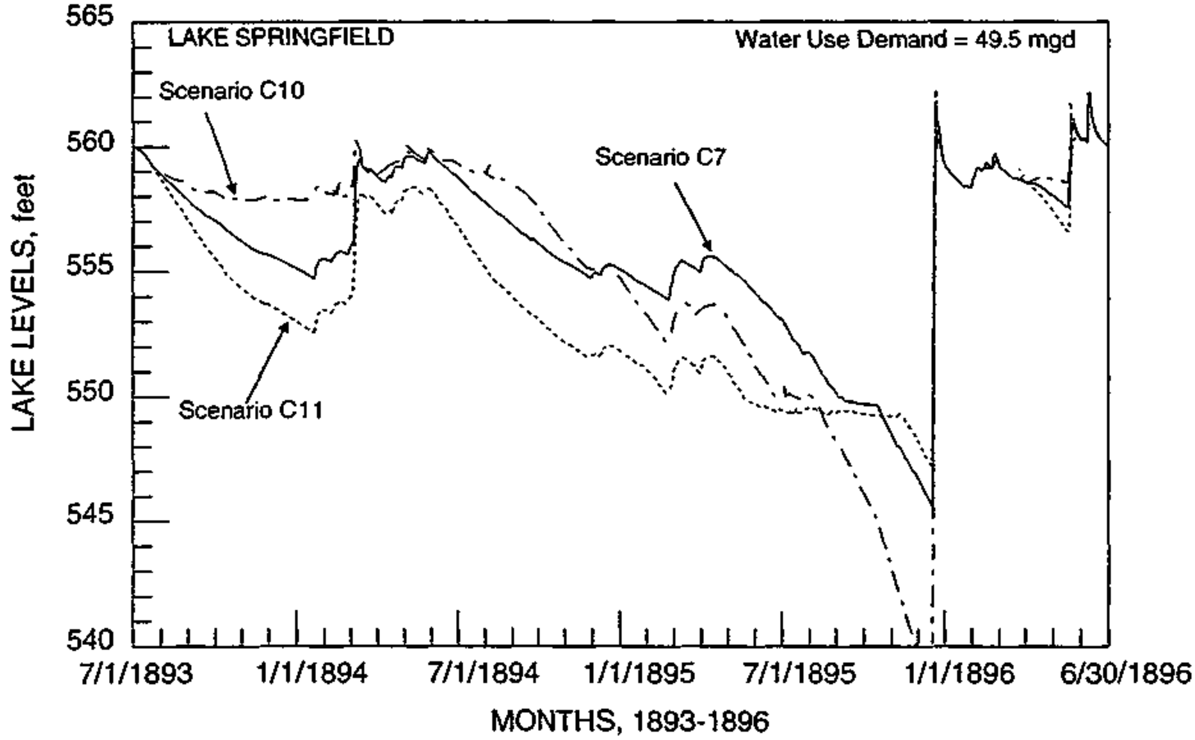

Figure 9. Simulated levels in Lake Springfield during the 1894-1895 drought: scenarios C7, C10, and C11

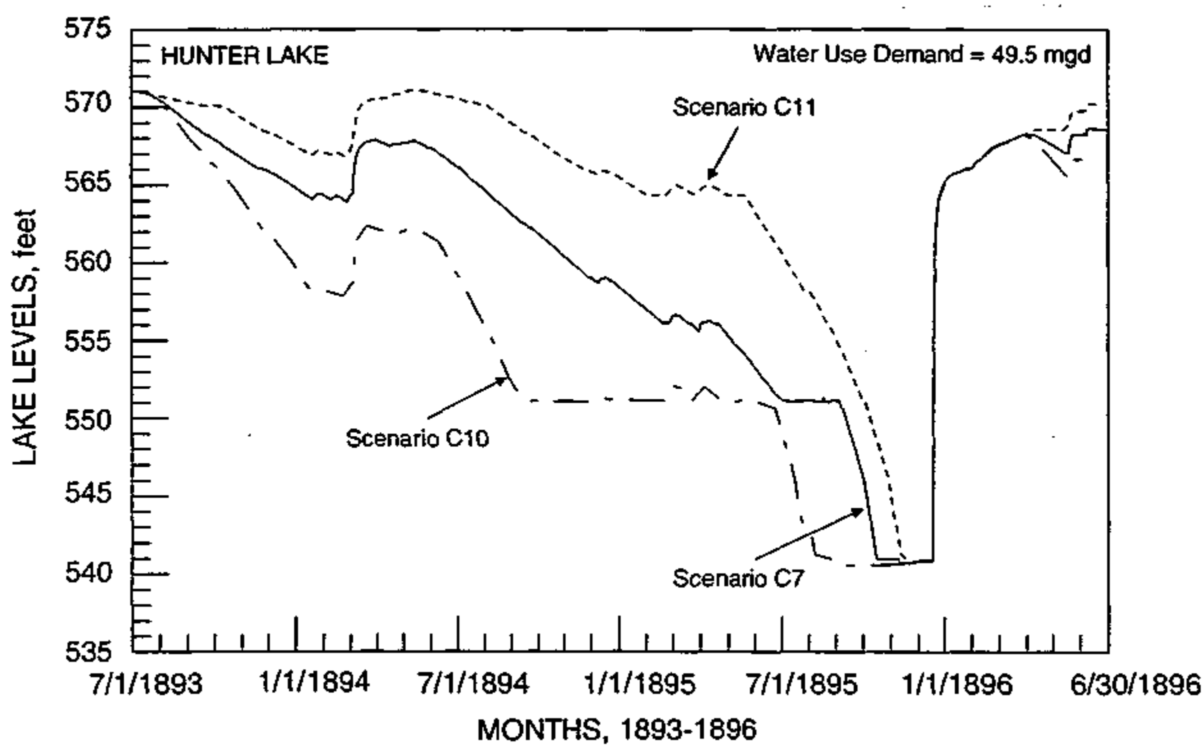

Figure 10. Simulated levels in Hunter Lake during the 1894-1895 drought: scenarios C7, C10, and C11

As with the Hunter Lake simulations, the yield of the 50- and 100-year droughts is greater when water is retained in Lick Creek Reservoir until Lake Springfield has been drawn down by 5 feet (TransOpt is 4). The difference in yield between an early transfer (TransOpt is 1) and later transfer (TransOpt is 4) from the Lick Creek Reservoir is generally about 1 mgd.

Drought yield is also impacted by the transfer rate from Lick Creek Reservoir (QLick), and its impact is greater when there is an earlier transfer of water (TransOpt is 1). Maximum yields for the 50- and 100-year droughts are obtained with a transfer rate of approximately 30 cfs when the Lick Creek Reservoir is designed for a pool elevation of 595 feet, and 20 cfs when the pool elevation is 585 feet msl.

Figures 11 and 12 illustrate the impact of the Lick Creek Reservoir transfer on the water supply system by comparing lake levels for the drought of 1953-1955 using scenarios D9 (TransOpt is 1, QLick=30 cfs) and D13 (TransOpt is 4, QLick=30 cfs). The demand rates used in these scenarios represents the comparative difference in the safe yield between these two scenarios. One of the most noticeable characteristics of the lake levels shown in these figures is the long duration of drawdown and recovery time associated with the 1953-1955 drought.

Maximum yield is obtained when water is pumped from the South Fork whenever Lake Springfield falls below the average pool (PumpOpt=0). If pumping does not begin until the Lake Springfield drawdown is 2 feet below the average pool, there is a reduction in the system yield ranging from 1.2 to 2.6 mgd, being roughly proportional to the reservoir's design capacity. This impact of PumpOpt on system yield is noticeably greater than that for the present system.

Scenarios D7, D20, D28, and D38 show the impact of when TransOpt is 6, which involves pumping from the South Fork in April-June whenever lake levels are below full pool. The increase of the 100-year yield associated with this option is 0.3 mgd when PumpOpt=0.0 feet and roughly 1.0 mgd when PumpOpt=2.0 feet.

Groundwater and Reclaimed Water

Pumpages from groundwater and/or reclaimed water are considered to be available on demand at a set pumping level. For examination of system yield, the source of this water is immaterial, only that the supply amount is constant and reliable. For discussion purposes, the source of the water is assumed to be groundwater pumpage. All simulations assume that the groundwater pumping is operated jointly with the use of Lake Springfield storage and the South Fork pumping facility.

Table 9 gives the yield amount using two general levels of groundwater pumpage, 6 and 12 mgd (scenario E8 provides an estimate for 15 mgd). Components of the water supply system used in conjunction with the groundwater pumpage are Lake Springfield, the South Fork pumping facility, and the Lick Creek Reservoir. The variables used in the simulations are: 1) the minimum elevation for Lake Springfield (MinElev), 2) the choice of when to transfer water from the Lick Creek Reservoir (TransOpt), 3) the depth below the average pool at which pumping from the South Fork commences (PumpOpt), 4) the transfer rate from the Lick Creek Reservoir (QLick), 5) the pool elevation of the Lick Creek Reservoir, and 6) depth below the average pool in Lake Springfield used to trigger pumping from groundwater (GWOpt).

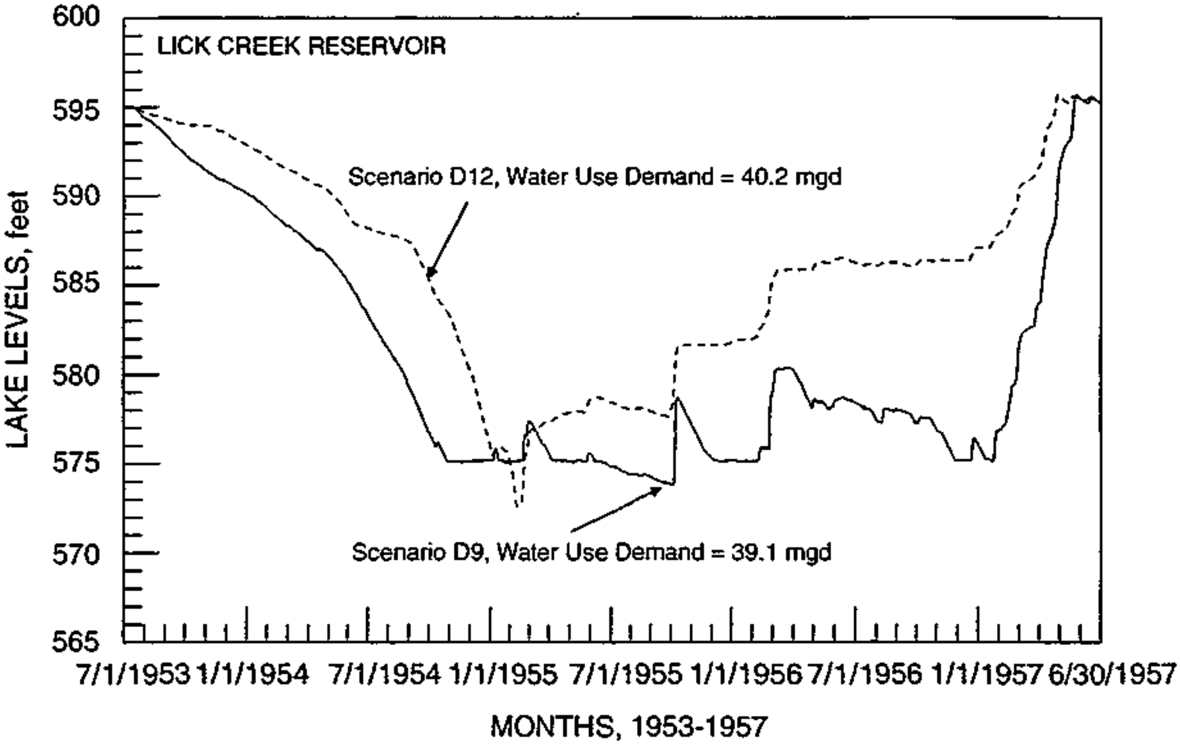

Figure 11. Simulated levels in Lake Springfield during the 1953-1955 drought: scenarios D9 and D12

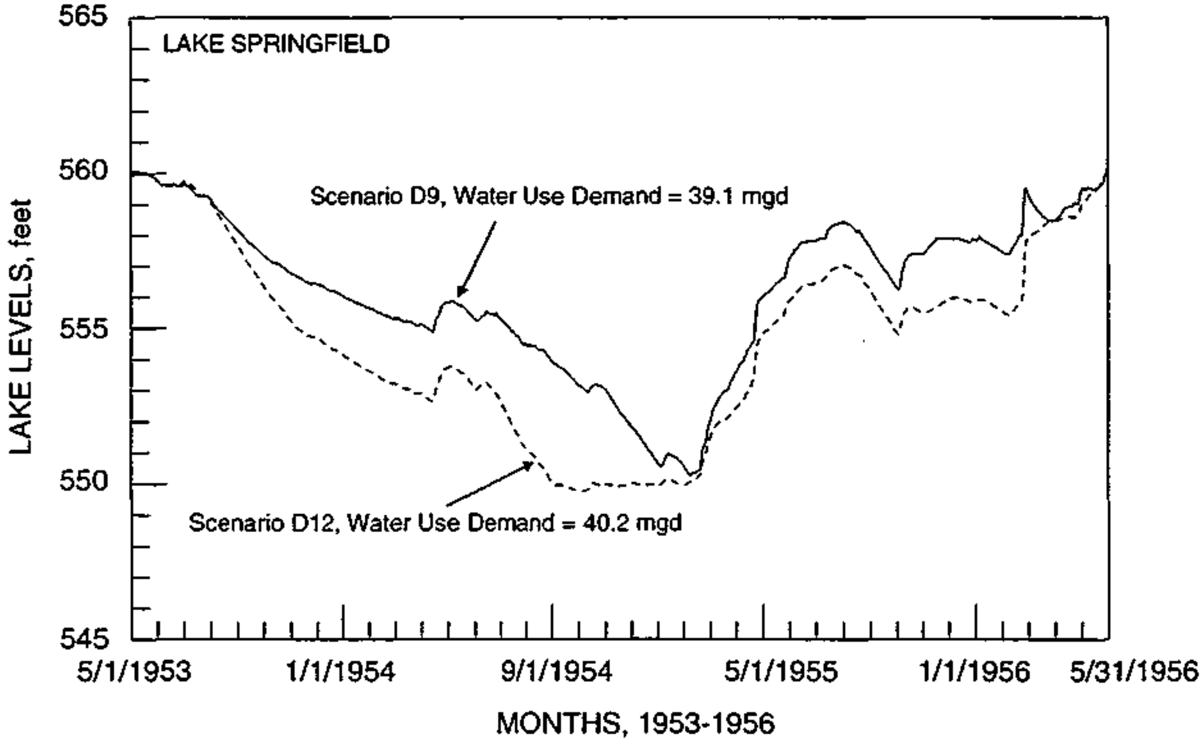

Figure 12. Simulated levels in Lick Creek Reservoir during the 1953-1955 drought: scenarios D9 and D12

The net yield for scenarios E1-E4 can be computed as the difference in yield when compared with scenario B4. The 100-year net yield using scenario E1 is 11.3 mgd. Thus if groundwater is pumped whenever Lake Springfield falls below the average pool (GWOpt=0.0 feet), the net yield of the groundwater source is roughly 94 percent of the 12 mgd yield as that provided if groundwater were pumped 100 percent of the time. If the groundwater pumpage is reduced to 6 mgd, as given in scenario E5, the net yield with GWOpt=0.0 feet is 5.5 mgd, or roughly 92 percent of that provided if the groundwater were pumped 100 percent of the time. Thus, if pumping is triggered when Lake Springfield is 2 feet below the average pool, the groundwater source can provide a net yield equal to approximately 80 percent of its sustainable pumping rate.

Table 13 provides the percent of time that groundwater and the South Fork flows would be pumped using 12 selected scenarios. Trigger levels used to initiate pumping in Lake Springfield have a significant effect on the amount of pumping that occurs from groundwater sources and the South Fork. When the trigger levels used for pumping from groundwater (GWOpt) and the South Fork (PumpOpt) are equal, then groundwater is pumped a greater portion of the time. This simply occurs because at times there is insufficient flow in the South Fork to pump at the full rate. When GWOpt is greater than PumpOpt, the amount of time when groundwater pumping is employed is greatly reduced. It may be desirable to have different trigger levels for the South Fork pumping and groundwater, as well as the pumping of reclaimed water, depending on the relative costs of pumping from each source.

Table 13. Percent of Time Groundwater and the South Fork are Pumped*

Scenario	*Groundwater*	*South Fork***
E1	26.6	6.0
E2	8.2	7.2
E3	3.7	6.8
E4	2.1	5.4
E5	11.3	4.0
E6	4.7	1.5
E12	17.4	10.0
E13	17.3	9.9
E14	2.6	9.0
E17	17.3	9.9
E18	2.1	8.6
E19	15.6	7.6

Notes: * Values are computed using a system demand rate equal to the 100-year yield for each scenario.
** The percentage of time listed for the South Fork is based on an equivalent time of pumping at full capacity (63 mgd).

Impact of Increasing the Pumping Rate at the South Fork Facility

The yield estimates presented in table 9 were developed using 63 mgd as the maximum pumping rate of the South Fork facility. Recent tests indicate that the actual maximum pumping rate is approximately 78 mgd, or roughly 25 percent greater than originally estimated. Yield calculations based on the higher pumping rate will produce increases in the system yield. Table 14 compares the system yield for seven operation scenarios using pumping rates of 63 and 78 mgd. For most scenarios these results indicate that the higher pumping rate produces a 0.6-0.8 mgd increase in the expected 100-year system yield. The increased yield is as much as 1.4 mgd with the Hunter Lake alternative and a delayed transfer of water from Hunter Lake to Lake Springfield (scenario C11). On the other hand, there is only a 0.3 mgd increase associated with scenario D26, which uses Lick Creek Reservoir with a pool elevation of 590 feet msl.

It is recommended that a consistent 0.7 mgd increase be applied for all other scenarios when estimating the system yields associated with the 78 mgd pumping rate at the South Fork facility. This consistent 0.7 mgd increase will apply to the yield estimates for present-day conditions, as provided in table 9, as well as the yields for future conditions, which will be presented in the next section.

Table 14. Comparison of System Yields at Different Pumping Rates

		Yields (mgd) for different recurrence intervals			
Operation scenario and pumping rate		*100-yr*	*50-yr*	*25-yr*	*10-yr*
B4)	63 mgd	27.2	30.5	47.8	68.4
	78 mgd	27.8	31.1	48.7	69.5
B5)	63 mgd	26.8	29.8	45.4	63.5
	78 mgd	27.6	30.6	46.2	64.1
C11)	63 mgd	50.1	54.2	73.8	94.4
	78 mgd	51.5	55.7	75.8	96.8
C14)	63 mgd	48.3	52.5	72.9	94.6
	78 mgd	48.9	53.1	74.1	96.6
D17)	63 mgd	38.8	42.3	59.2	77.4
	78 mgd	39.5	43.0	60.0	78.2
D26)	63 mgd	34.0	38.0	59.1	83.9
	78 mgd	34.3	38.3	59.3	83.9
E7)	63 mgd	36.5	39.7	55.8	73.1
	78 mgd	37.2	40.5	56.5	73.6

RESULTS OF THE SIMULATION ANALYSIS FOR FUTURE CONDITIONS

Future Capacities of Lake Springfield, Hunter Lake, and Lick Creek Reservoir

Reservoir Sedimentation Rates

Over time, the storage capacity of a reservoir will be reduced by the deposition of sediment carried by streams. The average rate of sedimentation in Lake Springfield is estimated to be 154 acre-feet per year, as determined using the 1984 sedimentation survey of the lake (Fitzpatrick et al., 1985) and earlier sedimentation studies. The expected average rate of sedimentation in the proposed Hunter Lake is 74 acre-feet per year, as estimated in Fitzpatrick and Knapp (1991).

The proposed Lick Creek Reservoir has a capacity-to-annual inflow ratio ranging from 0.27 at a pool of 585 feet, to 0.67 at 595 feet. The trap efficiency at these upper and lower pool levels is estimated to be 0.97 and 0.94, respectively, using the relationship established by Brune (1953). For simplicity in application, a trap efficiency of 0.96 was used for all pool levels. This closely matches the trap efficiencies expected for both Lake Springfield (0.96) and the proposed Hunter Lake (0.97). The average annual sediment inflow to the Lick Creek Reservoir was estimated to be 71.3 acre-feet per year using data included in Fitzpatrick and Keefer (1988). Using a trap efficiency of 0.96, it is estimated that an average of 68.5 acre-feet of sediment will be deposited in the Lick Creek Reservoir, equivalent to roughly 0.3 percent of the total capacity.

The trapping of sediment in the Lick Creek Reservoir will significantly reduce the amount of sediment flowing into Lake Springfield. With the Lick Creek Reservoir, it is estimated that the average annual sediment inflow into Lake Springfield will be reduced from 162 to 94 acre-feet. The average amount of sediment trapped by Lake Springfield is expected to be reduced from 154 to 89 acre-feet per year, or a 42 percent reduction in sedimentation.

Projected Future Capacities

When evaluating a proposed reservoir, it is common practice to select a hypothetical date of reservoir construction on which to base estimates of reservoir sedimentation and capacity. The year 2000 was chosen as a hypothetical construction date for the Lick Creek Reservoir and Hunter Lake, with full knowledge that such a construction date is entirely unrealizable. However, this provides a base condition from which to estimate the impacts of sedimentation on the system yield.

The storage capacities of Lake Springfield in the years 2000, 2025, and 2050 are projected to be 52,060, 48,200 and 44,340 acre-feet, respectively. If the proposed Lick Creek Reservoir were constructed in the year 2000, subsequent sedimentation losses would be reduced, and the projected capacities of Lake Springfield in 2025 and 2050 would be 49,835 and 47,610 acre-feet, respectively. Therefore the existence of the Lick Creek Reservoir would cause a net increase in the Lake Springfield volume of 1,635 and 3,270 acre-feet for the years 2025 and 2050, respectively.

Using an average annual sedimentation rate of 74 acre-feet, the projected capacity of Hunter Lake in 2025 and 2050 would be 44,750 and 42,900 acre-feet, respectively. The projected capacity of the Lick Creek reservoir in 2025 and 2050 is estimated for the three design pool elevations, as shown in table 15.

Table 15. Projected Storage Capacity of Lick Creek Reservoir

Design pool elevation (feet)	*Year 2000*	*Year 2025*	*Year 2050*
595	32,910	31,200	29,490
590	21,470	19,760	18,050
585	13,140	11,430	9,720

The vertical distribution of sediment deposition is also a concern for Lake Springfield, because operation alternatives address the use of that reservoir storage above the minimum elevation of 547 feet msl. Using sediment distribution data given in Fitzpatrick et al. (1985), it is estimated that approximately 40 percent of the projected sedimentation loss in Lake Springfield will occur at elevations higher than 547 feet msl. Thus, the reduction in yield caused by future sedimentation will be considerably less for those scenarios that employ only that storage above an elevation of 547 feet msl.

Future Drought Yields

Table 16 presents the future drought yields for selected operation scenarios, estimated using the water budget model and drought frequency analysis. The reductions in yield for Lake Springfield over the next 50 years are estimated to be roughly 4 and 1.6 mgd, as applied to minimum lake elevations of 540 and 547 feet msl, respectively.

If Hunter Lake is added to the present system, the 50-year reduction in system yield is roughly 6 and 3 mgd, as applied to the Lake Springfield minimum elevations of 540 and 547 feet msl, respectively. Approximately 2 mgd of these yield reductions are caused by sedimentation in Hunter Lake. The remainder is caused by sedimentation in Lake Springfield.

If the Lick Creek Reservoir is added to the present water supply system, the 50-year reduction in system yield (caused by sedimentation) is roughly 4 mgd and 2.5 mgd, using the same respective minimum lake elevations. Since the Lick Creek Reservoir is trapping the sediments that would otherwise be deposited in Lake Springfield, there is virtually no net change in the overall amount of sedimentation. In effect, the loss of yield in the Lick Creek Reservoir is compensated by a net increase in the Lake Springfield yield, associated with its net reduction in sedimentation. However, if the system operation employs a minimum level of 547 feet msl for Lake Springfield, there is a smaller compensatory gain in the usable storage of Lake Springfield. Thus the overall decrease in the system yield at a minimum elevation of 547 feet msl is 2.5 mgd.

Reservoir sedimentation over the next 50 years should not impact the net yield from either the South Fork pumping facility or groundwater pumpage. Potential impacts to the net yield from this sources would have occurred only if the critical drought duration of the system had been modified by the reduction in lake storage.

Table 16. Future Yields for Selected Scenarios

> **Notes:** Operation scenarios have the same identification number as those presented in table 9. Descriptions of the variables that define the operation scenarios are provided in more detail on pages 19-20.

Variables:
- minimum pool elevation of Lake Springfield (MinElev), in feet msl
- depth below average pool, in feet, used to trigger South Fork pumping (PumpOpt)
- options describing when to transfer water from the Lick Creek Reservoir (TransOpt)
- transfer rate from Hunter Lake to Lake Springfield, in cfs (QHunt)
- transfer rate from Lick Creek Reservoir to Lake Springfield, in cfs (QLick)
- full pool level for Lick Creek Reservoir (LCR Pool), in feet msl

	Yields (mgd) for different recurrence intervals			
Operation scenario	*100-yr*	*50-yr*	*25-yr*	*10-yr*
Lake Springfield and South Fork Pumping Facility				
B2) MinElev = 540, PumpOpt=0.0				
YEAR = 2000	33.1	37.1	58.2	83.2
YEAR = 2025	30.9	34.7	54.7	78.5
YEAR = 2050	28.8	32.3	50.6	72.4
B4) MinElev = 547, PumpOpt=0.0				
YEAR = 2000	27.2	30.5	47.8	68.4
YEAR = 2025	26.3	29.5	46.2	66.1
YEAR = 2050	25.5	28.5	44.6	63.7
B5) MinElev = 547, PumpOpt=2.0				
YEAR = 2000	26.8	29.8	45.4	63.5
YEAR = 2025	26.1	29.0	44.0	61.4
YEAR = 2050	25.2	28.0	42.6	59.4
Lake Springfield, South Fork Pumping Facility, and Hunter Lake				
C2) MinElev = 540, PumpOpt=0.0, TransOpt=1, QHunt=40				
YEAR = 2000	55.3	60.3	85.5	112.8
YEAR = 2025	52.5	57.4	81.8	108.4
YEAR = 2050	49.0	53.7	77.4	103.5
C4) MinElev = 540, PumpOpt=0.0, TransOpt=4, QHunt=40				
YEAR = 2000	55.9	60.8	84.7	110.3
YEAR = 2025	52.8	57.5	80.5	105.3
YEAR = 2050	50.4	54.8	76.4	99.4

Table 16. Continued

Operation scenario	Yields (mgd) for different recurrence intervals 100-yr	50-yr	25-yr	10-yr
C7) MinElev = 547, PumpOpt=0.0, TransOpt=1, QHunt=40				
YEAR = 2000	49.5	53.9	75.1	97.7
YEAR = 2025	47.8	52.2	73.5	96.0
YEAR = 2050	45.9	50.1	71.0	93.8
C11) MinElev = 547, PumpOpt=0.0, Trans0pt=4, QHunt=40				
YEAR = 2000	50.1	54.2	73.8	94.4
YEAR = 2025	48.8	52.6	71.8	91.2
YEAR = 2050	46.8	50.5	68.8	86.9
C14) MinElev = 547, PumpOpt=2.0, TransOpt=l, QHunt=40				
YEAR = 2000	48.3	52.5	72.9	94.6
YEAR = 2025	46.9	50.9	70.6	91.5
YEAR = 2050	45.3	49.2	68.1	88.3
C16) MinElev = 547, PumpOpt=2.0, TransOpt=4, QHunt=40				
YEAR = 2000	48.4	52.4	71.6	91.8
YEAR = 2025	46.9	50.7	69.2	88.6
YEAR = 2050	45.3	48.9	66.6	85.1
Lake Springfield, South Fork Pumping Facility, and Lick Creek Reservoir				
LCR Pool = 595				
D5) MinElev = 540, PumpOpt=0.0, TransOpt=4, QLick=30				
YEAR = 2000	47.0	51.7	75.4	101.7
YEAR = 2025	44.9	49.5	73.0	99.4
YEAR = 2050	42.9	47.4	70.7	97.2
D9) MinElev = 547, PumpOpt=0.0, TransOpt=l, QLick=30				
YEAR = 2000	40.5	44.8	67.2	92.8
YEAR = 2025	38.0	42.3	64.9	91.2
D10) MinElev = 547, PumpOpt=0.0, TransOpt=l, QLick=15				
YEAR = 2000	36.9	40.6	59.0	79.6
YEAR = 2025	36.4	40.0	57.9	77.8
D13) MinElev = 547, PumpOpt=0.0, TransOpt=4, QLick=30				
YEAR = 2000	41.7	45.7	65.9	88.1
YEAR = 2025	39.3	43.3	63.5	86.1

Table 16. Concluded

Operation scenario	*Yields (mgd) for different recurrence intervals*			
	100-yr	*50-yr*	*25-yr*	*10-yr*
D19) MinElev = 547, PumpOpt=2.0, TransOpt=4, QLick=30				
YEAR = 2000	39.6	43.5	63.0	84.6
YEAR = 2025	37.1	41.0	60.6	82.7
LCR Pool = 590				
D21) MinElev = 540, PumpOpt=0.0, TransOpt=4, QLick=30				
YEAR = 2000	41.4	46.2	70.8	99.4
YEAR = 2025	39.6	44.2	68.5	97.2
YEAR = 2050	37.1	41.7	65.7	94.4
D22) MinElev = 547, PumpOpt=0.0, TransOpt=l, QLick=30				
YEAR = 2000	35.1	39.2	60.9	86.8
YEAR = 2025	33.6	37.9	60.4	87.7
D23) MinElev = 547, PumpOpt=0.0, TransOpt=l, QLick=15				
YEAR = 2000	36.3	40.2	60.5	84.0
YEAR = 2025	34.6	38.3	56.9	78.2
D26) MinElev = 547, PumpOpt=2.0, TransOpt=4, QLick=30				
YEAR = 2000	34.0	38.0	59.1	83.9
YEAR = 2025	32.1	36.0	56.8	81.5
LCR Pool = 585				
D29) MinElev = 540, PumpOpt=0.0, TransOpt=4, QLick=15				
YEAR = 2000	38.0	42.3	64.9	91.2
YEAR = 2025	36.1	40.3	62.5	88.6
YEAR = 2050	33.7	37.8	60.0	86.6
D36) MinElev = 547, PumpOpt=2.0, TransOpt=4, QLick=30				
YEAR = 2000	31.0	34.8	54.5	78.0
YEAR = 2025	29.1	32.5	50.7	72.1

SUMMARY AND CONCLUSIONS

A water budget model was created to simulate the daily water budgets for the Springfield water supply system, including all existing and proposed sources of water. Water supply components include Lake Springfield, the proposed Hunter Lake, the proposed Lick Creek Reservoir, pumpage from the South Fork Sangamon River, pumpage from three potential groundwater sources, and waters reclaimed after being used for sluicing coal ash and filter backwash. The water budget of the system includes a daily accounting of lake storages, inflows into the lakes, net evaporation, withdrawals for water use, transfers to and from the lakes, and lake outflows.

Streamflow and lake evaporation inputs into the water budget model were simulated for the period 1891-1995 using historical precipitation and air temperature records. Inflows for Lake Springfield, Hunter Lake, and the Lick Creek Reservoir, and streamflows for the South Fork Sangamon River were simulated using a continuous simulation rainfall/runoff model. The model was calibrated to observed monthly flow records at five streamgage sites in the Springfield vicinity, covering portions of the years 1949-1995. By using measured precipitation records dating back to 1891, the modeling process is able to simulate the water budgets of many droughts for which there are no complete stream measurements, including four of the five worst droughts in the last century.

The water budget model is programmed so that the user may define various experimental operating conditions (or scenarios), such as selecting a set of system components to be simulated, and choosing when to pump water from available sources. The model computes the maximum yield that can be obtained using the selected scenario for each historical drought. A frequency analysis is employed to estimate the yield for the 10-, 25-, 50-, and 100-year droughts. The 100-year drought yield for each scenario provides the most important model result, since it is taken as the safe yield of the water supply system.

The following general conclusions may be drawn from the modeling results:

- The 100-year yield of the system will depend not only on the available water supply sources, but also upon operating decisions such as 1) how soon to begin pumping from the South Fork pumping facility and/or groundwater resources, 2) how much water to transfer from the potential second lake, and 3) the sequence in which the Lake Springfield water level is drawn down relative to that in the potential second lake.

- When using either Hunter Lake or the Lick Creek Reservoir, maximum yields are obtained with an operation policy that retains water in these second lakes until water levels in Lake Springfield have been drawn down well below the average pool level. The additional yield created by retaining water is generally in the range of 1 to 2 mgd.

- Maximum yields during severe droughts are obtained when the transfer rate from these second lakes (for transfer into Lake Springfield) are comparatively small, providing a gradual rather than rapid transfer of water. This is an extension of the previous conclusion, in that yields are higher when more water is retained in the second lake. The impact of the transfer rate on the 100-year yield is generally in the range of 1 to 2 mgd, but considerably larger in some cases as the transfer rate becomes undesirably great or small.

- The drought duration, defined as the time period between when the level in Lake Springfield first starts falling below full pool to the time of maximum drawdown, is 15 to 18 months for most severe droughts. (A severe drought is considered to be a drought having a recurrence interval greater than or equal to 20 years.) The duration for less severe droughts is usually 7 to 8 months. Thus, the water level in Lake Springfield will recover to full pool by mid- to late-spring for all but the most severe droughts.
- The combined yield provided by developing either Hunter Lake or the Lick Creek Reservoir is potentially 2-3 mgd greater than the simple sum of the yields for each component in the system. This apparent "synergy" in yield values occurs as a result of the difference in the critical drought durations for the individual components, as described more fully in the report.
- The net yield from the Lick Creek Reservoir is roughly proportional to the design reservoir storage, assuming that an operation policy is chosen that maximizes the net yield. Yield estimates are comparatively less sensitive to operation policies when the Lick Creek Reservoir has a smaller reservoir size, i.e., with a lower elevation for the full pool.
- Pumpages from groundwater and reclaimed water have a basic additive impact on overall system yields, assuming they provide a potentially constant rate of supply during droughts. The net yield provided by these sources is dependent on the sustainable pumping rate of the supply source and the level in Lake Springfield at which pumping is triggered. If pumping is triggered when Lake Springfield is 2 feet below the average pool, groundwater and/or reclaimed water can provide a net yield equal to approximately 80 percent of the sustainable pumping rate.
- The yield of the present water supply system is 26.8 mgd when: 1) the minimum operational level of Lake Springfield is given as 547 feet msl, and 2) pumping from the South Fork does not begin until Lake Springfield is 2 feet below the average pool.
- Over the next 50 years, sediment deposition will reduce the storage capacity of Lake Springfield, effectively reducing the yield of the water supply system. The yield reduction in the present system over the next 50 years is estimated to be 1.6 mgd, or an average reduction rate of 0.032 mgd per year.
- If the proposed Hunter Lake is added to the present water supply system, the maximum system yield will be 48.3 mgd when: 1) the minimum operational level of Lake Springfield is given as 547 feet msl, and 2) pumping from the South Fork does not begin until Lake Springfield is 2 feet below the average pool. The reduction in this system's yield over a 50-year period, as caused by reservoir sedimentation, is estimated to be 3 mgd.
- If the proposed Lick Creek Reservoir, at a design elevation of 595 feet msl, is added to the present system, the maximum system yield will be 39.6 mgd when: 1) the minimum operational level of Lake Springfield is given as 547 feet msl and 2) pumping from the South Fork does not begin until Lake Springfield is 2 feet below the average pool. The reduction in this system's yield over a 50-year period, as caused by reservoir sedimentation, is estimated to be 2.5 mgd.

REFERENCES

Brune, G.M. 1953. "Trap Efficiency of Reservoirs." *Transactions of the American Geophysical Union* 34 (3).

Crawford, Murphy, and Tilly, Inc., Consulting Engineers. 1965. *Water Supply, Treatment and Storage Facilities for the City of Springfield.*

Crawford, Murphy, and Tilly, Inc., Consulting Engineers. 1980. *Update Study of Water Supply Needs.*

Doorenbos, J., and W.O. Pruitt. 1977. *Guidelines for Predicting Crop Water Requirements.* Food and Agricultural Organization of the United Nations (FAO), Irrigation and Drainage Paper 24.

Durgunoglu, A., H.V. Knapp, and S.A. Changnon, Jr. 1987. *PACE Watershed Model (PWM): Volume I, Model Development.* Illinois State Water Survey Contract Report 437.

Fitzpatrick, W.P., W.C. Bogner, and N.G. Bhowmik. 1985. *Sedimentation Investigation of Lake Springfield, Springfield, Illinois.* Illinois State Water Survey Contract Report 363.

Fitzpatrick, W.P., and H.V. Knapp. 1991. *Drought Yields of Lake Springfield and Hunter Lake.* Illinois State Water Survey Contract Report 515.

Frevert, D.K., R.W. Hill, and B.C. Braaten. 1983. "Estimation of FAO Evapotranspiration Coefficients." *Proceedings of the ASCE,* Irrigation and Drainage Division 109(2): 265-273.

Hunter Lake Habitat Evaluation Procedure Team (HLHEP). 1992. *Habitat Evaluation Procedures Applied to the Proposed Hunter Lake (Lake II), Sangamon County, Illinois.* Prepared for City, Water, Light and Power, City of Springfield, IL, by the Hunter Lake HEP Team, Illinois Natural History Survey, U.S. Fish and Wildlife Service, Illinois Department of Conservation.

Knapp, H.V. 1990. *Kaskaskia River Basin Streamflow Assessment Model: Hydrologic Analysis.* Illinois State Water Survey Contract Report 499.

Knapp, H.V., T.W. Ortel, and R.S. Larson. 1991. *Hydrologic Modeling of the Fox River Watershed.* Illinois State Water Survey Contract Report 518.

Makowski, P.B., W.P. Fitzpatrick, and N.G. Bhowmik. 1986. *Reservoir Yield Analysis of Lake Springfield, Springfield, Illinois.* Illinois State Water Survey Contract Report 393.

Stall, J.B. 1964. *Low Flows of Illinois Streams for Impounding Reservoir Design.* Illinois State Water Survey Bulletin 51.

Terstriep, M.L., M. Demissie, D.C. Noel, and H.V. Knapp. 1982. *Hydrologic Design of Impounding Reservoirs in Illinois.* Illinois State Water Survey Bulletin 67.

U.S. Army Corps of Engineers. 1980. *Inspection Report, National Dam Safety Program: Spaulding Dam, Lake Springfield, Sangamon County, Illinois, Inventory Number 00749.* Department of the Army, Chicago District, Corps of Engineers.

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