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YIELD ANALYSIS OF LAKE SPRINGFIELD, SPRINGFIELD, ILLINOIS

by

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INTRODUCTION

This investigation of the yield of Lake Springfield was conducted under a cooperative agreement between the City of Springfield and the Illinois State Water Survey (ISWS). It is part of the continuing long-term research of the ISWS on the surface water resources of Illinois.

The net quantity of water available from a surface water impoundment is determined through a yield analysis. The intended purpose of a surface water impoundment is to redistribute the quantity of streamflow with respect to time and to provide a dependable supply throughout low flow periods. The yield of an impoundment is not constant over time since increased demand or the decrease in the storage volume of the impoundment will diminish the available yield. For this reason periodic investigations of the yield of a water supply are necessary.

Lake Springfield is the largest municipally owned lake in Illinois, with a surface area of 4000 acres and a storage capacity of 52,180 acre-feet (17 billion gallons) at normal pool elevation, as documented by a 1984 sedimentation survey. The lake and its 265-square-mile watershed are located in central Illinois south of the City of Springfield as shown in figure 1. The lake was created in 1934 by the impoundment of Sugar Creek, a tributary of the Sangamon River. The two major streams flowing into the lake are Sugar Creek and Lick Creek, which join at the upper end.

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 to the lake. This analysis is intended to evaluate the yield of Lake Springfield on the basis of its present and projected future capacity as influenced by the reduction of that capacity by sediment accumulation.

This study is an extension of the sedimentation survey completed in 1984 and the present water, sediment, and nutrient budget analysis for the lake. The 1984 survey was conducted by ISWS and the City of Springfield to determine the current storage capacity and capacity loss rate of the lake. This investigation documented a loss of 13 percent of the original capacity (7700 acre-feet or 2.5 billion gallons) since 1934 (Fitzpatrick et al., 1985).

Acknowledgments

This research project was conducted as part of the authors' regular duties at the Illinois State Water Survey under the administrative guidance of Richard J. Schicht, Acting Chief, and Michael L. Terstriep, Head of the

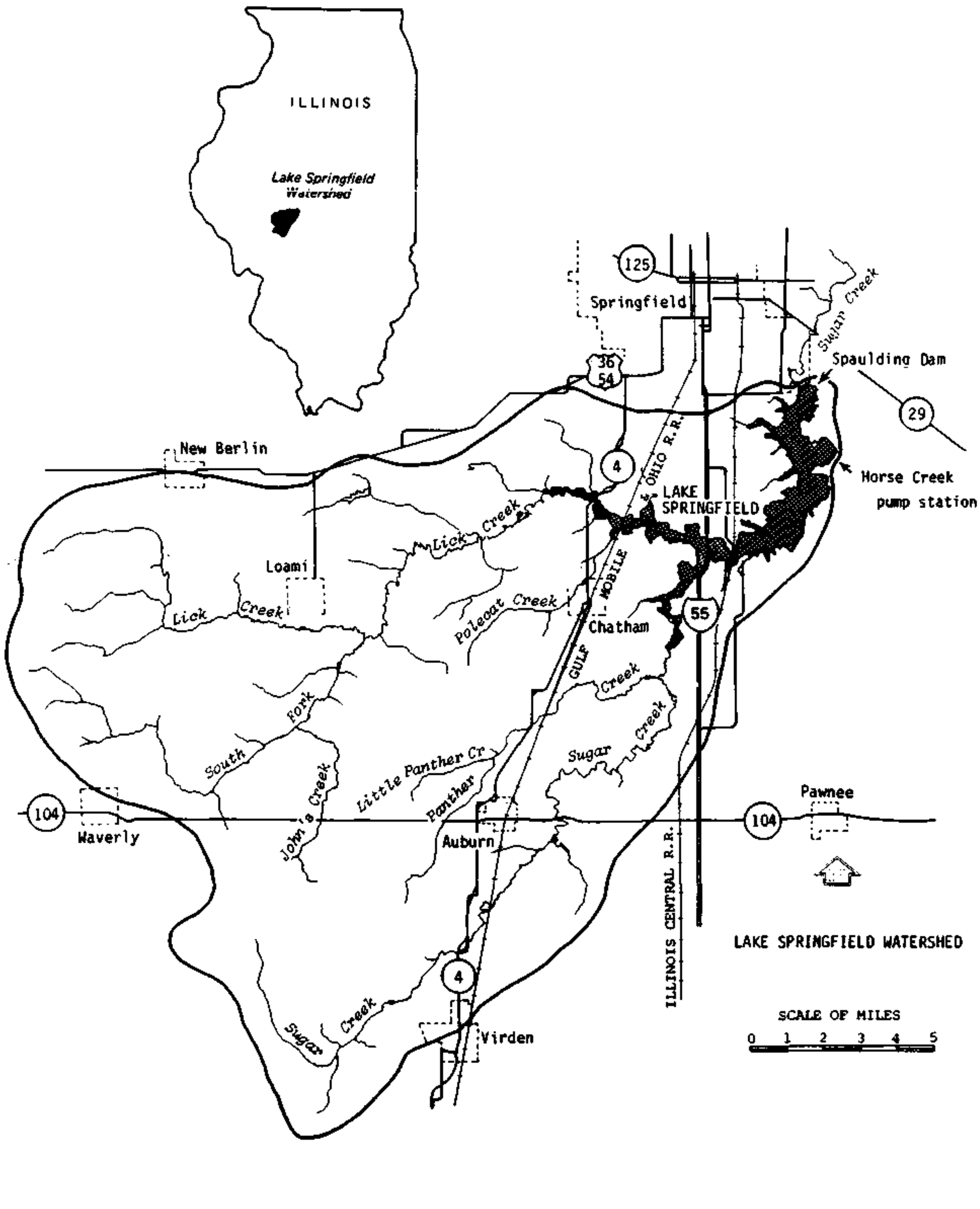

Figure 1. Location of Lake Springfield and its watershed

Surface Water Section. H. Vernon Knapp provided invaluable guidance in the streamflow analysis. Figures and illustrations for this report were prepared by John Brother, Jr., and Lynn Weiss. Gail Taylor edited the report and Kathleen Brown typed the rough drafts and the camera-ready copy.

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BACKGROUND

Watershed Characteristics

The Lake Springfield watershed is located south of Springfield, Illinois, in Sangamon, Morgan, and Macoupin Counties. The watershed area covers 265 square miles and is primarily a level- to gently-sloping plain which is incised in the lower portions by the valleys of Sugar and Lick Creeks. The streams in the upper portions of the watershed are shallow and less pronounced. Elevations vary from 700 feet msl at Waverly, Illinois, to a lake elevation of 560 feet msl.

The soils of the watershed formed in loess deposits up to 8 feet thick, which are underlain by Illinoian drift. The average gross erosion has been estimated as 4.0 tons per acre per year or a total of 601,000 tons per year for the watershed (Lee and Stall, 1977). The land use has been estimated as 88 percent cropland, 8 percent pasture, 1 percent woodland, and 3 percent other (Lee and Stall, 1977).

The climate of the Springfield region is typically continental with warm summers and cold winters. The following local climate data are summarized from the National Oceanic and Atmospheric Administration (1983). Annual precipitation averaged 35.47 inches for the period 1944 to 1983. Yearly extremes in precipitation were 48.12 inches in 1981 and 23.98 inches in 1953. Snowfall averaged 24.6 inches per year. The average annual temperature was 53.2 F and the extremes were 112 F in July 1954 and -24 F in February 1905. Annual averages of 5654 heating and 1165 cooling degree days occurred during the period 1951 to 1980. On the average, 50 thunderstorms occur during the year and snowfalls of 1 inch or more occur 8 days of the year.

Springfield Waterworks

The city of Springfield was chartered in 1840 with a population of approximately 2500. In 1845 the first public water supply consisted of four hand pumps placed one on each corner of the town square. In 1848 and 1853 the hand pumps were upgraded, but their capacity was inadequate for the growing city. A private company was organized in 1857 to find and develop artesian wells to supplement the supply of water. The project was a failure and was abandoned two years later. In 1860 a private waterworks company was purchased and plans were made to bring water from the Sangamon River. In 1866 work started on a pumphouse and infiltration gallery at the Sangamon River.

Over the next 40 years the waterworks were expanded by additional pumphouses, new water mains, and enlarged infiltration galleries and wells in the river valley. In 1908 a dam was built across the Sangamon River to augment the water supply during low flow on the river. In 1912 a new well field was installed together with a a pump with a capacity of 10 million gallons per day (MGD). In 1930, after the well field and river intakes proved to be inadequate, bonds were issued for the construction of a lake and water purification plant. The new lake was constructed by the damming of Sugar Creek, a tributary of the Sangamon River. It was completed in 1935 at a cost of $2.5 million. One year later the purification plant at the lake was completed.

Spaulding Dam extends in a northeast to southwest direction across the valley of Sugar Creek (figure 2). The dam is 1900 feet long and has a spillway elevation of 559.35 feet mean sea level (msl) (Crawford, Murphy and Tilly, Consulting Engineers, 1965). The water level of the lake is controlled by a set of five moveable gates, each 8 feet in height and 50 feet in width, installed into the spillway located at the southwest end of the dam.

The construction of the lake required the clearing of 4300 acres of the valley bottom. In addition to the main dam on Sugar Creek, a saddle dam was built 2 miles south of Spaulding Dam to raise the drainage divide between Horse Creek and Sugar Creek. During construction of the lake, road and railroad fills were riprapped as protection against wave erosion.

The stream channel of the pre-dam Sugar Creek was entrenched to a depth of 10 feet below the valley floor. The valley was relatively flat and averaged about one-half mile wide. When completed, the maximum depth of the lake was 35 feet.

The lake is approximately 12 miles in length extending south and west from the dam. It has a "Y" shape formed by the inundated valleys of Sugar and Lick Creeks, which join together in the upstream portion of the lake as shown in figures 1 and 2.

The lake is used as the source of the city's drinking water and also for boiler and cooling water for a coal-fired electrical power plant operated by the city. The water treatment plant and power plant are located along the lakeshore south of the dam.

A drought encompassing the period 1952 through 1955 caused a drop in the lake level of 12.6 feet below the spillway elevation. In reaction to this event, in 1955 the city constructed a channel dam across the South Fork of the Sangamon River below its confluence with Horse Creek, along with a pump station to provide supplemental water to the lake during periods when the lake level was low. The pump station has a rated capacity of 72 MGD, expandable to 80 MGD. During low flow periods the available flow from the South Fork and Horse Creek watersheds is often less than 72 MGD, with the result that the station is operated below its rated capacity.

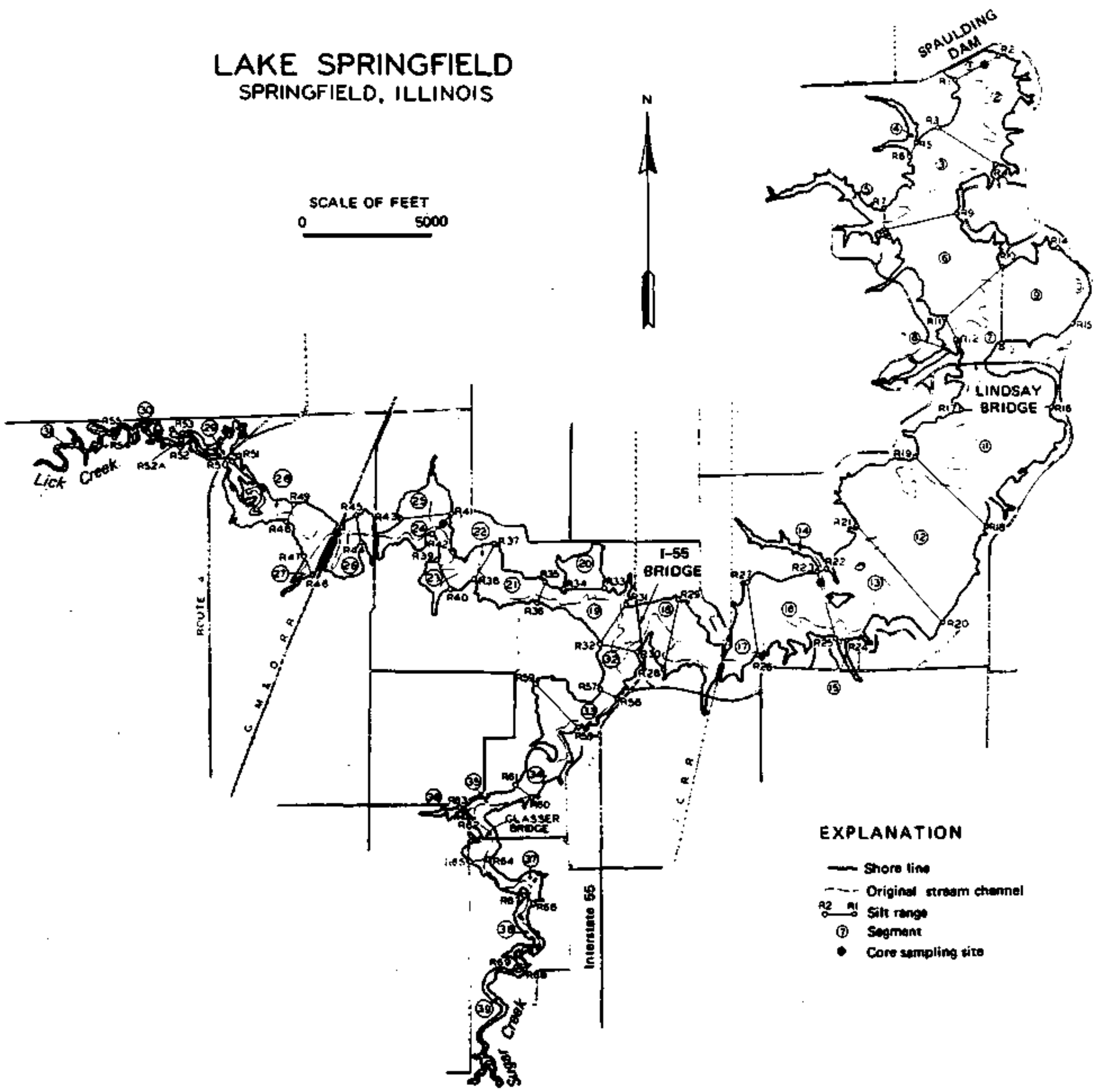


Figure 2. Lake Springfield

However, this station does provide needed supplemental inflow to the lake and provides operational flexibility in the management of the lake.

The normal pool of Lake Springfield is at an elevation of 559.35 feet msl. The basic management objective is to control the outflow of water from the lake at the dam so as to maintain the pool elevation at the spillway crest. The five moveable spillway gates are operated independently, and usually only one gate is used to lower the level of the lake. The basic procedure is to control the lake level by using as few gates as possible.

The spillway gates are lowered when the water surface of the lake exceeds a level of 0.5 feet above the spillway crest, and they are positioned to keep the lake level as close to the spillway elevation as possible. When the lake level rises to 1.0 foot above the spillway, the discharge at the spillway is increased by lowering additional gates. An operational concern is to minimize flooding in the Sugar Creek channel downstream of the dam. This is accomplished by raising and lowering the spillway gates slowly. The slow operation of the gates helps to prevent excessively large slugs of discharge downstream and to allow the Sugar Creek channel to convey the lake discharge as efficiently as possible. Manipulation of the gates in this manner also minimizes sudden fluctuations in lake level, which helps control lakeshore erosion and the resulting damages to piers, docks, and boat ramps.

The following general guidelines are implemented during low lake level periods in order to reduce the drawdown of the lake (City Water, Light and Power, 1985).

Lake level (feet, msl)	Course of action
559	-Begin pumping at the Horse Creek station
558	-Recycle clarified water from ash ponds to the lake
557	-Advise the public of low lake level -Initiate coordination of water conservation measures
556	-Advise public of emergency pumping from the Sangamon River -Initiate placement of temporary dams in the Sangamon River -Initiate water rate surcharge
555	-Request users to conserve water -Initiate pumping from the Sangamon River -Institute a water rate surcharge -Lower water system pressure by 5 psi (pounds per square inch)
554	-Reduce water system pressure by an additional 5 psi -Distribute "water saver" kits -Prepare ordinance prohibiting non-essential water use

553 -Initiate customer penalties concerning water use restrictions
-Prepare ordinance for possible allocation of water
-Begin audit of high water demand users

552 -Apply second water rate surcharge
-Intensify enforcement of water use restrictions
-Implement additional pressure reduction

551 -Prohibit outside water use
-Close all public water activities except for health necessities
-Investigate additional reduction in system pressure

550 -Intensify enforcement of prohibited uses
-Continue monitoring large water uses

YIELD ASSESSMENT

Water supply impoundments are intended to store streamflow in excess of the mean flow in order to provide a reliable quantity of water during low-flow periods. Since streamflow is highly variable, an impoundment serves to redistribute the inflowing water with respect to time in order to meet the anticipated water demand. The demand for water in an impoundment must be balanced against the supply, which is made up of the storage capacity and the inflow. If the demand is less than the supply, the impoundment will serve its intended purpose; if not, the supply will not meet the demand and a water shortage will occur. The maximum use of an impoundment is realized when the demand approaches the mean annual flow.

The yield of an impoundment is the amount of water which may be extracted during a specified time interval for a given set of conditions. The method of performing a yield analysis is detailed in water supply publications such as those by Clark et al. (1971) and Fair et al. (1971). The amount of water for withdrawal is dependent on the quantity of inflow, outflow, and change in storage within a period of time. Inflow to the system includes streamflow, direct precipitation, and pumpage. The outflow from the system includes evaporation, seepage through the bottom and sides of the impoundment, and dam and spillway gate leakage, as well as discharge over the spillway during periods of high flow. The change in storage in the system refers to the fluctuations of the water level that reflect changes in the storage held for a specified time interval and the loss of this storage over time due to sedimentation. These variables are shown schematically in figure 3.

Generally a yield analysis is performed to determine the usable amount of water that can be obtained from an impoundment. The available yield is then compared to the projected demand to determine whether any potential shortage exists. In addition to determining the yield, it is important to know lake levels, since Lake Springfield is used for recreation. To assess these lake levels the municipal demands were included in the analysis (see figure 3).

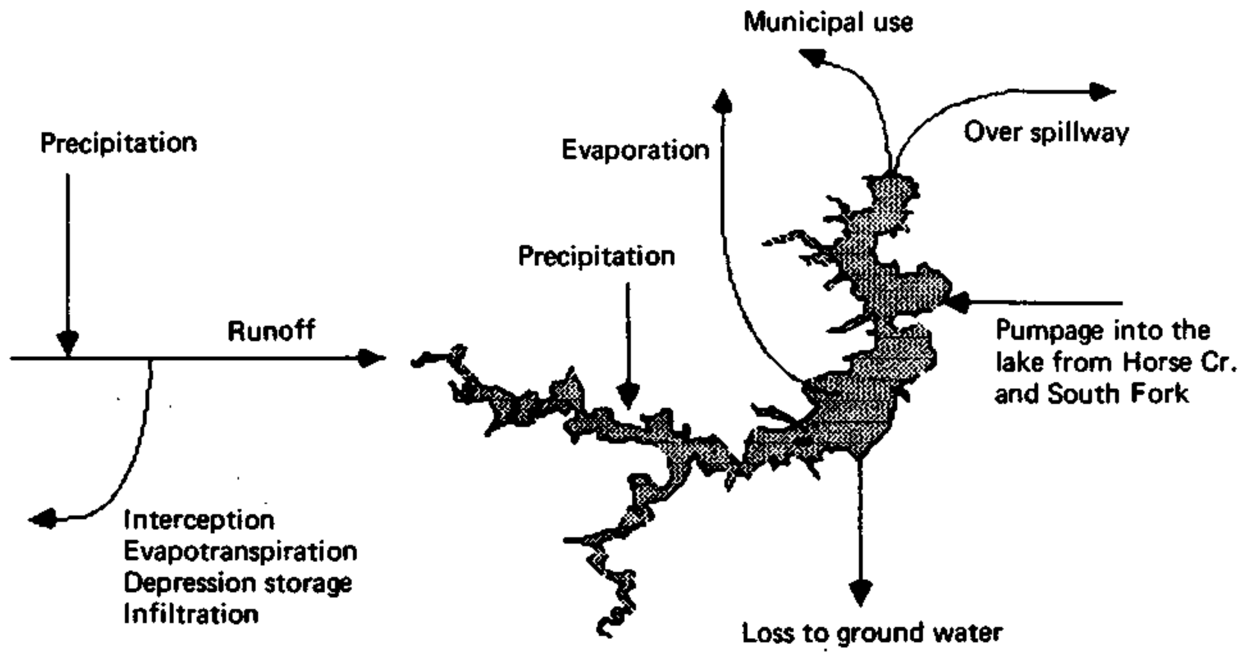


Figure 3. Schematic diagram of the water budget of Lake Springfield

The analytical tool used to assess the yield of an impoundment is the mass curve, also known as the Rippl Diagram method, in which the cumulative values of inflow are plotted against time (Chow, 1964). In this method the necessary impoundment capacity which meets a demand is determined from the difference between accumulative demand and accumulative inflow for a critical period of time. The deviation from the accumulative inflow and accumulative draft (demand) signifies spillage if the inflow curve is above the draft curve. If the inflow curve is below the draft curve, drawdown of the lake level is occurring. In this case, the maximum difference between the inflow and draft curves is used to determine the necessary storage capacity of the lake. More detail on the mass curve may be found in Chow (1964).

In a yield analysis the outflow is subtracted from the inflow and the volume of water stored in the impoundment. It is assumed that the entire capacity of the impoundment is used so that it is empty at the end of a drought. However, a percentage of the impoundment's storage capacity may be used to represent conditions such as a partially full lake or dead storage. The yield is the volume of water available for use. A stage-volume relationship allows the minimum elevation in the impoundment to be determined during a drought.

Both net evaporation and streamflow vary according to the duration and severity of the drought. In this study drought durations of 6, 9, 12, 18, 30, and 54 months were used, as well as droughts with return intervals of 10, 25, and 50 years. In addition, the drought of record was also investigated. Although concurrent return intervals of net evaporation and streamflow should not be expected, the same return intervals were used since this provides a worst case example.

Inflow

Streamflow is the primary source of inflow into Lake Springfield. In addition to water that flows into the lake from its watershed, flow is supplemented by pumpage from the Horse Creek station. In assessing the yield, it is critical to determine the quantity of water flowing into the lake from these sources. The yield of an impoundment is assessed to determine when low flows may cause critically low levels in the lake and shortages of water may occur. The initial step of a yield analysis is to determine these low flows.

The low flows were obtained from the monthly flow data, which were converted into running totals for each duration for the period of record. For drought flows the lowest values are paramount, so the results of the running totals above a certain value were cut off in forming the partial duration series. The results of the partial duration series were ranked, with the lowest total corresponding to the most severe drought. Ranking was done using Weibull's method (Chow, 1964) to obtain the mean recurrence interval in years. This method was repeated until all the desired durations were obtained.

Several drought durations were analyzed since the critical duration was unknown at the onset of the analysis. Durations of 6, 9, 12, 18, 30, and 54 months and recurrence intervals of 10, 25 and 50 years were investigated. A separate series was developed for each duration. Additional detail on the determination of drought flows may be found in Terstriep et al. (1982).

In order to draw on all available streamflow data in the region, the Streamflow Assessment Model (STREAM) was used (Knapp et ai., 1985b). This model is a product of a regional study which used the available streamgaging data in the area. The location parameters of the sites used to develop the flows were obtained from the user's manual (Knapp et al., 1985a). The input parameters to the model were chosen such that the flows to the lake did not include the municipal discharges below the dam. To determine the flows available to the Horse Creek station, the input parameters were chosen so as to include the flow withdrawn from the South Fork and Horse Creek watersheds that is pumped into Lake Springfield.

The method in STREAM for computing drought flows is identical to that described in Terstriep et al. in Bulletin 67 (1982). STREAM was selected for the determination of streamflow since it accurately describes the expected drought flows for a given drainage area. The model also differentiates between the present flow and the virgin flow (unaltered by human activities). The present flow is influenced by dams, withdrawals, and discharges. When the locations for discharge determination are chosen selectively, the model can provide flows to be used in the yield analysis.

The period of record of the data in the area was not of sufficient length to extrapolate the 100-year recurrence interval. Therefore, the low flows for the period of record were included to assess the yield of the lake.

Streamflow to the Lake

The main contributing streams to the lake are Lick and Sugar Creeks. There are two streamgaging stations on the watershed with historical data, located at Sugar Creek near Auburn and Lick Creek near Curran. These data along with others outside the basin were used to compute the flow to the lake. The flows used in the analysis were chosen to be the flows that entered the lake and did not include the effluent of the municipal sewage treatment plant which discharges below the dam. The flows into the lake for the 10-, 25-, and 50-year droughts as well as for the period of record are plotted in figure 4.

Horse Creek Pump Station

The Horse Creek pump station, located at the dividing dam along the east shore of the lake, provides supplemental inflow to the lake. Water is diverted to this station by a dam built across the South Fork downstream of the confluence of Horse Creek and the South Fork. A diversion channel was constructed from Horse Creek to the pumps. Therefore, the entire South Fork flow is available for pumpage along with the Horse Creek flow. This

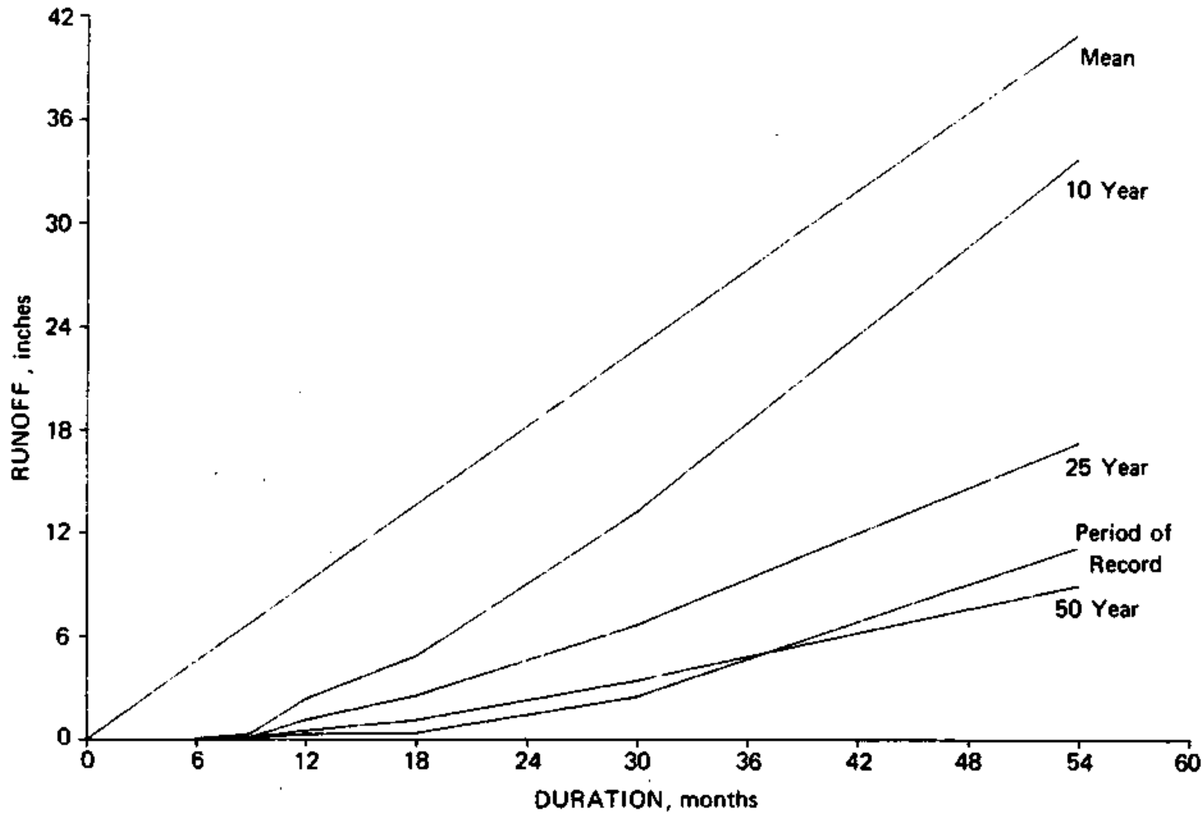


Figure 4. Mean and drought flows into Lake Springfield

configuration is essentially a side-channel reservoir. In order to assess the quantity of water available from this source a low flow analysis was performed on the Horse Creek and South Fork basins.

Streamflow records are available for six sites in the South Fork and Horse Creek basins. These include one immediately downstream of the dam on the South Fork. The historical data from this streamgage cannot be used directly since these data already include pumpage into the lake. To accurately assess the available flow so as not to include this pumpage, the flow in the South Fork was determined above the confluence with Horse Creek and the flow in Horse Creek was determined above the point of withdrawal into Lake Springfield.

Once obtained, these flows could not simply be added since that would imply that the recurrence intervals of the low flows from both watersheds were identical. Therefore, the differences between the virgin and present flows were obtained for the Horse Creek and South Fork locations for each return period and duration. The differences at these two locations were summed and then added to the virgin flow values obtained at the dam on the South Fork. The calculation may be seen in the following equation.

$$Q_{SF} = [(PRES\text{-}VIR)_{HC} + (PRES\text{-}VIR)_{SF}] + VIR_{SF}$$

where: Q_{SF} = flow in the South Fork available for pumpage

$(PRES\text{-}VIR)_{HC}$ = incremental flow in Horse Creek above diversion

$(PRES\text{-}VIR)_{SF}$ = incremental flow in the South Fork above confluence with Horse Creek

VIR_{SF} = virgin flow in the South Fork below the confluence with Horse Creek

The 10-, 25-, and 50-year drought flows, as well as the drought flows for the period of record, are plotted in figure 5.

In determining the flow available from the Horse Creek station it was assumed that pumpage would begin immediately at the onset of the drought and would continue as long as flow was available. Flow in the stream above the pumping capacity would spill over the dam. During low flow conditions, when one or both pumps exceeded the flow in the stream, the assumed mode of operation of the pumps would fully use the flow available in the stream. The pumps would not operate continuously but would be cycled on and off.

Losses

Losses which reduce the yield include evaporation from the surface of the impoundment, reduction in storage capacity because of sedimentation, seepage from the impoundment to the ground water, leakage from the gates and seepage through the dam, and loss of water needed to satisfy in-stream requirements.

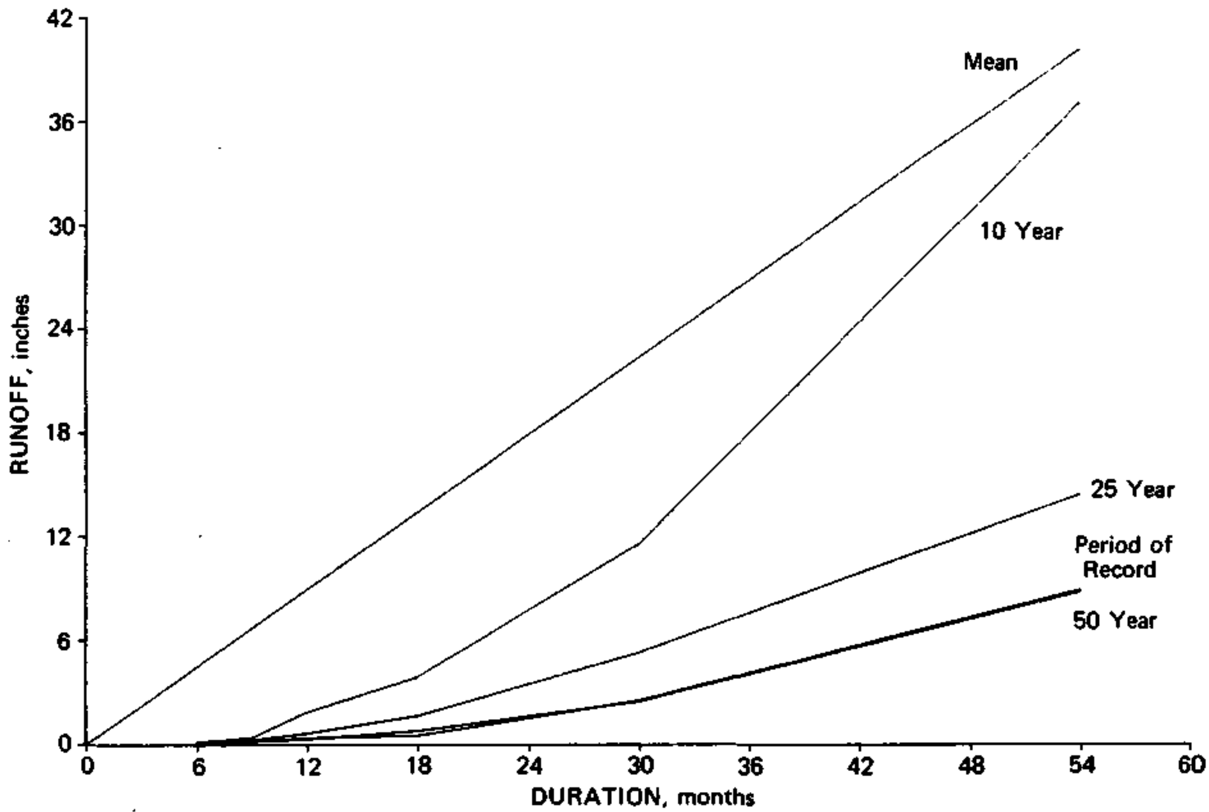


Figure 5. Mean and drought flows in the South Fork and Horse Creek basins

Evaporation

Evaporative loss is a primary consumptive loss reducing the yield of an impoundment. As with inflow, evaporation has return intervals and durations associated with it. In this study the term net evaporation is used and defined as the gross evaporation from the surface of the lake less the observed concurrent precipitation falling directly on the lake. The net evaporation values for Springfield used in this study are given by Terstriep et al. (1982). The methodology used in this study was derived primarily from Roberts and Stall (1967).

When assessing the yield of an impoundment, it is assumed that over the duration of a drought the surface area of the lake will decrease from 100 percent at the beginning of the drought to 0 percent at the end. This stems from the assumption that the impoundment is full at the beginning of the drought and empty at the end of the drought so that the entire volume of the impoundment is used. For calculation of evaporation during the course of a drought, the value of 65 percent of the surface of the impoundment at spillway elevation has been recommended for use as the effective surface area for the course of the drought (Hudson and Roberts, 1955). On the basis of the area and volume relationships obtained from the 1984 sedimentation survey of Lake Springfield (Fitzpatrick et al., 1985), a constant draft completely emptying the lake would result in a mean lake surface area of 63.9 percent during the emptying of the lake. Since this value is virtually identical to the 65 percent value mentioned above, the value of 65 percent of the lake area was used as the effective area for calculation of evaporation. If the lake is not empty at the end of a drought or full at the beginning, the area exposed to evaporation will be different than 65 percent, thereby changing this loss component.

Assuming beginning lake elevations of 558 and 556 feet msl, a complete drawdown will result in averages of 67.6 and 67.8 percent, respectively, of the surface area of the lake being exposed during the course of a drought. Drawing the lake level down to 543 feet msl from 560 and 558 feet msl will result in 66.9 and 67.0 percent, respectively, of the surface of the lake being exposed to evaporation during the drought. The variations are minor when compared with the other components, so 65 percent has been used for all cases. The 10-, 25-, and 50-year evaporation rates are presented in figure 6 along with evaporation rates for the period of record.

The heated discharge to the lake from the power plant undoubtedly raises the evaporation rate. This item is discussed under power plant usage.

Sedimentation

The erosion and transport of soil in a watershed deliver sediment to an impoundment downstream. Soil particles carried by streamflow are entrained by the velocity of the flow. When a stream flows into an impoundment the velocity of the water decreases and the particles drop out of suspension, resulting in sedimentation. Sedimentation reduces the water storage capacity of the impoundment over time and therefore affects the

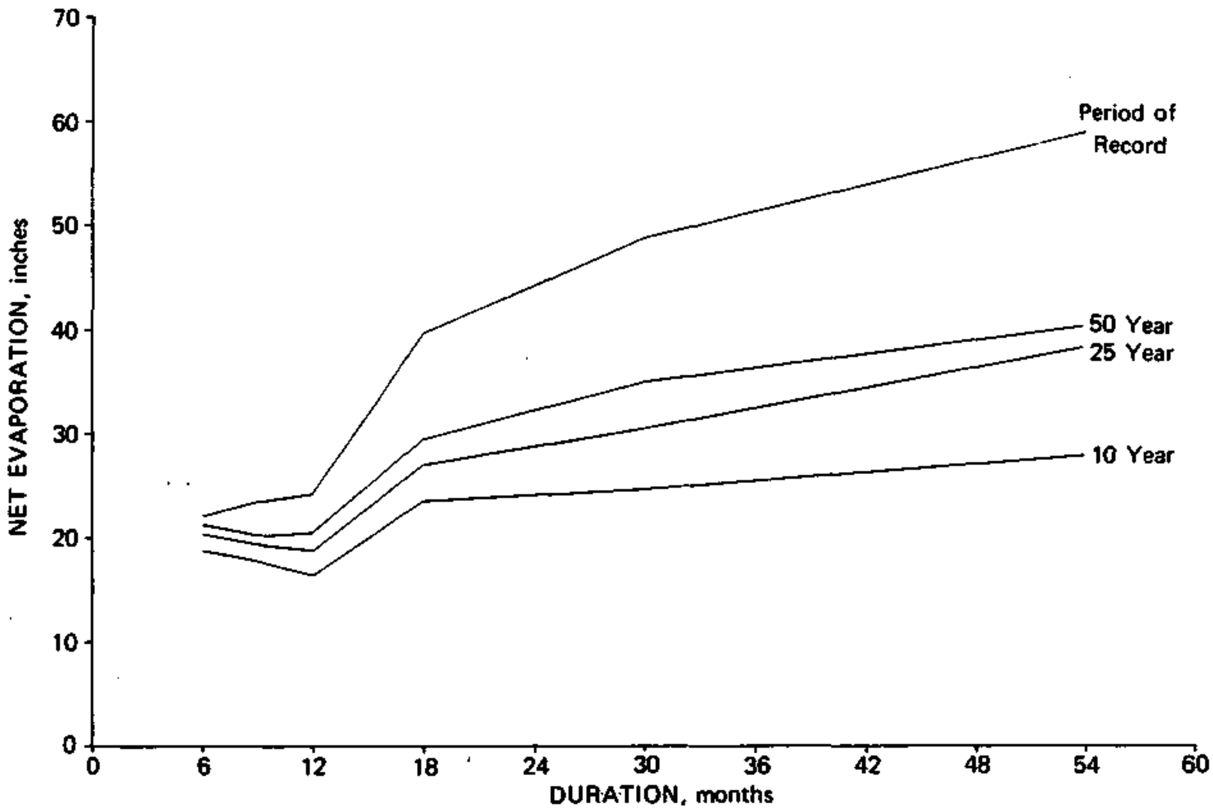


Figure 6. Net evaporation from Lake Springfield
for various drought recurrence intervals

yield. The volume loss rate of an impoundment is principally dependent on the weight of the sediment deposited in the lake and the density of the deposited material. As the sediment becomes more dense, it occupies less volume. Lake drawdowns result in the compaction of the deposited sediment due to the dewatering effects and tend to mitigate the effects of sedimentation on the storage capacity.

The lake storage versus lake elevation curves are presented in figure 7 for several dates. The 1984 sedimentation investigation of the lake showed that the 50-year volume loss rate over the period 1934 through 1984 was the same as the rate from 1977 to 1984: 0.26 percent per year of the original storage capacity (Fitzpatrick et al., 1985). This rate will be used to project the future capacity loss rate for the yield analysis. The 1984 lake capacity is used for the present capacity in the yield analysis.

Seepage to Ground Water

If the water surface of the impoundment is above the ground-water level, as is the case for Lake Springfield, water will flow from the impoundment to the ground water. However, due to the poor well yields in the area of the impoundment, there are few ground-water data available to evaluate ground-water seepage from the lake. Therefore, a comprehensive regional study of the Sangamon River basin was used to supply the necessary information to estimate the seepage from the lake (O'Hearn and Williams, 1982). This study revealed that in the vicinity of the lake, the ground-water yield from sand and glacial aquifers was less than 20 gallons per minute (gpm) due to the thin layer of drift material. This is a very low rate, which indicates little movement of water through the glacial material. The study indicated that municipal and industrial water supplies are developed from sources other than ground water.

The study also showed that the bedrock occurs close to the surface in several areas around the lake. This bedrock consists mainly of shale with thin interbedded limestone, sandstone, and coal of the Modesto and Bond Formations of Pennsylvanian age. These formations have yields below 10 gpm and are not aquifers. The low hydraulic conductivity suggests that there is minimal flow from the lake to the ground water. Thus, seepage losses from the lake are assumed to be negligible.

Gate Leakage and Dam Seepage

This component of the yield analysis considers the flow that is lost due to leakage around the spillway gates and seepage through the dam. These quantities were estimated by City Water, Light and Power (CWLP).

The gates are 8 feet high with the sill at an elevation of 552 feet mean sea level (msl). No leakage occurs when the lake elevation drops below the sill of the gates. Similarly, as the lake level falls the driving head causing seepage through the dam will be less, thereby reducing the rate of seepage. The total seepage and leakage from the lake is estimated at 0.7 million gallons per day (MGD) when the lake level is at the spillway crest.

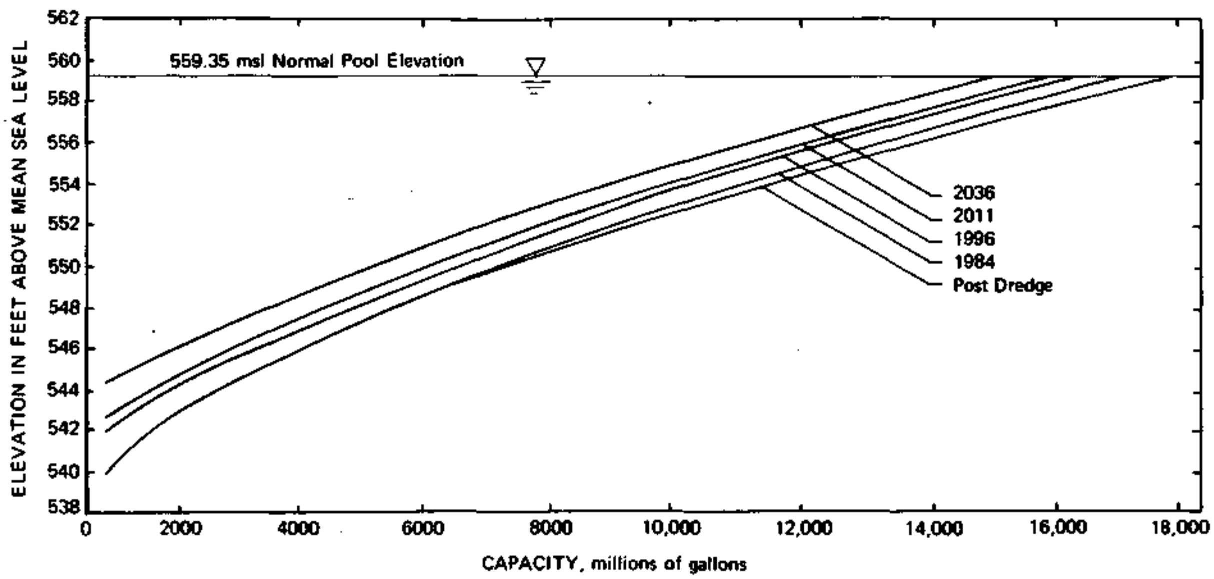


Figure 7. Lake Springfield stage-capacity curves

In assessing the yield of an impoundment it is assumed that the entire storage capacity is used. A reduction was made in the gate and dam losses in a manner similar to that made for evaporation to account for variations in the lake level. There is little variation in the losses when the drought is assumed to begin when the lake is other than full and to end when it is other than empty; therefore a combined leakage and seepage of 0.45 MGD during the course of a drought will be used for all cases. This value is used with the assumption that the dam and gate structures will remain in their present condition and that no rehabilitative measures will be adopted.

In-Stream Requirements

The withdrawal of water from any stream has the potential of greatly disturbing the stream environment as well as preventing in-stream needs from being met downstream. Future regulations may require restrictions on stream withdrawals, especially during low flow periods, to insure some level of base flow in streams. The quantity of flow which must remain to satisfy in-stream uses is not well defined. In the context of this report the policy governing low flow pumpage is based on a combination of the 7-day 10-year low flow and the 75 percent flow (Knapp, 1982).

In-stream requirements may not be possible for Sugar Creek downstream of the dam since water cannot be released when the water level is below the gates. The treated effluent from the sewage treatment plant contributes to the low flow below the dam. Horse Creek and the South Fork may come under these requirements, and therefore this yield analysis will consider the possibility that the withdrawal of water from these sources may be restricted.

The 7-day 10-year flow is the 7-day flow that can be expected once every 10 years, while the 75 percent flow is the flow that is exceeded 75 percent of the time. At the Horse Creek pump station the 7-day 10-year flow is 0.80 cubic feet per second (cfs) and the 75 percent flow is 37.0 cfs. The equations used to find the amount of flow available for pumpage are:

$$QA = \max \begin{cases} Q-Q75 \\ (Q-Q7,10)/2 \end{cases}$$

in which Q is the flow in the stream, QA is the flow available for pumpage, Q75 is the 75 percent duration flow, and Q7,10 is the 7-day 10-year flow.

<u>Municipal Use</u>

In addition to the losses previously discussed, there is a municipal draft on the lake. Normally the municipal uses are not included in a yield analysis. When designing an impoundment, the yield is the amount available for municipal use. With the municipal uses included in the analysis, the yield analysis allows the lake levels to be assessed under draft conditions. The municipal uses are for potable supply (domestic consumption) and the power plant.

Potable Supply

This is the amount of water treated and pumped for residential, commercial, and industrial use. The present level was determined from records furnished by CWLP. The present average annual consumption is 18.0 MGD. A plot of the historical average monthly and yearly water consumption may be seen in figure 8.

Power Plant Use

In generating electricity the power plant located by the dam makes use of water from the lake. These uses include potable supply, ash handling, and forced evaporation. The potable uses are included in the metered amount in the potable supply.

Raw water is taken from the lake for the purpose of handling the ash generated from burning coal. The water is used to transport the ash from the boiler and scrubber to the settling lagoons downstream of the dam. The supernate then flows back into Sugar Creek downstream of the dam. CWLP has two 4-MGD pumps at the pits for water recovery to the lake.

Forced evaporation is the increased evaporation caused by the elevated temperature of the water used to cool the steam of the turbines which is then returned to the lake. CWLP furnished a 5-MGD estimate of consumption for the combined nonmetered uses at the power plant.

RESULTS

In assessing the yield from Lake Springfield, municipal uses were included in the draft in some cases. In these cases the results of the yield analyses are the surpluses that may be obtained from the lake over and above the present water usage. This procedure was used so the yield would reflect the stage of the lake under realistic demands. Municipal uses were excluded from most of the scenarios so as to allow comparison of the yield against the projected demands by CWLP.

Many possible combinations of the variables were used in determining the yield. It was assumed that rates of seepage to ground water, gate leakage, and dam seepage would not change between scenarios. The variable factors included in the analysis were the amount of flow pumped by the Horse Creek pump station from the South Fork of the Sangamon River, amount of volume in the lake available for storage as determined by loss due to future sedimentation, gains due to dredging, and lake level constraints.

These variations were combined into 11 scenarios which were investigated in this study. These scenarios are summarized in table 1, and

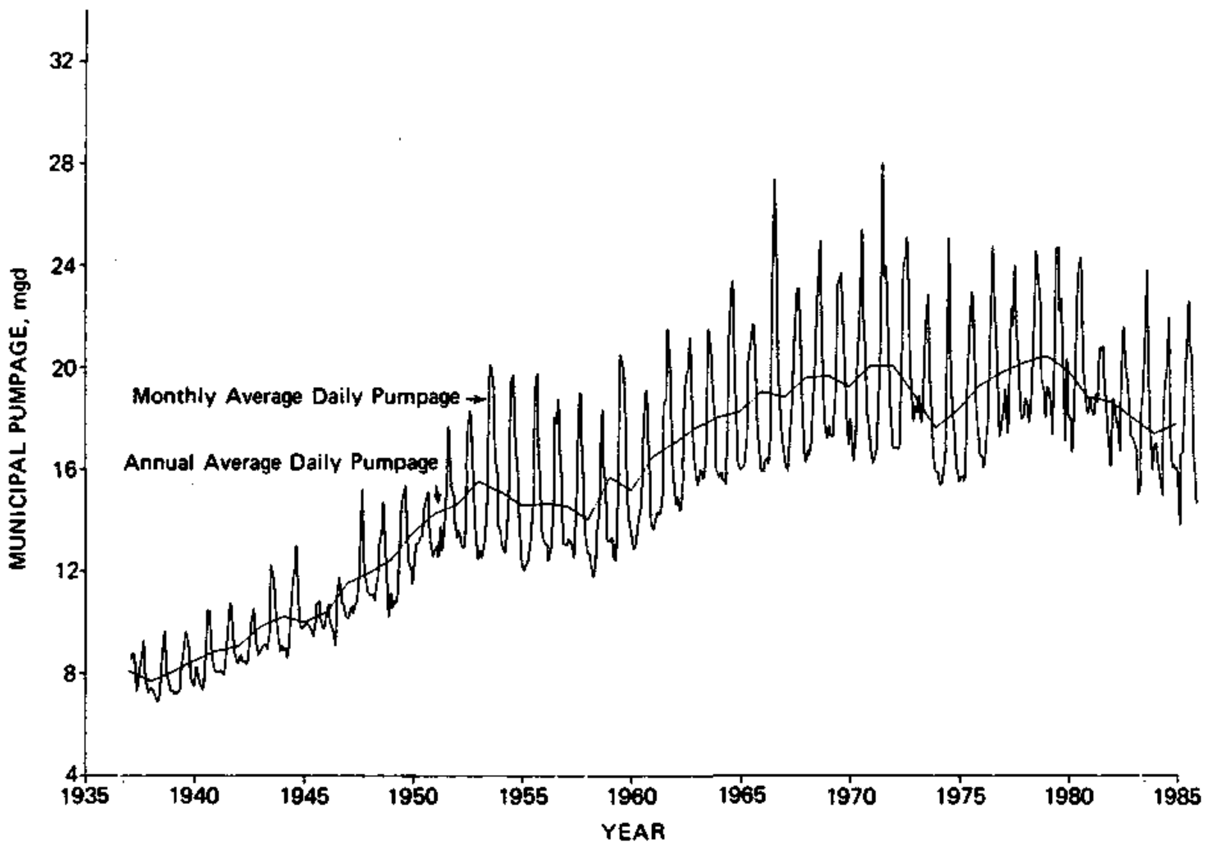


Figure 8. Average monthly and yearly water consumption for Lake Springfield

Table 1. Summary of Scenarios Investigated for the Yield Analysis
(Results for Each Scenario Are Plotted in Appendix A)

Scenario	Variables Investigated
1	Complete usage of Horse Creek pump station; current lake capacity
2	No usage of Horse Creek pump station; current lake capacity
3	Pumpage from Horse Creek station up to 7-day 10-year low flow; current lake capacity
4	Pumpage from Horse Creek station up to 7-day 10-year low flow; estimated lake capacity for the year 2034
5	Pumpage from Horse Creek station up to 7-day 10-year low flow; drought starting at lake elevation of 557.4 feet msl
6	Pumpage from Horse Creek station up to 7-day 10-year low flow; drought starting at lake elevation of 555.4 feet msl
7	Pumpage from Horse Creek station up to 7-day 10-year low flow; maintenance of a minimum lake elevation of 543 feet msl
8	Pumpage from Horse Creek station up to 7-day 10-year low flow, drought starting at elevation of 557.4 feet msl, and maintenance of a minimum lake elevation of 543 feet msl
9	Pumpage from Horse Creek station up to 7-day 10-year low flow; increased lake capacity through the dredging of 1700 acre-feet
10*	Pumpage from Horse Creek station up to 7-day 10-year low flow, current lake capacity, and present municipal consumption
11*	Pumpage from Horse Creek station up to 7-day 10-year low flow, drought starting at lake elevation of 557.4 feet msl, and present municipal consumption

* Municipal draft included to assess lake levels

Note: Unless otherwise indicated, all scenarios consider that the lake level will be at the spillway crest (559.35 feet msl) at the beginning of a drought and that the entire lake capacity will be used.

the results for each scenario are plotted in appendix A. The factors used in the scenarios are in addition to the variations in streamflow and evaporation for droughts with 10-, 25-, and 50-year return intervals, for the drought flows of record, and for droughts with durations of 6, 9, 12, 18, 30, and 54 months. The results of the yield analysis are presented in appendix B in millions of gallons per day (MGD) or as lake levels in feet msl.

Results for all 11 scenarios were plotted for recurrence intervals of 10, 25, and 50 years, for the drought of record, and for durations of 6, 9, 12, 18, 30, and 54 months. The majority of the scenarios reflect the present lake volume and low flow pumpage by the Horse Creek station. Each scenario was designed to highlight a particular possible variable so that its relative importance might be weighed against that of the other variables.

Scenario 2 is based on no pumpage by the Horse Creek station. By excluding pumpage by the Horse Creek station and using the present volume of the lake, scenario 2 illustrates the importance of this pumpage. (The results of scenario 2 and all the other scenarios may be seen in appendix A.) Scenario 2 resulted in one of the smallest yields of those investigated. The lowest yield in this scenario (27.3 MGD) occurred during the drought of record. Excluding the period-of-record droughts, the 50-year return interval drought in scenario 2 produced the lowest yield of all the droughts in the scenarios investigated: 33.3 MGD.

Scenario 3 further demonstrates the importance of supplemental pumpage. The conditions in scenario 3 were the same as for scenario 2 except that there was pumpage by the Horse Creek station which allowed in-stream flow requirements to be met. Scenario 3 allows direct comparison between no pumpage and pumpage allowing in-stream flow requirements to be met. The pumpage increased the yield under the worst drought conditions (the period of record) 34 percent over nonpumpage. Complete pumpage by the Horse Creek station is presented in scenario 1. This complete pumpage increased yields in the period of record by 60 percent over no pumpage and by 19 percent over pumpage that allowed in-stream flow conditions to be met.

Scenario 9 also is based on pumpage from the Horse Creek station, but the volume of the lake is considered to be increased to 53,880 acre-feet by the dredging of 3.6 percent. The thrust of scenario 9 was to assess the impacts of dredging. Dredging increased the critical lake yield by 3 percent over that of scenario 3 for the drought of record.

Scenario 4 represents the reduction in lake capacity due to continued sedimentation over 50 years. This condition represents the worst case of sedimentation of those investigated. This worst case allows the assessment of the lake yield for a substantial loss of capacity due to sedimentation 50 years hence. In scenario 4 the drought of record and a loss in lake capacity due to sedimentation produce a yield 5 MGD larger than in scenario 2 in which there is no pumpage by the Horse Creek station. The reduced lake capacity decreases the yield by 4.2 MGD or 12 percent over the levels in scenario 3.

Scenarios 5 and 6 are based on the onset of a drought while the lake level is not at the spillway crest. In scenario 5 the lake level is 2 feet below capacity, and in scenario 6 the lake level is 4 feet below capacity at the onset of the drought. These scenarios illustrate the effects of a drought that occurs when the lake is not full. The lake capacity in the upper 2 and 4 feet represents 14 and 29 percent of the total volume in the lake, respectively. The yield of the lake produced by scenario 6 is the lowest yield of all the scenarios: 27.1 MGD for the drought of record.

In scenarios 7 and 8 it was assumed that a minimum lake level of 543 feet msl is required to maintain municipal uses. In this bottom portion of the lake there is 5600 acre-feet of storage or 11 percent of the capacity at the spillway crest. In scenario 7 the lake level was assumed to be at the spillway crest at the beginning of the drought, while in scenario 8 the lake level was assumed to be 2 feet below the spillway. Scenario 7 produced a yield 3.4 MGD or 9 percent less than scenario 3; however, scenario 8 produced a yield 7.9 MGD or 22 percent less than scenario 3. This shows the importance of an initial low lake level combined with requiring a reserve of capacity in the lake.

The last two scenarios (10 and 11) incorporate the present municipal demand on the lake so that lake levels may be assessed. Both these scenarios are based on pumpage from the Horse Creek pump station allowing for in-stream requirements to be met. In scenario 10 the drought starts when the lake level is at the spillway crest elevation and in scenario 11 the drought starts with a lake level 2 feet below the crest. The drought of record produced lake levels for scenarios 10 and 11 of 553.9 and 547.0 feet MSL, respectively. This again emphasizes the importance of a lake being at its capacity at the onset of the drought.

Additional scenarios may be developed from the scenarios presented here. For example, if the yield for a 50-year drought with the lake dredged and no pumpage from the Horse Creek station for an 18-month duration is desired, then the difference between the present conditions with pumpage satisfying in-stream requirements and without pumpage (scenarios 3 and 2, respectively) is first obtained. In this case the difference is 11.3 million gallons per day (MGD), which represents the amount that is pumped by the Horse Creek station. Assuming the lake has been dredged, the yield of the lake is 49.5 MGD with pumpage and 38.2 MGD without pumpage. Therefore, it can be seen from comparing 38.2 MGD and the value of scenario 2 of 37.0 MGD that dredging contributes 1.2 MGD to the yield of the lake for a 50-year drought of an 18-month duration.

CONCLUSIONS

For the 11 scenarios investigated in this study, the yield of the lake was sufficient to supply the municipal water requirements, assuming a domestic use of 18 MGD. However, problems might occur in the operation of the power plant if water levels fall below 546 feet mean sea level. Lake levels below 543 feet mean sea level would cause problems with the intake to the water treatment plant. In the 11 scenarios, the minimum yield was 27.1 million gallons per day (MGD) (scenario 6), which was produced by considering that the drought started when the lake level was 4 feet below the spillway. Scenario 2, representing no pumpage, had a minimum yield of 27.3 MGD. Scenario 2 demonstrates the importance of pumpage from outside the watershed of the lake. Scenario 6 demonstrates the importance of having the lake full at the beginning of a drought, since 29 percent of the volume of the lake is in the upper 4 feet. The only input control over the lake level during a drought is pumpage by the Horse Creek station. There is some control over the amount of water used for municipal purposes as indicated by the drought plan to be implemented by the city.

It was determined that for the short-duration drought (six months) the demand on the lake is satisfied by the water stored in the lake since the inflow to the lake during this time is minimal. However, for a drought with a longer duration, the yield of the lake is more dependent on the inflow than on the storage since the inflow is much greater than the storage.

The results are presented for drought recurrence intervals of 10, 25, and 50 years, as well as for the period of record. It must be stressed that it is possible that there may be several droughts occurring within a given period, or none at all. It is therefore desirable to expect that the worst case scenario might occur at any time. Pumpage by the Horse Creek station should be an integral part of the water management plan. However, fluctuations in the water level of the lake should be expected even with pumpage.

REFERENCES

Chow, V.T. 1964. Handbook of Applied Hydrology. McGraw-Hill Book Company, New York, New York.

City Water, Light and Power. 1985. Emergency Water Supply Plan. Permit Application to the U.S. Army Corps of Engineers.

Clark, J.W., W. Viessman, Jr., and M.J. Hammer. 1971. Water Supply and Pollution Control. International Textbook Company, New York, New York.

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

Fair, G.M., J.C. Geyer, and D.A. Okum. 1971. Elements of Water Supply and Wastewater Disposal. John Wiley and Sons, Inc., New York, New York.

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

Hudson, H.E., Jr., and W.J. Roberts. 1955. Illinois Drouth With Special Reference to Impounding Reservoir Design. Illinois State Water Survey Bulletin 43, Champaign, Illinois.

Knapp, H.V. 1982. Hydrologic Design of Side-Channel Reservoirs in Illinois. Illinois State Water Survey Bulletin 66, Champaign, Illinois.

Knapp, H.V., D.C. Noel, M.L. Terstriep, and K.P. Singh. 1985a. Streamflow Assessment Model for the Sangamon River Basin in Illinois, User's Manual. Illinois State Water Survey Contract Report 358, Champaign, Illinois.

Knapp, H.V., M.L. Terstriep, K.P. Singh, and D.C. Noel. 1985b. Sangamon River Basin Streamflow Assessment Model: Hydrologic Analysis. Illinois State Water Survey Contract Report 368, Champaign, Illinois.

Lee, M.T., and J.B. Stall. 1977. Sediment and Soil Loss in Illinois. Illinois State Water Survey Project Report to the Illinois Institute for Environmental Quality, Champaign, Illinois.

National Oceanic and Atmospheric Administration. 1983. Local Climatological Data, Annual Summary with Comparative Data, 1983. National Climatic Data Center, Asheville, North Carolina.

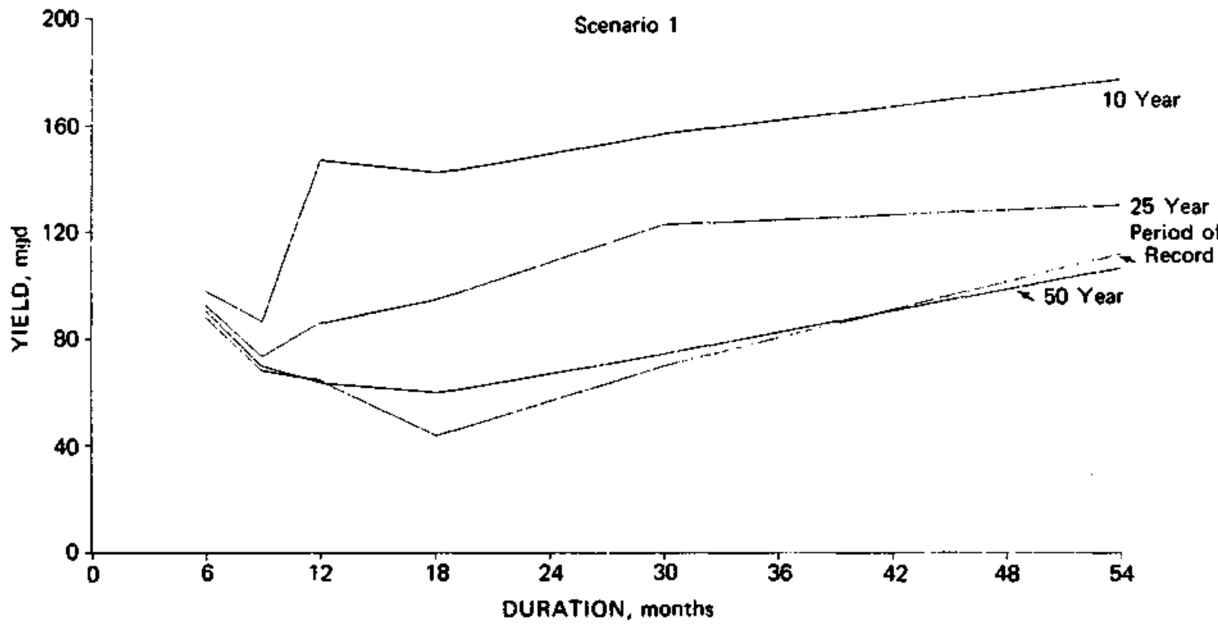
O'Hearn, M., and T.L. Williams. 1982. A Summary of Information Related to the Comprehensive Management of Groundwater and Surface Water Resources in the Sangamon River Basin, Illinois. Illinois State Water Survey Contract Report 299, Champaign, Illinois.

Roberts, W.J., and J.B. Stall. 1967. Lake Evaporation in Illinois. Illinois State Water Survey Report of Investigation 57, Champaign, Illinois.

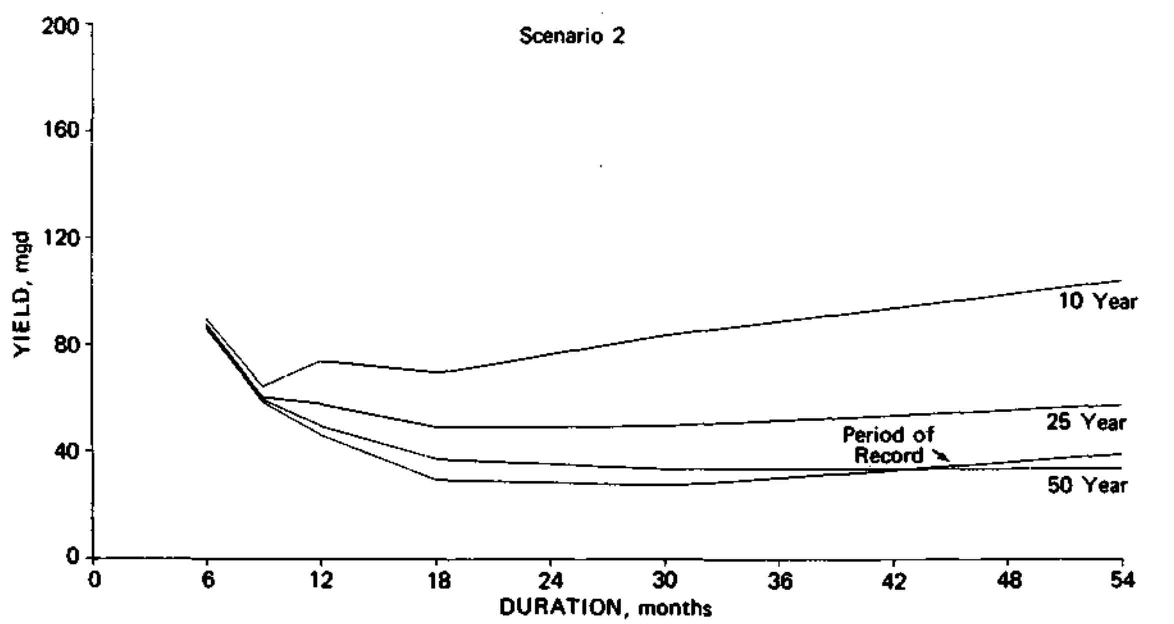
Terstriep, M.L., M. Demissie, D.C. Noel, and H.V. Knapp. 1982. Hydrologic Design of Impounding Reservoirs in Illinois. Illinois State Water Survey Bulletin 67, Champaign, Illinois.

APPENDIX A

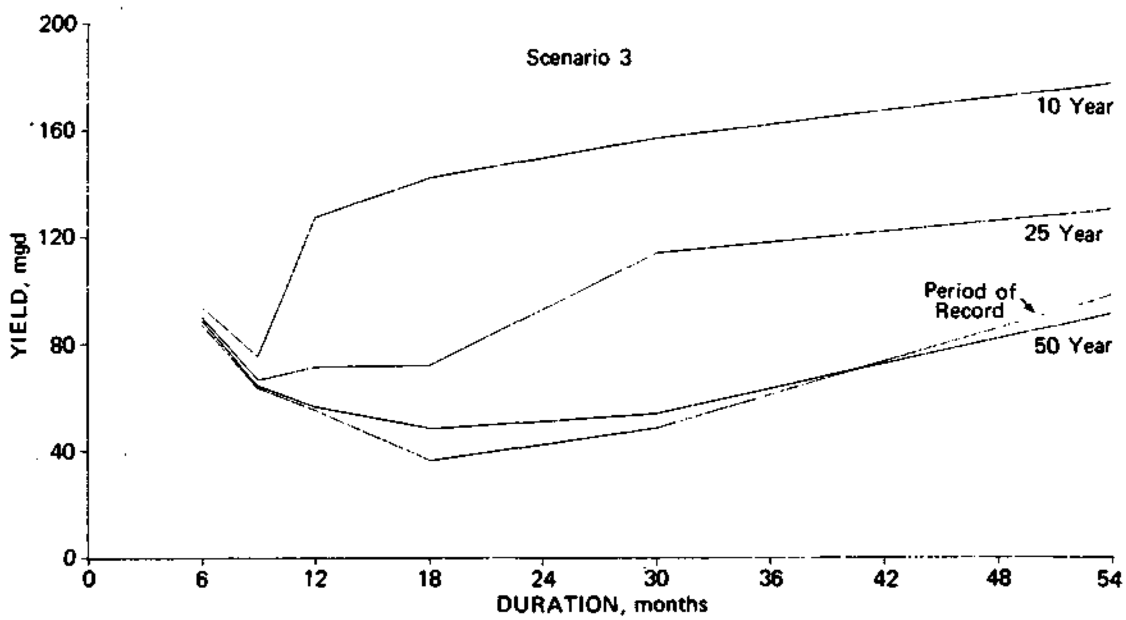
Results of Yield Analyses for the 11 Scenarios



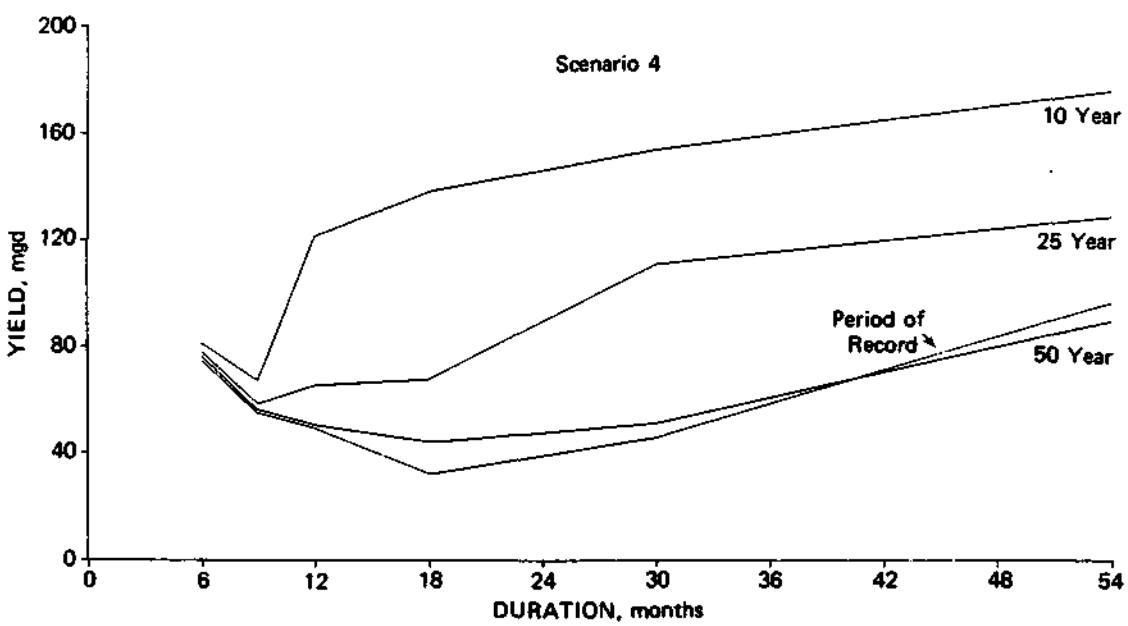
Scenario 1. Complete usage of Horse Creek pump station; current lake capacity



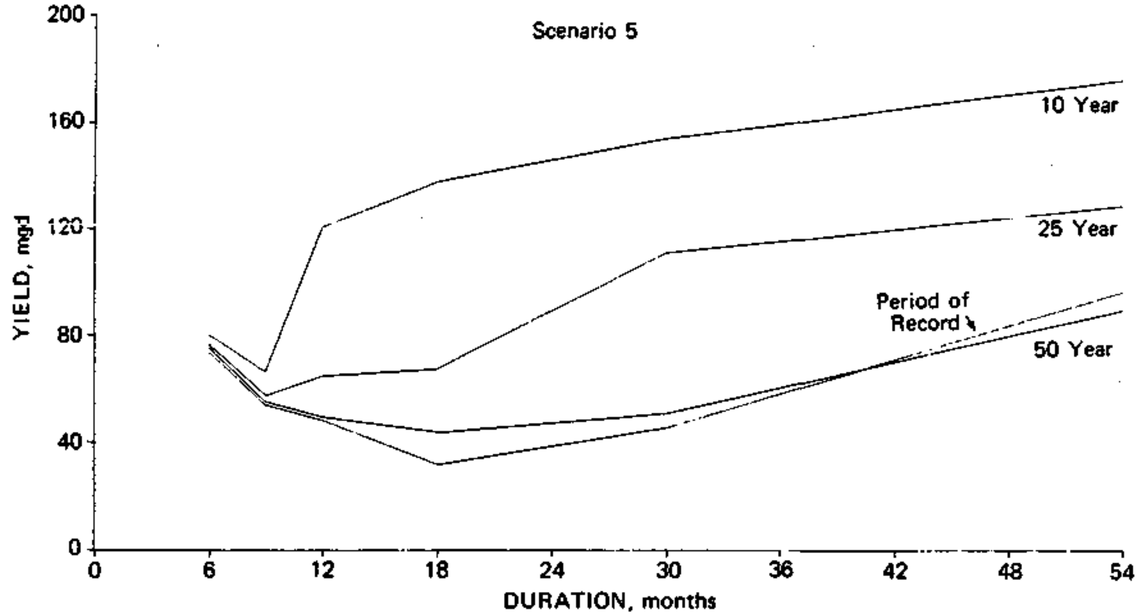
Scenario 2. No usage of Horse Creek pump station; current lake capacity



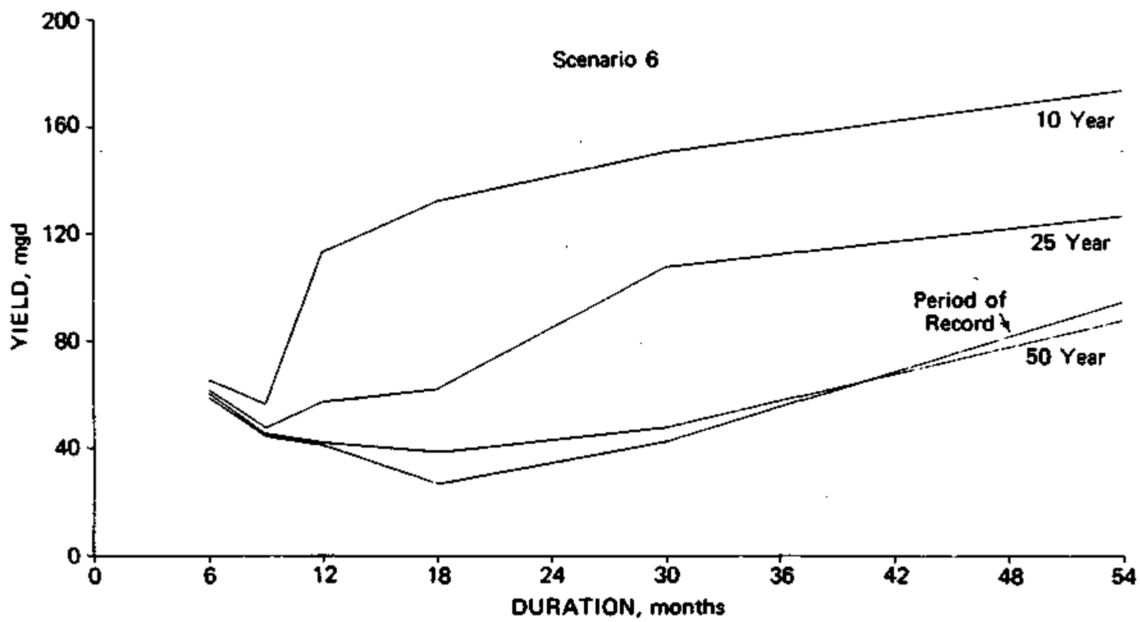
Scenario 3. Pumpage from Horse Creek station up to 7-day 10-year low flow; current lake capacity



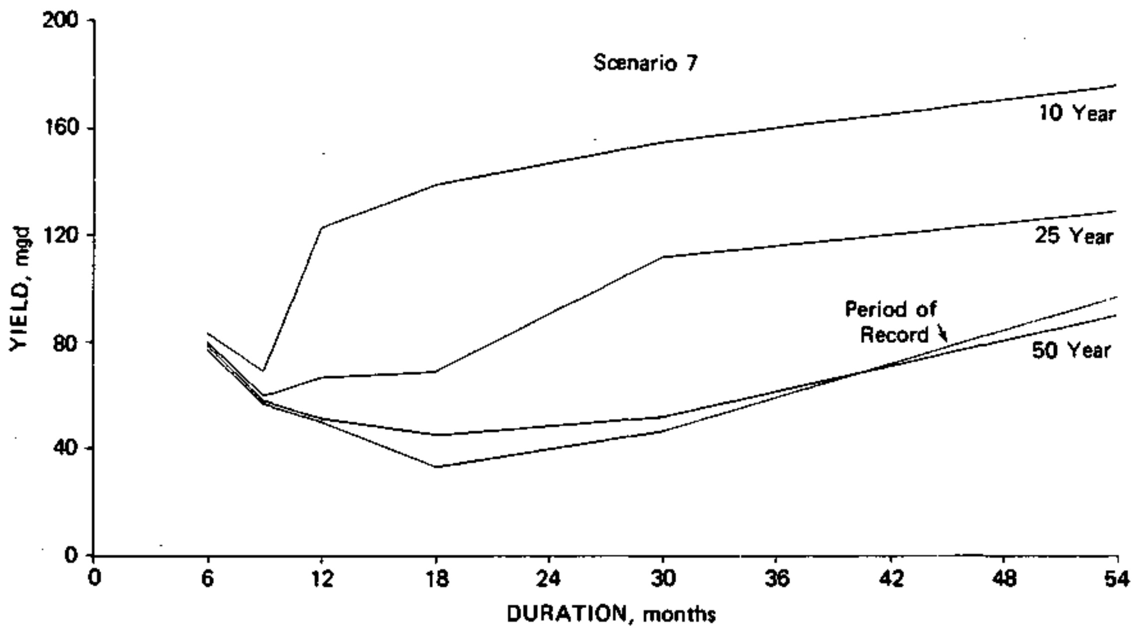
Scenario 4. Pumpage from Horse Creek station up to 7-day 10-year low flow; estimated lake capacity for the year 2034



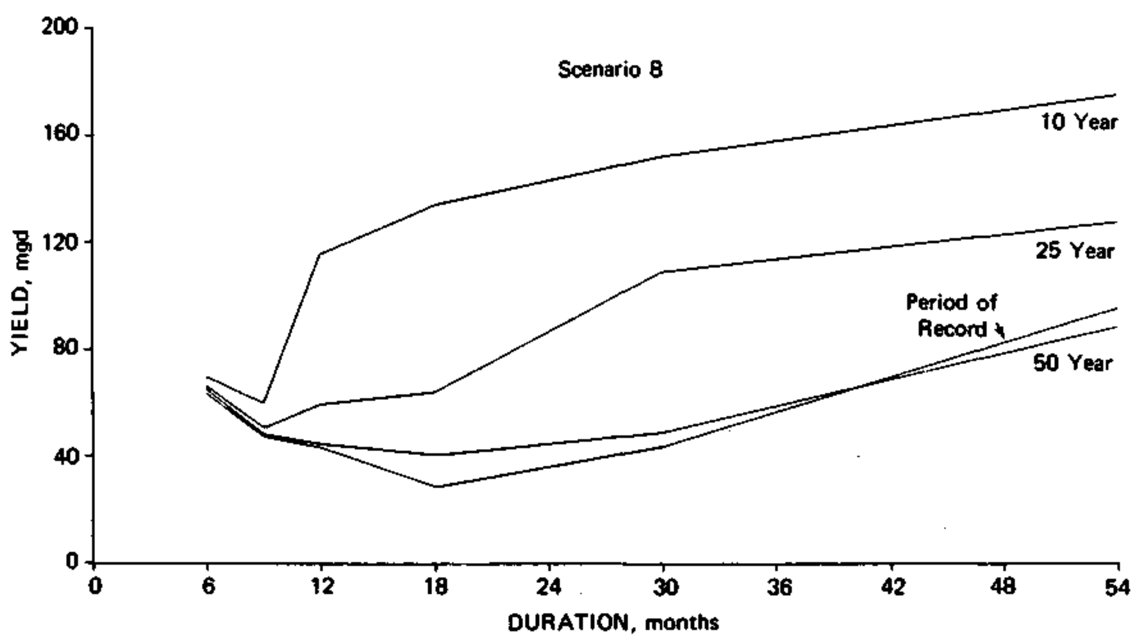
Scenario 5. Pumpage from Horse Creek station up to 7-day 10-year low flow; drought starting at lake elevation of 557.4 feet msl



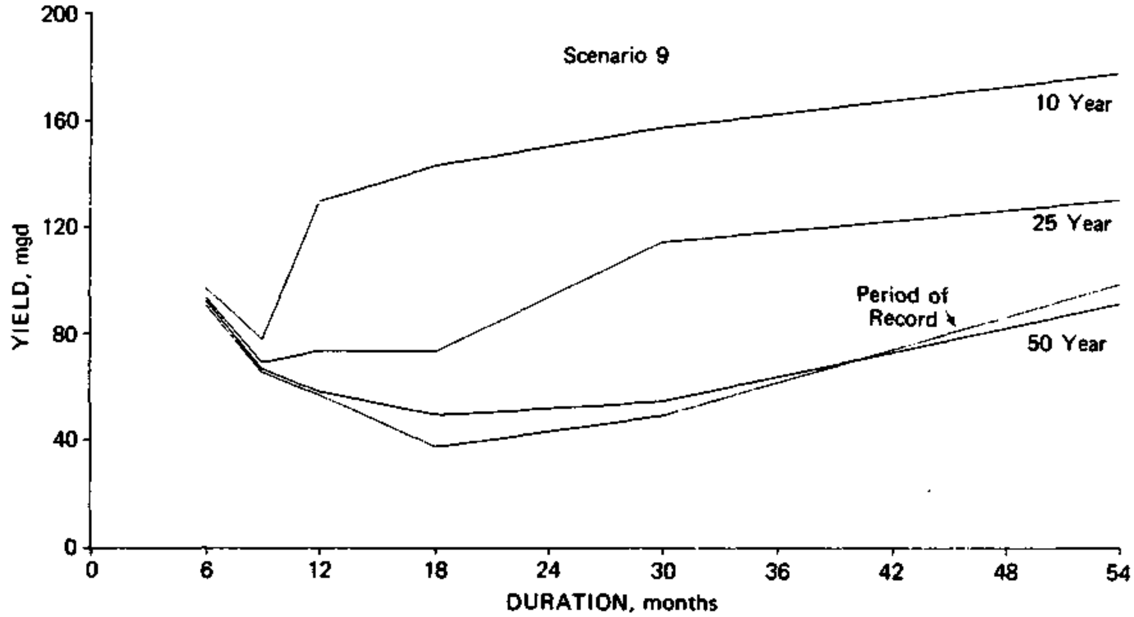
Scenario 6. Pumpage from Horse Creek station up to 7-day 10-year low flow; drought starting at lake elevation of 555.4 feet msl



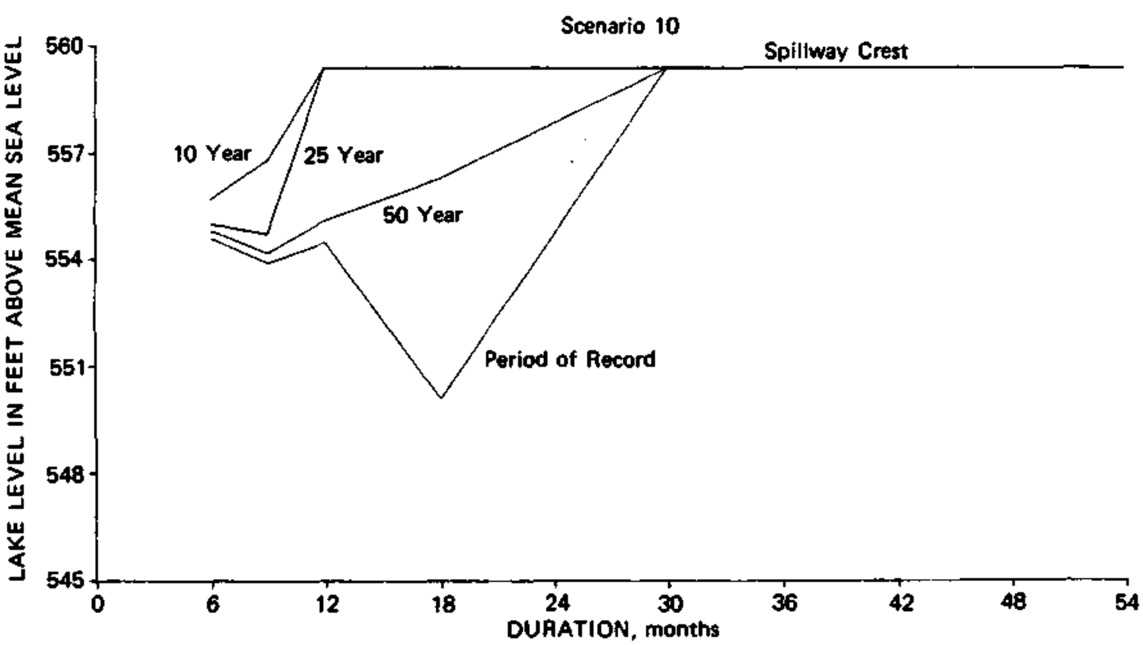
Scenario 7. Pumpage from Horse Creek station up to 7-day 10-year low flow; maintenance of a minimum lake elevation of 543 feet msl ,



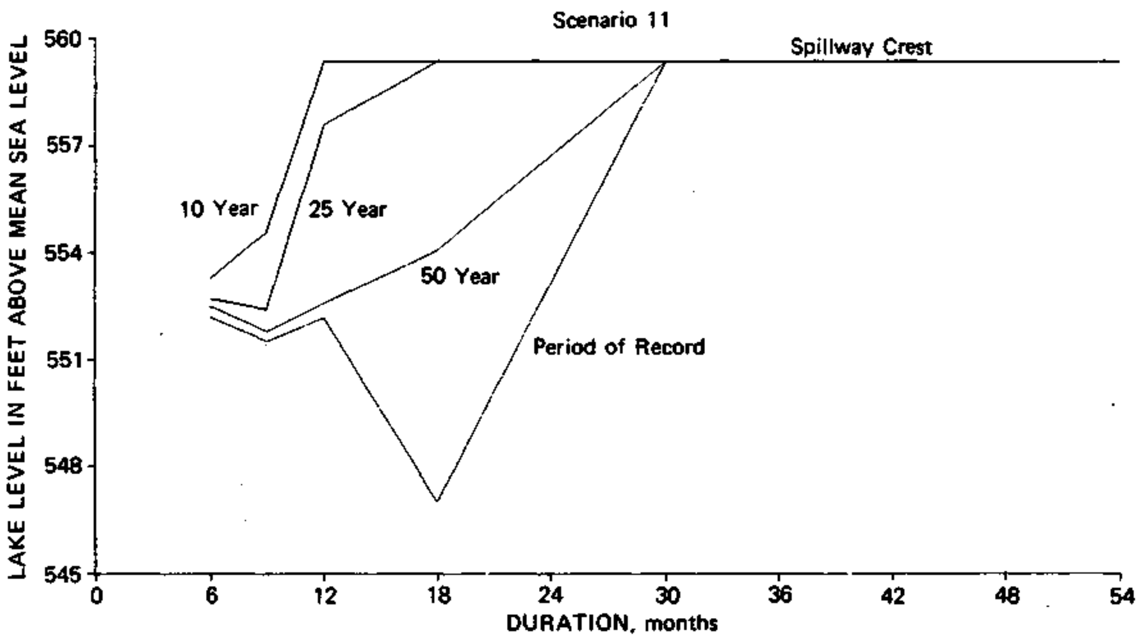
Scenario 8. Pumpage from Horse Creek station up to 7-day 10-year low flow, drought starting at elevation of 557.4 feet msl, and maintenance of a minimum lake elevation of 543 feet msl



Scenario 9. Pumpage from Horse Creek station up to 7-day 10-year low flow; increased lake capacity through the dredging of 1700 acre-feet



Scenario 10. Pumpage from Horse Creek station up to 7-day 10-year low flow, current lake capacity, and present municipal consumption



Scenario 11. Pumpage from Horse Creek station up to 7-day 10-year low flow, drought starting at lake elevation of 557.4 feet msl, and present municipal consumption

APPENDIX B

Yields for Lake Springfield for Various Scenarios, Drought Recurrence Intervals, and Durations

	Scenario 1 (MGD)	2 (MGD)	3 (MGD)	4 (MGD)	5 (MGD)	6 (MGD)	7 (MGD)	8 (MGD)	9 (MGD)	10 (ft msl)	11 (ft msl)
10 yr											
6 mo	97.8	89.5	93.6	81.2	80.1	65.4	83.3	69.8	97.0	555.7	553.3
9 mo	85.5	64.4	75.4	67.1	66.4	56.6	68.6	59.6	77.7	556.8	554.6
12 mo	147.1	74.0	128.0	121.8	121.3	113.9	122.9	116.1	129.7	559.4	559.4
18 mo	142.5	69.4	142.5	138.3	138.0	133.1	139.0	134.5	143.6	559.4	559.4
30 mo	157.2	84.1	157.2	154.7	154.5	151.5	155.1	152.4	157.9	559.4	559.4
54 mo	177.7	104.6	177.7	176.3	176.2	174.5	176.5	175.5	178.1	559.4	559.4
25 yr											
6 mo	92.5	87.6	90.0	77.6	76.5	61.8	79.8	66.2	93.4	555.0	552.7
9 mo	73.3	60.3	66.8	58.5	57.7	48.0	59.9	50.9	69.0	554.7	552.4
12 mo	85.8	57.7	71.7	65.5	65.0	57.7	66.6	59.9	73.5	559.4	557.6
18 mo	95.2	49.2	72.1	68.0	67.6	62.7	68.7	64.2	73.3	559.4	559.4
30 mo	123.2	50.1	114.1	111.6	111.4	108.4	112.0	109.3	114.8	559.4	559.4
54 mo	130.6	57.5	130.6	129.2	129.1	127.4	129.4	127.9	130.9	559.4	559.4
50 yr											
6 mo	90.7	86.9	88.8	76.3	75.2	60.6	78.5	65.0	92.2	554.8	552.5
9 mo	69.4	59.2	64.3	56.0	55.3	45.5	57.5	48.4	66.6	554.2	551.8
12 mo	63.4	49.5	56.4	50.2	49.6	42.3	51.2	44.5	58.1	555.1	552.6
18 mo	59.8	37.0	48.3	44.2	43.8	39.0	44.9	40.4	49.5	556.3	554.1
30 mo	74.7	33.3	54.0	51.5	51.3	48.4	51.9	49.2	54.7	559.4	559.4
54 mo	106.8	33.8	91.2	89.8	89.7	88.0	90.0	88.5	91.5	559.4	559.4
Period of Record											
6 mo	88.1	86.2	87.1	74.7	73.6	58.9	76.8	63.3	90.5	554.6	552.2
9 mo	68.1	58.5	63.3	55.0	54.2	44.5	56.4	47.4	65.5	553.9	551.5
12 mo	64.1	46.4	55.2	49.0	48.4	41.1	50.1	43.3	56.9	554.5	552.2
18 mo	43.6	29.5	36.5	32.3	32.0	27.1	33.1	28.6	37.6	550.1	547.0
30 mo	70.0	27.3	48.6	46.1	45.9	43.0	46.6	43.9	49.3	559.4	559.4
54 mo	112.2	39.2	98.2	96.8	96.7	95.1	97.1	95.6	98.6	559.4	559.4