



Illinois State Water Survey

HYDROLOGY DIVISION

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DROUGHT YIELDS OF LAKE SPRINGFIELD AND HUNTER LAKE

By

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Prepared for the
City of Springfield

Champaign, Illinois
August 1991



Illinois Department of Energy and Natural Resources

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CONTENTS

Introduction	1
Acknowledgements	1
Background	3
Watershed Characteristics	3
Springfield Waterworks	3
Operational Constraints on the Lake	4
Drought Yield Assessment Data	5
Lake Capacity and Morphology Analyses	6
Lake Springfield Sedimentation and Volume losses	6
Capacity Loss from Sedimentation	6
Lake Springfield Dredging	7
Lake Springfield Volume and Morphology	7
Hunter Lake Volume and Morphology	7
Drought Inflow Analysis	9
Available Streamflow Records	10
Streamflow Frequency Analysis	12
Determination of Pumpage from the South Fork Sangamon River	21
Effect on Yield of Not Pumping at the Start of the Drought Period	26
System Losses	27
Net Evaporation	27
Projected Future Sedimentation	28
Seepage to Ground Water	28
Gate Leakage and Dam Seepage	29
Municipal Uses	29
Public Water Supply	29
Power Plant Usage	30
Drought Scenarios and Probability Analyses	31
Lake Springfield Scenarios	32
Hunter Lake Scenarios	32
Drought Probabilities	32
Yield Calculations and Pool Level Simulations	36
Yield Calculation Model	36
Pool Level Simulation Model	36
Results	38
Net Yields	38
Lake Springfield	38
Hunter Lake	42
Pool Level Response Simulation	43
Draft and Minimum Lake Elevation	46
Conclusions	50
Appendixes	52
Lake Springfield and Hunter Lake Yield Results	53
Pool Level Simulation Plots	55
References	61

TABLES

Table 1.	Drought Flow-Frequency Estimates of Inflow to Lake Springfield and the Proposed Hunter Lake (average inflow, cfs)	9
Table 2.	Average Amount of Flow Available for Pumping in the South Fork Sangamon River: Present and With Hunter Lake (cfs)	10
Table 3.	Streamgaging Stations in the Springfield Area	11
Table 4.	Major Droughts Observed at the Springfield, Rochester, Taylorville, and Pawnee Gages	13
Table 5.	Major Droughts Observed at Macoupin Creek near Kane and the Sangamon River at Monticello	15
Table 6.	Drought Flow-Frequency Estimates for the South Fork Sangamon River Near Rochester (average flow, cfs)	18
Table 7.	Comparison of Regression Equations with Estimated Flow Frequency for Streamgages in the Springfield Area (average flow, cfs)	20
Table 8.	Percentage of Total Drought Flow above 98 cfs that Cannot Be Pumped, South Fork Sangamon River near Rochester	23
Table 9.	Period of Drawdown to be Expected at Hunter Lake (months)	25
Table 10.	Drought Flow-Frequency Estimates for the South Fork Sangamon River near Rochester, with Hunter Lake (average flow, cfs)	26
Table 11.	Lake Springfield Drought Scenarios	33
Table 12.	Hunter Lake Drought Scenarios	34
Table 13.	Probability that an Extreme Event of a Given Recurrence Interval Will Be Equaled or Exceeded during a Given Planning Period (percent)	35
Table 14.	Lake Springfield Yields during Low Frequency 18-Month (Critical Duration) Droughts, with and without a Restriction on Minimum Lake Elevation (mgd)	39
Table 15.	Lake Springfield Drought Scenario Worksheet	40
Table 16.	Hunter Lake Yields During Low Frequency Droughts of 18- and 30-Month Duration (mgd)	42
Table 17.	Hunter Lake Drought Scenario Worksheet	44
Table 18.	Combined Yields of Lake Springfield and Hunter Lake (mgd)	51

FIGURES

Figure 1.	Location of Lake Springfield and the proposed Hunter Lake	2
Figure 2.	Schematic diagram of the variables in a water budget	5
Figure 3.	Lake Springfield stage-capacity relationships, 1984 to 2040	8
Figure 4.	Hunter Lake stage-capacity relationships, 1990 to 2040	8
Figure 5.	Streamgaging stations in the Springfield area	11
Figure 6.	Flow-frequency relationship of 18-month droughts; a) Macoupin Creek near Kane, b) Sangamon River at Monticello, and c) South Fork near Rochester	17
Figure 7.	The amount of water that can be pumped from the South Fork station during a drought year (cfs)	22
Figure 8.	Probability of drought occurrence within specific planning periods	35
Figure 9.	Lake Springfield pool level simulations, scenario B (25.45 mgd average draft, 1990 capacity, no minimum pool, South Fork pumping, no Hunter Lake, lake full at onset)	45
Figure 10.	Lake Springfield pool level simulations, scenario C (25.45 mgd average draft, 1990 capacity, no minimum pool, no South Fork pumping, no Hunter Lake, lake full at onset)	45
Figure 11.	Hunter Lake pool level simulations, scenario O (no draft, 1990 capacity, lake full at onset)	47
Figure 12.	Hunter Lake pool level simulations Scenario R (no draft, 2040 capacity, lake full at onset)	47
Figure 13.	Simulation of minimum elevation for Lake Springfield versus draft during the 100-year drought (South Fork pumping, no Hunter Lake, lake full at onset)	49
Figure 14.	Simulation of minimum elevation for Hunter Lake versus draft during the 100-year drought (no draft, lake full at onset)	49

INTRODUCTION

This investigation of the yields of Lake Springfield and Hunter Lake was performed under a cooperative agreement between the city of Springfield and the Illinois State Water Survey (ISWS). This research was performed to update and expand on an earlier study of the yield of Lake Springfield performed by the ISWS in 1986 (Makowski, Fitzpatrick, and Bhowmik, 1986). The present study considers the changes to the system produced by the recent dredging of the upper portions of the lake, storage capacity losses due to sedimentation, and the additional drought yield available from the proposed new Hunter Lake.

The net quantity of water available from a lake is determined through a yield analysis. The intended purpose of a water supply lake is to redistribute the quantity of streamflow with respect to time and thus provide a dependable supply through drier low-flow periods. The yield of a lake is not constant over time and will vary with changes in such factors as lake storage capacity.

Lake Springfield is the largest municipally owned lake in Illinois, with a surface area of 4,000 acres and a storage capacity of 53,600 acre-feet (17.5 billion gallons) at normal pool elevation. The lake is located in central Illinois south of the city of Springfield (figure 1), and has a watershed area of 265 square miles. The lake was created in 1934 by the impoundment of Sugar Creek, a tributary of the Sangamon River of the Illinois River basin.

Hunter Lake is a proposed reservoir intended to augment the city's raw water supply. The proposed reservoir will inundate 3,010 acres and impound 46,600 acre-feet (15.2 billion gallons) at normal pool elevation. The proposed lake site, shown in figure 1, is the Horse and Brush Creek basin, tributary to the South Fork River of the Sangamon River basin.

Acknowledgments

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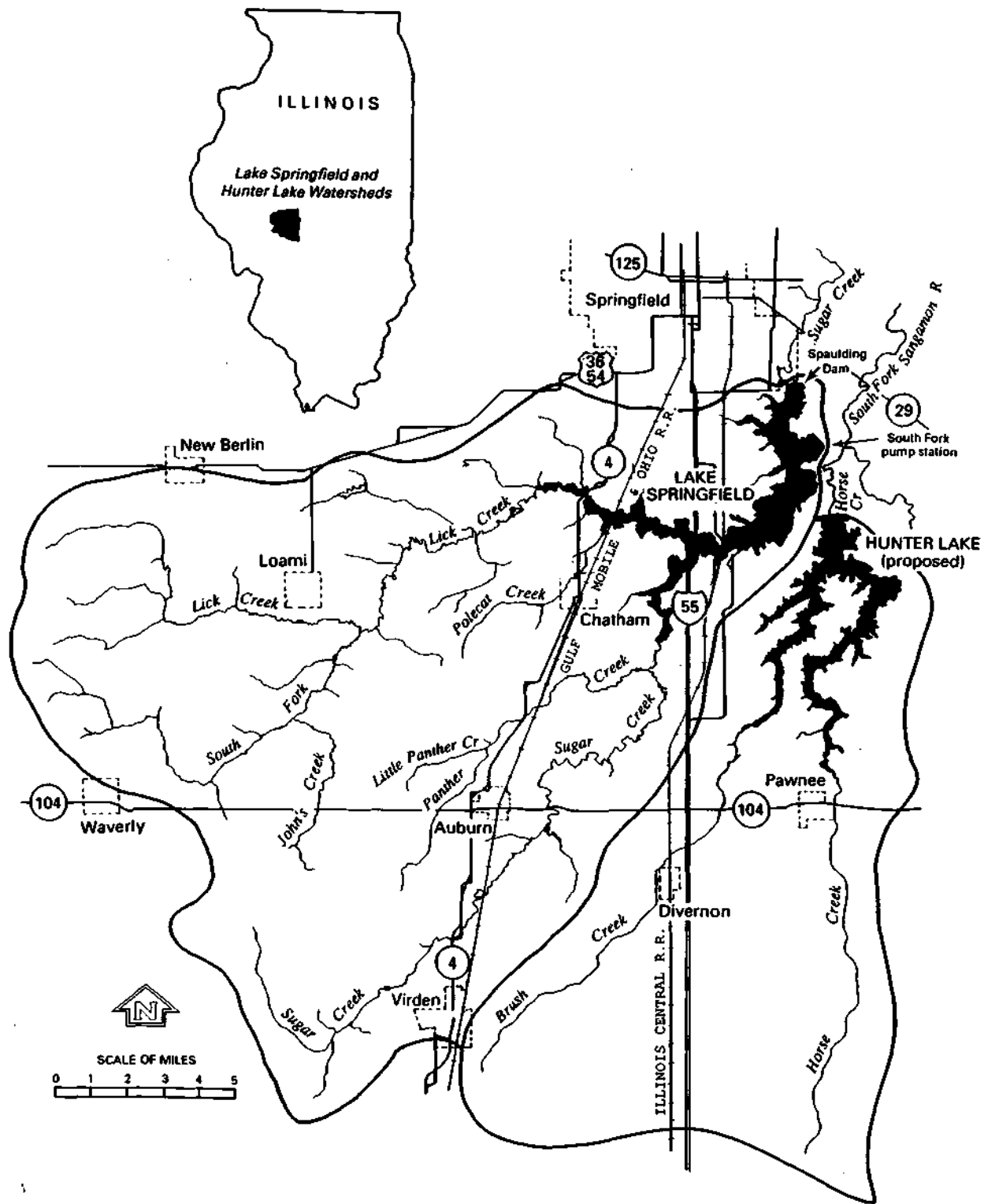


Figure 1. Location of Lake Springfield and the proposed Hunter Lake

BACKGROUND

Watershed Characteristics

The watersheds of Lake Springfield and the proposed Hunter Lake are located south of Springfield, Illinois, in Sangamon, Morgan, and Macoupin Counties. The watershed areas of Lake Springfield and Hunter Lake are 265 and 130 square miles, respectively. Land use in the watershed is primarily agricultural, and approximately 88% of the Lake Springfield watershed is classified as cropland (Lee and Stall, 1977).

The climate of the Springfield region is typically continental, with warm summers and cold winters. Precipitation averages 35.47 inches per year, with yearly extremes of 53.58 inches in 1990 and 23.98 inches in 1953.

Springfield Waterworks

The city's principal source of water is Lake Springfield. The lake was constructed in 1934 with an original storage capacity of 69,900 acre-feet (19.5 billion gallons) and a surface area of more than 4,000 acres (6.5 square miles). The lake supplies water for the city's water treatment plant and coal-fired electrical power plants located along the lakeshore south of the dam.

An additional source of water was developed by the city in 1955 with the construction of a channel dam across the South Fork of the Sangamon River and a pump station to lift water impounded by the channel dam to Lake Springfield. The additional water provided by the South Fork pump station helps to stabilize the pool level in Lake Springfield during drier low-flow periods and increases the available yield of the lake. The pump station, with a rated capacity of 63 million gallons per day (mgd), is typically operated during low-flow periods when the elevation of Lake Springfield drops 1 to 2 feet below normal pool elevation. However, during low-flow periods, the available flow in the South Fork is often less than the rated capacity of the pump station, with the result that the station is operated below capacity.

The city of Springfield has commenced permitting efforts for the construction of a new lake to increase the available water supply during drought conditions. Preliminary design data for the new Hunter Lake indicate an initial storage capacity of 46,600 acre-feet (15.2 billion gallons) and a surface area of 3,010 acres (4.7 square miles). The proposed spillway elevation is 571.00 feet above mean sea level (feet msl), nearly 12 feet above the spillway elevation of Lake Springfield at 559.35 feet msl. Provisions for the transfer of water from Hunter Lake to Lake Springfield are part of the design of the new lake.

Operational Constraints on the Lake

Typically, a lake yield assessment assumes that the entire volume of a lake is available for use during a drought. However, in some circumstances operational constraints may prevent or restrict the amount of water available for withdrawal from a lake.

The use of the lake for both cooling water and municipal water supply will place limits on the amount of water that can be withdrawn for potable uses, while still maintaining enough water in the lake for cooling purposes. R.W. Beck and Associates (1988) reviewed the impact of lake drawdown on the power plant cooling operation with the use of a hydrothermal model of Lake Springfield and an analysis of the lake temperature response. They concluded that, at a lake pool elevation of 546 feet msl, the temperature of the cooling water would exceed the maximum acceptable intake temperature established by CWLP for operating the power plant at full capacity. A 1983 study by Crawford, Murphy, and Tilly, Inc., concluded that the city's utility plants would experience severe operational difficulties related to pump intakes at a lake pool elevation of 546 feet msl, and that 543 feet msl was the minimum water level for the operation of both the power and water plants (CMT, 1983).

Since both these previous studies indicated that utility operational problems would occur at a lake elevation of 546 feet msl, this yield analysis will use a minimum lake elevation of 547 feet msl to represent the lowest elevation of the lake for operating the water and power plants at full capacity. However, in extreme drought conditions it may be desirable to operate the water and power plants at reduced capacity and if necessary modify the plant water intakes and pumping facilities to allow greater utilization of the lake capacity. Therefore this yield analysis will also determine the available supply utilizing the entire capacity of the lake.

DROUGHT YIELD ASSESSMENT DATA

The yield of a lake is the amount of water that can be withdrawn during a specific time interval for a given set of hydrologic and climatic conditions. The yield of a lake is expressed in terms of the average quantity of water available from the lake over time within specific historical probabilities of drought return intervals (frequency of occurrence) and drought durations. In general, the amount of water available for withdrawal from a lake over a given time period depends on the quantity of inflow to the lake, the outflow from the lake, and the change in storage in the lake. Inflow to the lake includes streamflow, direct precipitation, ground-water inflow to the lake, and water diverted into the lake. The outflow from a lake includes evaporation from the lake surface, seepage through the bottom and sides of the lake, dam and spillway leakage, and outflow from the lake through the spillway. The change in storage in a lake represents the quantity of water held in the lake as well as the loss of storage due to sedimentation-induced volume losses. These variables are shown schematically in figure 2, and their analysis is designated a "water budget."

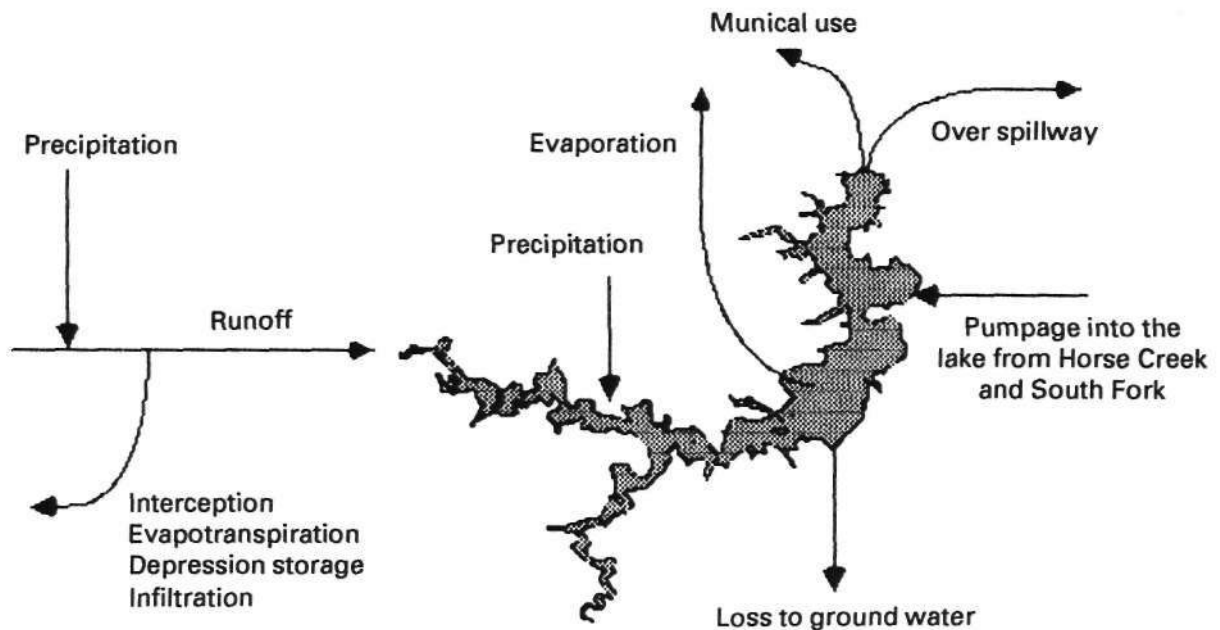


Figure 2. Schematic diagram of the variables in a water budget

Lake Capacity and Morphology Analyses

Lake Springfield Sedimentation and Volume Losses

A lake's water storage is replenished by runoff from its watershed. In addition to providing a catchment for runoff that resupplies the lake storage, the watershed also contributes sediment, which is entrained by runoff water and carried into the lake. When a stream flows into a lake, the velocity of the water decreases and the sediment particles drop out of suspension and settle onto the lakebed. The resulting sedimentation reduces the water storage capacity of the lake over time and therefore affects the yield of the lake.

A hydrographic sedimentation survey of Lake Springfield was last performed in 1984 for the purpose of assessing the lake's storage capacity loss and its morphological change as a result of sedimentation (Fitzpatrick et al., 1985). The 1984 survey found that Lake Springfield had lost, on average, 0.26% of its capacity each year due to sedimentation. This rate is relatively low in comparison with other large reservoirs in Illinois, although the effects of lost storage capacity can impact the available drought water supply. In 1984 Lake Springfield had a storage capacity of 52,200 acre-feet (17 billion gallons). This represents a loss of 7,700 acre-feet of storage, due to the accumulation of 6.5 million tons of sediment since the lake's construction in 1934. The average capacity loss in these 50 years was 154 acre-feet (50 million gallons) per year.

Capacity Loss from Sedimentation

The 1990 capacity of Lake Springfield was estimated by evaluating the changes in storage volume since the 1984 survey. Volume in the lake has changed as a result of: 1) sedimentation over the period 1984-1990, and 2) dredging of the upper portion of the lake from 1987 through 1989.

The results of the 1984 sedimentation survey were reviewed to determine the pattern of sedimentation in the lake and estimate the 1990 capacity. The capacity loss in the downstream, undredged portion of the lake was estimated to be 460 acre-feet over the period 1984-1990. This capacity loss was estimated using the average loss rate per year that was measured in this area of lake between the 1934 and 1984 surveys. The capacity of the upper portion of the lake, representing the dredged areas, was estimated by adding the volume of dredged sediment to the capacity measured by the 1984 survey and then subtracting the estimated volume loss due to sedimentation since the completion of the dredging project in 1989. Sedimentation losses in the upstream portion of the lake following the dredging were estimated as 80 acre-feet for the period 1989-1990. Therefore the total

capacity loss in Lake Springfield due to sedimentation since the 1984 survey is estimated to be 540 acre-feet.

Lake Springfield Dredging

The city of Springfield dredged the upper portion of the lake over the period 1985-1989 to restore lost recreational uses, fishery and wildlife habitat, and sediment trapping capacity. During this period nearly 2,000 acre-feet of sediment were hydraulically dredged from the lake upstream of the Interstate 55 bridge (figure 1). The dredging restored more than 650 million gallons of storage capacity to the lake and significantly changed the morphology of the upstream portion. As a result, an updated analysis of the stage-volume-area relationship of the lake was needed to assess the response of Lake Springfield to various drought scenarios.

Analyses of the topographic cross sections of the dredged areas of the lake measured after the completion of the dredging were conducted to recompute the hydrographic contours. To determine changes in lake morphology, these contours were compared with contour maps of the upper portion of the lake that were developed following the 1984 survey. Most of the lakebed dredging was confined to normal pool depths of less than 5 feet. The additional storage capacity in the upper elevations of the pool will help reduce the lake-level fluctuations due to water supply withdrawals during drought periods.

Lake Springfield Volume and Morphology

This analysis found that the 1990 volume of the lake was 53,600 acre-feet (17.5 billion gallons) as a result of 1) the dredge excavation of 2,000 acre-feet and 2) the loss of 540 acre-feet of storage due to sedimentation during the period 1984-1990. The 1990 and 1984 stage-capacity relationships of Lake Springfield are shown in figure 3. Predicted stage-capacity relationships for 2025 and 2040 are also presented in figure 3. The estimation of these predicted values is described in the section "System Losses; Projected Future Sedimentation."

Hunter Lake Volume and Morphology

Preliminary design data prepared by Hanson Engineers, Inc., was used to determine the stage-capacity relationship of the proposed lake at the current planned spillway elevation of 571 feet msl (preliminary design data dated 11/14/89). At a spillway elevation of 571 feet msl, Hunter Lake will have a storage capacity of 46,600 acre-feet (15.2 billion gallons). The stage-capacity relationship of Hunter Lake for 1990 and predicted values for 2025 and 2040 are presented in figure 4. Estimation of the 2025 and 2040 capacities is described in the section "System Losses; Projected Future Sedimentation."

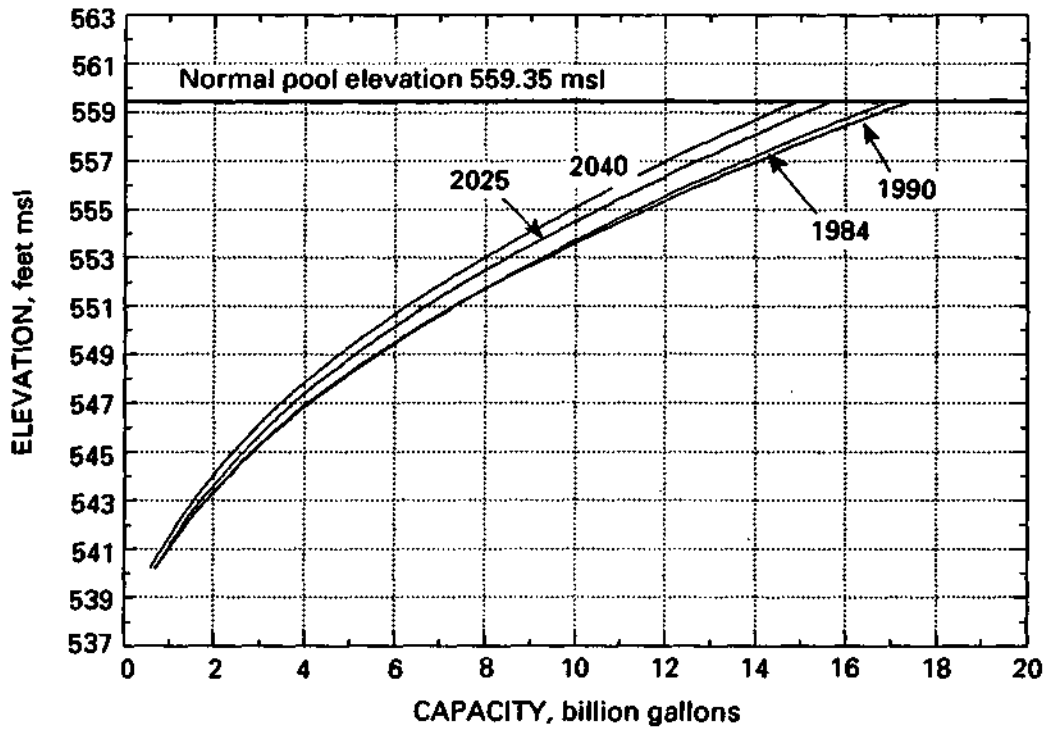


Figure 3. Lake Springfield stage-capacity relationships, 1984 to 2040

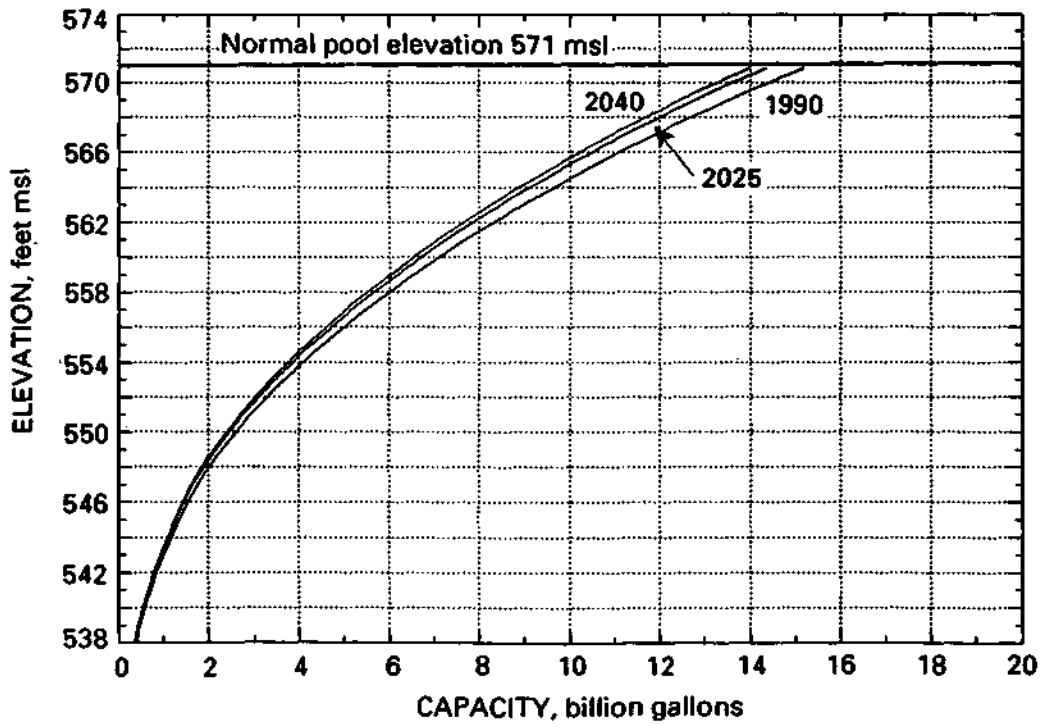


Figure 4. Hunter Lake stage-capacity relationships, 1990 to 2040

Drought Inflow Analysis

An analysis of the yield of the Lake Springfield/Hunter Lake water supply system requires an estimate of 1) drought inflow to Lake Springfield, 2) drought inflow to the proposed Hunter Lake, and 3) the flow available for pumping from the South Fork Sangamon River near Rochester. These flow estimates, whose development is described later in this section, are summarized in tables 1 and 2. Table 1 provides estimates of the drought inflow to Lake Springfield and the proposed Hunter Lake for different drought recurrences. Table 2 provides estimates of the amount of water that can be pumped from the South Fork Sangamon River (South Fork pump station) during the same drought recurrences. The amount of flow that is "available for pumping" from the South Fork pump station represents only a portion of the total amount of flow in the South Fork Sangamon River. It is computed as the total flow minus both the high flows, which cannot feasibly be pumped, and some low flows, which for water quality reasons, remain unpumped. The flow available for pumping is normally a small portion of the overall flow in the South Fork, but is a major portion of the flow in the river during drought conditions.

Table 1. Drought Flow-Frequency Estimates of Inflow to Lake Springfield and the Proposed Hunter Lake (average inflow, cfs)

<u>Drought duration</u>	Recurrence interval				1953-1954 <u>draught</u>
	<u>10 years</u>	<u>25 years</u>	<u>50 years</u>	<u>100 years</u>	
Lake Springfield					
6 month	4.7	2.2	1.3	0.80	1.0
9 month	16	7.6	3.8	2.2	3.1
12 month	33	16	9.2	5.3	6.8
18 month	45	21	13	7.2	7.0
30 month	77	35	24	14	15
54 month	143	73	51	30	36
Hunter Lake					
6-month	1.9	0.65	0.26	0.10	0.17
9-month	8.6	3.8	1.8	0.90	1.4
12-month	17	8.4	5.0	3.1	3.8
18-month	22	11	6.8	4.3	4.2
30-month	38	20	13	7.6	8.0
54-month	68	39	27	17	20

**Table 2. Average Amount of Flow Available for Pumping in the South Fork
- Sangamon Riven Present and with Hunter Lake (cfs)**

<u>Drought duration</u>	Recurrence interval				1953-1954 <u>drought</u>
	<u>10 years</u>	<u>25 years</u>	<u>50 years</u>	<u>100 years</u>	
Present					
6-month	11	4.2	2.0	0.5	1.2
9-month	34	13	7.7	4.1	6.2
12-month	50	29	17	11	11
18-month	52	29	18	11	13
30-month	76	52	35	20	24
54-month	125	79	46	29	43
With Hunter Lake					
6-month	8.0	2.7	1.0	0.2	0.6
9-month	28	10	6.0	3.0	4.7
12-month	44	25	15	10	10
18-month	47	24	14	10	12
30-month	73	44	29	18	22
54-month	123	73	38	25	38

Available Streamflow Records

Nine continuous streamflow gages are located in or near the Lake Springfield and proposed Hunter Lake watersheds. These gaging stations are identified in table 3, and their location is given in figure 5. Table 3 also identifies two long-term stations, the Sangamon River at Monticello and Macoupin Creek near Kane, which are not in the immediate vicinity of Lake Springfield, although they were used to provide additional information on the frequencies of severe droughts.

Two gages, Sugar Creek near Auburn and Lick Creek near Curran, are located in the Lake Springfield watershed. These gages were originally operated by the Illinois Department of Transportation, Division of Water Resources (IDOT), previous to 1982. Since 1985 the gages have been jointly operated by ISWS and CWLP. These two gages are listed as stage gages and were not used in the flow-frequency analysis because very few discharge measurements were made prior to 1985, and a reliable rating curve could not be established for these earlier years.

Of the seven U.S. Geological Survey (USGS) gaging records in the immediate vicinity of Lake Springfield, the Rochester, Springfield, and Taylorville records have the longest period of record and therefore provide the best information for defining the flow-frequency relationship of infrequent droughts. Other USGS records for Divernon, Pawnee, Kincaid, and Nokomis were of limited use because only a few drought events have been measured during each station's period of record. However, the Pawnee gage is located

Table 3. Streamgaging Stations in the Springfield Area

<u>Index number and location</u>	<u>Drainage area (sq mi)</u>	<u>Number of years</u>	<u>Period(s) of record</u>
<i>USGS Continuous Discharge Records</i>			
574000 South Fork Sangamon near Nokomis	11.0	25	(1951-1975)
574500 Flat Branch near Taylorville	276.	33	(1949-1982)
575500 South Fork Sangamon at Kincaid	562.	29	(1917-1927; 1929-1930; 1932-1933; 1945-1961)
575800 Horse Creek near Pawnee	52.2	18	(1967-1985)
575830 Brush Creek near Divernon	32.4	9	(1973-1982)
576000 South Fork Sangamon near Rochester	867.	40	(1949-1989)
577500 Spring Creek near Springfield	107.	42	(1947-1989)
<i>IDOT/ISWS/CWLP Continuous Stage Records</i>			
SG03746 Sugar Creek near Auburn	49.1	36	(1949-1982; 1985-1988)
SG03747 Lick Creek near Curran	99.6	29	(1949-1978; 1985-1988)
<i>USGS Long-Term Continuous Discharge Records</i>			
572000 Sangamon River at Monticello	550.	79	(1908-1912; 1914-1989)
587000 Macoupin Creek near Kane	868.	61	(1921-1933; 1940-1989)

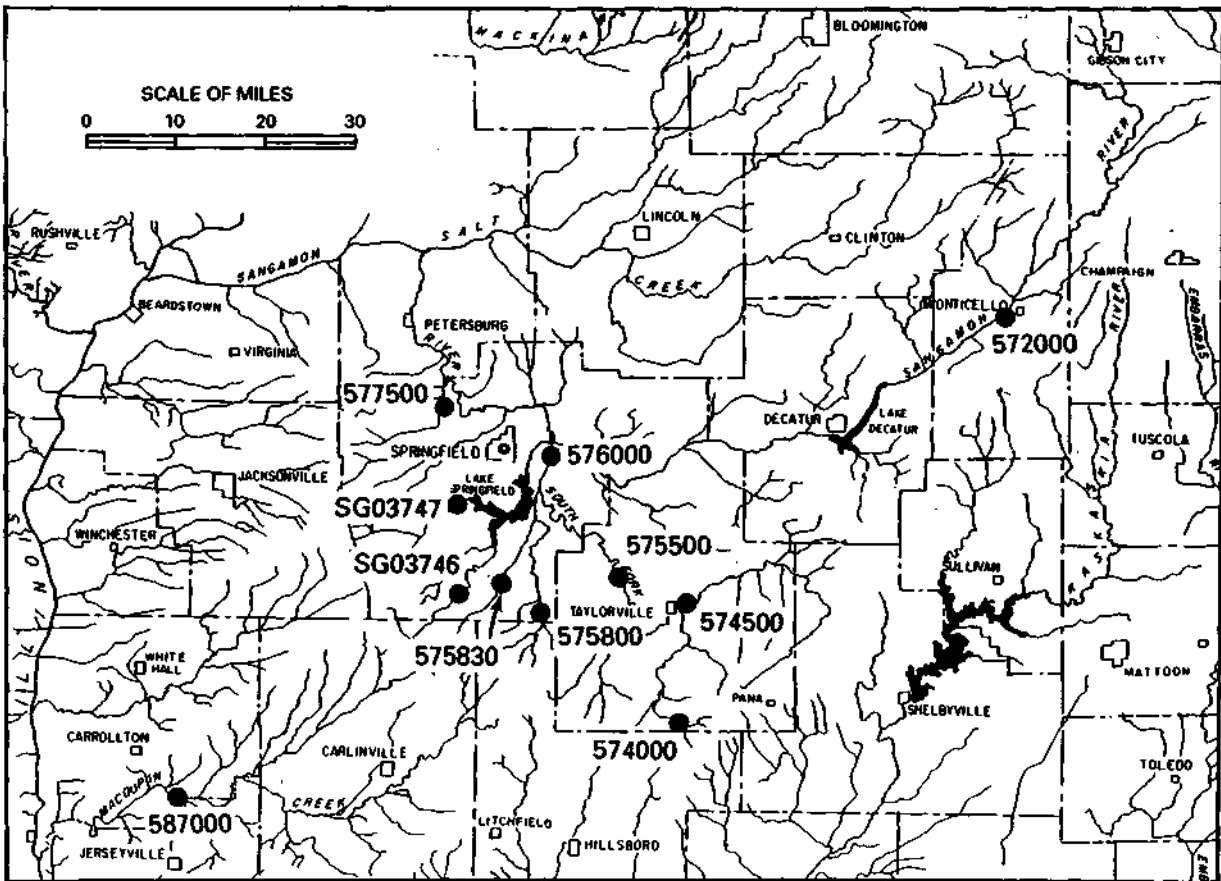


Figure 5. Streamgaging stations in the Springfield area

in the watershed of the proposed Hunter Lake, and for this reason it was included in the analysis for comparison.

The Springfield, Taylorville, and Pawnee flow records are fairly indicative of unaltered or natural flow conditions. Streamflow at the Rochester gage is altered when the South Fork pump station is operated and, to a lesser extent, by reservoirs in the South Fork watershed. The natural flow conditions at Rochester are estimated by adding the amount of water pumped at the station to the measured flow record.

Streamflow Frequency Analysis

The analysis of streamflow frequency for the Lake Springfield/Hunter Lake water supply system employs three steps:

1. Analyze the long-term streamflow records in central Illinois to estimate recurrence intervals for the more severe droughts on record.
2. Compute the drought flow-versus-frequency relationship for the gaging station on the South Fork Sangamon River near Rochester. This information is used to determine the yield of the South Fork pump station. This flow-frequency analysis employs drought information from the flow record at each gage, as well as the recurrence for infrequent events estimated in step one.
3. Compute the drought flow-versus-frequency relationship for Lake Springfield and Hunter Lake. Since gaging records are not available or are too short to provide good drought-frequency information, regional drought-flow equations are employed to define flow frequency at these sites.

Step 1. Analysis of Infrequent Events Using Long-Term Streamflow Records

Use of long-term gaging records outside the watershed. The short- and medium-length gage records in and near the Lake Springfield/Hunter Lake watersheds generally provide poor information about the frequency of severe droughts. This is illustrated by examining the drought flows measured at some of the gaging stations closest to the Lake Springfield area. Table 4 lists the flow values at the Springfield, Rochester, Taylorville, and Pawnee streamgages for the most severe droughts on record. Six drought durations are provided: 6 months; 9 months, 12 months, 18 months, 30 months, and 54 months. The flow values listed in table 4 for the 1953-1954 drought are significantly less than the flows for all other droughts measured at these stations. The differential in these drought flows suggests that the 1953-1954 drought was particularly intense, and that the droughts of 1964, 1976, and 1988 were comparatively mild. This disparity causes the estimation of flow frequency for extreme droughts (25-, 50-, and 100-year droughts) to be particularly difficult and of limited reliability.

Table 4. Major Droughts Observed at the Springfield, Rochester, Taylorville, and Pawnee Gages

<u>Duration and Rank</u>	Location, year of the drought, and average flow (cfs)			
	<u>Springfield</u>	<u>Rochester</u>	<u>Taylorville</u>	<u>Pawnee</u>
6-month drought				
#1	1953- 0.05	1953- 4.2	1953- 0.2	1976- 0.0
#2	1952- 0.08	1964- 7.5	1976- 1.4	1979- 0.2
#3	1976- 0.46	1976- 7.8	1964- 2.2	1978- 0.4
#4	1964- 1.4	1988- 12	1954- 2.3	
9-month drought				
#1	1953- 0.16	1953- 10	1953- 2.6	1976- 1.0
#2	1976- 2.9	1976- 22	1976- 6.5	1980- 2.1
#3	1955- 3.6	1964- 35	1954- 9.0	1979- 4.0
#4	1988- 5.7	1954- 36	1980- 11	
12-month drought				
#1	1954- 1.0	1954- 24	1954- 6.4	1976- 3.6
#2	1956- 9.3	1976- 45	1952- 42	1980- 5.8
#3	1976-10	1964-107	1976- 51	1971-11
#4	1988 -11	1988 -118	1964 - 52	
18-month drought				
#1	1954- 1.8	1954- 23	1954- 5.7	1980- 7.1
#2	1956-14	1964-142	1976- 53	1976- 9.9
#3	1963-16	1988-144	1964- 56	1971-15
#4	1988-17	1980-151	1980- 62	
30-month drought				
#1	1954- 4.1	1954- 66	1954- 20	1976-14
#2	1964-28	1964-185	1964- 70	1980-19
#3	1988-30	1976-239	1976-102	1971-24
#4	1976-37	1988-244	1980-119	
54-month drought				
#1	1954-11	1954-124	1954- 51	1976-27
#2	1964-40	1964-274	1964- 98	1971-34
#3	1988-47	1988-336	1976-162	1980-62

However, the knowledge of drought events in the region extends beyond the 15- to 40-year records provided by these gages. Information on droughts that occurred prior to 1953 can be obtained from other streamgages in central Illinois. Two long-term stream gages, on the Sangamon River at Monticello and on Macoupin Creek near Kane, are used in the analysis to provide an additional measure for comparing historical droughts and drought frequency. The lengths of record for the Sangamon River and Macoupin Creek gages are 80 years and 62 years, respectively. Most severe droughts generally affect a large region with similar intensity; therefore the severe droughts at these two stations must also have been severe droughts in the Lake Springfield area. Information at these two gages provides additional data to help establish flow-frequency relationships for extreme drought events.

Historical droughts. Table 5 ranks the most severe droughts from the Macoupin Creek and Sangamon River gages. The lowest drought flows at both Kane and Monticello were measured during the 1953-1954 drought. However, several other droughts, particularly that of 1931, had low streamflows comparable to those of the 1953-1954 event. The recurrence interval of streamflow for any individual drought, such as the 1953-1954 event, is not totally constant over the duration of that drought. A drought that is especially severe over a 9-month period may only be a moderate 18-month drought if the following months are not particularly dry. For this reason, the ranks of most of the droughts given in table 5 will vary with drought duration.

The length of drought that will be most critical for a particular water supply reservoir depends upon the amount of storage in a reservoir, the average withdrawal rate, and the recurrence interval of the drought. The critical drought duration for a reservoir is the period between the onset of drought (when the reservoir level first falls below normal pool) and the time of greatest drawdown. For Lake Springfield, the 1953-1954 drought had a critical duration of 18 months and a recurrence interval of close to 100 years. The most recent drought, in 1988, had a critical duration at Lake Springfield of 6 months and is estimated to have a recurrence of approximately 12 to 15 years.

Estimation of recurrence intervals. The recurrence interval for droughts measured at the long-term stations was estimated using a graphic technique described as follows. For a given drought, an initial estimate of its frequency, f , is computed by the formula:

$$f=n/(N+1) \tag{1}$$

where N is the number of years of the streamflow record and n represents the rank of the drought in the flow record ($n=1$ represents the drought of record; $n=2$ is the second worst

Table 5. Major Droughts Observed at Macoupin Creek near Kane and the Sangamon River at Monticello

<u>Duration and rank</u>	<u>Year of the drought and average flow (cfs)</u>	
	<u>Kane</u>	<u>Monticello</u>
6-month		
#1	1952- 5.5	1931- 7.1
#2	1953- 5.8	1953- 8.1
#3	1964- 8.4	1976- 8.3
#4	1960- 11	1964- 9.0
#5	1980 - 12	1988 - 9.7
#6	1988- 13	1944- 11
#7	1979- 17	1940- 12
#8	1976- 18	1954- 12
9-month		
#1	1953 - 8.4	1931 - 10
#2	1931- 16	1964- 18
#3	1964- 23	1940- 26
#4	1980- 25	1953- 27
#5	1988- 33	1917- 32
#6	1922 - 33	1976 - 34
#7	1940- 35	1944- 35
#8	1976 - 38	1988 - 42
12-month		
#1	1954- 13	1931 - 34
#2	1931 - 24	1934- 61
#3	1940- 64	1954- 68
#4	1956- 67	1964- 82
#5	1964 - 69	1976 - 93
#6	1980- 80	1914- 97
#7	1953 - 100	1940 - 101
#8	1988 - 117	1988 - 113
18-month		
#1	1954 - 26	1954 - 57
#2	1931 - 38	1931 - 69
#3	1956- 71	1934- 87
#4	1980- 99	1940- 96
#5	1964-104	1964-113
#6	1976 - 142	1917 - 152
#7	1959-151	1988-177
30-month		
#1	1954- 55	1954-104
#2	1931-116	1931-107
#3	1964 - 138	1964 - 175
#4	1976 - 234	1940 - 189
#5	1959-235	1988-213
#6	1988 - 254	1934 - 226
54-month		
#1	1954- 73	1954-153
#2	1931-218	1931-177
#3	1964 - 242	1964 - 228
#4	1988-323	1917-275
#5	1959 - 356	1940 - 323
#6	1980-411	1988-325

drought on record, etc.). The magnitude of the drought flows is then plotted versus the estimated frequency using a logarithm-versus-normal probability (log-Gaussian) scale. An example of this is shown in figures 6a and 6b for the 18-month droughts observed at the Kane and Monticello gages, respectively. The recurrence interval of the drought in years, RI, is estimated as the inverse of the frequency ($RI = 1/f$).

If the initial estimates of the drought frequency using equation 1 are valid, then a plot of drought flow versus frequency should indicate a fairly smooth curve. The data points shown in figure 6a for the Macoupin Creek gage and in figure 6b for the Sangamon River gage are close to fitting a smooth curve, indicating a consistent flow-frequency relationship. For these particular examples, the 1953-1954 drought is estimated to have a recurrence interval of 60 to 100 years. None of the droughts that have occurred following the 1953-1954 drought have associated recurrence intervals greater than 20 years.

Step 2. Analysis of Drought Flows for the South Fork Sangamon River near Rochester

Figure 6c shows a plot of the flow-frequency relationship for observed droughts at the South Fork Sangamon River gage near Rochester. The plotting positions established by equation 1 show an abrupt change in drought flows between the first- and second-ranked droughts during the period of record. This abrupt change occurs because no severe droughts occurred in the 40-year record other than that of 1953-1954. The analysis of long-term gaging records indicates that if the gaging record near Rochester extended back to cover the period 1920-1949, several other severe droughts would also have been recorded. If this were the case, the flow-frequency curve for the Rochester gage would look more like the curves for the Monticello and Kane records shown in figures 6a and 6b. This assumes that the droughts measured at the Monticello and Kane gages previous to 1949 would have also occurred at Rochester. [Again, this is not a loose assumption. For example, data from the fragmented gaging record for the South Fork at Kincaid (upstream of Rochester) indicate extremely low streamflow several times prior to 1949, particularly during 1930.] Because the plotted points in figure 6c do not show a smooth flow-frequency relationship, the estimates of drought frequency provided by equation 1 for the South Fork are believed to be inconsistent and misrepresentative.

The drought-flow frequency curves for different stream locations in a hydrologically similar area should plot as essentially parallel lines. For this reason, the "consistent" flow-frequency curve for the Rochester gage should look more like the curves shown in figures 6a and 6b. The curve presented in figure 6c provides a valid estimate of drought-flow frequency for the South Fork. The flow-frequency curve for Rochester shows that the recurrence intervals for the 1964, 1976, and 1988 droughts (at the 18-month duration) are

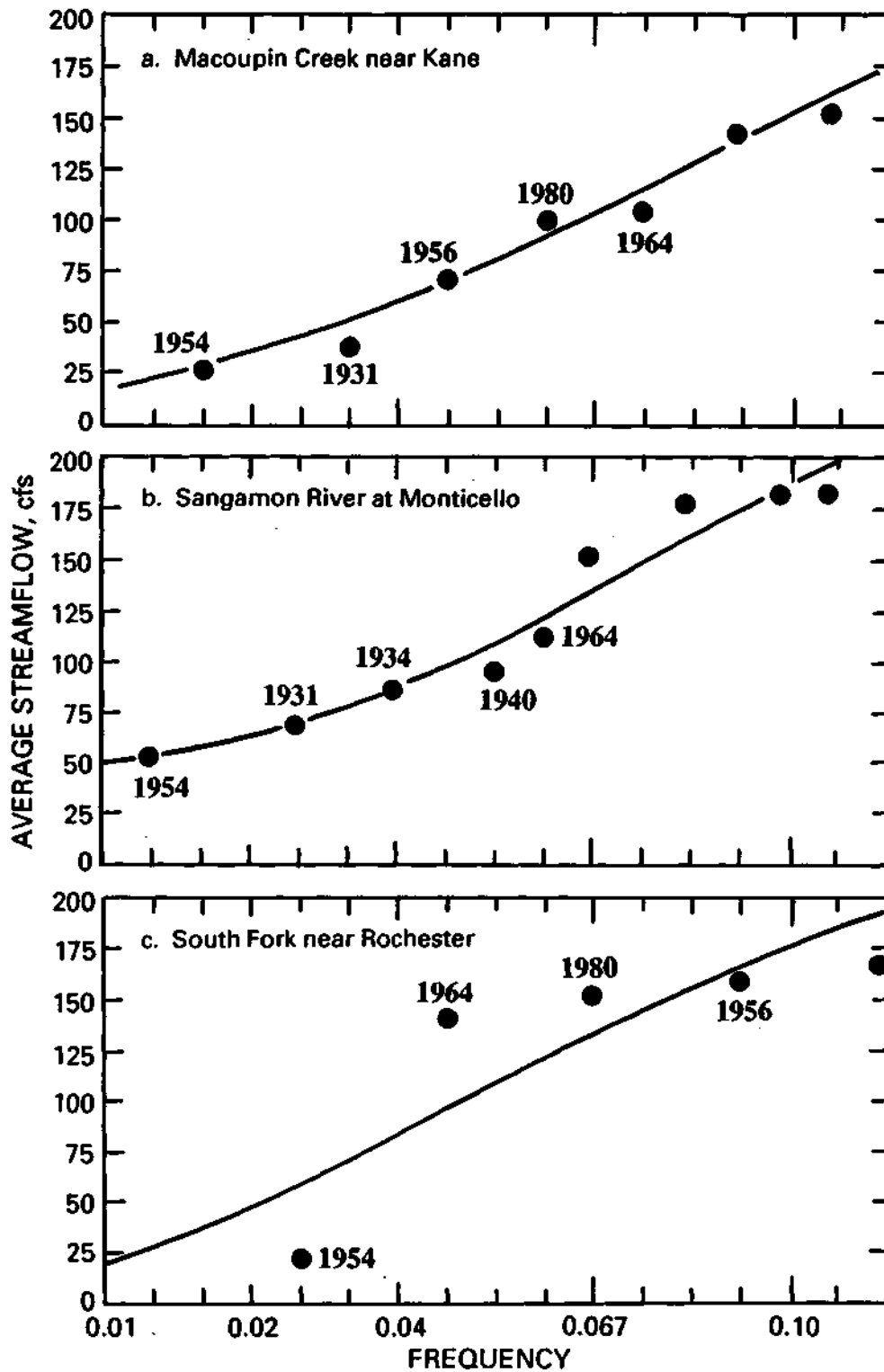


Figure 6. Flow-frequency relationship of 18-month droughts; a) Macoupin Creek near Kane, b) Sangamon River at Monticello, and c) South Fork near Rochester

likely to be 15 years or less. The recurrence interval for the 18-month 1953-1954 drought is approximately 100 years. Estimates of the drought flow-frequency relationship for other durations at the Rochester gage are provided in table 6. Note that the values in table 6, which describe the frequency of streamflow in the South Fork Sangamon River, differ from the values in table 1, which show the portion of flow available for pumping.

Table 6. Drought Flow-Frequency Estimates for the South Fork Sangamon River near Rochester (average flow, cfs)

<u>Duration</u>	Recurrence interval				1953-1954 <u>drought</u>
	<u>10 years</u>	<u>25 years</u>	<u>50 years</u>	<u>100 years</u>	
6-month	14	7.2	5.0	3.5	4.2
9-month	45	19	12	7.5	10
12-month	126	66	34	18	24
18-month	180	91	49	24	23
30-month	285	190	120	62	66
54-month	500	310	170	102	124

Step 3. Regional Drought Analysis for the Lake Springfield and Hunter Lake Sites

Inflows to Lake Springfield and the proposed Hunter Lake are not directly measured, nor are the gaging records for locations within these watersheds sufficiently long to estimate drought frequency reliably. The Lake Springfield watershed contains two streamgages: Sugar Creek near Auburn and Lick Creek near Curran. The period of record for these gages is provided in table 3. The flow stages at each of these gages were continuously monitored for more than 30 years. But, prior to 1985, the discharge measurements were taken infrequently, and therefore are inadequate to define reliable flow quantities for that period.

The proposed site of Hunter Lake is located in the Horse Creek watershed. Streamflow records are available on Horse Creek at Pawnee, which was gaged from 1967 to 1985; and on Brush Creek near Divernon (1973 to 1982). The records at both gages cover periods with above-average streamflow. An examination of several streamgages in the region indicates that the average streamflow for 1967-1985 was more than 20% above the long-term average. The 18-year period of record for the Pawnee gage contains only one mild drought event. For this reason, the 25-, 50-, and 100-year drought flows cannot be adequately estimated using the available gage records. Drought-flow frequencies for both

Lake Springfield and Hunter Lake are instead estimated with equations developed using an analysis of regional streamflow records.

Regional equations. Regression equations developed by Knapp (1990) were used to estimate the drought-flow frequency for the Lake Springfield and Hunter Lake watersheds for the 10-, 25-, and 50-year droughts. The 100-year drought was extrapolated from these values by using a log-probability (log-Gaussian) scale and maintaining the slopes presented in figure 6. These estimates are provided in table 1.

Table 1 also lists estimates of inflow to Lake Springfield and Hunter Lake during the 1953-1954 drought of record. These estimates were developed by duplicating the severity of the drought observed at the Rochester gaging station during the same 1953-1954 period. A ratio was established to relate the 1953-1954 flows at Rochester to both the estimated 50-year and 100-year drought flows. Equation 2 provides an example of how this ratio was computed for the 12-month drought:

$$\begin{aligned} \text{Rochester 12-month ratio (R)} &= (Q_{12,1953} - Q_{12,100}) / (Q_{12,50} - Q_{12,100}) \quad (2) \\ &= (23.8 - 18) / (34 - 18) = 0.362 \end{aligned}$$

Note: $Q_{12,100}$ = the 12-month, 100-year drought,
 $Q_{12,50}$ = the 12-month, 50-year drought
 $Q_{12,1953}$ = the 12-month flow during the 1953-1954 drought

The ratio defined by equation 2 is used to "estimate the 12-month 1953-1954 flow for Hunter Lake, as shown in equation 3:

$$\begin{aligned} \text{1953-1954 Hunter Lake 12-month flow} &= Q_{12,100} + R (Q_{12,50} - Q_{12,100}) \quad (3) \\ &= 3.1 + 0.362 (5.0 - 3.1) = 3.8 \text{ cfs} \end{aligned}$$

Verification of regional equations. The equations used to develop the flow-frequency values in table 1 were developed for use in a portion of the Kaskaskia River watershed that is hydrologically similar to the Lake Springfield area. This regional similarity in drought hydrology was identified in ISWS Bulletin 67 (Terstriep et al., 1982). The appropriateness of using the equations in the Springfield area was verified by comparing equation results with drought frequencies estimated for three gaging records: the South Fork near Rochester, Spring Creek near Springfield, and Flat Branch near Taylorville. This comparison is provided in table 7. The comparison also presents estimates from the equations used in the previous 1986 yield analysis (Makowski et al., 1986). The new equations more closely match the estimated flows for the infrequent drought events, particularly for droughts of longer duration.

Table 7. Comparison of Regression Equations with Estimated Flow Frequency for Streamgages in the Springfield Area (average flow, cfs)

Location and recurrence interval	Drought duration (months)					
	6	9	12	18	30	54
Rochester - 10 years						
Record	14	45	126	180	285	500
Old equation	11	37	119	173	293	517
New equation	22	63	141	166	281	453
Rochester - 25 years						
Record	7.2	19	66	91	190	310
Old equation	3.9	15	37	61	132	212
New equation	10	29	63	83	148	262
Rochester - 50 years						
Record	5.0	12	34	49	120	170
Old equation	2.3	7.7	14	20	46	98
New equation	5.9	13	30	45	97	165
Springfield - 10 years						
Record	14	5.2	14	24	39	62
Old equation	0.8	3.9	13	20	36	65
New equation	1.4	6.8	14	18	31	55
Springfield - 25 years						
Record	0.5	2.0	5.8	9.6	23	35
Old equation	0.1	1.4	4.1	7.3	17	26
New equation	0.5	3.0	6.7	8.9	16	31
Springfield - 50 years						
Record	0.2	0.8	2.9	4.5	11	22
Old equation	0.02	0.7	1.6	2.4	5.6	12
New equation	0.2	1.5	4.0	5.4	10	22
Taylorville - 10 years						
Record	3.0	11	60	75	130	198
Old equation	2.7	11	36	53	93	165
New equation	5.6	21	42	53	90	162
Taylorville - 25 years						
Record	1.2	5.6	26	33	82	106
Old equation	0.7	4.1	11	19	42	67
New equation	2.2	9.6	20	26	46	92
Taylorville - 50 years						
Record	0.5	3.0	14	17	42	70
Old equation	0.3	2.1	4.4	6.3	15	31
New equation	1.1	4.4	12	16	31	65

NOTES: Old equation = used in Makowski et al. (1986).
New equation = from Knapp (1990).

Determination of Pumpage from the South Fork Sangamon River

The South Fork pump station serves as a valuable supplement for water to the Springfield system. A low channel dam, located just downstream of the confluence of Horse Creek and the South Fork Sangamon River, retains the streamflow, and pumps are operated when the water level behind the dam is sufficiently high. The two pumps at the South Fork station have a combined rating capacity of 63 mgd, or approximately 98 cubic feet per second (cfs). Any flow in the South Fork Sangamon River above the rate of 98 cfs will be expected to flow past the station unpumped. All the flows below 98 cfs are theoretically available for pumping into Lake Springfield. But during periods of extreme low flow, when a sufficiently high water level cannot be maintained behind the channel dam, the water stagnates and anaerobic conditions occur. Under these circumstances, the water behind the dam is released downstream. This condition occurs when the flow in the South Fork is less than 10 cfs.

Throughout an extended drought, the amount of water released past the channel dam may be as large as 10 cfs when pumping is first discontinued; or it may be less than 1 cfs, either during those periods when pumping occurs or at times of extreme low streamflow. Over the duration of the drought, the average amount of flow released is approximately 3 cfs. This value was obtained from streamflow records measured at the Rochester gage, directly downstream of the pump station. During recent dry periods (in 1976, 1987, 1988, and 1989) an average low flow of 2.1 to 3.5 cfs was released past the pump station. The measured flow at the gage (outflow), average pumping, and computed inflow to the pump station for these dry years are presented as follows:

	Inflow (cfs)	Pumped (cfs)	Outflow (cfs)
Aug 1976 - Jan 1977	8.9	5.4	3.5
Sep 1987 - Nov 1987	13.3	9.9	3.4
Jun 1988 - Oct 1988	12.6	10.0	2.6
Oct 1989 - Jan 1990	na	na	2.1

NOTE: na = not available.

The computations of available pumping from the South Fork developed in this study assume that 1) an average of 3 cfs will not be pumped during dry periods because of poor water quality, and 2) all flows in excess of 98 cfs will likewise not be pumped. The amount available for pumping using these assumptions is illustrated in figure 7.

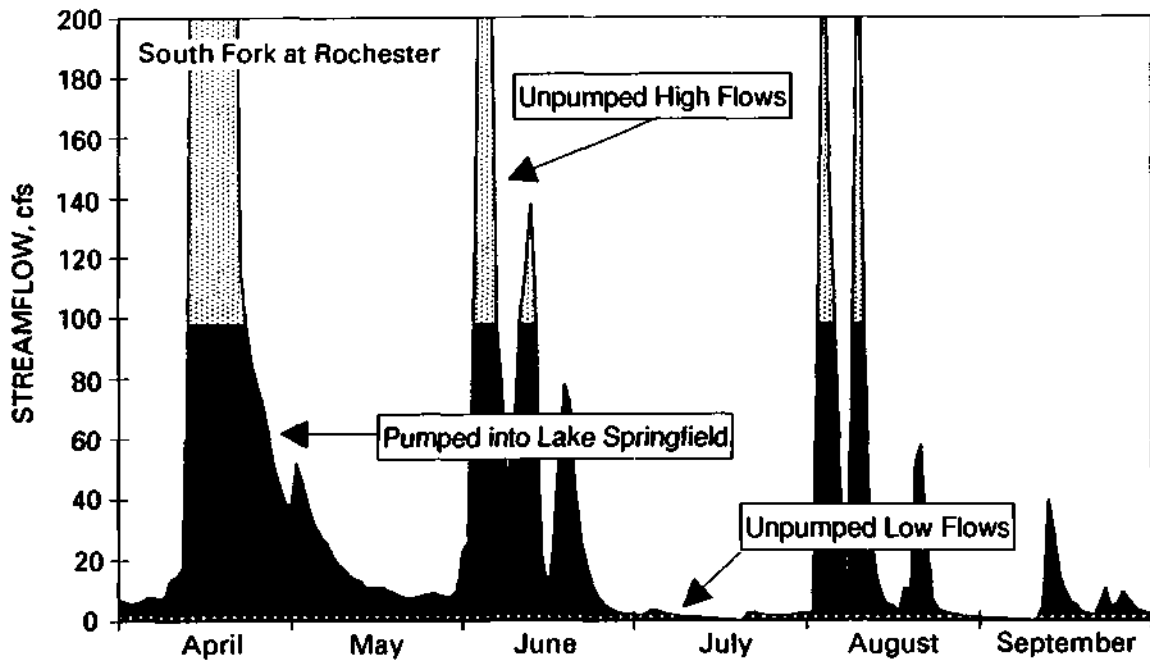


Figure 7. The amount of water that can be pumped from the South Fork station during a drought year (cfs)

The next step in determining the flow available for pumping involves estimating the proportion of total flow that occurs above the 98 cfs (63 mgd) pumping rate during droughts. The flow records at the Rochester gage were examined to identify this proportion. For each major drought, the average drought flow and the average amount of flow that occurs in excess of 98 cfs is identified in table 8.

A linear regression was performed on the data in table 8 to create an equation that predicts the amount of water available for pumping (Q_{pump}) from the average flow in the stream during a particular drought (Q). The regression equations are listed as follows:

- | | | |
|----------|----------------------------------|-----|
| 6-month | $Q_{\text{pump}} = Q - 3.0$ | (4) |
| 9-month | $Q_{\text{pump}} = 0.79 Q - 1.8$ | (5) |
| 12-month | $Q_{\text{pump}} = 0.36 Q + 5.0$ | (6) |
| 18-month | $Q_{\text{pump}} = 0.26 Q + 5.0$ | (7) |
| 30-month | $Q_{\text{pump}} = 0.25 Q + 5.0$ | (8) |
| 54-month | $Q_{\text{pump}} = 0.24 Q + 5.0$ | (9) |

Table 8. Percentage of Total Drought Flow above 98 cfs that Cannot Be Pumped, South Fork Sangamon River near Rochester

Drought duration and year of occurrence	Average drought flow (cfs)	Percentage of total flow above 98 cfs	Average flow rate (cfs) above 98 cfs
6-month			
1976	3.2	0%	0.0
1953	4.2	0%	0.0
1964	7.5	0%	0.0
1988	12.2	6%	0.7
1952	12.6	0%	0.0
9-month			
1953	10	8%	0.8
1976	22	14%	3.1
1964	35	17%	6.0
1954	36	14%	5.0
1980	41	22%	9.1
1988	46	20%	9.2
12-month			
1954	24	42%	10
1976	45	25%	11
1964	107	58%	61
1988	118	57%	67
1980	146	72%	106
18-month			
1954	23	36%	8.4
1964	142	88%	126
1980	151	74%	111
1976	167	62%	103
1988	191	71%	132
30-month			
1954	66	63%	39
1964	185	58%	103
1976	239	71%	168
1988	273	78%	209
54-month			
1954	126	62%	78
1964	274	68%	186
1988	336	81%	272

Equations 4 through 9 were used to determine the average amount of flow available for pumping in the South Fork Sangamon River for the 10-, 25-, 50- and 100-year drought events. These values are listed in table 2.

Estimated Effect of Hunter Lake on Pumping from the South Fork

Hunter Lake will be constructed on the Horse Creek tributary to the South Fork and will effectively capture all runoff from its portion of the South Fork watershed during drought periods. Under present conditions without the lake, Horse Creek has no flow for a 2- or 3-month period in many years. With the presence of Hunter Lake, the duration of little or no flow during droughts (excluding minimum releases) will be significantly prolonged. This will cause a reduction in the flow in the South Fork Sangamon River at the South Fork pump station, which is located 4 miles downstream of the proposed dam site.

For purposes of the analysis, the outflow from Hunter Lake during drought periods is separated into three categories:

- Minimum flow releases. The minimum flow release from Hunter Lake during these drought conditions will pass by the South Fork pump station. Because the minimum flow release is not available for pumping, its magnitude does not directly affect the amount of water that can be pumped into Lake Springfield from the South Fork Sangamon River.
- Flows withdrawn for diversion/pumping into Lake Springfield. These flows may either be diverted directly to Lake Springfield or released into Horse Creek for the specific purpose of being pumped (from the South Fork station) into Lake Springfield. Flows withdrawn or released for this purpose are designated as part of the yield of Hunter Lake, and therefore are not considered part of the "available flow" for computing yield at the South Fork pump station.
- Uncontrolled overflow from the lake when the normal pool elevation is exceeded. The uncontrolled overflow is not part of the yield of Hunter Lake. This flow category is the only outflow from Hunter Lake that is considered "available for pumping" at the South Fork station.

During drought conditions the lake level will be below the normal pool elevation for an extended period. The only outflows during this period will be purposely released, either as minimum low flows or withdrawals. Therefore they are not considered available for pumping at the South Fork station, and the yield from the pump station will consequently be reduced for the period that the lake level is drawn down. The duration of prolonged drawdown in the lake is a function of the total amount of water leaving the lake via minimum releases and withdrawals.

The relationship between the total amount of water released from Hunter Lake and the duration of the drawdown is given in table 9. The duration of the drawdown is minimized when the lake experiences no withdrawals and no flow releases. For the 10-year drought, the minimum duration of drawdown is 9 months; for the 50- and 100-year droughts, it is 18 months. When the water supply withdrawals and minimum releases total as much as 5 mgd, the period of drawdown can be as long as 30 months. It is reasonable, therefore, to assume that Horse Creek will contribute little or no flow to the amount available for pumping from the South Fork station during severe droughts.

Horse Creek accounts for approximately 15% of the total watershed area of the South Fork Sangamon River at the pump station, and therefore approximately 15% of the average flow. However, during drought periods the contribution of flow from Horse Creek is estimated to be 20%. The contribution during droughts (20%) is greater than the average (15%) because several impoundments in the watershed (Lake Taylorville and Sangchris Lake) do not contribute flow during dry periods.

With the presence of Hunter Lake, the drought flows on the South Fork Sangamon River are reduced. The drought flows under this condition were estimated using the Illinois Streamflow Assessment Model (Knapp et al., 1985; Knapp, 1990) and are shown in table 10. Table 2 provides the altered effect on the amount of flow available for pumping from the South Fork. These latter values are computed by applying equations 2 through 6 to the altered flow estimates for the South Fork, which relate streamflow to available pumping.

Table 9. Period of Drawdown to be Expected at Hunter Lake (months)

Average total of withdrawals and minimum releases (mgd)	Recurrence interval			
	10 years	25 years	50years	100 years
0	9	11	18	20
1	9	12	20	27
3	10	18	22	30
5	12	20	30	32
10	15	30	32	54

Table 10. Drought-Flow Frequency Estimates for the South Fork Sangamon River near Rochester, with Hunter Lake (average flow, cfs)

<u>Duration</u>	Recurrence Interval				1953-1954 drought
	<u>10 years</u>	<u>25 years</u>	<u>50 years</u>	<u>100 years</u>	
6-month	14	7.2	5.0	3.5	4.2
9-month	45	19	12	7.5	10
12-month	126	66	34	18	24
18-month	180	91	49	24	23
30-month	285	190	120	62	66
54-month	500	310	170	102	124

Effect on Yield of Not Pumping at the Start of the Drought Period

The yields of the South Fork pump station, given in table 1, represent operating conditions such that the pumps are turned on shortly after the level of Lake Springfield falls below its normal pool. Under alternative management policies, pumping could start only after the reservoir level has fallen 2 to 4 feet. Under these latter conditions, the yield of the pump station should be reduced by the amount of water that could have been pumped while the lake level was dropping.

Some of the most severe droughts at Lake Springfield (1953-1954, 1964, 1977, 1980, and 1988) were examined to indicate how much the yield would be reduced by delayed pumping. During each of the droughts examined, lake drawdown began in early to late summer. The onset of each of these droughts also corresponds to the most intense portion of the drought, with both low streamflows and high evaporative losses from the lake. For each of these droughts and the present rate of municipal water use, Lake Springfield could be expected to experience an initial drawdown of 3 or 4 feet in less than four months. This four months of drawdown is concurrent with a period of very low streamflow in the South Fork Sangamon River. The cumulative streamflow in the South Fork for these five historical droughts, over the four months concurrent with the lake drawdown, ranges from 1,000 acre-feet to 4,500 acre-feet. Of the maximum amount of streamflow (4,500 cfs), less than 3,600 acre-feet would likely be available for pumping. It is concluded that, if pumping during droughts is not initiated until after the reservoir has a significant drawdown, the total yield of the South Fork pump station will likely be reduced less than 3,600 acre-feet. Over an 18-month drought, this 3,600 acre-feet is equivalent to approximately 2 mgd.

System Losses

Net Evaporation

Evaporation from the surface of a lake is one of the largest loss components in a yield analysis. In this analysis evaporative losses are considered in terms of net evaporation which is defined as the total evaporation from the surface of the lake less the direct precipitation falling on the lake surface. The evaporation values used in this study were derived from ISWS Bulletin 67, *Hydrologic Design of Impounding Reservoirs in Illinois* (Terstriep et al., 1982). The methodology used for determining evaporative losses in this study was derived primarily from ISWS Report of Investigation 57, *Lake Evaporation in Illinois* (Roberts and Stall, 1967).

The evaporation values for Illinois in Bulletin 67 are presented in terms of inches of evaporation. In order to determine the quantity of water lost to evaporation during droughts of various durations and frequencies, and to apply these results to the planning scenarios, values of inches of evaporation were multiplied by an estimated evaporative surface area.

In a yield assessment of a lake, it is typically assumed that the entire volume of the lake is available for use and that over the duration of a drought the lake will be emptied, resulting in an average evaporative surface area equivalent to 65% of the lake's area at normal pool elevation (Hudson and Roberts, 1955; Roberts and Stall, 1967; Terstriep et al., 1982). This technique, which is applicable to lake yield scenarios with no restrictions on minimum allowed pool elevation, will be used in this analysis for most planning scenarios. However, some of the lake yield scenarios considered in this work will address conditions in which only the volume of the lake above a set minimum elevation is available for use during droughts. In these situations the evaporative area of the lake is determined as 65% of the area of the lake above the set minimum elevation. Evaporative areas used in the yield scenarios for Lake Springfield were based on the estimated 1989 lake stage-area distribution. The design stage-area distribution data for the proposed Hunter Lake was used to determine the evaporative areas of this lake for all years.

Evaporation is not constant. Like streamflow, it will vary over time and exhibit statistical return intervals and durations. More than 68 years of meteorological data on evaporation for the Springfield area were analyzed in Bulletin 67 to compute lake evaporation rates for droughts up to the 100-year recurrence and 60-month duration. These values were used in this study for both Hunter Lake and Lake Springfield.

Projected Future Sedimentation

Sedimentation will diminish the storage capacity of a lake over time and will therefore impact the available water supply yield of the lake. The future impact of sedimentation storage losses in Lake Springfield and Hunter Lake was estimated by extending the capacity loss rate that was measured in Lake Springfield by the 1984 sedimentation survey (Fitzpatrick et al., 1985).

The 50 year (1934-1984) average sedimentation rate of Lake Springfield was 154 acre-feet per year. Extrapolating this rate through the years 2025 and 2040 indicates that Lake Springfield will lose approximately 5,400 acre-feet (1.8 billion gallons) and 7,700 acre-feet (2.5 billion gallons) of storage in the next 35 and 50 years, respectively. Subtracting these values from the estimated 1990 capacity of 53,600 acre-feet results in a projected capacity in the year 2025 of 48,200 acre-feet (15.7 billion gallons) and 45,900 acre-feet (15.0 billion gallons) in the year 2040 (figure 3).

The sedimentation rate observed in Lake Springfield over the past 50 years is not directly applicable to Hunter Lake due to differences in the sizes of their watersheds and other factors related to slight differences in land use, soils, and lake trapping efficiency. Assuming that the future sedimentation rate of Hunter Lake will be similar to that of Lake Springfield in terms of watershed sediment yield, the capacity of Hunter Lake in the years 2025 and 2040 was estimated by applying the average capacity loss rate per acre of watershed observed in Lake Springfield to the watershed area of Hunter Lake. Therefore, the estimated 2025 capacity of Hunter Lake is 44,000 acre-feet (14.3 billion gallons). The 2040 capacity of Hunter Lake is estimated to be approximately 42,900 acre-feet (14.0 billion gallons) due to a projected loss of 3,700 acre-feet (1.2 billion gallons) of storage to sedimentation over the next 50 years (figure 4).

Seepage to Ground Water

In general, if the water surface of a lake is above the local ground-water elevation, water will flow out of the bottom and sides of the lake to the ground water. Due to the relatively low yield from ground water wells in the vicinity of Lake Springfield, few data are currently available to directly evaluate ground-water losses from the lake. Therefore, the losses from Lake Springfield and the proposed Hunter Lake were estimated based on data provided by a regional study of the ground-water resources of the Sangamon River basin (O'Hearn and Williams, 1982). This regional study found that in the vicinity of Lake Springfield, the ground-water yield from shallow sand-and-gravel aquifers was less than 20 gallons per minute, which indicated little movement of water through the glacial materials. The regional study also showed that the bedrock of the area, consisting of shale with

interbedded limestone, sandstone, and coal of the Modesto and Bond Formations, had yields of less than 10 gallons per minute. The low hydraulic conductivity suggests little flow from the lake to the ground water and negligible seepage losses.

Gate Leakage and Dam Seepage

This component of the yield analysis addresses the quantity of water lost out of the lake due to leakage around the spillway gates and seepage through the dam. These values were estimated based on data provided by CWLP.

The spillway gates of Lake Springfield are 8 feet high with a sill elevation of 551.35 feet msl. No leakage will occur through the gates when the lake elevation drops below the sill elevation. Similarly, as the lake elevation falls, the driving head causing seepage through the dam will also decrease. Based on data provided by CWLP, at a normal pool elevation of 559.35 msl the total seepage and leakage from Lake Springfield was estimated to be 0.7 mgd. A reduction in the average loss for this component was made to represent the change in losses as a result of fluctuating pool elevation. The average loss through the course of a drought was estimated as 0.45 mgd.

The losses attributed to gate leakage and dam seepage will decrease over time as the lake storage capacity is used. If the operation of the reservoir is constrained so that the storage below a minimum elevation is not used, then the average gate leakage and dam seepage over the duration of a drought will be greater than a situation in which the entire lake capacity is used. However, the effect of such operational constraints on gate leakage and dam seepage is relatively minor, and is neglected herein.

Municipal Uses

Public Water Supply

Draft on the lake for municipal public water supply is not generally included as an input parameter in assessing the yield of a lake, since the purpose of the yield analysis is to determine the maximum safe value of this draft. Municipal water supply is included in the simulation of lake pool level changes during various droughts for the purpose of simulating the minimum lake elevation resulting from different scenarios. The lake level simulations can then be used to assess potential impacts on water intakes, power plant cooling efficiency, and recreational uses of the lake.

Power Plant Usage

The city's coal-fired power plants located near Spaulding Dam make use of the water in Lake Springfield for cooling and ash-handling purposes. Cooling water withdrawn from the lake is returned to the lake and results in forced evaporation, that is, an increase in lake evaporation caused by elevating the temperature of the water.

Water is also withdrawn for the purpose of handling the ash generated at the power plant. This water is used to transport the ash from the boiler and scrubber to the settling lagoons downstream of the lake. Typically, the supernate from the ash lagoons is discharged to Sugar Creek downstream of the lake. However, the water is available for recycling back into the lake if needed. Forced evaporation and water withdrawn for ash handling from Lake Springfield is approximately 5 mgd according to CWLP.

Power plant usage was not included in determining the maximum net yield of the lake, but it has been included in the simulation of the lake pool elevation during various droughts.

DROUGHT SCENARIOS AND PROBABILITY ANALYSES

Different scenarios related to the operation of Lake Springfield and Hunter Lake were simulated in the yield analysis to determine the impact of varied conditions on available yield. The impact of the following five basic variables was examined:

- (1) Lake Storage Capacity. The impact of sedimentation and storage capacity changes on net yield was evaluated by using four alternative estimates of total storage capacity in Lake Springfield: 1) the 1984 volume prior to the recent dredging project, 2) the estimated 1990 volume following dredging, 3) the estimated volume of the lake in the year 2025, and 4) the estimated volume in the year 2040.

In a similar manner, the effects of sedimentation on reduced total storage capacity and yield in Hunter Lake were analyzed by using three volumes: 1) the initial Hunter Lake (1990) volume, 2) the estimated volume 35 years after construction (2025), and 3) the estimated volume 50 years after construction (2040).

- (2) Minimum Pool Elevation. The impact of changing the minimum allowed pool elevation in Lake Springfield was analyzed by estimating yield based on the available storage volume in the lake at levels above 547 feet msl and at 550 feet msl, as well as for complete use of the lake down to an elevation of 530 feet msl.
- (3) Use of the South Fork Pump Station. The supplemental supply of water to Lake Springfield available from the South Fork pump station was omitted in one scenario to determine the impact of this component on available yield.
- (4) Effect of Hunter Lake on South Fork Pumping. The construction of Hunter Lake will reduce streamflow available for withdrawals from the South Fork basin and therefore impact the yield of Lake Springfield. The impact of Hunter Lake on Lake Springfield's yield was simulated in several scenarios.
- (5) Lake Drawdown at the Onset of the Drought. Scenarios were added to the analyses for both lakes to evaluate the impact of the pools being drawn down 2 feet prior to the onset of drought conditions.

The last variable, which addresses conditions in which the lakes may be below spillway level at the drought onset, was added for comparison with earlier yield studies of Lake Springfield and to represent possible conditions in which the lake may be intentionally drawn down for such purposes as spillway maintenance. However, the analytical methodologies traditionally employed in a yield assessment of water supply lakes define that the drought starts when the lake drops below spillway level under normal operating conditions. Therefore, the scenarios that address starting conditions in which the lake is below spillway level must be viewed as the result of an intentional drawdown of the lake. An associated issue, the impact of not pumping from the South Fork station until the lake level has fallen, is briefly examined in the section: "Drought Inflow Analysis; Determination of Pumping from the South Fork Sangamon River."

Lake Springfield Scenarios

The alternative values of the five drought variables associated with the Lake Springfield analysis can be combined into 96 possible drought scenarios. Of these 96 possible combinations, fourteen scenarios were analyzed; and these are described in table 11. The scenarios include all four different lake storage capacities, representing the lake's total storage capacity for the years 1984,1990, 2025, and 2040; the impact on yield of minimum acceptable pool elevations of 530,547, and 550 feet msl; and the impact on yield of the construction of Hunter Lake. The reduction in yield cause by not using the South Fork pump station was examined in one scenario (scenario C). The impact of lake drawdown at the onset of a drought is evaluated by comparing the available yield from the lake at full pool elevation (559.35 feet msl) with the yield from the lake with the pool drawn down 2 feet (557.35 feet msl) at the beginning of a drought.

The 14 different scenarios were chosen to isolate the impact of specific variables. Any of the remaining 82 possible drought scenarios can be evaluated by comparing the impact of an isolated variable among similar scenarios and then adding or subtracting the impact of a specific variable on one of the 14 given scenarios.

Hunter Lake Scenarios

The two variables examined in the Hunter Lake scenarios are the lake storage capacity (addressing the decrease in total storage due to sedimentation) and the lake drawdown at the onset of a drought. The alternative values of these two variables could be combined into six possible drought scenarios. Of these, four drought scenarios for Hunter Lake were examined (table 12). In combination with the 96 possible scenarios that could be developed from the data on Lake Springfield, literally hundreds of individual combinations could be generated from the data presented.

Drought Probabilities

This investigation reviewed statistical drought recurrences of 10, 25, 50, and 100 years. The inverse of the recurrence interval is the drought frequency, which represents the probability of the drought occurrence in any given year. Therefore the recurrences examined by this investigation correspond to an annual probability of occurrence of 10, 4, 2, and 1 %, respectively. Of further concern to resource planning is the probability of an extreme event occurring during a given planning period. The probability Z that an extreme event of a given recurrence interval T will be exceeded in a planning period of N years is determined from equation 10:

$$Z = 1-(1-(1/T))^N \quad (10)$$

Table 11. Lake Springfield Drought Scenarios

Scenario	Variable					Pool level simulation
	(1)	(9)	(3)	(4)	(5)	
A	1984	None	Yes	No	559.35	Yes
B	1990	None	Yes	No	559.35	Yes
C	1990	None	No	No	559.35	Yes
D	1990	547.0	Yes	No	559.35	No
E	1990	550.0	Yes	No	559.35	No
F	1990	None	Yes	Yes	559.35	Yes
G	1990	547.0	Yes	Yes	559.35	Yes
H	1990	None	Yes	No	557.35	Yes
I	1990	547.0	Yes	No	557.35	No
J	1990	None	Yes	No	557.35	No
K	1990	547.0	Yes	No	557.35	No
L	2025	None	Yes	No	559.35	Yes
M	2025	None	Yes	Yes	559.35	No
N	2040	None	Yes	No	559.35	Yes

Description of Variables **NOTES:**

Variable 1: Lake capacity	Capacity is estimated for years 1990, 2025, and 2040 based on changes due to sedimentation and dredging.
Variable 2: Minimum allowed pool elevation (feet msl)	None - The entire lake capacity is available for withdrawal.
Variable 3: Use of South Fork pump station	Yes - The station is used, and the diversion rate is equal to the maximum available, given the practical limits of the pump station. No - No pumping occurs.
Variable 4: Effect of Hunter Lake on pumping	Yes - The effect of Hunter Lake on pumping from the South Fork station is simulated. No - The effect is not simulated.
Variable 5: Pool elevation at drought onset	559.35 - Simulation of the drought begins at normal pool, 557.35 - Simulation begins with pool drawn down 2 feet.
Pool level simulation	Yes - Simulated pool levels for this scenario are provided in the appendix.

Table 12. Hunter Lake Drought Scenarios

Scenario	Variable		Pool level simulation
	(1)	(5)	
O	1990	571.0	Yes
P	1990	569.0	Yes
Q	2025	571.0	Yes
R	2040	571.0	Yes

Description of Variables NOTES:

Variable 1: Lake capacity	1990 volume represents the initial lake capacity, estimated from design data. Volumes for 2025 and 2040 represent conditions 35 and 50 years after construction, respectively, and are estimated by projecting sedimentation rates.
Variable 5: Pool elevation at drought onset	571.0- Simulation of the drought begins at normal pool, 569.0 - Simulation begins with pool drawn down 2 feet.
Pool level simulation	Yes - Simulated pool levels for this scenario are provided in the appendix. All scenarios use the entire lake volume, with no draft from the lake, and no restrictions on minimum pool elevation.

Equation 10 and table 13 can be used to determine the probability of the occurrence of various droughts within a given time period. For example, the 50-year drought has a 2% or 1-in-50 chance of occurring in any given year and a 39.7% chance of occurring within the next 25 years. The statistical probability that the 100-year drought will occur within a 25-year or 50-year planning period is 22.2% and 39.5%, respectively (table 13). Therefore there is a 1-in-4.5 chance that within the next 25 years a drought equal to or worse than the 100-year drought will occur, and a 1-in-2.5 chance that it will occur within the next 50 years. These probabilities remain constant over time and are not dependent on the number of years since the last occurrence of the particular drought of interest. Therefore, although the 1953-1954 drought's 18- and 30-month durations had recurrence intervals of approximately 100 years, and although this drought occurred only 40 years ago, the probability of a similar event recurring in the future remains constant. From table 13 it can be seen that in any given year, a 100-year drought similar to the 1953-1954 drought of record (18- and 30-month durations) has a probability of occurrence of 1.0%, and within the next 50 years the probability of occurrence is 39.5%. Figure 8 graphically illustrates the probability of various droughts occurring within a 10-, 25-, and 50-year planning period.

Table 13. Probability that an Extreme Event of a Given Recurrence Interval Will Be Equaled or Exceeded during a Given Planning Period (percent)

Recurrence Interval (years)	1 year	Planning period			
		10 years	25 years	50 years	100 years
1	100.0	100.0	100.0	100.0	100.0
10	10.0	65.1	92.8	99.5	100.0
25	4.0	33.5	64.0	87.0	98.3
50	2.0	18.3	39.7	63.6	86.7
100	1.0	9.6	22.2	39.5	63.4

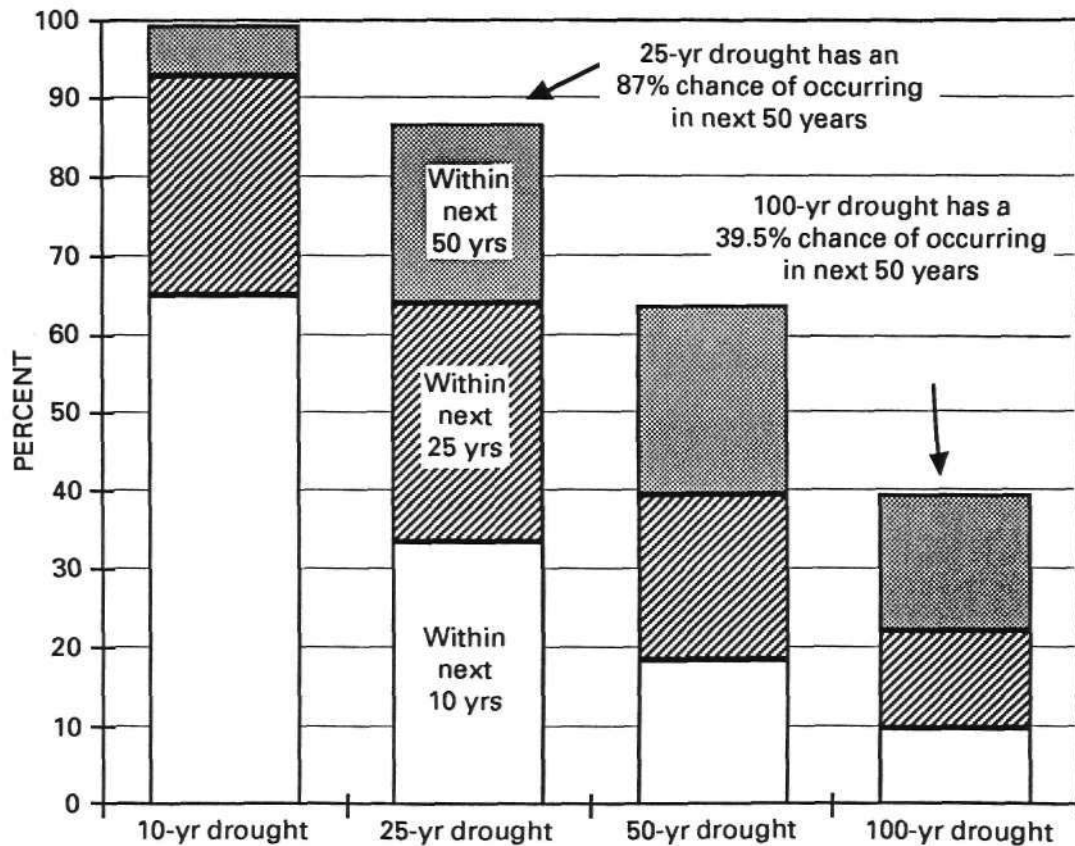


Figure 8. Probability of drought occurrence within specific planning periods

YIELD CALCULATIONS AND POOL LEVEL SIMULATIONS

Yield Calculation Model

The yield of a lake is determined as the difference between the available sources of water and the system losses. The yield includes the variables of inflow, outflow, and storage in the lake. The variables considered in this analysis are shown schematically in figure 2. Basically, the sources of water to the system are established for a specific time interval under consideration: inflow to the lake from runoff from the watershed, the quantity of water held in storage in the lake and the supplemental inflow from the diversion of South Fork water at the city's pump station. Subtracted from the total sources of water are the loss components of seepage, leakage, and evaporation. The resulting value represents the net yield of the lake, which is the quantity of water available for use over the time interval under consideration. Each yield scenario investigated by this analysis consisted of a matrix of 30 different droughts representing six durations and five recurrence intervals. A microcomputer-based analytical model was developed, which calculated the net yield of the lake for any combination of scenarios related to the model input variables. This model allowed the relatively rapid recalculation of the lake's net yield for various drought scenarios and the determination of the significance of changes in input variables such as total lake storage capacity on the resulting net yield of the lake. This model will be valuable for future studies of the yield of Lake Springfield and Hunter Lake, in considering additional planning scenarios, and in testing the impact of changing input variables related to lake inflow, outflow, operational constraints, and management options.

Pool Level Simulation Model

A second analytical tool developed by this investigation was a lake response model that simulated the remaining lake storage capacity and pool elevation at the end of each of the 30 different droughts for each planning scenario. In this model the consumptive use of water by the city's water treatment plant and electric power plant were added to the other losses associated with evaporation, seepage, and leakage to determine the net draft on the lake for each of the 30 droughts. Net draft on the lake was calculated and subtracted from available sources of water (inflow, diversion, and lake storage) to determine the volume of water remaining in the lake at the end of each of the droughts. An input file containing the measured lake stage capacity distribution from the 1984 sedimentation survey and the calculated values for the years 1990, 2025, and 2040 were used by the simulation model to determine the pool elevation of Lake Springfield at the end of each of the 30 different drought recurrence intervals and durations. A similar stage capacity distribution file was

used by the simulation model to assess the pool elevation response of Hunter Lake. The data on Hunter Lake were developed from the design data for this lake and the estimated future volume losses and remaining capacity in the years 2025 and 2040.

RESULTS

Net Yields

Lake Springfield

In this analysis, 14 scenarios addressing five different variables related to Lake Springfield were considered (table 11). The variables are: lake capacity, lake pool level at the onset of drought, operational constraints related to minimum acceptable lake drawdown, diversion from the South Fork, and the impact of the construction of Hunter Lake on the quantity of water available for diversion from the South Fork. In all scenarios it was assumed that seepage to ground water, dam seepage, and gate leakage would not change. The yield results for the various droughts-considered in the 14 scenarios are presented in the appendix to this report.

To evaluate the impact of the various scenarios, it is useful to compare the impact of changes in the system with present baseline conditions related to the operation of the lake, its current volume, and the current available supplemental supply from the South Fork pump station. Scenario B is representative of the current baseline conditions, assuming the entire volume of the lake is available for use. The lowest net yield in this scenario (37.5 mgd) occurs during the 100-year drought at a duration of 18 months. The 100-year drought of 30-month duration would result in a net yield of 39.1 mgd. The lowest net yield for the 1953-1954 simulated drought conditions is 39.0 mgd, at a duration of 18 months.

The impact of imposing operational constraints on the minimum allowed lake pool level during a drought can be determined by comparing the results of scenario B with scenario E. In scenario E the minimum allowed lake elevation is 550.00 feet msl, which results in decreases in net yield of approximately 14 and 9 mgd for the 18- and 30-month durations, respectively. Therefore, constraining the minimum lake elevation at 550.00 feet msl will result in an 18-month yield of 24.6 mgd for the 1953-1954 simulated drought conditions, which is 63% of the yield available from utilizing the entire lake capacity. The 18-month, 100-year drought yield at the constrained minimum pool level is 25.0 mgd, which represents 64% of the yield available from the assumed baseline conditions. A restriction on the allowed minimum lake pool elevation of 547 feet msl (scenario D) will result in a higher yield than scenario E. The 18-month, 100-year drought yield for scenario D is approximately 10 mgd less than if the entire lake capacity is available (table 14).

Table 14. Lake Springfield Yields during Low Frequency 18-Month (Critical Duration) Droughts, with and without a Restriction on Minimum Lake Elevation (mgd)

Drought frequency	1990		2025		2040	
	547 msl min.*	No min eley.#	547 msl min.	No min elev.	547 msl min.	No min eley.
50-year	37.6	47.2	34.4	44.0	33.0	42.6
100-year	29.4	39.1	26.2	35.9	24.8	34.5
1953-1954 drought	29.0	39.0	25.8	35.8	24.4	34.4

NOTES:

- (1) Yield is based on lake capacity in the given year.
- (2) * Minimum allowed lake pool elevation of 547 feet msl, lake full at drought onset, no Hunter Lake, maximum available South Fork pumpage.
- (3) # No minimum lake pool elevation, lake full at drought onset, no Hunter Lake, maximum available South Fork pumpage.

The benefits of the operation of the South Fork pump station to the available net yield from Lake Springfield can be determined by comparing the results of scenario C with scenario B. Scenario C assumes that no water would be diverted to Lake Springfield from the South Fork, which resulted in a 30-month yield for the simulated 1953-1954 drought of 24.4 mgd, which is 61% of the yield available from the lake with the additional water supplied by the South Fork pump station. Comparison of the two scenarios shows that the use of the pump station will shift the duration of lowest yield and the timing of drought recovery from 30 months to 18 months for nearly all drought recurrences.

The yield results presented in the appendix can be used to compare the impact of various scenarios on the drought yield by isolating the effects of specific variables on net yield. For the convenience of the reader, table 15 shows the specific impacts of each of the variables on the yield of Lake Springfield during all drought conditions reviewed by this analysis. This table is constructed as a worksheet that can be used to calculate the available yield from the lake for any of the 96 possible combinations of the five drought variables considered by this research. In this table the current baseline conditions are defined as: Lake Springfield at full pool at drought onset, no restrictions on minimum lake elevation, present 1990 capacity, full use of the South Fork pump station, and no second lake. To determine the effects of the construction of Hunter Lake on the available supplemental supply of water from the South Fork River and the resulting net yield of Lake Springfield,

Table 15. Lake Springfield Drought Scenario Worksheet

Recurrence interval and duration	(1) Baseline conditions	(2) Effect of dredging	(3) No SF pumping	(4) 547 feet msl	(5) 550 feet msl	(6) Hunter Lake	(7) Down 2 at onset	(8) 2025 capacity	(9) 2040 capacity	(10)
10-year										
6-month	97.8	2.5	7.1	27.6	40.4	1.9	13.7	9.6	13.7	_____
9-month	91.1	1.7	22.0	18.3	26.9	3.9	9.2	6.4	9.2	_____
12-month	97.8	1.3	32.3	13.7	20.1	3.9	6.9	4.8	6.9	_____
18-month	90.9	0.8	33.6	9.4	13.7	3.2	4.6	3.2	4.6	_____
30-month	115.4	0.5	49.1	5.7	8.2	1.9	2.7	1.9	2.7	_____
54-month	182.1	0.3	80.8	3.2	4.6	1.3	1.5	1.1	1.5	_____
25-year										
6-month	91.1	2.5	2.7	27.8	40.6	1.0	13.7	9.6	13.7	_____
9-month	71.5	1.7	8.4	18.5	27.0	1.9	9.2	6.4	9.2	_____
12-month	72.6	1.3	18.7	13.8	20.2	2.6	6.9	4.8	6.9	_____
18-month	60.1	0.8	18.7	9.5	13.9	3.2	4.6	3.2	4.6	_____
30-month	72.6	0.5	33.6	5.8	8.4	5.2	2.7	1.9	2.7	_____
54-month	106.6	0.3	51.1	3.3	4.8	3.9	1.5	1.1	1.5	_____
50-year										
6-month	88.8	2.5	1.3	27.9	40.8	0.6	13.7	9.6	13.7	_____
9-month	65.3	1.7	5.0	18.5	27.1	1.1	9.2	6.4	9.2	_____
12-month	60.2	1.3	11.0	13.9	20.3	1.3	6.9	4.8	6.9	_____
18-month	47.2	0.8	11.6	9.6	14.0	2.6	4.6	3.2	4.6	_____
30-month	53.8	0.5	22.6	5.9	8.5	3.9	2.7	1.9	2.7	_____
54-month	71.1	0.3	29.7	3.3	4.8	5.2	1.5	1.1	1.5	_____
100-year										
6-month	87.4	2.5	0.3	27.9	40.8	0.2	13.7	9.6	13.7	_____
9-month	61.8	1.7	2.6	18.6	27.1	0.7	9.2	6.4	9.2	_____
12-month	53.5	1.3	7.1	14.0	20.4	0.6	6.9	4.8	6.9	_____
18-month	39.1	0.8	7.1	9.7	14.0	0.6	4.6	3.2	4.6	_____
30-month	37.5	0.5	12.9	6.0	8.6	1.3	2.7	1.9	2.7	_____
54-month	46.4	0.3	18.7	3.4	4.9	2.6	1.5	1.1	1.5	_____

Table 15. Concluded

Recurrence interval and duration	(1) Baseline conditions	(2) Effect of dredging	(3) No SF pumping	(4) 547 feet msl	(5) 550 feet msl	(6) Hunter Lake at onset	(7) Down 2'	(8) 2025 capacity	(9) 2040 capacity	(10)
1953-1954 drought										
6-month	87.7	2.5	0.8	28.0	40.9	0.4	13.7	9.6	13.7	_____
9-month	63.0	1.7	4.0	18.8	27.4	1.0	9.2	6.4	9.2	_____
12-month	54.0	1.3	7.1	14.1	20.6	0.6	6.9	4.8	6.9	_____
18-month	39.0	0.8	8.4	10.0	14.4	0.6	4.6	3.2	4.6	_____
30-month	40.0	0.5	15.5	6.2	8.9	1.3	2.7	1.9	2.7	_____
54-month	58.6	0.3	27.8	3.6	5.1	3.2	1.5	1.1	1.5	_____

Description of variables:

- (1) Baseline conditions = 1990 lake volume after dredging, lake at full pool at drought onset, no restrictions on the minimum pool level, maximum available pumping from the South Fork station, and no Hunter Lake.
- (2) Effects of drainage: subtract from (1) to determine the yield prior to the recent dredging.
- (3) No SF pumping: subtract from (1) to determine the yield without any pumping from the South Fork station.
- (4) 547 feet msl: subtract from (1) to determine the yield with this restriction on the minimum lake elevation.
- (5) 550 feet msl: subtract from (1) to determine the yield with this restriction on the minimum lake elevation.
- (6) Hunter Lake: subtract from (1) to determine the reduced yield of Lake Springfield associated with Hunter Lake's impact on South Fork pumping.
- (7) Down 2' at onset: subtract from (1) to determine the yield with the lake drawn down at the start of the drought.
- (8) 2025 capacity: subtract from (1) to determine the yield available in 2025 after 35 years of sedimentation.
- (9) 2040 capacity: subtract from (1) to determine the yield available in 2040 after 50 years of sedimentation.
- (10) This column provided for calculating yield for each new scenario.

subtract the effects of the presence of the second lake (column 6) from the baseline conditions (column 1). The presence of Hunter Lake will decrease the available net yield from Lake Springfield during the 18-month, 100-year drought by 0.6 mgd as compared to the baseline conditions, for a total available yield of 38.5 mgd.

Hunter Lake

In this analysis four scenarios addressing two different variables related to Hunter Lake were considered. These variables, given in table 12, include the impacts of future sedimentation and volume loss, and lake pool levels at the drought onset. All scenarios assumed that seepage to ground water, dam seepage, and gate leakage would not change. The yield results for the various droughts considered in the four scenarios are presented in the appendix to this report.

Scenario O is used to represent the baseline conditions related to lake capacity, pool elevation at the onset of drought, and no transfer of water to Lake Springfield. This scenario shows that the critical-duration drought of low net yield is 30 months for all recurrences. The lowest net yield for this scenario is 18.5 mgd in the 30-month drought of record that simulates conditions during 1953-1954 (table 16). In general most of the scenarios exhibited the lowest net yield during the 30-month duration droughts.

As discussed in the previous section on the yield results for Lake Springfield, the yield results in the appendix can be used to compare the impact of various scenarios on

Table 16. Hunter Lake Yields during Low Frequency Droughts of 18- and 30-Month Duration (mgd)

Drought frequency	1990		2025		2040	
	18-mo.	30-mo.	18-mo.	30-mo.	18-mo.	30-mo.
50-year	28.8	22.6	27.3	21.7	26.6	21.3
100-year	27.1	18.8	25.5	17.9	24.9	17.5
1953-1954 drought	26.1	18.5	24.6	17.6	23.9	17.2

NOTES: (1) Yield is based on lake capacity in the given year.

(2) No restrictions were place on minimum lake pool elevation, and the lake was assumed full at drought onset.

net yield by isolating the effects of specific variables on the yield. A calculation worksheet is presented in table 17, making it possible to combine and construct six different scenarios from the data presented.

Pool Level Response Simulation

The change in pool levels driven by the demands on the lakes during drought can have a significant impact on the operation of the power and water plants as well as on recreational uses of the lake. The lake simulation model developed by this research is capable of predicting pool level response to any combinations of variables used in this yield analysis. Eleven simulation runs were performed: seven runs for Lake Springfield and four runs for Hunter Lake. Pool level simulation runs were not performed for scenarios that place a restriction on minimum allowed lake pool elevation, since these scenarios were developed to determine the maximum net yield available with these restrictions.

To simulate the pool level response during droughts, it is necessary to establish a draft rate on the lake that represents consumptive withdrawals by the municipal utilities: All the simulations for Lake Springfield assumed that the municipal water and power plant drafts were 20 and 5 mgd, respectively. In simulating the response of Hunter Lake, four scenarios assumed no demand on the lake for water use, and two scenarios were constructed to simulate the response of the lake to the transfer of water to Lake Springfield. Initial simulation runs indicated that the simulated draft rate in nearly all the planning scenarios would not completely utilize the lake capacity during the droughts considered. Therefore the average evaporative area of the lake will be larger than the 65% of normal pool area typically used in yield analyses. An average lake evaporative surface area equivalent to 90% of the area at normal pool elevation was selected for the lake pool level simulations. This value should tend to slightly overestimate total evaporation from the lake in most planning scenarios.

Two simulations related to Lake Springfield are presented in figures 9 and 10. Figure 9 is a simulation of scenario B which represents current baseline conditions. Scenario C (figure 10) shows the effect of no diversion of water from the South Fork. Comparison of these figures shows that without the use of diverted water from the South Fork, the lake would be depleted during the 100-year and 1953-1954 droughts (figure 10) and that a 50-year drought would draw the lake down to an elevation of 547 feet msl at the 30-month duration. The simulation for scenario C indicates that the pool elevation of utility operational difficulty (547 feet msl) would occur approximately 15 months into the 100-year and 1953-1954 droughts. In contrast, the effects of using the South Fork pump station shown in figure 9 (scenario B) indicate that for the droughts considered, the lake will

Table 17. Hunter Lake Drought Scenario Worksheet

Drought frequency and duration	(D) Baseline conditions	(2) Lake 2 feet down at onset	(3) 2025 capacity	(4) 2040 capacity	(5)
10-year					
6-month	78.5	9.5	4.7	6.6	_____
9-month	57.1	6.3	3.1	4.4	_____
12-month	50.0	4.7	2.3	3.3	_____
18-month	39.5	3.2	1.6	2.2	_____
30-month	39.4	1.9	0.9	1.3	_____
54-month	52.2	1.1	0.5	0.7	_____
25-year					
6-month	77.2	9.5	4.7	6.6	_____
9-month	53.7	6.3	3.1	4.4	_____
12-month	43.8	4.7	2.3	3.3	_____
18-month	31.8	3.2	1.6	2.2	_____
30-month	27.2	1.9	0.9	1.3	_____
54 -month	32.5	1.1	0.5	0.7	_____
50-year					
6-month	76.7	9.5	4.7	6.6	_____
9-month	52.2	6.3	3.1	4.4	_____
12-month	41.4	4.7	2.3	3.3	_____
18-month	28.8	3.2	1.6	2.2	_____
30-month	22.6	1.9	0.9	1.3	_____
54-month	25.1	1.1	0.5	0.7	_____
100-year					
6-month	76.5	9.5	4.7	6.6	_____
9-month	51.6	6.3	3.1	4.4	_____
12-month	40.0	4.7	2.3	3.3	_____
18-month	27.1	3.2	1.6	2.2	_____
30-month	18.8	1.9	0.9	1.3	_____
54-month	18.6	1.1	0.5	0.7	_____
1953-1954 drought					
6-month	76.4	9.5	4.7	6.6	_____
9-month	51.4	6.3	3.1	4.4	_____
12-month	40.1	4.7	2.3	3.3	_____
18-month	26.1	3.2	1.6	2.2	_____
30-month	18.5	1.9	0.9	1.3	_____
54-month	20.1	1.1	0.5	0.7	_____

- (1) Baseline conditions: 1990 lake volume, lake at full pool at drought onset, no transfer to Lake Springfield, no minimum pool elevations.
- (2) Effect when the lake is down by 2 feet at the onset of the drought. Subtract from (1) to determine yield.
- (3) 2025 capacity, after 35 years of sedimentation: subtract from (1) to determine yield.
- (4) 2040 capacity, after 50 years of sedimentation: subtract from (1) to determine yield.
- (5) Column provided for calculating new yield scenarios.

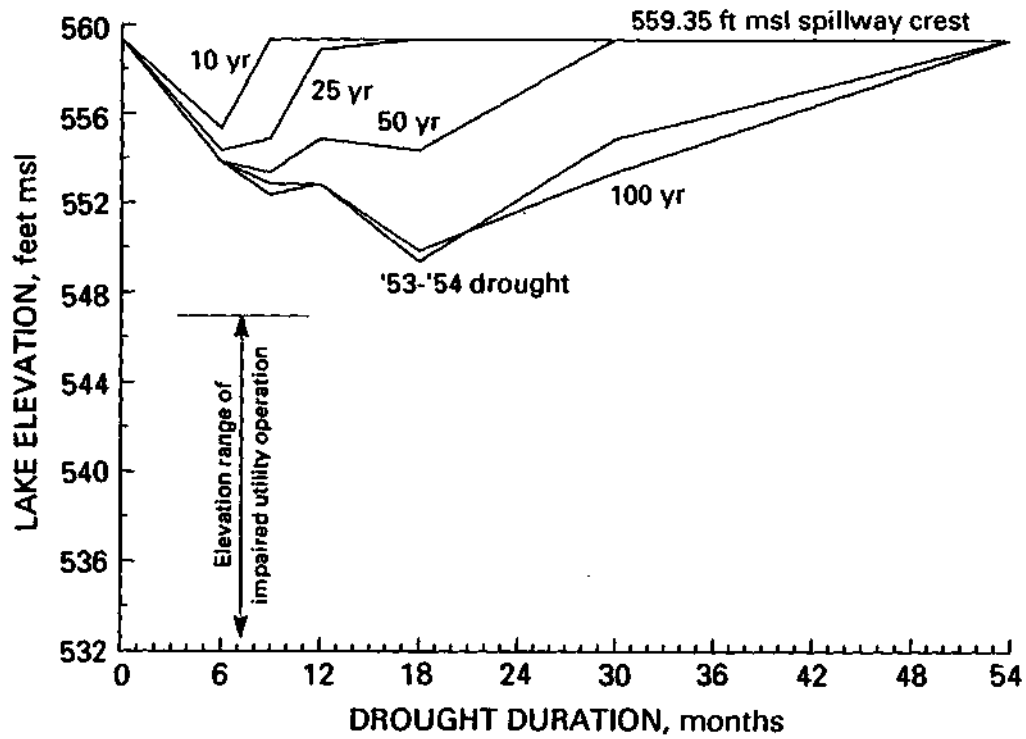


Figure 9. Lake Springfield pool level simulations, scenario B (25.45 mgd average draft, 1990 capacity, no minimum pool, South Fork pumping, no Hunter Lake, lake full at onset)

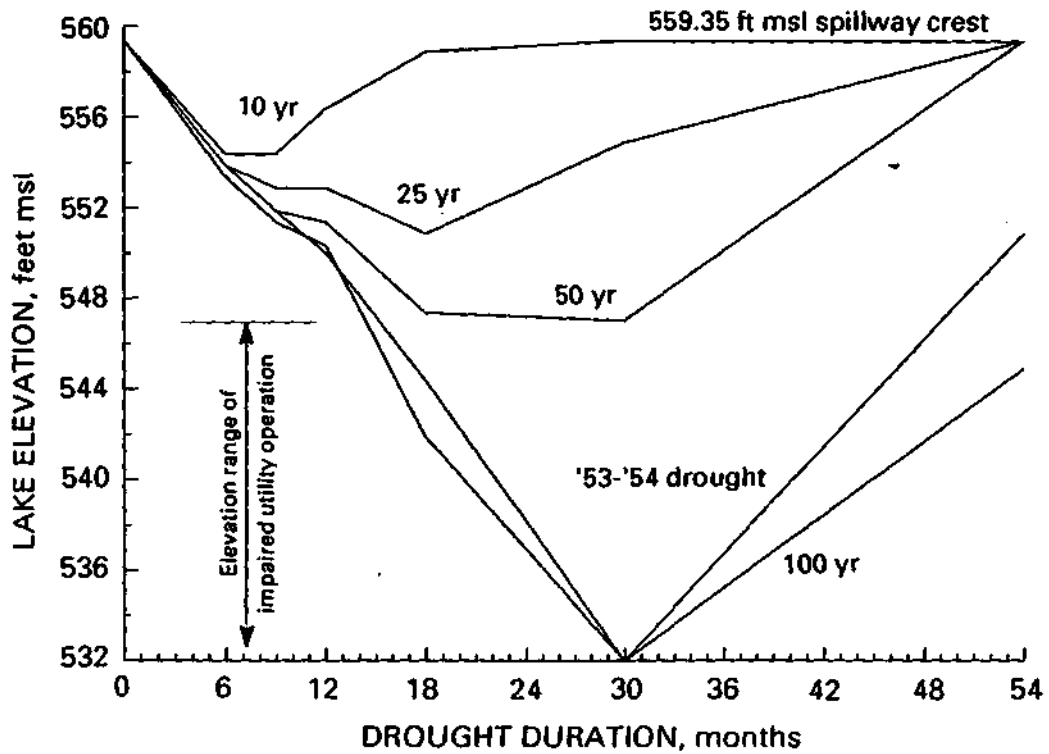


Figure 10. Lake Springfield pool level simulations, scenario C (25.45 mgd average draft, 1990 capacity, no minimum pool, no South Fork pumping, no Hunter Lake, lake full at onset)

remain well above 547-feet msl elevation given the demand assumptions used in this simulation.

Two simulation results for Hunter Lake are shown in figures 11 and 12. Figure 11 demonstrates the response of the lake during the various droughts considered with no draft on the lake (scenario O). Comparing these figures shows that the level of Hunter Lake will drop by approximately 2 feet due to evaporative and miscellaneous losses (figure 11).

The remaining lake response simulations for Hunter Lake and Lake Springfield are presented in the appendix.

Draft and Minimum Lake Elevation

The results of the yield calculation and lake pool level simulation models were combined for the purpose of predicting the minimum lake elevations that would result from various draft rates. Essentially, scenarios A, B, L, N, O, Q, and R were run for various lake capacities to determine the lowest net yield and the corresponding drought durations possible from a volume of the lake contained above a set elevation. The average evaporative area of each lake was adjusted in each simulation run to equal 65% of the lake area above the set elevation. This analysis was performed based on lake stage-capacity relationships for the years 1984, 1990, 2025, and 2040 to simulate the effects of capacity loss on minimum lake level. This analysis was intended to demonstrate the highest average demand that could be placed on the lakes for any given desired minimum lake elevation. The 100-year recurrence drought was selected for this analysis, and the results are presented in graphic form in figures 13 and 14.

To determine the maximum average draft available from the lakes, given a set of minimum allowed pool elevations, enter the graphs from the vertical y-axis at the elevation of interest and read to the right to the intersection with the lake capacity curves to determine the draft. For example (figure 13), if the minimum elevation of interest is 547 feet msl, Lake Springfield could provide approximately 29 mgd with its 1990 capacity. For the same elevation and the estimated future capacity anticipated for the year 2040, the draft decreases to approximately 26 mgd, demonstrating the effects of capacity loss on the lake yield. These graphs can also predict the minimum lake elevation anticipated for the 100-year drought for a given draft rate and lake storage capacity. For example, the current demand of 25.45 mgd would result in a minimum elevation in Lake Springfield of approximately 550 feet msl (9 feet below the spillway) with the 1990 lake capacity, and 548 feet msl (11 feet below the spillway) with the anticipated capacity in 2040.

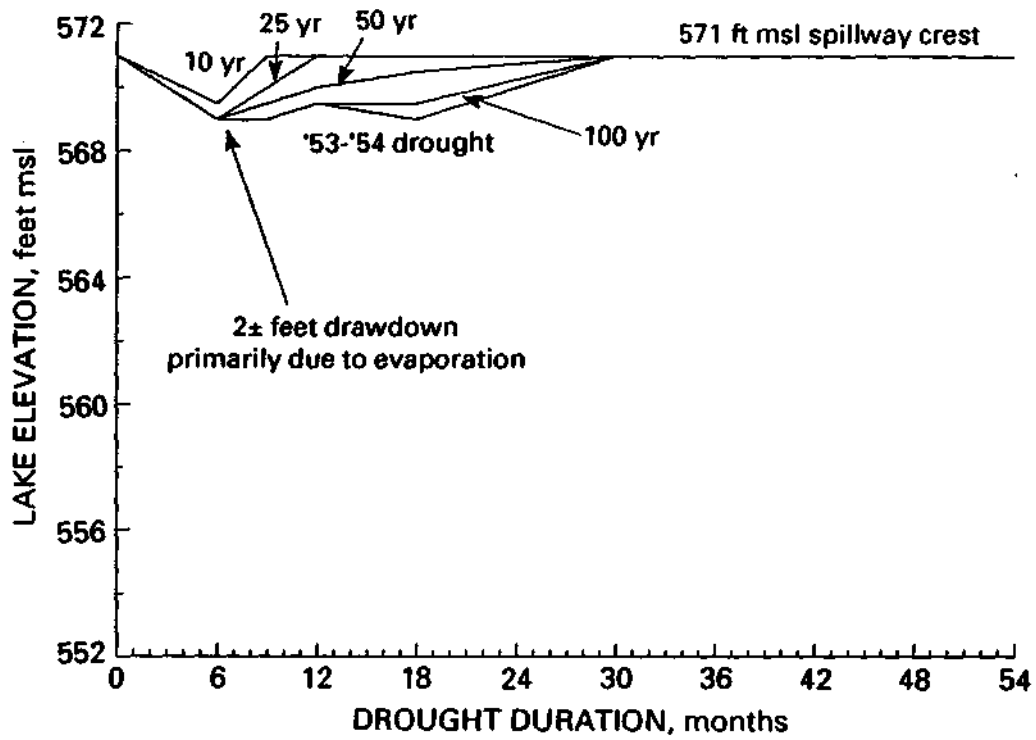


Figure 11. Hunter Lake pool level simulations, scenario O (no draft, 1990 capacity, lake full at onset)

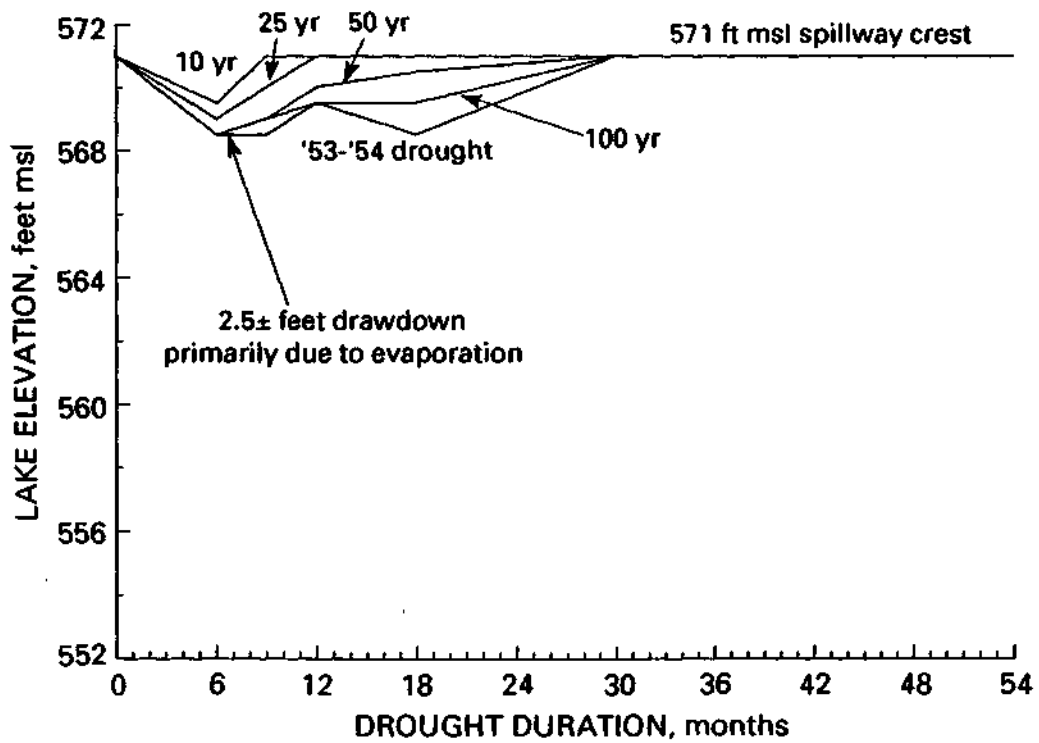


Figure 12. Hunter Lake pool level simulations, scenario R (no draft, 2040 capacity, lake full at onset)

The minimum lake elevation over the duration of a drought will depend on the draft rate imposed on the lake. In general, for the 100-year frequency drought the minimum elevation in Lake Springfield will be reached in 6 to 9 months at draft rates less than 20 mgd'. At medium draft rates of 20 to 35 mgd the minimum elevation will be reached in approximately 18 months. At higher draft rates in excess of 35 mgd the minimum elevation will be reached in approximately 30 months. In Hunter Lake the lowest lake levels during the 100-year drought will occur at 6 to 9 months for low drafts (less than 2 mgd), at approximately 18 months for medium drafts (2 to 5 mgd), and at 30 to 54 months for relatively high drafts (greater than 5 mgd).

Figures 13 and 14 show that the available net yield of the lakes will decrease over time. Lake Springfield has gained approximately 0.5 mgd in maximum net yield during the 100-year drought as a result of the recent lake dredging project. The increase can be observed (figure 13) in the relative position of the lake capacity curves for 1984 and 1990: for any given draft the resulting minimum lake elevation is higher for 1990 conditions than for 1984 conditions.

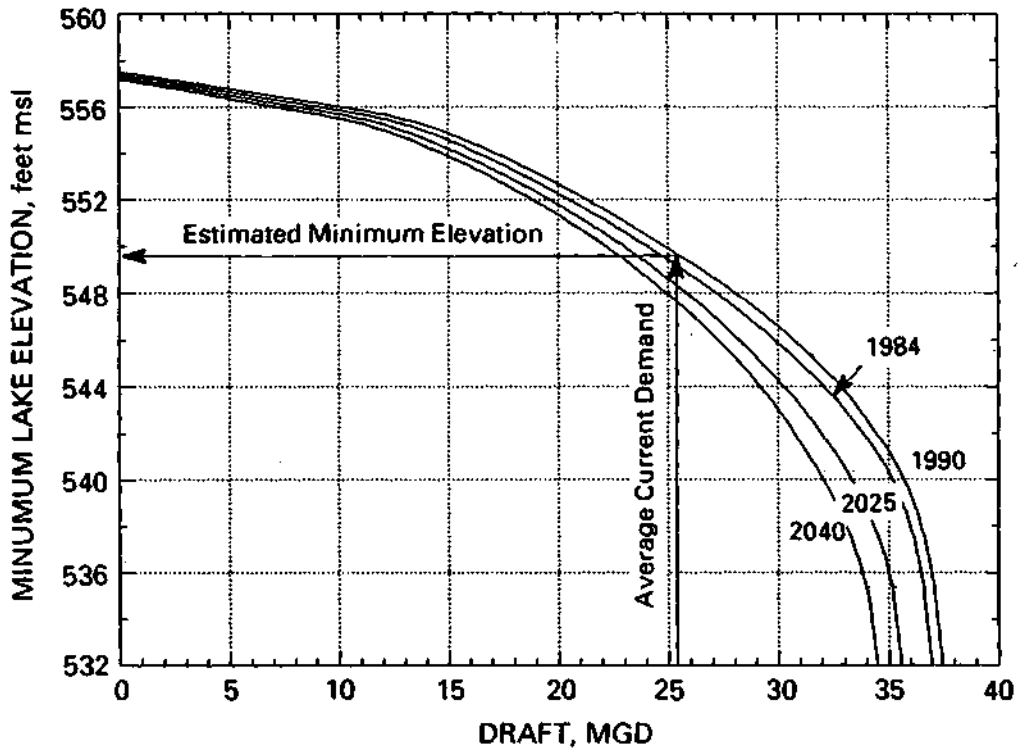


Figure 13. Simulation of minimum elevation for Lake Springfield versus draft during the 100-year drought (South Fork pumping, no Hunter Lake, lake full at onset)

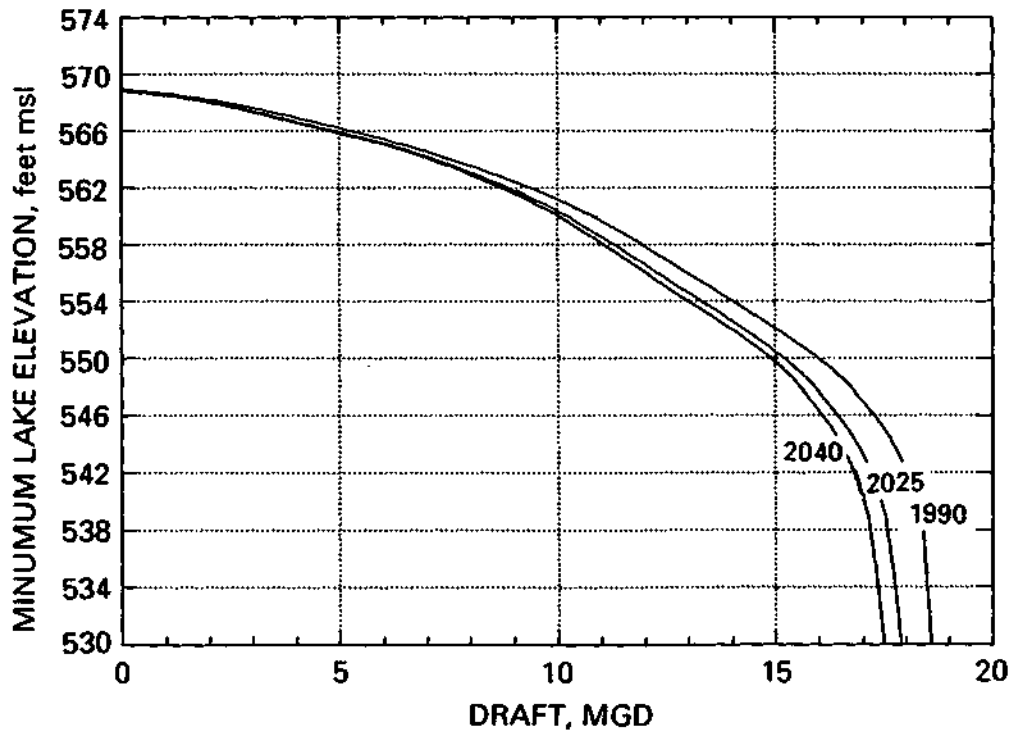


Figure 14. Simulation of minimum elevation for Hunter Lake versus draft during the 100-year drought (no draft, lake full at onset)

CONCLUSIONS

The critical drought for Lake Springfield is the 18-month duration in nearly all recurrences. The critical drought defines the drought duration that will place the greatest demands on the lake and the point at which the net yield available from inflow to the lake in combination with in-lake storage will be lowest. Given the present storage capacity of the lake and the utility operational restrictions related to minimum acceptable pool elevation (547 feet msl), the 100 year and the 1953-1954 critical yields (18-month duration) are 29.4 and 29.0 mgd, respectively (scenario D). Sedimentation will continue to deplete the storage capacity of Lake Springfield. An examination of table 15 indicates that in 35 years, given the same limitations on minimum lake elevation (547 feet msl), the 100-year and 1953-1954 critical yields (18-month duration) will be reduced to 26.2 and 25.8 mgd, respectively. Under the same pool level restrictions, the effects of sedimentation by the year 2040 will result in 100-year and 1953-1954 critical yields (18-month duration) of 24.8 and 24.4 mgd, respectively. These results do not consider operational alternatives for increasing the critical yield of the lake, such as recycling of ash-handling water from the power plant or extending the ability of the power and water plants to operate with lower lake levels.

The critical drought for Hunter Lake is the 30-month duration in nearly all of the recurrences reviewed in this analysis. With the present design storage capacity of the lake and no restrictions on the minimum pool elevation, the 100-year and 1953-1954 critical yields (30-month duration) are 18.8 and 18.5 mgd, respectively (scenario O). Sedimentation will also reduce the available yield from Hunter Lake, with the result that the 35- and 50-year impacts of sedimentation will reduce the critical yields by 0.9 and 1.3 mgd, respectively, during the 100-year drought (30-month duration).

The critical drought for the two-lake system is the 30-month duration, when the supplemental supply from the South Fork pump station is reduced slightly due to the construction of Hunter Lake. The minimum combined yields during the critical drought from the two lakes, given the present lake capacities and a minimum lake level of 547 feet msl on Lake Springfield, are 50.1 and 51.0 mgd during the 100-year and 1953-1954 droughts (30-month duration), respectively. The combined yields of the two lakes for droughts of low frequency and longer duration, with the present and future lake capacities, are presented in table 18.

Table 18 shows that the combined yield of the two lakes is more than sufficient to supply the current demand of approximately 25 mgd. Note that the combined yields presented in table 18 are the simple sums of the individual lake yields. Given the different sizes of the lakes and the contributing watersheds and the differences in the critical

duration drought between the two lakes, the available yield of the two-lake system could be increased by selectively withdrawing water from each lake during a drought to optimize the combined yield. In addition, potential future regulations related to minimum release rates from Hunter Lake and possible restrictions on minimum pool drawdown in the lakes may impact the available yield of the two-lake system.

The combined yield of the two lakes for other planning scenarios and droughts can be determined by summing the yield results for compatible scenarios developed in the drought yield worksheets or the data presented in the appendix.

Table 18. Combined Yields of Lake Springfield and Hunter Lake (mgd)

Drought frequency	1990		2025		2040	
	18-month	30-month	18-month	30-month	18-month	30-month
50-year	63.8	66.6	59.0	63.8	57.0	62.6
100-year	55.9	49.0	51.1	46.2	49.1	45.0
1953-1954 drought	54.5	51.0	49.7	48.2	47.7	47.0

NOTES: (1) Combined yield is based on lake capacity in the given year.

(2) Yields are determined by the sum of the individual lake yields with a restriction of 547 feet msl on minimum allowed elevation of Lake Springfield.

APPENDIXES

Page 53	Lake Springfield and Hunter Lake Yield Results
Page 55	Pool Level Simulation Plots

Lake Springfield and Hunter Lake Yield Results (mgd)

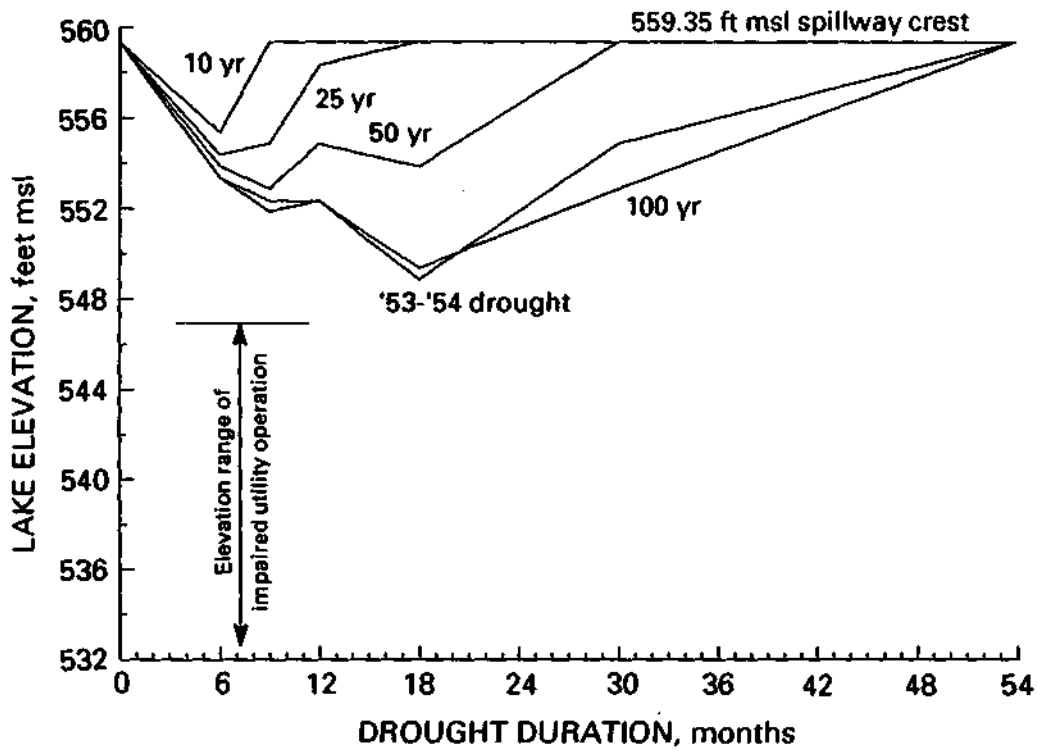
Recurrence interval and duration	Lake Springfield scenarios								
	A	B	C	D	E	F	G	H	I
10-year									
6-month	95.3	97.8	90.7	70.2	57.4	95.8	68.2	84.0	56.4
9-month	89.4	91.1	69.2	72.8	64.3	87.3	68.9	82.0	63.6
12-month	96.5	97.8	65.5	84.1	77.7	93.9	80.2	90.9	77.2
18-month	90.0	90.9	57.3	81.5	77.2	87.7	78.3	86.3	76.9
30-month	114.9	115.4	66.3	109.7	107.1	113.4	107.8	112.6	107.0
54-month	181.9	182.1	101.3	179.0	177.5	180.8	177.7	180.6	177.4
25-year									
6-month	88.6	91.1	88.4	63.3	50.5	90.2	62.4	77.4	49.6
9-month	69.8	71.5	63.0	53.0	<i>44.5</i>	69.5	51.1	62.3	<i>43.8</i>
12-month	71.3	72.6	53.9	58.8	52.4	70.0	56.2	65.7	51.9
18-month	59.2	60.1	41.3	50.5	46.2	56.8	47.3	55.5	46.0
30-month	72.1	72.6	<i>39.0</i>	66.8	64.2	67.4	61.6	69.8	64.0
54-month	106.3	106.6	55.5	103.3	101.8	102.7	99.4	105.0	101.7
50-year									
6-month	86.2	88.8	87.5	60.9	48.0	88.1	60.2	75.0	47.1
9-month	63.6	65.3	60.3	46.8	38.2	64.2	45.7	56.2	37.6
12-month	58.9	60.2	49.2	46.2	39.8	58.9	44.9	53.3	39.4
18-month	46.4	47.2	35.6	37.6	33.3	44.7	35.0	42.7	33.0
30-month	53.3	53.8	<i>31.2</i>	47.9	45.3	49.9	44.0	51.1	45.2
54-month	70.8	71.1	41.3	67.7	66.2	65.9	62.5	69.5	66.2
100-year									
6-month	84.8	87.4	87.0	59.4	46.6	87.2	59.2	73.6	45.7
9-month	60.1	61.8	59.2	43.3	34.7	61.1	42.6	52.7	34.1
12-month	52.3	53.5	46.4	39.6	33.1	52.9	38.9	46.7	32.7
18-month	38.2	39.1	31.9	<i>29.4</i>	<i>25.0</i>	38.4	28.7	34.5	24.8
30-month	37.0	37.5	24.6	31.6	28.9	36.2	30.3	34.8	28.8
54-month	46.1	46.4	27.7	43.1	41.6	43.8	40.5	44.9	41.5
1953-1954 drought									
6-month	85.2	87.7	86.9	59.7	46.8	87.3	59.3	74.0	46.0
9-month	61.3	63.0	59.0	44.3	35.7	62.1	43.3	53.9	35.1
12-month	52.7	54.0	46.9	39.9	33.4	53.4	39.2	47.1	33.0
18-month	38.2	39.0	30.6	29.0	24.6	38.4	28.4	34.4	24.4
30-month	39.4	40.0	24.4	33.7	31.0	38.7	32.5	37.2	31.0
54-month	58.3	58.6	30.8	55.0	53.5	55.4	51.8	57.1	53.5

NOTE: Lowest yield for each scenario and recurrence interval is highlighted in bold italics.

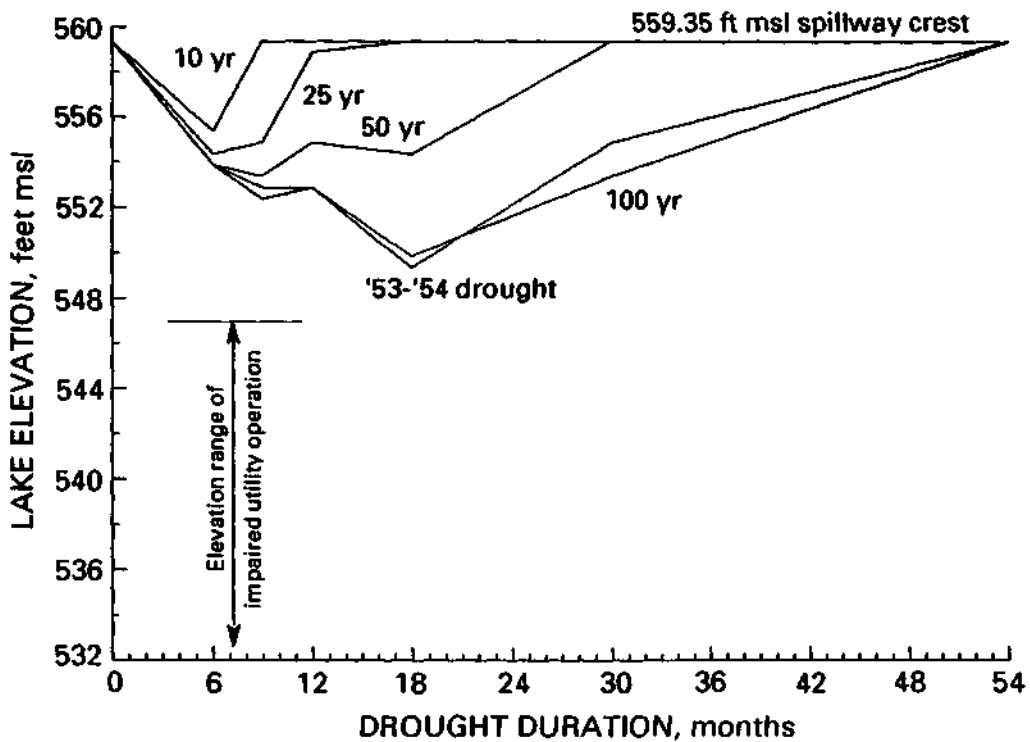
Lake Springfield and Hunter Lake Yield Results (mgd), Concluded

Recurrence interval and duration	Lake Springfield scenarios					Hunter Lake scenarios			
	J	K	L	M	N	O	P	Q	R
10-year									
6-month	82.1	54.5	88.1	86.2	85.0	78.5	69.0	73.8	71.9
9-month	78.1	59.8	84.7	80.8	82.0	57.1	50.8	54.0	52.7
12-month	87.0	73.3	93.0	89.1	90.9	50.0	45.3	47.7	46.7
18-month	83.1	73.7	87.7	84.5	86.3	39.5	36.3	37.9	37.3
30-month	110.7	105.0	113.5	111.5	112.6	39.4	37.5	38.4	38.0
54-month	179.3	176.1	181.1	179.8	180.6	52.2	51.1	51.6	51.4
25-year									
6-month	76.4	48.6	81.5	80.5	77.4	77.2	67.8	72.6	70.6
9-month	60.4	41.9	65.0	63.1	62.3	53.7	47.4	50.6	49.3
12-month	63.2	49.3	67.8	65.2	65.7	43.8	39.1	41.5	40.5
18-month	52.2	42.7	56.8	53.6	55.5	31.8	28.7	30.3	29.6
30-month	64.7	58.9	70.6	65.6	69.8	27.2	25.3	26.3	25.9
54-month	101.2	97.8	105.5	101.6	105.0	32.5	31.4	32.0	31.8
50-year									
6-month	74.4	46.5	79.1	78.5	75.0	76.7	67.2	72.1	70.1
9-month	55.1	36.5	58.9	57.8	56.2	52.2	45.9	49.1	47.8
12-month	52.0	38.1	55.3	54.1	53.3	41.4	36.6	39.0	38.1
18-month	40.1	30.5	44.0	41.4	42.7	28.8	25.6	27.3	26.6
30-month	47.2	41.3	51.9	48.0	51.1	22.6	20.7	21.7	21.3
54-month	64.4	61.0	70.0	64.8	69.5	25.1	24.1	24.6	24.4
100-year									
6-month	73.4	45.5	77.7	77.5	73.6	76.5	67.0	71.9	69.9
9-month	52.0	33.4	55.4	54.7	52.7	51.6	45.3	48.5	47.2
12-month	46.0	32.1	48.7	48.1	46.7	40.0	35.3	37.7	36.7
18-month	33.8	24.2	35.8	35.2	34.5	27.1	23.9	25.5	24.9
30-month	33.5	27.5	35.6	34.3	34.8	18.8	17.0	17.9	17.5
54-month	42.3	39.0	45.4	42.8	44.9	18.6	17.6	18.1	17.9
1953-1954 drought									
6-month	73.6	45.6	78.1	77.7	74.0	76.4	66.9	71.7	69.8
9-month	52.9	34.1	56.6	55.6	53.9	51.4	45.0	48.3	46.9
12-month	46.5	32.4	49.2	48.5	47.1	40.1	35.3	37.7	36.8
18-month	33.8	23.8	35.8	35.2	34.3	26.1	23.0	24.6	23.9
30-month	35.9	29.7	38.0	36.7	37.2	18.5	16.6	17.6	17.2
54-month	53.8	50.3	57.5	54.3	57.1	20.1	19.0	19.6	19.3

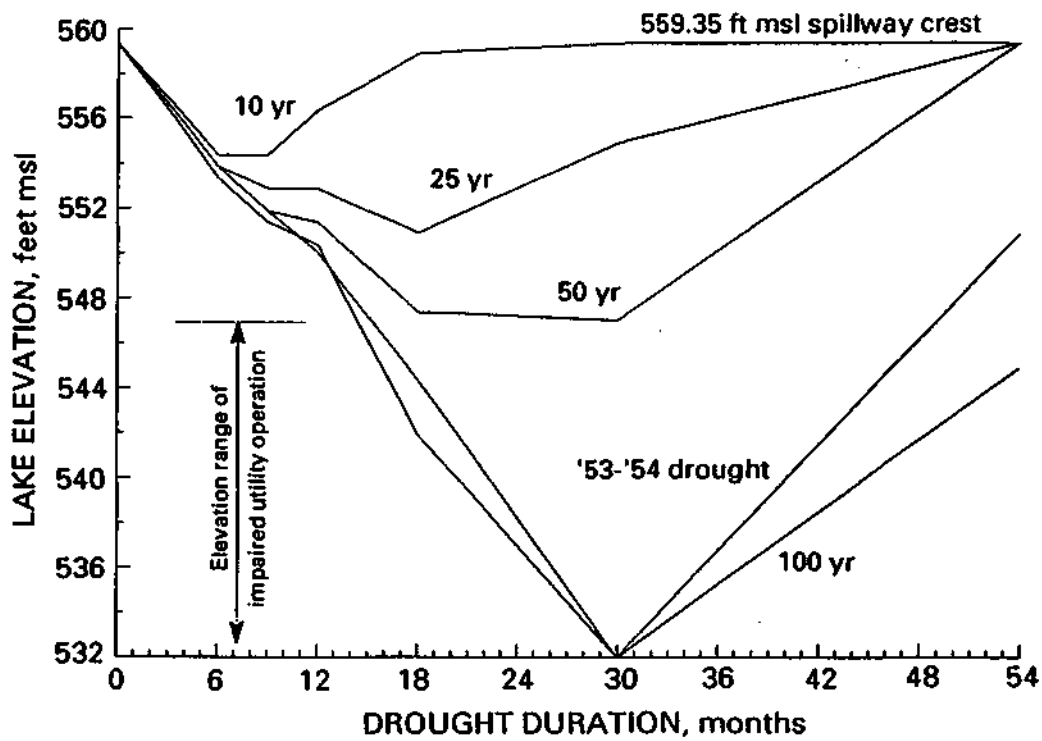
NOTE: Lowest yield for each scenario and recurrence interval is highlighted in bold italics.



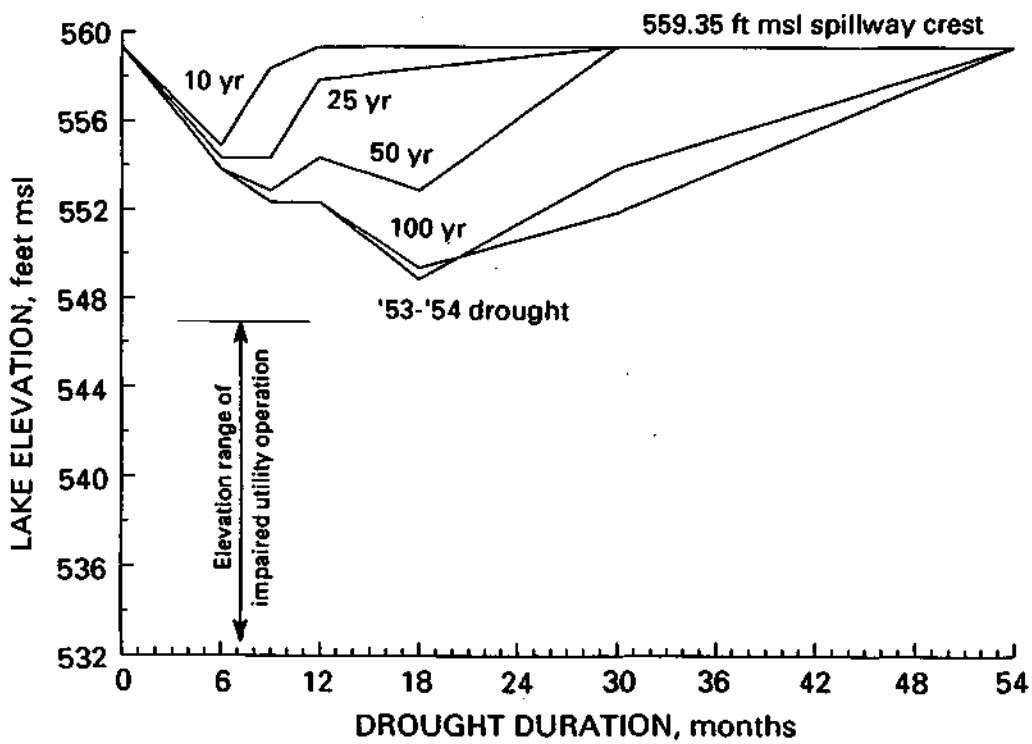
Scenario A, Lake Springfield pool level simulation (25.45 mgd average draft, 1984 capacity, no minimum pool, South Fork pumping, no Hunter Lake, lake full at onset)



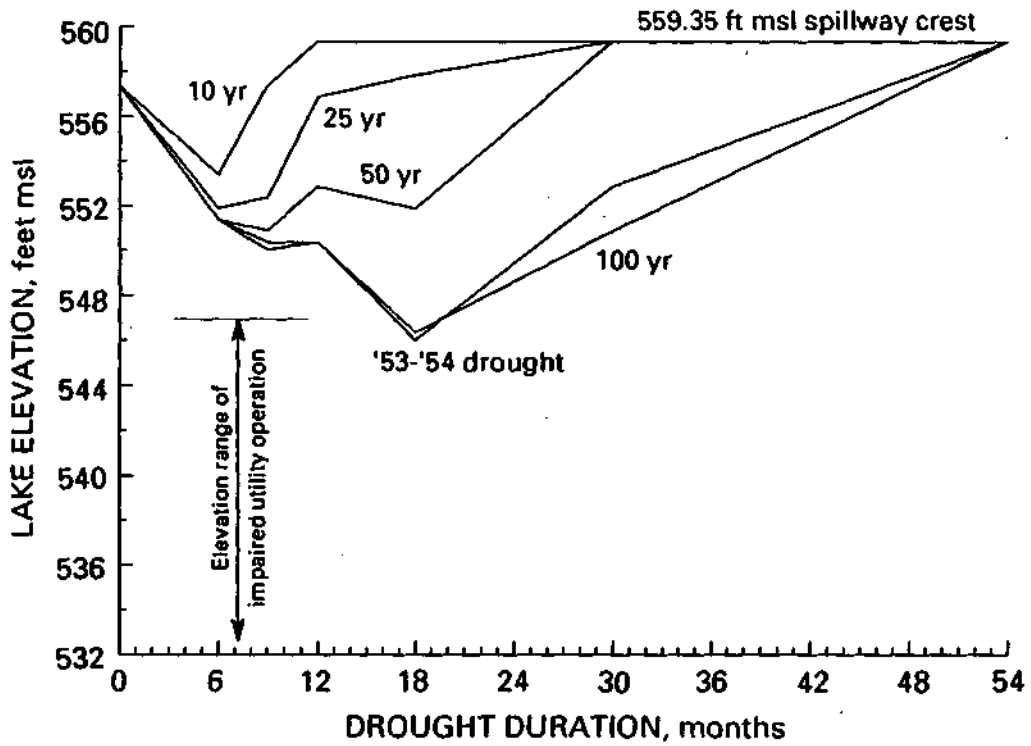
Scenario B, Lake Springfield pool level simulation (25.45 mgd average draft, 1990 capacity, no minimum pool, South Fork pumping, no Hunter Lake, lake full at onset)



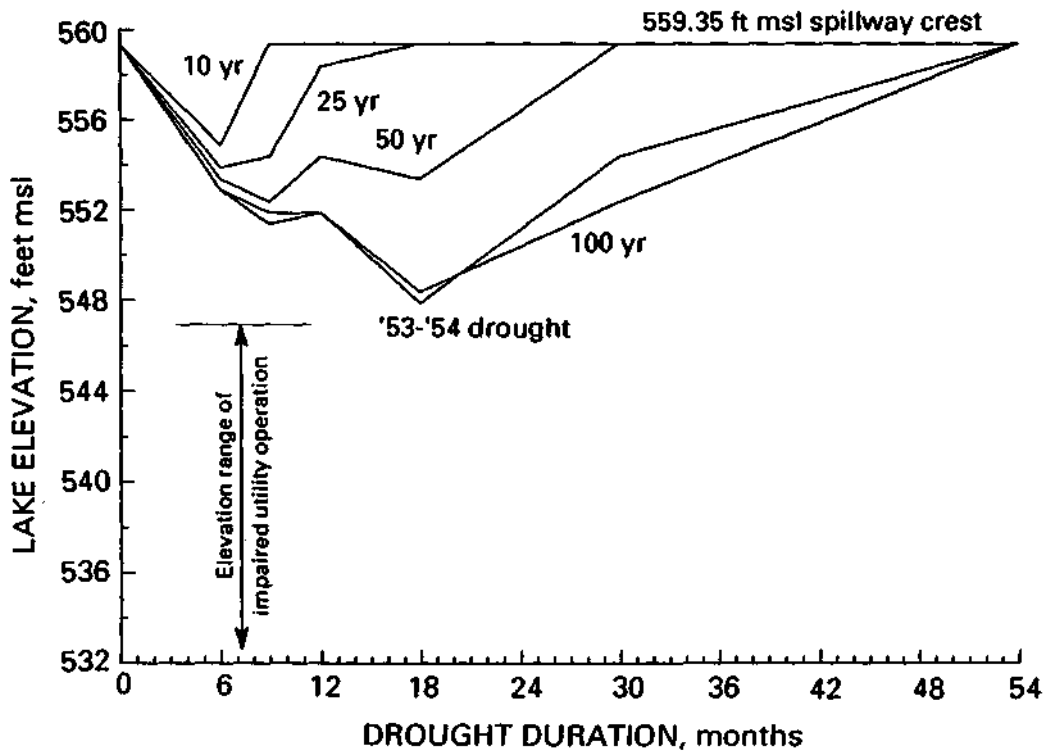
Scenario C, Lake Springfield pool level simulation (25.45 mgd average draft, 1990 capacity, no minimum pool, no South Fork pumping, no Hunter Lake, lake full at onset)



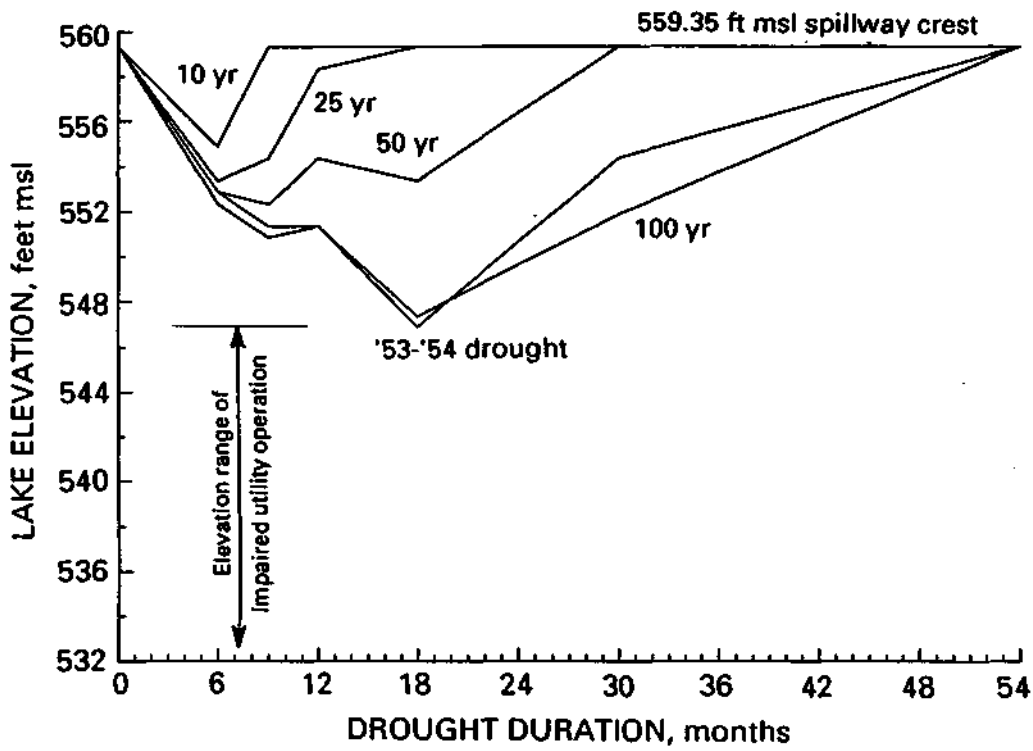
Scenario F, Lake Springfield pool level simulation (25.45 mgd average draft, 1990 capacity, no minimum pool, South Fork pumping, with Hunter Lake, lake full at onset)



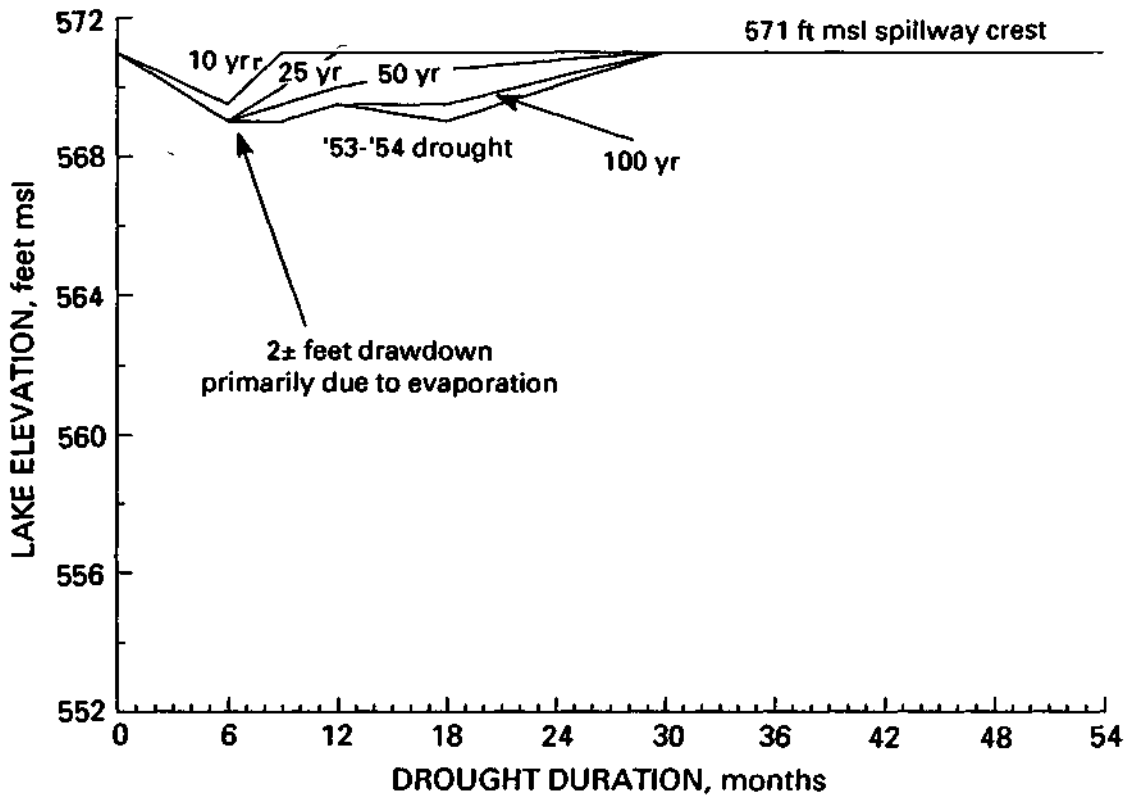
Scenario H, Lake Springfield pool level simulation (25.45 mgd average draft, 1990 capacity, no minimum pool, South Fork pumping, no Hunter Lake, lake 2 feet down at onset)



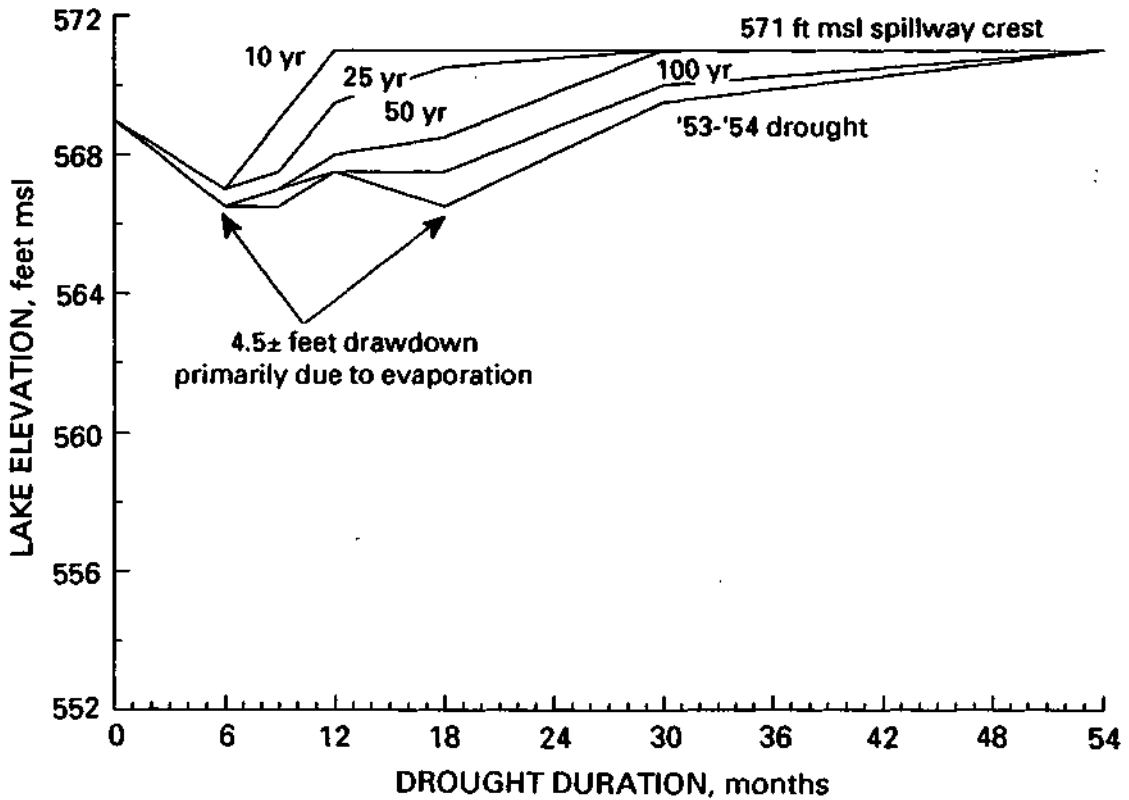
Scenario L, Lake Springfield pool level simulation (25.45 mgd average draft, 2025 capacity, no minimum pool, South Fork pumping, no Hunter Lake, lake full at onset)



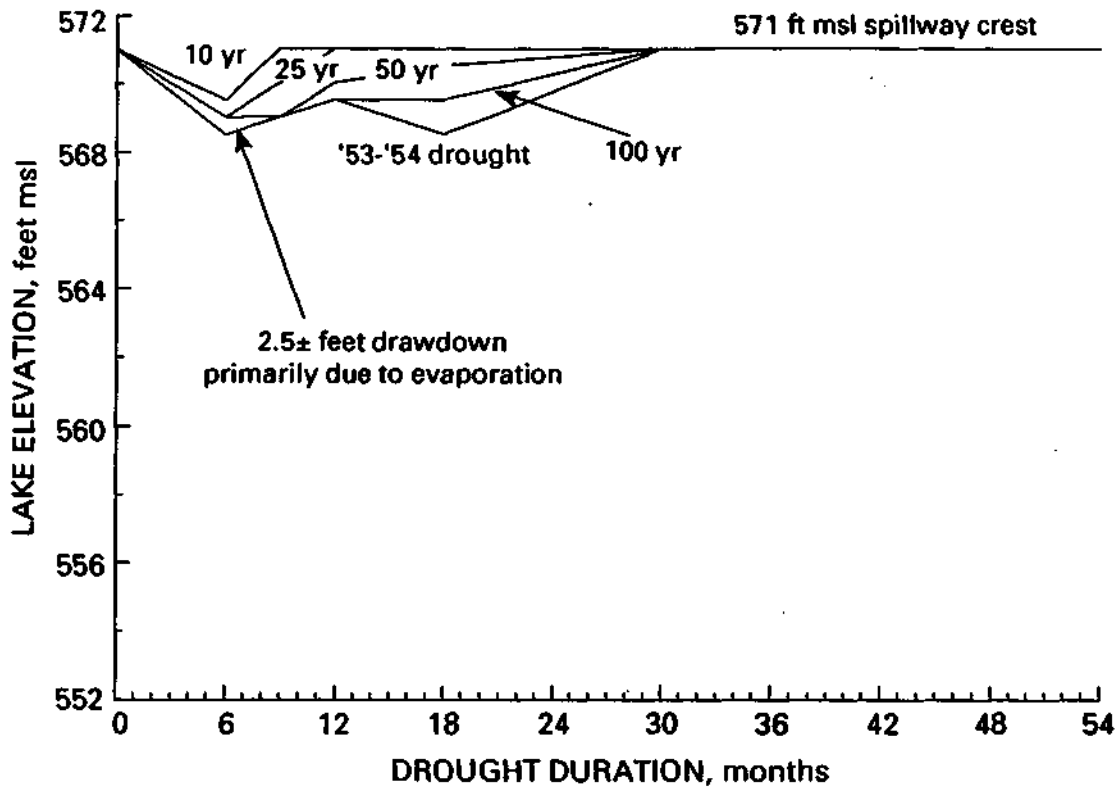
Scenario N, Lake Springfield pool level simulation (25.45 mgd average draft, 2040 capacity, no minimum pool, South Fork pumping, no Hunter Lake, lake full at onset)



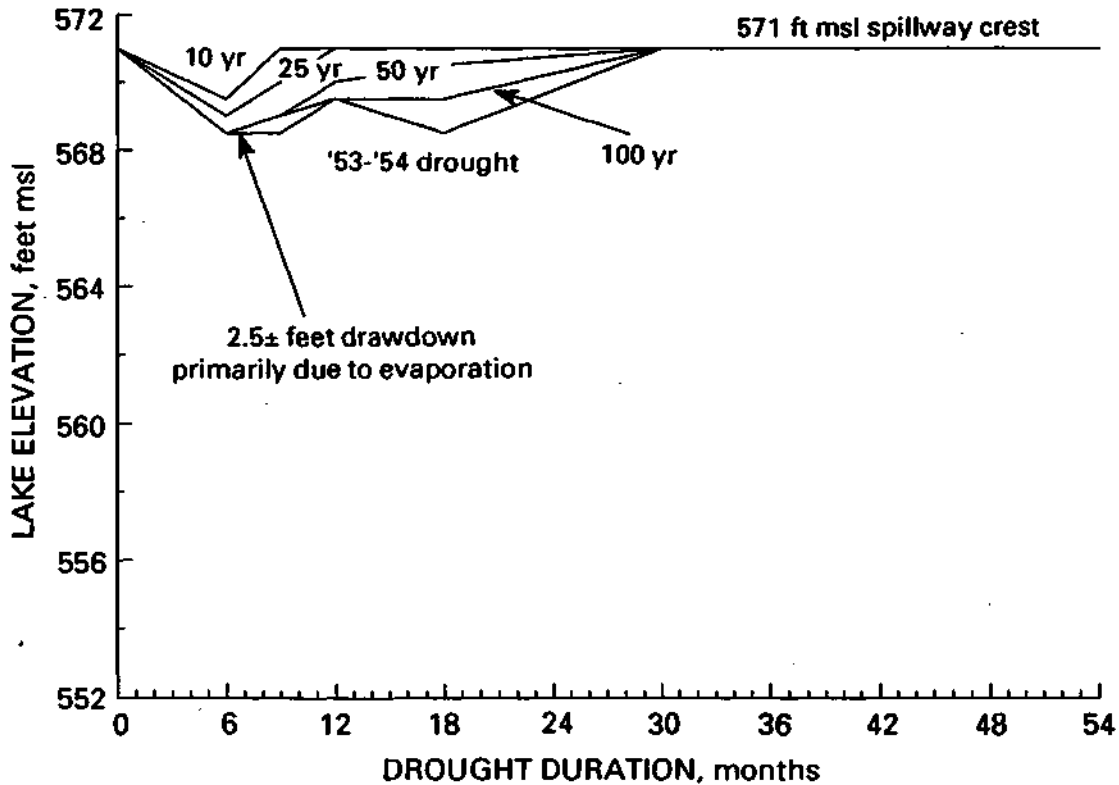
Scenario O, Hunter Lake pool level simulation (no draft, 1990 capacity, lake full at onset)



Scenario P, Hunter Lake pool level simulation (no draft, 1990 capacity, lake 2 feet down at onset)



Scenario Q, Hunter Lake pool level simulation (no draft, capacity after 35 years of sedimentation, lake full at onset)



Scenario R, Hunter Lake pool level simulation (no draft, capacity after 50 years of sedimentation, lake full at onset)

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