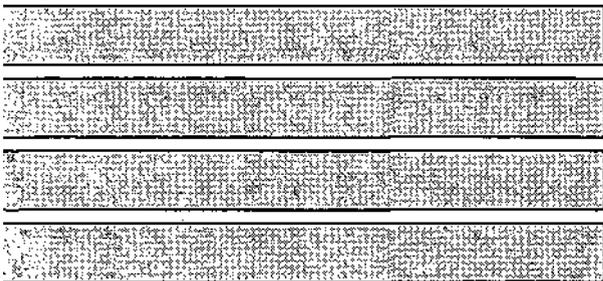# Water Quality Evaluations
for Lake Springfield and Proposed Hunter Lake
and Proposed Lick Creek Reservoir

by

Deva K. Borah, Raman K. Raman, Shun Dar Lin,
H. Vernon Knapp, and T.W. David Soong

Illinois State Water Survey
Hydrology and Chemistry Divisions
Champaign, Illinois

A Division of the Illinois Department of Natural Resources

WATER QUALITY EVALUATIONS
FOR LAKE SPRINGFIELD AND PROPOSED HUNTER LAKE
AND PROPOSED LICK CREEK RESERVOIR

By

Deva K. Borah
Raman K. Raman
Shun Dar Lin
H. Vernon Knapp
T.W. David Soong

Illinois State Water Survey
Champaign, IL

**Prepared for the
City of Springfield**

December 1997

CONTENTS

Page

LIST OF TABLES

LIST OF FIGURES

Page

LIST OF FIGURES (continued)

LIST OF FIGURES (concluded)

INTRODUCTION

Lake Springfield is the water supply reservoir for the city of Springfield and for several small nearby communities. Water from the lake is also used for cooling the city's power plant complex. The lake is operated and maintained by City Water Light and Power (CWLP), city of Springfield. The lake has a surface area of 4,000 acres (6.25 square miles) and a storage capacity of 53,600 acre-feet (17.5 billion gallons) at full pool and was completed in 1935 by the impoundment of Sugar Creek, a tributary of the Sangamon River of the Illinois River basin. The 265-square-mile watershed of the lake is primarily agricultural with 88% cropland (Lee and Stall, 1977). Figure 1 shows the location of the lake and its watershed. The principal tributaries contributing flows to Lake Springfield are Lick Creek and Sugar Creek. Spillway crest (full pool) elevation of the lake is at 560 feet. Figure 2 shows normal pool levels in Lake Springfield based on 62 years (1936-1997) of lake-level records, data provided by CWLP. As shown in this figure, monthly average lake levels varied from nearly 557.78 feet in November to 559.79 feet in June.

As the principal water supply source for the city of Springfield, Lake Springfield was adequate until the 1952-1955 drought during which the lake elevation receded to 12.6 feet below the spillway crest. The city installed a channel dam in the South Fork Sangamon River, immediately downstream of its confluence with Horse Creek, to create an impoundment and divert water to the South Fork pump station (Figure 1). This facility was constructed near a dividing dam on the east shore of Lake Springfield to augment the water supply. The channel dam has hinges at the base to allow normal river flow by laying the dam flat on the riverbed when impoundment is not needed. Water is diverted through Horse Creek upstream, and through an approximately ¼-mile-long diversion channel emerging from Horse Creek at approximately ½ mile upstream of the channel dam. Pumps were placed in service in Spring 1955. Additional water from the South Fork pump station helps to stabilize the pool level in Lake Springfield during low-flow periods and increases the available yield of the lake. With a rated capacity of 63 million gallons per day (mgd), the pump station 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 flows in the South Fork Sangamon and Horse Creek are 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 been investigating several alternative sources of supplemental water supply. City-sponsored investigations by Crawford, Murphy & Tilly, Inc., or CMT (1965, 1980, and 1983) were part of that effort. Most of those reports concluded that the most viable and economic supplemental source of water supply was a surface water supply reservoir formed by impounding Horse Creek. On December 20, 1988, the Springfield City Council enacted an ordinance authorizing the development of Lake Springfield II, subsequently named Hunter Lake, on Horse Creek for supplemental water supply (Department of Public Utilities, 1988).
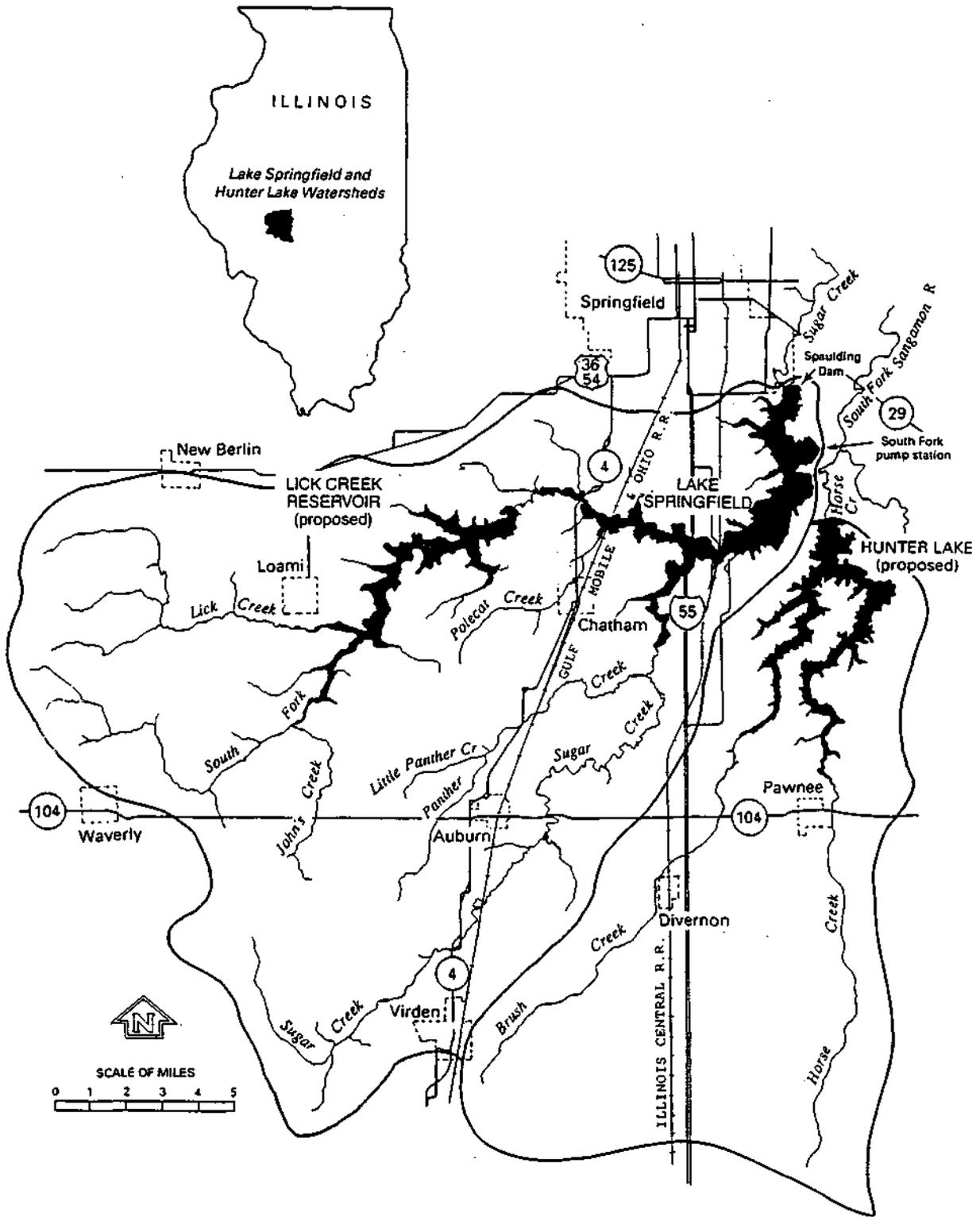
Figure 1. Locations of Lake Springfield and proposed Hunter Lake
and proposed Lick Creek Reservoir
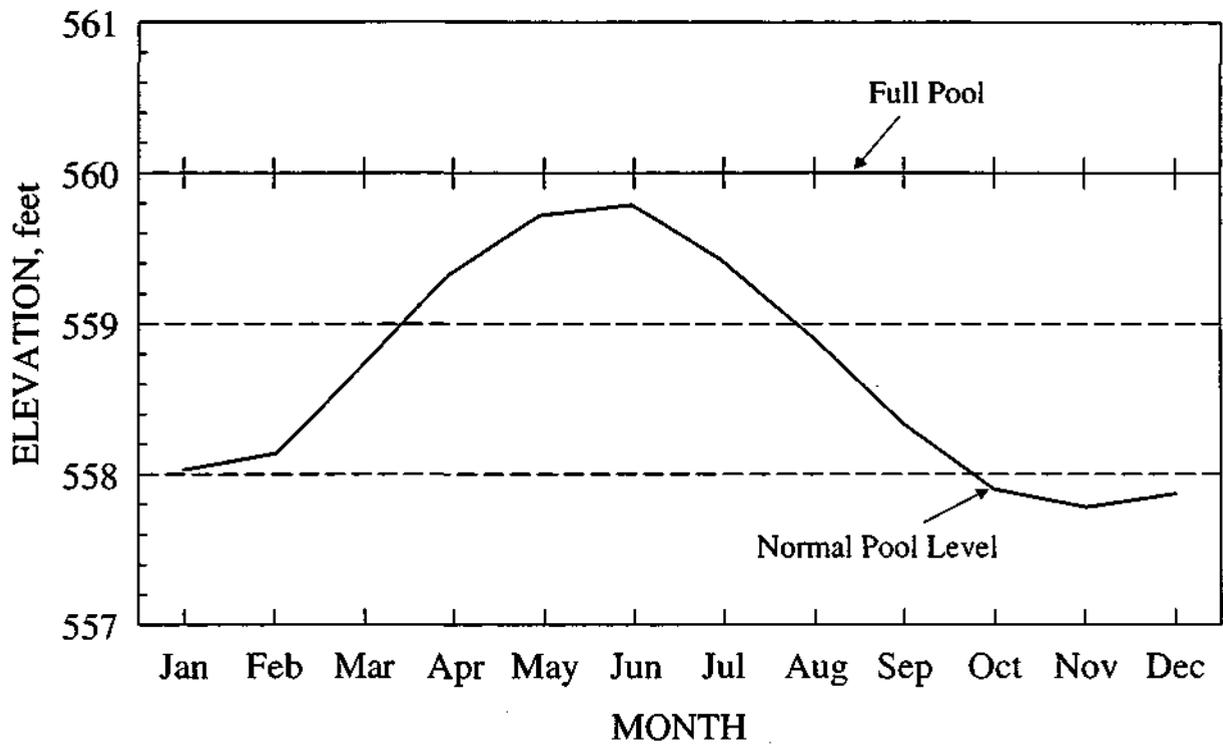
Figure 2. Normal pool level in Lake Springfield based on monthly average
lake levels observed, 1936-1997

The proposed Hunter Lake with 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) will be located just southeast of Lake Springfield (Figure 1). The 128-square-mile watershed of Hunter Lake will share its western boundary with the eastern boundary of the Lake Springfield watershed. Similar to the Lake Springfield watershed, the Hunter Lake watershed is also primarily agricultural with 88% cropland (CMT, 1994). The principal tributaries contributing flows to Hunter Lake are Horse Creek and Brush Creek. Transfer of water from Hunter Lake to Lake Springfield is expected to use the existing channel dam, diversion network, and the South Fork pump station described above. Hunter Lake will supply water to this diversion scheme for transfer to Lake Springfield to supplement its water needs.

A second reservoir has been proposed on Lick Creek immediately upstream of Lake Springfield (Figure 1) as an alternative to Hunter Lake. According to Knapp (1996), this proposed Lick Creek Reservoir would have a drainage area of approximately 110 square miles within the Lake Springfield watershed, normal pool elevation of 590 feet above mean sea level, and surface area and volume of approximately 1,946 acres and 21,500 acre-feet, respectively. Springfield CWLP has also considered a normal pool elevation of 595 feet, which would increase the surface area and volume to 2,630 acres and 33,000 acre-feet, respectively. Water quality modeling of only the former dimension will be conducted. The transfer scheme from Lick Creek Reservoir to Lake Springfield would be much simpler compared to the proposed transfer scheme from Hunter Lake. Since Lick Creek Reservoir would be located immediately upstream of Lake Springfield on Lick Creek, a simple release mechanism would be sufficient to supplement Lake Springfield water.

Concerns have been raised about the water quality of the proposed Hunter Lake and Lick Creek Reservoir, as well as Lake Springfield, during dry and prolonged drawdown periods. During the drought of 1988-1989 in central Illinois, the city of Bloomington was faced with both water scarcity and poor raw water quality in its impounded water sources (Lake Bloomington and Lake Evergreen). Taste and odor problems due to algal blooms were the major water quality concern (Shultz, 1997, personal communication). The city did not have any in-lake management practices for the lakes at that time. The city has subsequently installed destratification systems in each of its two water supply impoundments.

Water quality conditions in Lake Springfield are affected by thermal loading from the power plant's cooling water discharges, so it is extremely important to investigate thermal loading impacts and water quality conditions in this lake during prolonged droughts. It is also important to conduct thorough investigations on water quantity and quality conditions in the two proposed lakes before undertaking the extensive project of building either. Therefore, the following objectives are set for this study:

- Investigate the water quality conditions of Lake Springfield using monitored data, and through calibration and verification of a simulation model.

4

- Using the calibrated and verified model, predict water quantity and quality conditions in Lake Springfield and the proposed Hunter Lake and proposed Lick Creek Reservoir, including thermal loading effects in Lake Springfield, during a prolonged drought period, similar to 1953-1954, and with selected operating procedures.

- Using the calibrated and verified model, predict water quality conditions in all three lakes during severe drawdown situations.

- Using the calibrated and verified model, predict the impact of additional thermal discharges from the power plant on Lake Springfield expected during severe drought conditions.

The U.S. Army Corps of Engineers' (1986a, 1989) HEC-5Q model for Simulation of Flood Control and Conservation Systems with Water Quality Analysis was selected for the above investigations and predictions; The model simulates operations of a reservoir system for flood control and conservation purposes. The water quality analysis includes water temperature, three conservative and three nonconservative constituents, dissolved oxygen (DO), and a phytoplankton option.

The HEC-5Q model was calibrated for Lake Springfield using a data set monitored in 1986, and verified using data from the drought years of 1988 and 1953-1954. Flow and concentrations of the chemical constituents monitored during these years were used for calibration and verification. Missing data were estimated. Verification with 1953-1954 drought data involved only lake water levels since water quality data for this period were not available. The calibrated and verified model was used to predict surface elevations and constituent concentrations in the waters of Lake Springfield, Hunter Lake, and Lick Creek Reservoir individually and in combination during a prolonged drought period, under selected operating scenarios. Actual weather data and estimated flow during a 20-month period in 1953-1954, the most severe drought of record, were used to represent the prolonged drought period. Monitored flow and water quality data in Hunter Lake watershed for the 1990-1991 period (CMT, 1994) were available for use in these predictions along with other monitored and estimated data. The model was then used to evaluate, hypothetically, water quality in the three lakes for certain drawdown levels, including severe conditions, and the impact of additional thermal discharges from the power plant on Lake Springfield expected during severe droughts.

Before describing the modeling study and the results, a brief review of past studies of Lake Springfield and the proposed Hunter Lake, existing monitored data, and a brief description of the HEC-5Q model are provided.

Acknowledgments

PAST STUDIES AND AVAILABLE DATA

Literature was reviewed in search of data for water quality modeling of Lake Springfield and the proposed Hunter Lake and Lick Creek Reservoir. An inspection report for the National Dam Safety Program of the Department of the Army (1980), Chicago District, Corps of Engineers on Spaulding Dam and Lake Springfield contains substantial descriptive and physical data for Lake Springfield, and its control structures, including Spaulding Dam, which creates the impoundment for Lake Springfield.

Several studies have been reported on water, sediment, and nutrient budgets for Lake Springfield. One of the earliest studies was a sedimentation investigation of Lake Springfield by Fitzpatrick, Bogner, and Bhowmik (1985), whose results have been used by others in subsequent studies of the lake. Fitzpatrick and Keefer (1988) reported results of a two-year field monitoring study (May 15, 1985 - May 14, 1987) to assess the hydrologic, sediment, and nutrient budgets of the Lake Springfield watershed. Fitzpatrick and Knapp (1991) performed drought yield analyses of Lake Springfield and Hunter Lake. These investigators developed and presented current (1990) stage-capacity relationships for both lakes, considering a 1987-1990 dredging of the upper portion of Lake Springfield, and future (2025 and 2040) stage-capacity relations considering projected future sedimentation. The U.S. Environmental Protection Agency (USEPA) Clean Lakes Program Phase I and Phase II reports for Lake Springfield by CWLP (1987; 1992a) documented the historical background for Lake Springfield, and monitored data on hydrology and water quality.

Monitoring data for Hunter Lake watershed is limited. CMT (1994) monitored water, sediment, and nutrients at three sites in the Hunter Lake watershed for a period of one year, starting April 1990 and ending April 1991. The monitoring sites were at Horse Creek, Brush Creek, and at the proposed dam site (Figure 1). The investigators reported continuous flow and rainfall measurements of two storms: one during November 27-29, 1990, and the other during December 2-4, 1990. Data reported for a 13-hour storm on May 4, 1991 included: continuous flow, turbidity, total suspended solids, and rainfall measurements. Water, sediment, nutrient, and other water quality parameters were measured once every month throughout the one-year monitoring period. One grab sample obtained at each of the three stations on an unspecified collection date was analyzed for pesticides. The investigators computed and presented budgets of all the water quality parameters based on loading equations derived from the observed data. That study also presented monthly budgets of precipitation, flow, ammonia nitrogen, nitrate-nitrogen, total Kjeldahl nitrogen, dissolved nitrate, total phosphorous, soluble phosphorus, dissolved solids, total suspended solids, volatile suspended solids, alkalinity, hardness, total iron, turbidity, dissolved oxygen saturation, dissolved oxygen (DO), temperature, fecal coliform, and pH for the three monitoring stations.

In another study, CMT (1993) investigated the point source discharges located in the Hunter Lake watershed. The investigators found seven point source sites, of which only three sources were of concern: Virden East sewage treatment plant (STP), Pawnee

wastewater treatment facility (WWTF), and Divernon WWTF. Reporting a decision of the Illinois Environmental Protection Agency (IEPA) on the Virden East STP, CMT (1993) states, "The discharge from the Virden facility is located between 9 and 10 stream miles upstream from the upper end of Hunter Lake. This length of free flowing stream was sufficient for IEPA to determine that the construction of Hunter Lake would not impact this facility's discharge limits." Divernon WWTF is located approximately three miles upstream of the upper end of Hunter Lake along Brush Creek. Modeling of dissolved oxygen using Streetor-Phelps analysis showed no impact on Hunter Lake water quality. Only Pawnee WWTF, which is located 600 feet from the lake boundary on Horse Creek, could cause water quality problems for Hunter Lake. Suggestions to eliminate water quality impacts of Pawnee WWTF included more stringent effluent limitations or alternative mitigation schemes, such as relocation of discharge to the South Fork Sangamon River, discharge of wastewater to Springfield Metro Sanitary District, construction of new treatment facilities, or elimination of discharge by land application.

The Hunter Lake Habitat Evaluation Procedure (HEP) team (1992) reported their findings on habitats in the Hunter Lake watershed, the impact of the project, and their recommended management. Other lake water quality studies in similar geographic regions, such as Lake Bloomington studies by Kothandaraman and Evans (1970; 1971), and the proposed Middle Fork Vermilion Reservoir study by the Illinois State Water Survey Water Quality Section (1975) also provided information useful to the current study.

THE HEC-5Q MODEL

The U.S. Army Corps of Engineers' (1986a) HEC-5Q model for Simulation of Flood Control and Conservation Systems with Water Quality Analysis was selected for this study. The model has two distinct modules: a flow simulation module and a water quality simulation module. The flow simulation module is the original U.S. Army Corps of Engineers' (1982; 1989) HEC-5 model, developed to assist in planning studies for evaluating proposed reservoirs in a system and to assist in sizing the flood control and conservation storage requirements for each project recommended for the system. The model can also be useful for selecting proper reservoir operational releases for hydropower, water supply, and flood control. The model basically routes water through a reservoir and stream network using a selection of standard routing techniques.

The water quality simulation module (U.S. Army Corps of Engineers, 1986a) accepts system flows generated by the flow simulation module and computes the vertical distribution of temperature and other constituents in the reservoir and the water quality in associated reaches downstream. This module was developed so that temperature and selected conservative and nonconservative constituents, including dissolved oxygen (DO), could be included as a consideration in planning studies. A conservative constituent, such as chloride, is one that does not undergo changes mediated by biological activities. On the other hand, nonconservative constituents, such as DO, nitrate-nitrogen, ammonium-nitrogen, and phosphate-phosphorus, are those that undergo changes mediated by biological activities.

The water quality simulation module of HEC-5Q model includes simulation of two alternative options. The variable constituents for one option include: water temperature, up to three conservative and up to three nonconservative constituents, and DO with certain restrictions. The restrictions are that water temperature must always be simulated, a maximum of two oxygen-consuming constituents may be simulated, only one nonconservative constituent not connected with the DO cycle may be simulated, and at least one oxygen-consuming constituent must be simulated as a nonconservative constituent to be able to simulate DO. The second option, the phytoplankton option, simulates eight constituents: water temperature, total dissolved solids, nitrate-nitrogen, phosphate-phosphorus, phytoplankton, carbonaceous biological oxygen demand, ammonia nitrogen, and DO. In this option, none of these constituents may be omitted.

The reservoirs are represented conceptually by a series of one-dimensional horizontal slices. Each horizontal slice or layered volume element is characterized by an area, thickness, and volume. Within each element, the water is assumed to be fully mixed. Each horizontal layer is assumed to be completely homogeneous with all isopleths parallel to the water surface both laterally and longitudinally. Vertical advection is governed by the location of inflow to and outflow from the reservoir. Computation of the zones of distribution and withdrawal for inflows and outflows are of considerable significance in operation of the model. The Waterways Experiment Station (WES) withdrawal method (Bohan and Grace, 1973) is used to determine the allocation of

outflow. The Debler (1959) inflow allocation method is used to place inflows. Vertical advection and effective diffusion are the two transport mechanisms used in the model to transport water quality constituents between elements.

Reservoir dimension limitations include: 50 volume elements per reservoir, one flood control outlet, one uncontrolled spillway, and a selective withdrawal system composed of two wet wells, containing up to eight ports each. The wet wells are commonly known as intakes, located inside the lake, through which water for water treatment plants and/or power plants is withdrawn.

Stage-area-storage-discharge relations are the basic physical data for reservoirs. Reservoir storage allocations are required among five zones: inactive, buffer, conservation, flood control, and emergency flood surcharge storage or top of the dam. In the current study for drought conditions, accurate definition of only the inactive zone is important. Inactive zone is the reservoir zone below the lowest water intake level. The water quality module requires additional relationships of stage with dam widths representing effective reservoir withdrawal widths. Specifications for the outlet structures include flood control outlet, uncontrolled spillway, and wet wells. Outlet specifications are virtual widths, maximum allowable flow rates, and elevations.

Based on the simulation period and time step, the model can be operated in two different modes: annual and long-term simulation modes. The annual simulation mode uses the daily time step, and simulations are limited to periods within one calendar year. Flow data must be furnished at one-day intervals for this mode. Because model calibration must be done using the annual simulation mode, this mode is also referred to as calibration mode. Longer time intervals (generally monthly) are used for the long-term simulation mode, and there are no limits for the simulation period. Flow data must be furnished at longer time intervals (generally 30 days) for this mode.

The U.S. Army Corps of Engineers (1986b) applied the HEC-5Q model to the Kanawha River basin in West Virginia to demonstrate its validity, and to provide an example for those who might apply the model to other river basins. It was a cooperative study between the staff of the Hydrologic Engineering Center (HEC), who developed the model, and the Huntington District, Ohio River Division, Office of the Chief of Engineers, who had knowledge of the river basin and data availability. The model network consisted of the headwater reach of Kanawha River above Winfield Lock and Dam, two adjacent impoundment reservoirs, two tributaries connecting these two reservoirs to the Kanawha River, and a third tributary that received water from another impoundment reservoir.

The first step of the above study involved data assembly. The second step involved use of utility programs WEATHER and HEATX to process meteorological data from the National Climatic Center, and GEDA to process channel cross-sectional dats. The third step involved model calibration, the most difficult task in the procedure because it involved modification of model inputs for each trial execution. Model inputs that

usually change are parameters not easily measurable nor available, such as reservoir diffusion coefficients, the distribution of absorbed radiation, and the estimated spatial and temporal variation of the inflow water quality concentrations at all boundaries. The fourth step was model verification by applying the model to an independent period of data without modifying the calibration parameters.

The above simulations used a daily time interval. A trial model run was made for October 1976. Calibration used the 1979 and 1980 data. When data for 1983 were available, verification analyses were performed. In both calibration and verification, simulations were made for a four-month period, June through September each year. Model coefficients, parameters, and watershed flow quality were kept constant in both the calibration and verification runs. Model performances during calibration and verification were evaluated based on comparisons between predicted constituent concentrations in the reservoir layers and observed values. Only the temperature and DO results were reported. Some comparisons were good and some were not. However, the reservoir reproductions were considered good in general. This Corps of Engineers study provided useful guidance to the current modeling study.

MODEL NETWORK AND DATA PREPARATION

Two model networks, one with Lake Springfield and the proposed Hunter Lake (Figure 3), and the other with Lake Springfield and the proposed Lick Creek Reservoir (Figure 4), were established for water quality simulations using the HEC-5Q model. The first network (Figure 3) includes Lake Springfield as node (or control point) CP-10, Hunter Lake as node CP-20, and four channel reaches connecting three downstream nodes (CP-30, CP-40, and CP-50), respectively, located at the confluence of Horse Creek and South Fork Sangamon River; the confluence of Horse Creek, Sugar Creek, and the Sangamon River; and a downstream point on the Sangamon River. The downstream nodes were introduced as dummy nodes to satisfy model requirements. Major tributaries contributing to Lake Springfield are Lick Creek and Sugar Creek, and major tributaries contributing to Hunter Lake are Brush Creek and Horse Creek. Inflows from other tributaries and sub-basins are considered as local contributions.

The second network (Figure 4) includes Lick Creek Reservoir as node CP-10, Lake Springfield as node CP-40, and three channel reaches connecting three additional nodes: confluence of Lick Creek and Polecat Creek (CP-20), confluence of Lick Creek and Sugar Creek (CP-30), and confluence of Sugar Creek and Sangamon River (CP-50). In addition to contributions of local tributaries and sub-basins, Lick Creek Reservoir will receive inflows from Lick Creek and South Fork of Lick Creek, and Lake Springfield will receive inflows from Lick Creek Reservoir releases, Polecat Creek, and Sugar Creek (Figure 4).

Model inputs were prepared using data gathered from various sources listed above in the "Past Studies and Available Data" section of the report. Information, reports, and data gathered during visits and through correspondence with Springfield CWLP filled many data gaps. Visual inspection of the control structures and waterways during a field visit in September 1996 were helpful in preparing model networks and input data.

Lake Springfield's stage-area-storage-discharge-dam width relations were obtained from a combination of three different sources: Department of the Army (1980) inspection report for the National Dam Safety Program, and reports by Fitzpatrick et al. (1985) and Fitzpatrick and Knapp (1991). Elevations at lake bottom, spillway crest (full pool), and top of dam are 535, 560, and 570 feet, respectively. Reservoir storage allocations were estimated among the five zones (inactive, buffer, conservation, flood control, and emergency), based on the lake operation procedures described in the above sources and as described by Springfield CWLP staff. Since only low flows and drought conditions were simulated in this study, accurate determination of the inactive zone was important. Outlet specifications were taken and estimated from documents provided by CWLP staff.
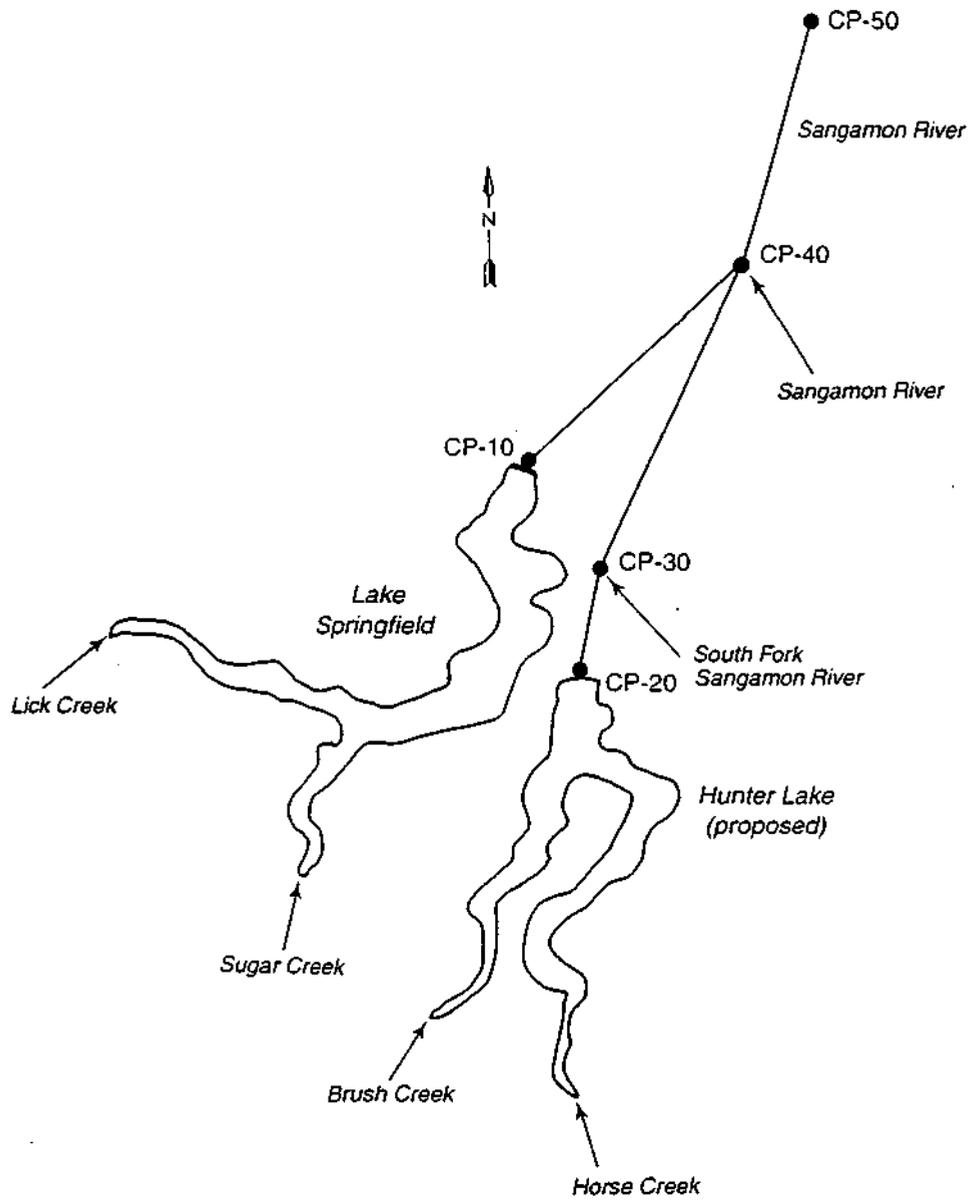
Figure 3. HEC-5Q model network of Lake Springfield and proposed Hunter Lake
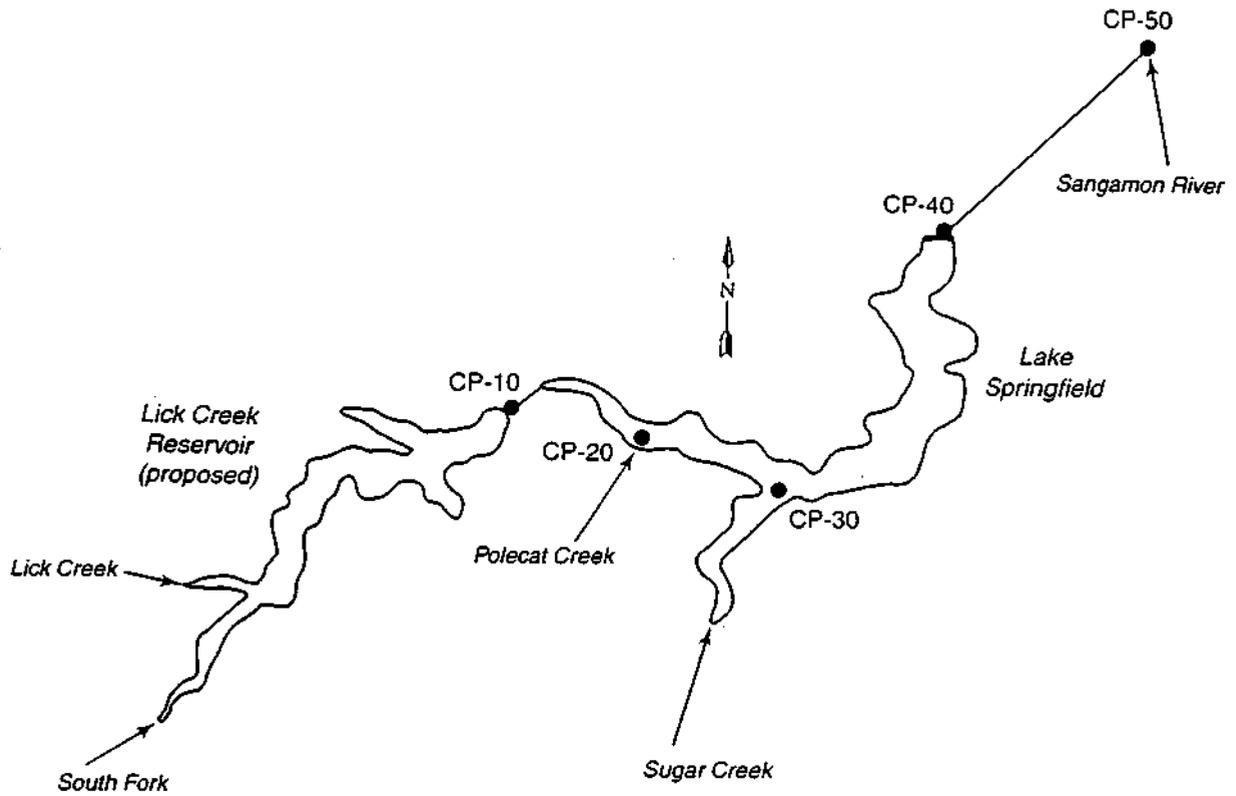
Figure 4. HEC-5Q model network of Lake Springfield and proposed
Lick Creek Reservoir

The stage-storage relation for the proposed Hunter Lake was obtained from Fitzpatrick and Knapp (1991). The stage-area relation was estimated from the stage-storage relation. CWLP provided dam and spillway dimensions from their design documents. Stage versus dam widths were estimated from these documents. Lake bed, full pool, and top of dam elevations are 525, 571, and 583 feet, respectively. A stage-discharge relation was developed using standard weir formula, and coefficient values used by the Department of the Army (1980) for Lake Springfield. Reservoir storage allocations for the five zones, and outlet specifications were estimated. Hunter Lake elevations were expressed with reference to the National Geodetic Vertical Datum (NGVD). However, Lake Springfield elevations were expressed with reference to an old standard 0.65 feet higher than the NGVD. Since these two lakes were modeled independently without any direct interaction, no attempt was made to adjust elevations of either one.

Knapp (1996) provided stage-area-storage relations for Lick Creek Reservoir. Elevations of reservoir bed and full pool are 560 and 590 feet, respectively. At the time this modeling study was conducted, detailed design for Lick Creek Reservoir dam and outlet works was not available. Therefore, dimensions and specifications of these structures were assumed to be the same as those for Hunter Lake. Accordingly, dam widths at different stages were estimated, and discharges were computed using the same formula, coefficient values, and dimensions as Hunter Lake. Reservoir storage allocations for the five zones were also estimated using similar operating procedures.

Meteorological data (cloud cover, wind speed, air temperature, dew point temperature, and short wave solar radiation) were provided by the Midwestern Climate Center, ISWS. The HEC-5Q utility program HEATX was used to compute daily equilibrium temperature, coefficient of heat exchange, short wave solar radiation, and wind speed with proper units as required by the model.

Fitzpatrick and Keefer (1988) observed and recorded in ISWS open files Lake Springfield's daily inflows from the upstream tributaries, direct sub-basin contributions, and pumped contributions from the South Fork Sangamon River and Horse Creek for a two-year monitoring period (1985-1987). These records were used in the calibration runs of the model. The remaining tributary inflows and direct sub-basin contributions to Lake Springfield, Hunter Lake, and Lick Creek Reservoir, which were used as model inputs, were estimated using the ISWS watershed simulation model (Durgunoglu et al., 1987) as part of the Phase II component (Knapp 1997), a parallel component of this study.

In addition to spillway overflows during and after rainfall events, water is withdrawn constantly from Lake Springfield to supply a water treatment plant and cool a power plant. Table 1 shows the CWLP historical water use data in ISWS open file records from the Illinois Water Inventory Program (IWIP). The average public water supply withdrawal rate from these historical values is 21 mgd. As shown in Table 1, the yearly water supply consumption has been almost constant. Therefore, in this modeling

study, the average withdrawal rate for water supply was taken as 21 mgd or 33 cubic feet per second (cfs).

From the records shown in Table 1, the average power plant withdrawal rate from all the units is computed as 280 mgd. As shown in this table, yearly power plant withdrawal has been increased substantially in recent years with a maximum average rate of 307 mgd in 1995. The rate varies on a day to day basis. Based on information gathered from plant operators during a site visit on September 13, 1996, the average power plant supply is taken as 394 mgd or 610 cfs for this modeling study. A small portion of the intake water is used to divert coal ashes from the power plant to a coal ash pond. For this modeling study, the amount of the coal ash diversion was estimated to be 4 mgd or 7 cfs. Recent monitoring has indicated that the diversion amount is closer to 8 mgd. The remainder and bulk of the intake water, roughly 390 mgd (603 cfs), is circulated through the power plant and returned to the lake. This return water is an average of 15-20°F warmer than the intake water. Average dam and gate leakage was estimated to be 1 cfs (Fitzpatrick and Keefer, 1988). Therefore, on top of the natural inflows and outflows from Lake Springfield, a constant inflow of 603 cfs and a constant outflow of 644 cfs were added. The above flow values were used while calibrating the model with 1986 data, and were revised based on observations and projections while verifying the model with 1988 and 1953-1954 data, and finally while evaluating water quantity and quality in the lake for future prolonged drought periods.

Table 1. Historical Water Use and Power Generation by Springfield City Water Light and Power

Year	Public water supply (mil. gal.)	Power plant Dallman units (mil. gal.)	Power plant Lakeside unit (mil. gal.)	Power generation (mil. kwh)
1996	7,990	108,638	--------	1,888
1995	7,829	101,800	10,300	-------
1994	7,807	104,000	7,700	1,723
1993	7,442	94,100	10,700	1,749
1992	7,665	86,754	11,163	1,495
1991	7,607	94,778	8,510	1,674
1990	7,572	89,999	8,284	------
1989	------	68,597	6,075	1,558
1988	8,175	96,907	9,618	1,500
1987	8,075	92,718	9,612	1,384
1986	7,578	85,963	12,765	1,330
1985	6,490	93,706	5,196	1,238
1984	7,185	95,870	13,706	------

Unlike Lake Springfield, there will be no return flows to Hunter Lake and Lick Creek Reservoir. All inflows to these lakes will be natural and from the upstream tributaries and sub-basin's direct contributions. There will be releases from these lakes depending on supplemental requirements of Lake Springfield. Operating scenarios of these lakes were developed, and downstream releases were determined for model input, as described later in the report.

Constituent concentrations of the inflow water to Lake Springfield and Lick Creek Reservoir were estimated based on water quality observations on Lick Creek near Loami, IL (Figure 1), data available in ISWS open file records. Since the observations were made only at a specific location, representative constituent concentrations to Lake Springfield were obtained by adjusting the estimated values during model calibration, a procedure used and suggested by developers of the model (U.S. Army Corps of Engineers, 1986b). Constituent concentrations with inflow water to Hunter Lake were estimated based on observations made by CMT (1994) on Horse Creek and Brush Creek during their one-year (1990-1991) monitoring period.

In addition to inflows and their constituent concentrations, the model requires initial storage and initial constituent concentrations at different layers of the lake to start simulation. These conditions are time dependent on the beginning of a simulation period. These values were obtained from observations, if available; otherwise, values were estimated based on seasonal observations of years other than the year of the simulation period. Dissolved oxygen demand by benthic materials at lake bed were estimated for model input. Diffusion coefficients, decay coefficients, and thermal correction factors were taken from the literature and adjusted during calibration. Finally, gate operation data were input.

Constituent concentrations in different layers of Lake Springfield were obtained from personal correspondence with CWLP staff and from their USEPA Clean Lakes Program Phase I and Phase II reports (CWLP, 1987; 1992a). These data were observed by CWLP and their contractors for an extended period of time. These data were used for initial conditions, as described above, and in calibration and verification of the model on Lake Springfield.

MODEL CALIBRATION ON LAKE SPRINGFIELD

The HEC-5Q model was calibrated on Lake Springfield. Extensive flow and water quality data have been collected on Lake Springfield and its watershed since completion of lake construction in 1935. Without monitored data, calibration is impossible. Therefore, the model can be calibrated only on Lake Springfield. For calibrating the HEC-5Q model, both flow and water quality data monitored in the lake and also in the watershed are required. As mentioned earlier, water quality monitoring and collection of data on Lake Springfield have been recorded by CWLP (1987, 1992a) from 1986 to 1994. Fitzpatrick and Keefer (1988) monitored inflow and water quality to Lake Springfield, and outflow from Lake Springfield for a two-year period, starting May 1985 and ending May 1987. Therefore, the year 1986 was found to be the most appropriate time period for calibration of the model.

A six-month period, April 1-September 30, 1986, was selected for the calibration. Water quality characteristics in Illinois are found to deteriorate during warm summer months, particularly in the hypolimnetic zone of the lake. Thermal stratification depletes oxygen and increases nutrients and other mineral constituents in the deep waters during summer months, resulting in very poor water quality characteristics. Also, the biological productivity and nutrient uptake in the lake increase during the summer period. Characterization of water quality changes in impounded waters during the warmer period compared to winter months is generally considered critical. Because of these considerations and because of the availability of observed data during this period only, the April 1-September 30 period was chosen for model calibration, verification, and water quality prediction.

Daily inflows to Lake Springfield from Lick Creek, Sugar Creek, direct tributaries, Panther Creek, and Polecat Creek, and daily outflows from Lake Springfield during the above period, as observed by Fitzpatrick and Keefer (1988), were obtained from ISWS open file records. Inflows from all sources were added. As discussed earlier, a constant flow of 603 cfs from the thermal power plant was added to the inflows. In addition to these inflows, 244 million gallons of water was pumped to Lake Springfield from Horse Creek and the South Fork Sangamon River during the month of September. Therefore, a constant equivalent flow of 13 cfs was added to the daily inflows of September.

Spillway overflows were observed only during the months of May and June 1986. As discussed earlier, in addition to the spillway overflows, water is continually withdrawn from the lake to the water treatment plant and to the power plant at average rates of 33 cfs and 610 cfs, respectively. Assuming a 1 cfs loss due to dam and gate leakage, a constant outflow of 644 cfs must be added to the spillway overflows. The model computes outflows from the lake during the simulation using the stage-discharge relation provided in the input. Therefore, the stage-discharge relation, which was initially based on the weir formula and computes only spillway overflow, was revised by adding 644 cfs starting at the intake level. Gate control data were prepared based on the ratios of

spillway discharge, flow to water treatment plant as wet well 1, and flow to power plant as wet well 2 with respect to the total outflow, computed by adding 644 cfs to spillway discharges.

Meteorological data, as described earlier, for the entire year of 1986 were acquired from the Midwestern Climate Center, ISWS, and model inputs were prepared. Before preparing the water quality data, constituents must be selected for analyses and simulation. Eight constituents were simulated:

1. Temperature
2. Total dissolved solids
3. Nitrate-nitrogen
4. Phosphate-phosphorus
5. Total Kjeldahl nitrogen
6. Ultimate biological oxygen demand.
7. Ammonia nitrogen, and
8. Dissolved oxygen

Although all eight constituents were simulated, because of data availability and importance of the constituents to this study, special attention was given to constituents 1, 3, 4, and 8 while calibrating and verifying the model, and finally evaluating the lakes. Simulations, results, and discussions of only these constituents are reported here. Although constituents 2, 5, and 6 are also important in water quality evaluations, lack of adequate information on these preclude discussions on them. There were no total dissolved solids and ultimate biological oxygen demand data for Lake Springfield. There was only one set of total Kjeldahl nitrogen data for the lake. Consequently, these three constituents could not be calibrated, verified, and accurately predicted by the model.

Concentrations of the above constituents in the inflow water to Lake Springfield were estimated based on monitored data on Lick Creek near Loami, IL (ISWS open file record). The monitored data were based on 13 instantaneous samples collected at approximately equal time intervals (days) during March-September 1986. Values were entered at the instantaneous times (days), and the model interpolated daily inflow concentrations throughout the six-month simulation period. Constituent concentrations of the lake water were observed on the same 13 days as the inflow concentrations. Profiles of temperature and DO concentration at 2-foot intervals were available. Concentrations of the remaining constituents were available only at the surface and at the bottom layers. Observations at monitoring station 1 (CWLP 1987) near the spillway were used in this study.

A major portion of Lake Springfield's inflow water was the recycled water (603 cfs) from the power plant. This water was withdrawn from the lake with the same constituent concentrations as lake water. After circulating through the power plant, the water increases in temperature, as recorded by CWLP in open files, known as the Discharge Monitoring Report (DMR). In the absence of monitored data, concentrations of

the other constituents in the recycled water were assumed to be the same as the source water, i.e., the lake water. Concentrations of DO and nitrate-nitrogen are not likely to change in the power plant cooling process as this occurs in a closed environment for a short duration. However, the percent saturation value will be much higher with the increase in temperature. It is a common occurrence that oxygen remains dissolved even under 150-200% saturated level, the saturation conditions resulting from photosynthesis. The biological processes affecting the DO is also not likely to be significant.

Representative temperature and constituent concentrations of the total inflow water to Lake Springfield were computed by weighting the temperature and concentrations of the individual sources in proportion to their respective water flow rates. In the weighted average computations, only two distinct water sources were considered: one was the inflow water from the watershed, a combination of all the upstream tributaries and direct contributions, and the other was the recycled water from the power plant. As discussed earlier, temperature and constituent concentrations in the inflow water from the watershed were estimated based on observations on Lick Creek near Loami, IL, and constituent concentrations in recycled water from the power plant were the same as concentrations in lake water. Temperature in the recycled water was taken from CWLP-DMR, which recorded separate temperatures from Dallman 31, 32, and 33 Power Plant units, and from the Lakeside Power Plant. Temperatures from Dallman units were averaged. These averaged temperatures were weighted with the temperature from the Lakeside Power Plant in proportion to the respective capacities documented in the "Water Flow Schematic CWLP Plant Complex": Dallman units recycled 80% of the water, and Lakeside Power Plant recycled 20%. However, according to historical water use, shown in Table 1, the percentages were approximately 90% and 10%. Influence of this 10% difference is practically negligible, since the average temperature variations between the units were not so high.

A 2-foot layer thickness was used for modeling the reservoir water temperature and constituents. The initial temperature and constituent concentrations in these reservoir layers were taken from the observations of April 8, 1986. Observed profiles of temperature and DO at 2-foot intervals were available and were directly input as initial conditions. Concentrations of other constituents were interpolated from the observed concentrations at the surface and bottom layers. Benthic oxygen demands at different layers were estimated and input.

For the first calibration run, all other model parameters, constants, and coefficients were taken from the examples included in the HEC-5Q User's Manual (U.S. Army Corps of Engineers, 1986a), as default values. The model performed surprisingly well although there were some discrepancies. Several runs were made to overcome the discrepancies by changing the model constants and coefficients, and also by changing the inflow constituent concentrations. Inflow constituent concentrations were found to be the most sensitive input to the model, a finding supported by experience of the model developers (U.S. Army Corps of Engineers, 1986b). As discussed earlier, this report

presents simulations of only water surface elevation, temperature, nitrate-nitrogen, phosphate-phosphorus, and DO.

Table 2 provides a list of the important model parameters and their calibrated values. Table 3 provides temperatures and constituent concentrations of the inflow water, as calibrated. Only some of the nitrate-nitrogen and DO values of Table 3 were adjusted during calibration, the remaining values were based on observed data and the weighted average computations mentioned above. The lowest DO concentration of 3.15 mg/L on 07/02/86 (Table 3) was the result of low lake water concentrations on that day, varying from 5.1 mg/L at the surface to 0.4 mg/L at the bottom (shown later in Figure 6). Figures 5-9 compare model predictions and observations of temperature and the constituents. Figures 6 and 9 show respective constituent concentrations at the surface and bottom 2-foot layers of water, while Figures 7 and 8 show vertical profiles of temperature and DO, respectively, for the days having observed data.

Model predictions for lake level (Figure 5) and temporal variation in temperature (Figure 6) agreed very closely with observed values. The temporal variations in DO for the lake surface (Figure 6) defined the trend very well with the observed values scattered equally on either side of the trend line. The model accurately simulated the oxygen depletion during the period mid-May through mid-August. However, the recovery of oxygen concentrations predicted in the bottom waters of the lake were much higher than the observed values, differing by about 2 to 3 mg/L. The predicted vertical profiles of temperatures and DO values shown in Figures 7 and 8 for different dates were in close agreement and defined trends in variations well within practical limits. Predictions for nitrate-nitrogen were excellent above 1.0 mg/L (Figure 9). The scatter or deviation of the observed phosphate-phosphorus values from the predicted values for lake surface appeared to be more pronounced during the period of June to September (Figure 9). The predicted values of about 0.2 mg/L were in close agreement with the mean and maximum values of 0.11 and 0.17 mg/L for the period 1979 to 1984, as reported by CWLP (1987).

Table 2. Important HEC-5Q Model Parameters and Calibrated Values

Parameter description	Value	Unit
Fraction of solar radiation absorbed in a top layer of water	0.4	
Depth of the top water layer where solar radiation is absorbed	2.0	feet
Water column minimum stability	0.01	$kg/m^3/m$
Water column critical stability	10^{-6} $kg/m^3/m$	
Diffusion coefficient	10^{-4}	m^2/s
Empirical constant for computing diffusion coefficient	-0.7	
Decay coefficient at 20°C for carbonaceous BOD	0.1	

Table 3. Input Temperatures and Constituent Concentrations with Inflows

Date	Temperature (°F)	Dissolved oxygen (mg/L)	Nitrate nitrogen (mg/L)	Phosphate phosphorus (mg/L)
03/11/86	59.6	11.80	3.89	0.154
04/08/86	72.0	10.21	3.64	0.109
05/06/86	78.0	8.93	1.50	0.073
05/21/86	76.5	6.03	0.50	0.085
06/03/86	81.0	7.33	0.50	0.108
06/17/86	91.0	8.27	0.50	0.130
07/02/86	92.0	3.15	0.20	0.335
07/16/86	100.6	7.09	0.05	0.229
08/05/86	94.0	8.09	0.06	0.264
08/25/86	91.0	5.92	0.08	0.196
09/08/86	85.0	4.89	0.09	0.292
09/26/86	89.5	6.63	-----	------
09/30/86	88.6	7.23	0.10	0.220
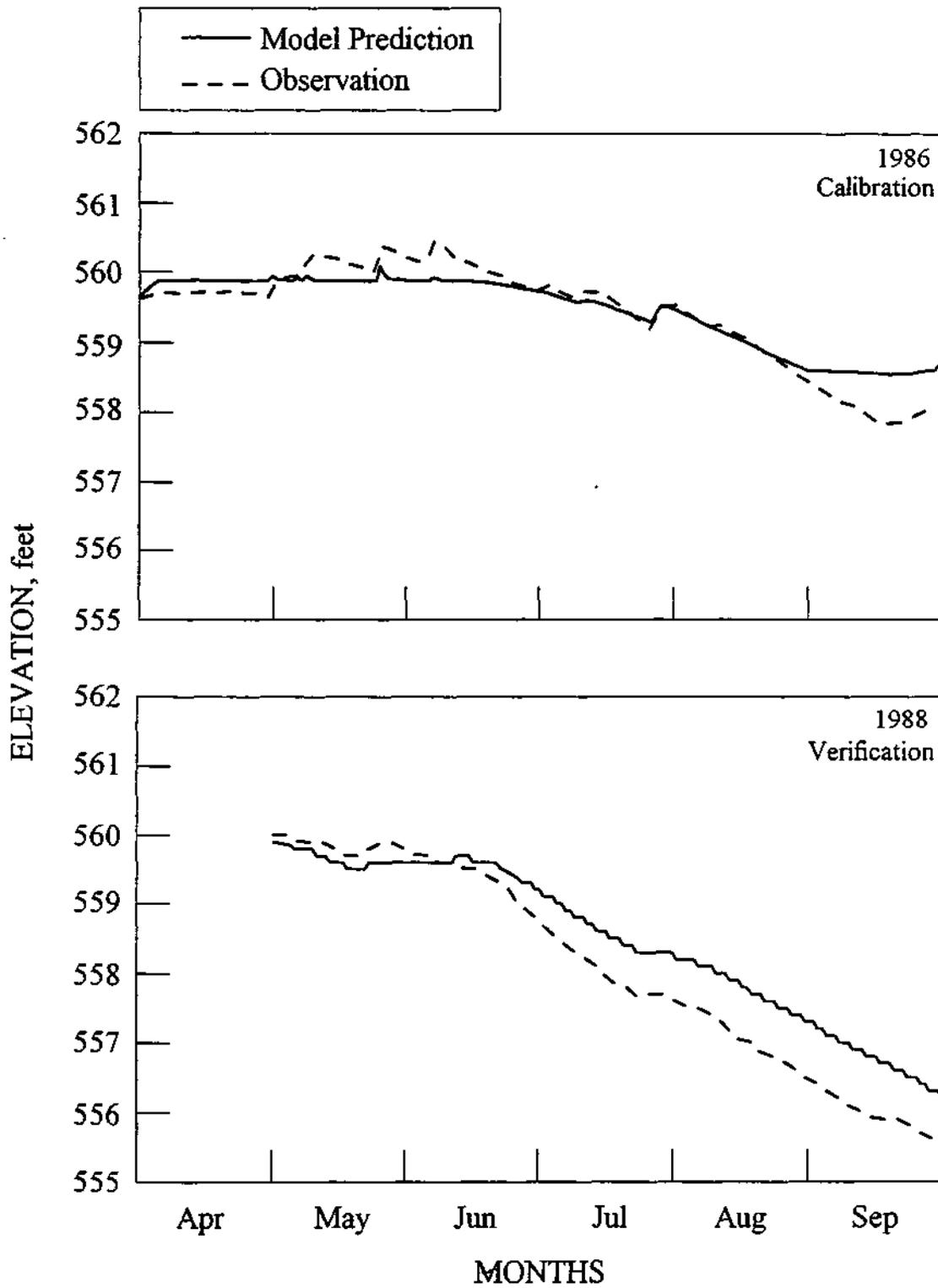
Figure 5. Water surface elevation in Lake Springfield: comparisons of model predictions and observations while calibrating and verifying HEC-5Q model

Figure 6. Temperature and dissolved oxygen in Lake Springfield: comparisons of model predictions and observations while calibrating HEC-5Q model

Figure 7(a). Vertical profiles of temperature in Lake Springfield during 1986: comparisons of model predictions and observations while calibrating HEC-5Q model

Figure 7(b). Vertical profiles of temperature in Lake Springfield during 1986:
comparisons of model predictions and observations
while calibrating HEC-5Q model

Figure 8(a). Vertical profiles of dissolved oxygen in Lake Springfield during
1986: comparisons of model predictions and observations
while calibrating HEC-5Q model

Figure 8(b). Vertical profiles of dissolved oxygen in Lake Springfield during 1986: comparisons of model predictions and observations while calibrating HEC-5Q model

Figure 9. Nitrate-nitrogen and phosphate-phosphorus in Lake Springfield:
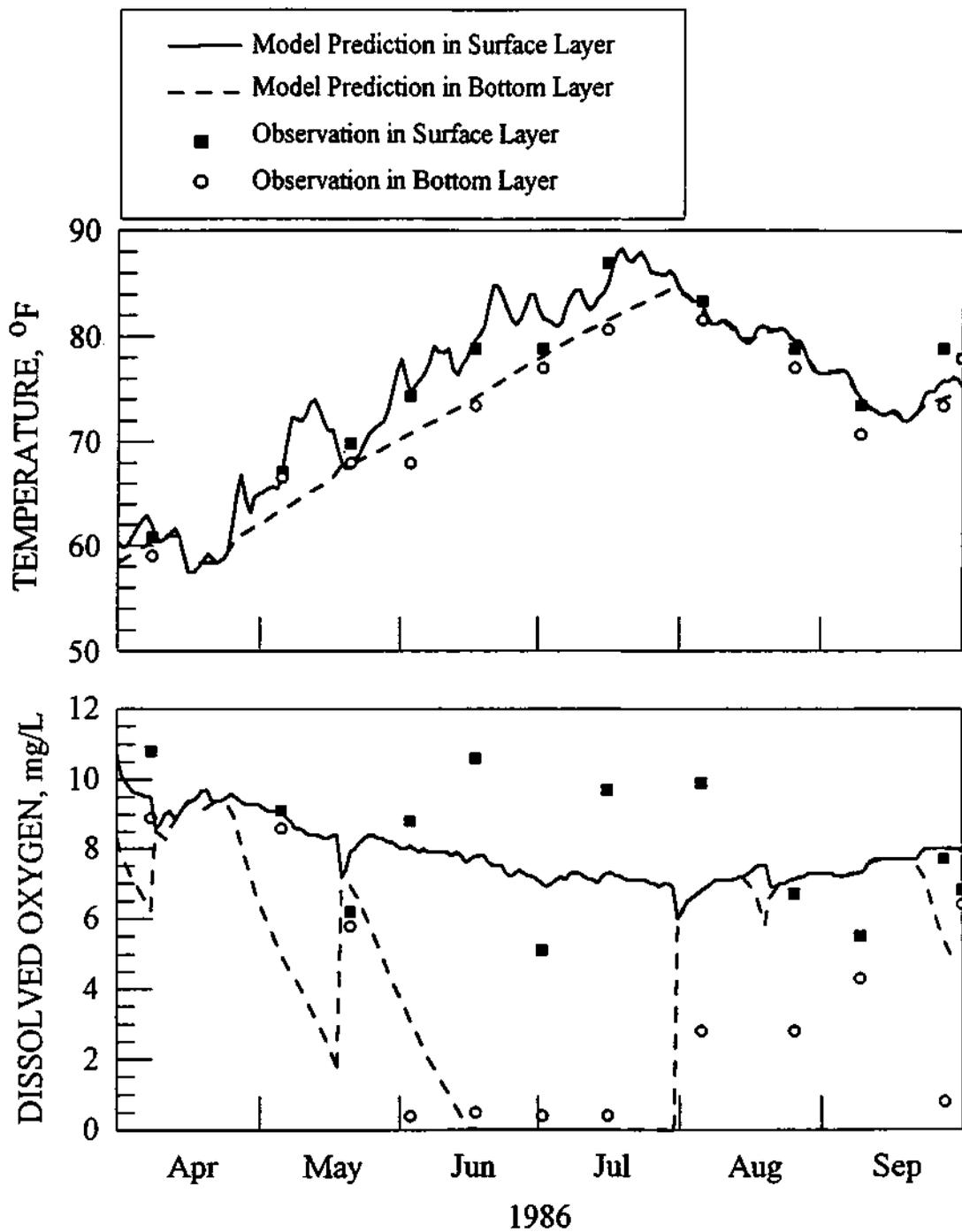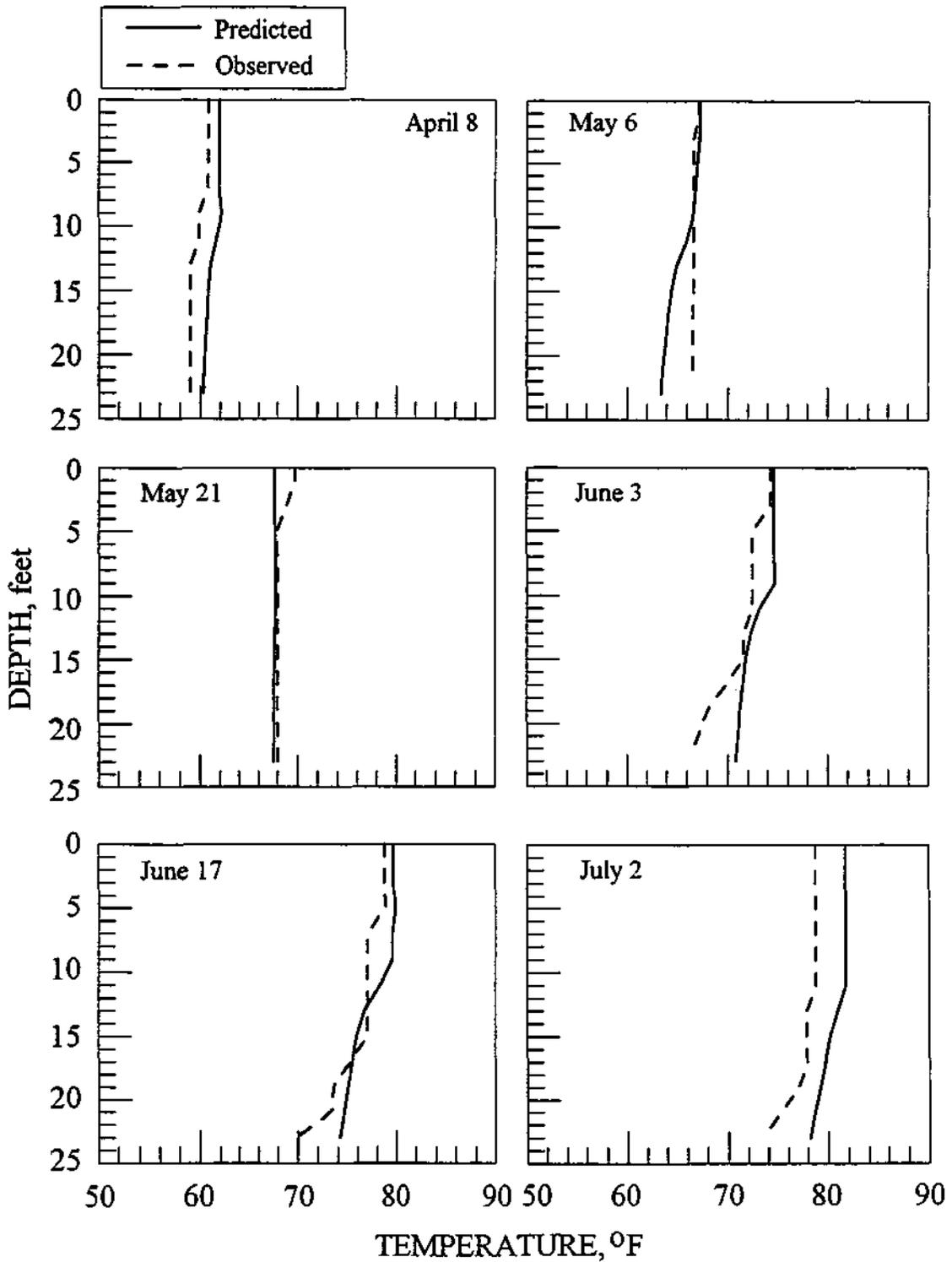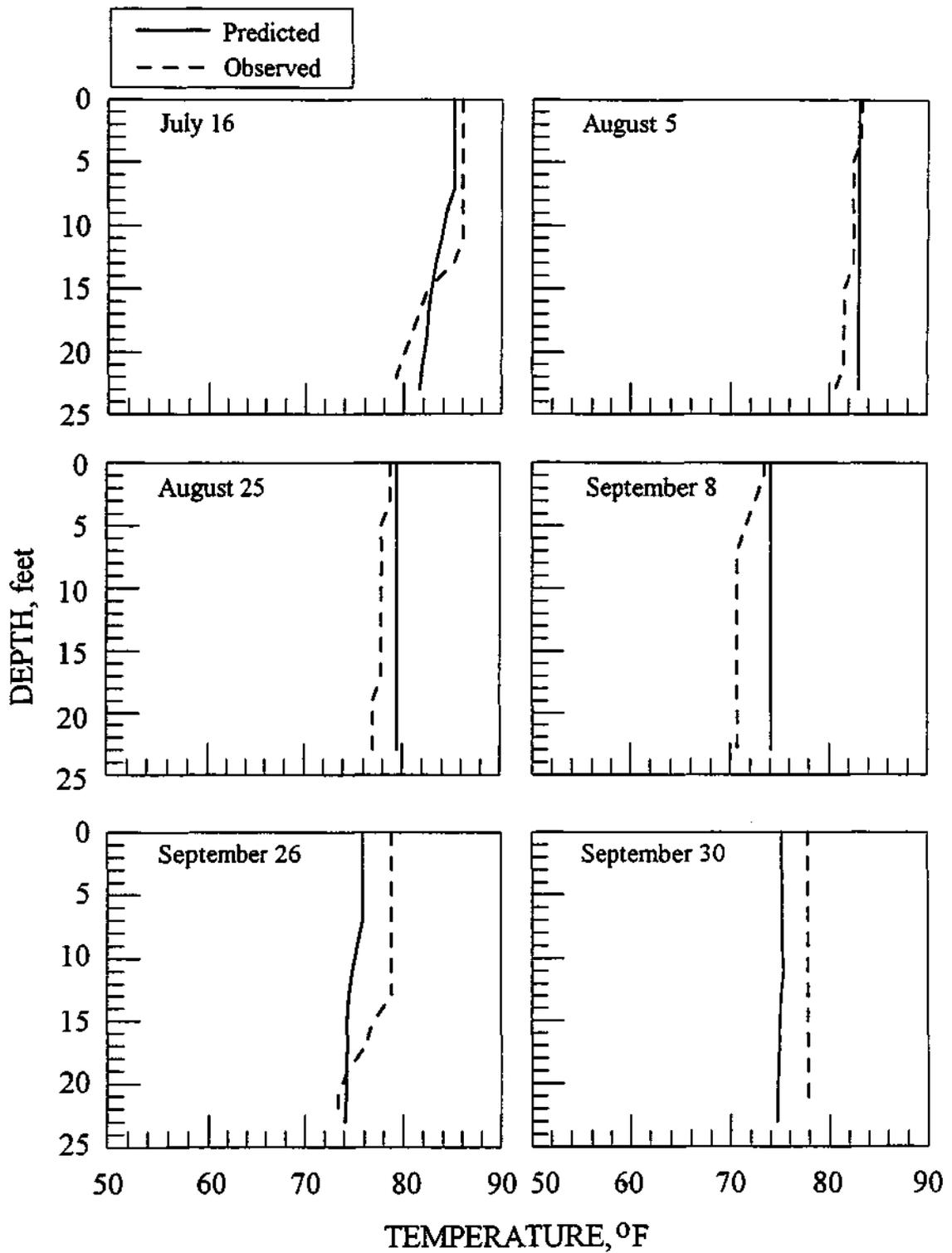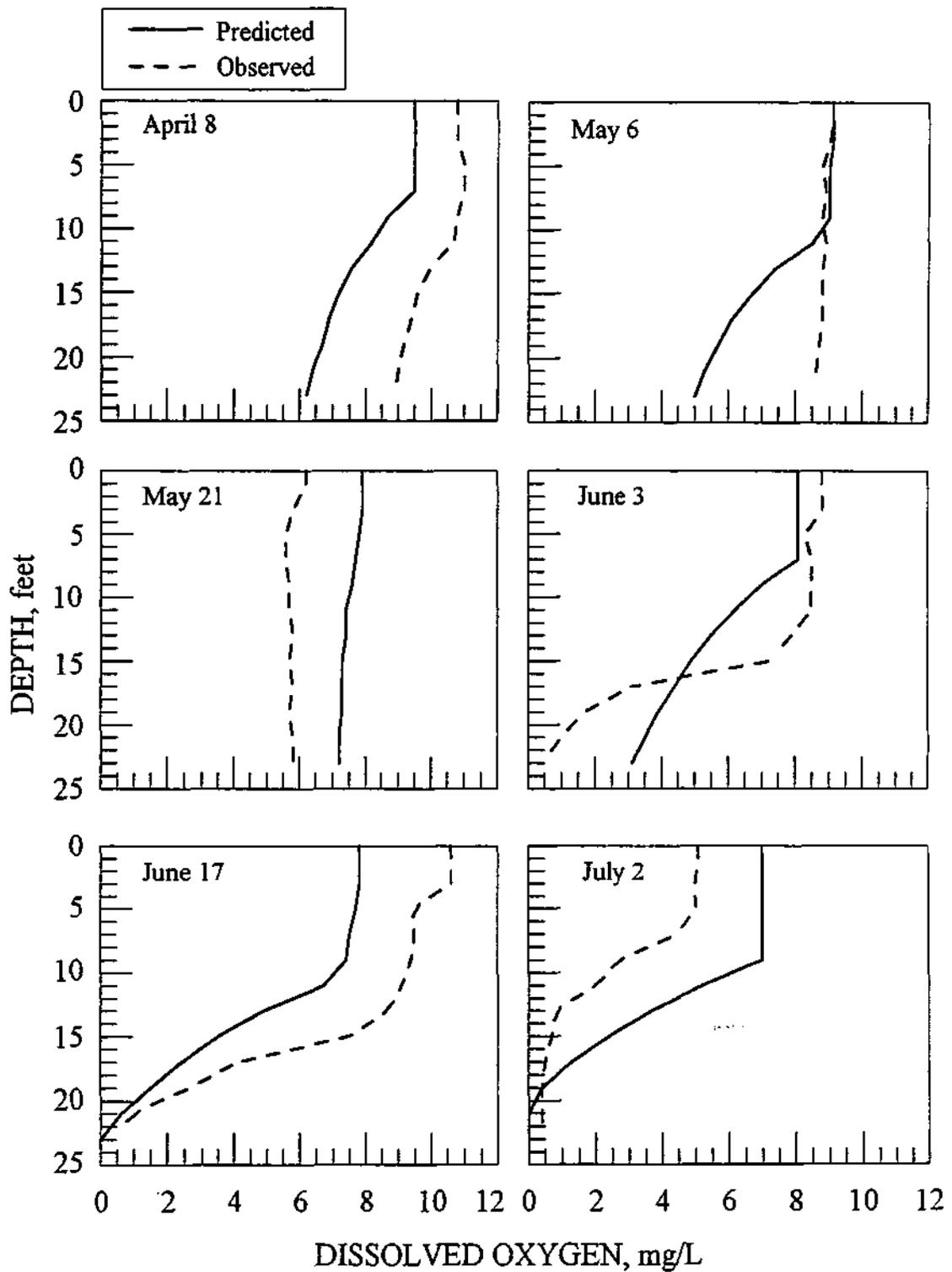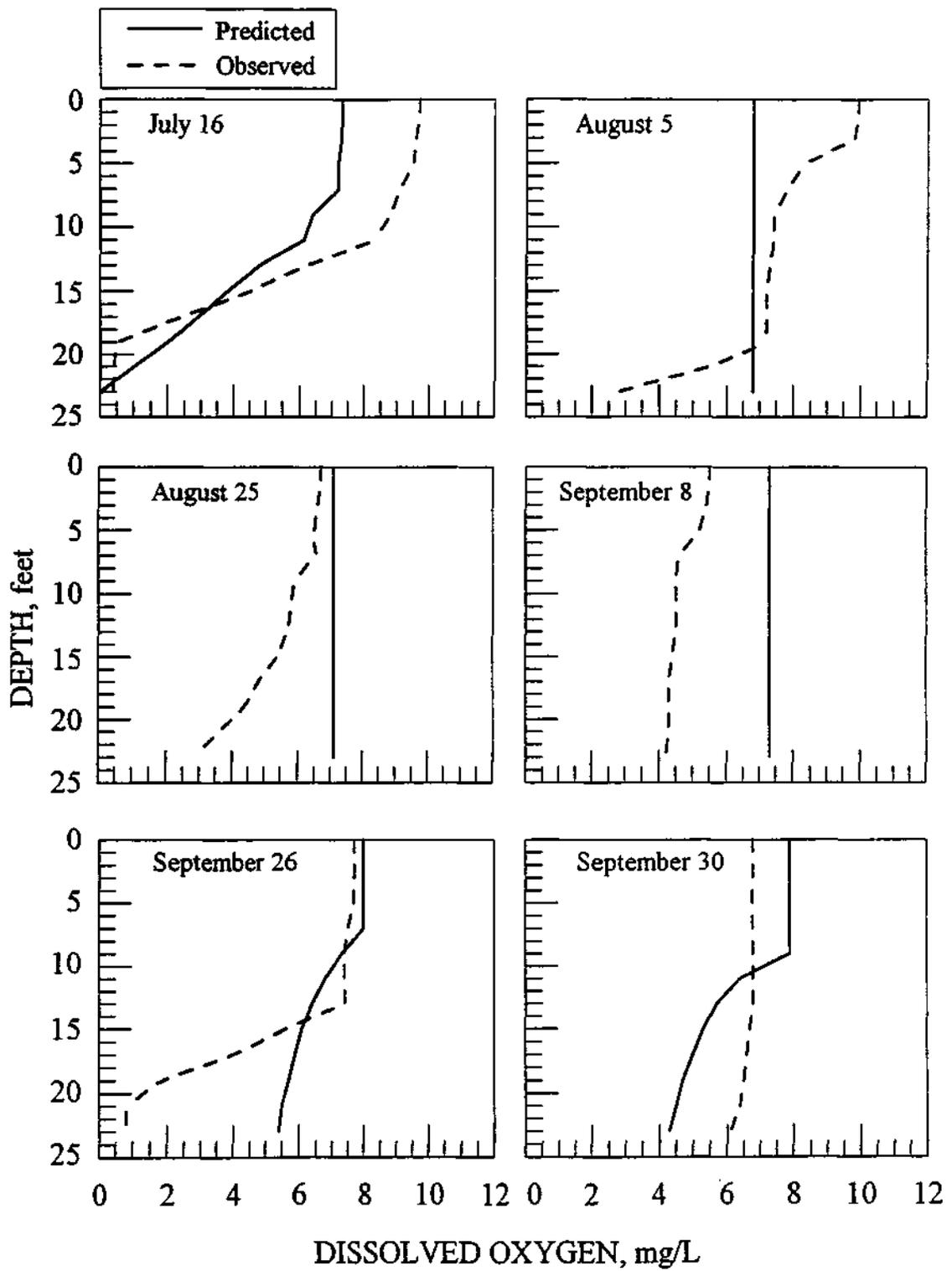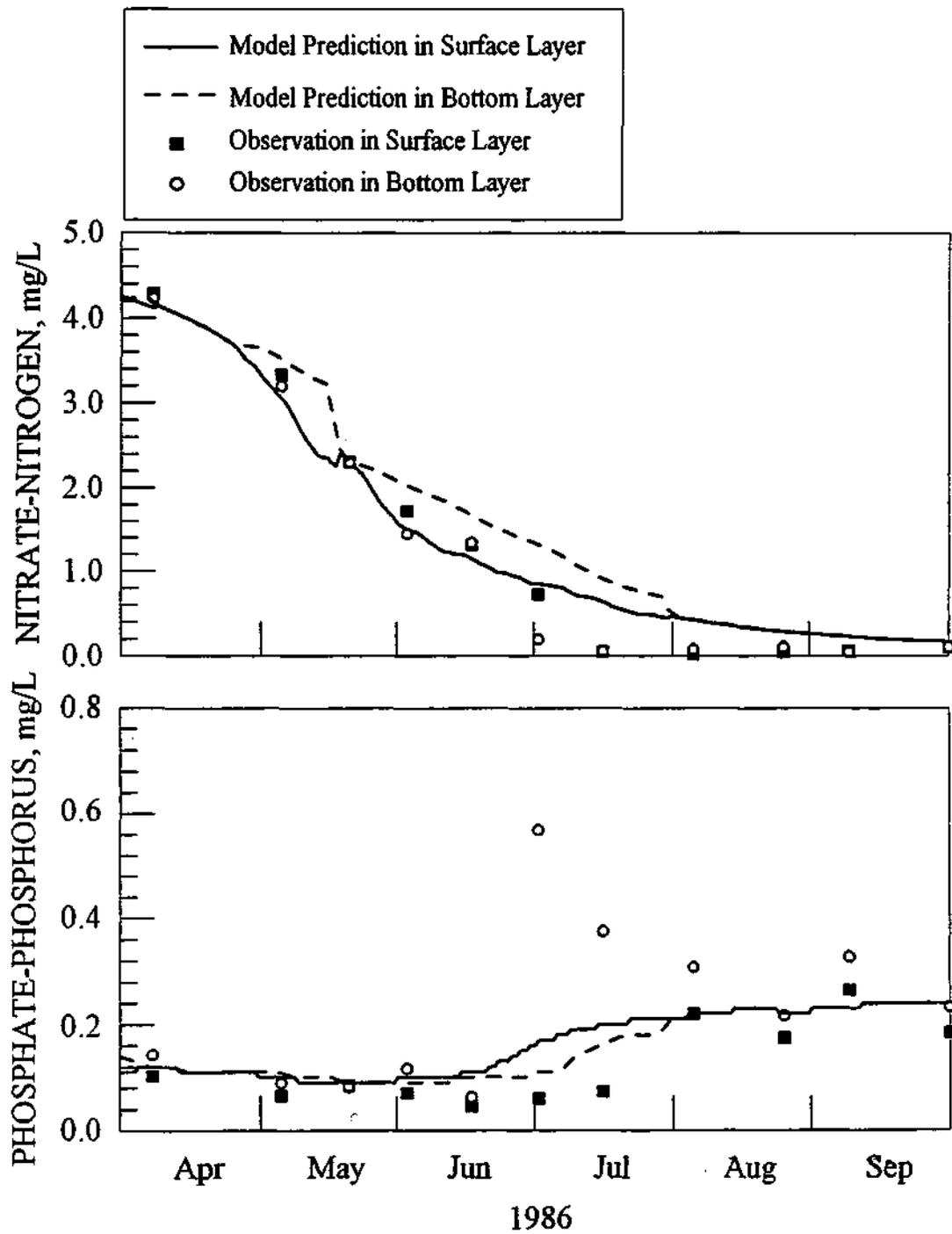comparisons of model predictions and observations
while calibrating HEC-5Q model

MODEL VERIFICATION ON LAKE SPRINGFIELD

Before using a model to predict the impact of certain changes in the system, the model must be verified with observed data collected from independent events other than those used for calibration. This is an important step in modeling physical processes to examine validity of the model and consistency of the model parameters in a physical system, and finally establishing confidence in model predictions. In this study, the HEC-5Q model, calibrated for Lake Springfield using 1986 data, was verified on the same lake using 1988 and 1953-1954 data. Since the primary objective of this study was to predict water quality conditions in the lakes under extreme drawdown and prolonged drought periods, the two drought periods of 1988 and 1953-1954 were selected to verify the model. The 1953-1954 drought was the most severe drought in recorded history. The 1988 drought is the most recent drought for which water quality records are available. Based on data availability, the complete model with all the selected water quality parameters was verified with the 1988 drought; however, only the water surface elevation was verified with the 1953-1954 drought period.

Verification with 1988 Data

Based on data availability, a five-month period, May 1-September 30, 1988, was selected for verification. Since monitored data were not available, daily inflows to Lake Springfield from all the sources, and monthly net evaporation were estimated using the ISWS watershed simulation model (Durgunoglu et al., 1987; Knapp, 1997). Observed lake levels and constituent concentrations for this period were available with data provided by Springfield CWLP, and these data were used to estimate initial lake volume and constituent concentrations, and finally for comparison with temporal variations of lake levels and constituent concentrations for verification. Daily quantities of water supply withdrawals and supply from the South Fork pump station were available. As discussed earlier, average power plant withdrawal of 610 cfs, and leakage of 1 cfs were assumed, and a total of 611 cfs was added to daily water supply withdrawal rates to represent total daily outflows from the lake. Based on discussion with CWLP staff, the average rate of recycled water from the power plant back into the lake was revised. Diversion of water to the ash pond was revised to 7 mgd (11 cfs), and a new forced evaporation rate of 2.4 mgd (4 cfs) was added. Forced evaporation occurs at the power plant while the water cools off the heat generated there. After deducting this 15 cfs diversion and loss from the 610 cfs of power plant withdrawal, a constant recycled rate of 595 cfs was added to the daily inflows to Lake Springfield. Temperatures of inflows were revised based on temperatures of the recycled water, as recorded in CWLP-DMR for the above period.

Meteorological data, as described earlier, for the entire year of 1988 were acquired from the Midwestern Climate Center, ISWS, and model inputs were prepared using the procedures described earlier. Remaining inputs and model parameters were kept the same as for the calibration run.

With the above inputs from the 1988 simulation period, the model was run to verify its performance and accuracy of the predicted results. Figure 5, described earlier, also shows the comparison between predicted and observed water surface elevations for the 1988 simulation period. The model predicted water surface elevation very closely for the first month and a half, and gradually overpredicted with differences up to 0.65 feet, but following exactly the same declining pattern. The differences in prediction may be due to round off errors, inflow estimates, and insufficient detailed inflow-outflow data. Figure 10 shows comparisons of predicted and observed temperature and DO. Predictions of surface and bottom temperatures and bottom DO are very good for the months of May, June, and September. Dissolved oxygen predictions in the surface layer are reasonable for the months of June, August, and September. Although the remaining predictions of temperature and DO shown in Figure 10 deviate from the instantaneous observations, they are within the expected range of values for such times of the year. Figure 11 shows comparisons of predicted and observed nitrate-nitrogen and phosphate-phosphorus. Observations were available only for three data points without any distinction for surface and bottom layers. The comparisons shown in Figure 11 are very good in terms of both magnitude and trend.

Based on the above comparisons of model predictions and observations, it can be concluded that the model was satisfactorily verified on Lake Springfield with data from the 1988 drought period.
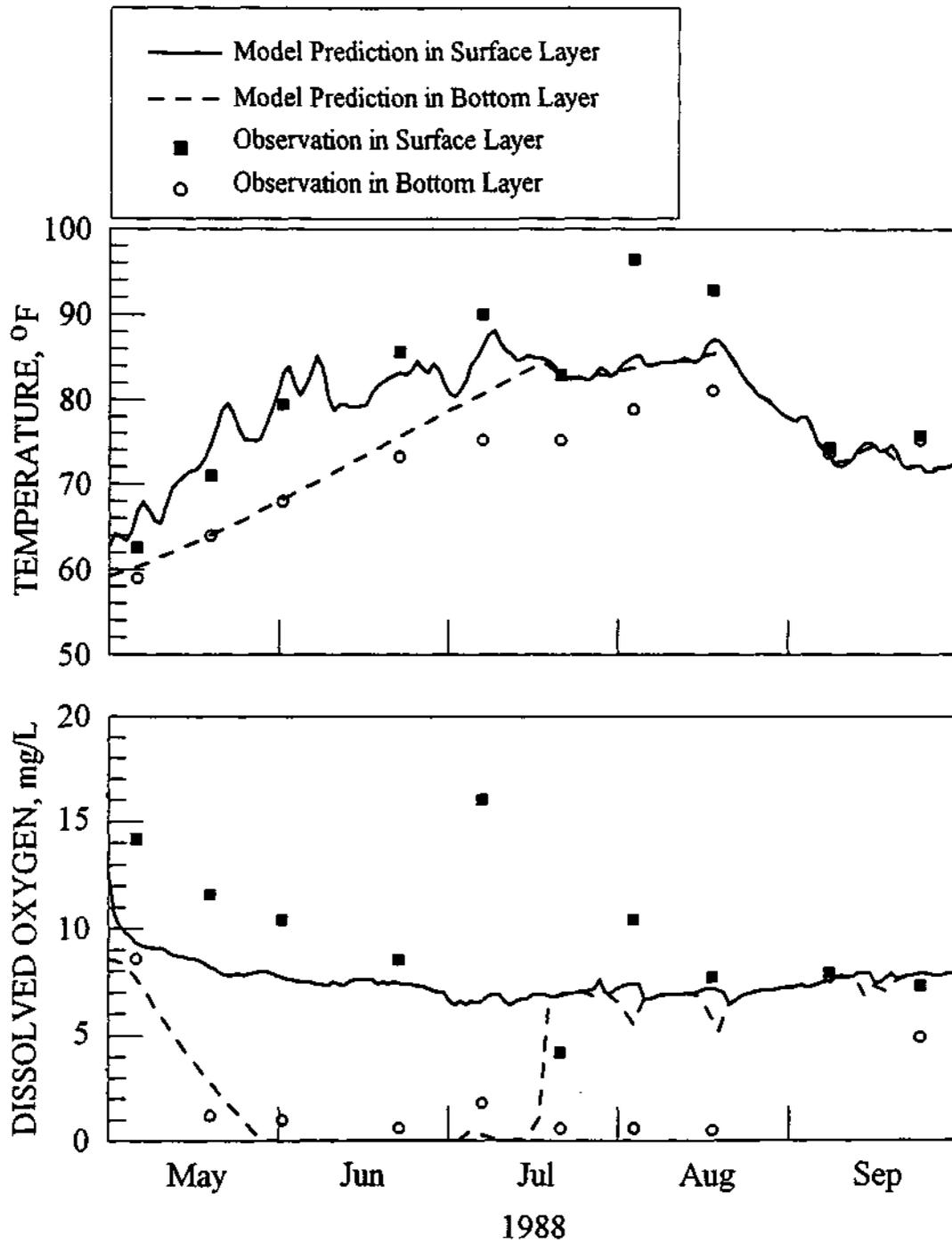
Figure 10. Temperature and dissolved oxygen in Lake Springfield: comparisons of model predictions and observations while verifying HEC-5Q model
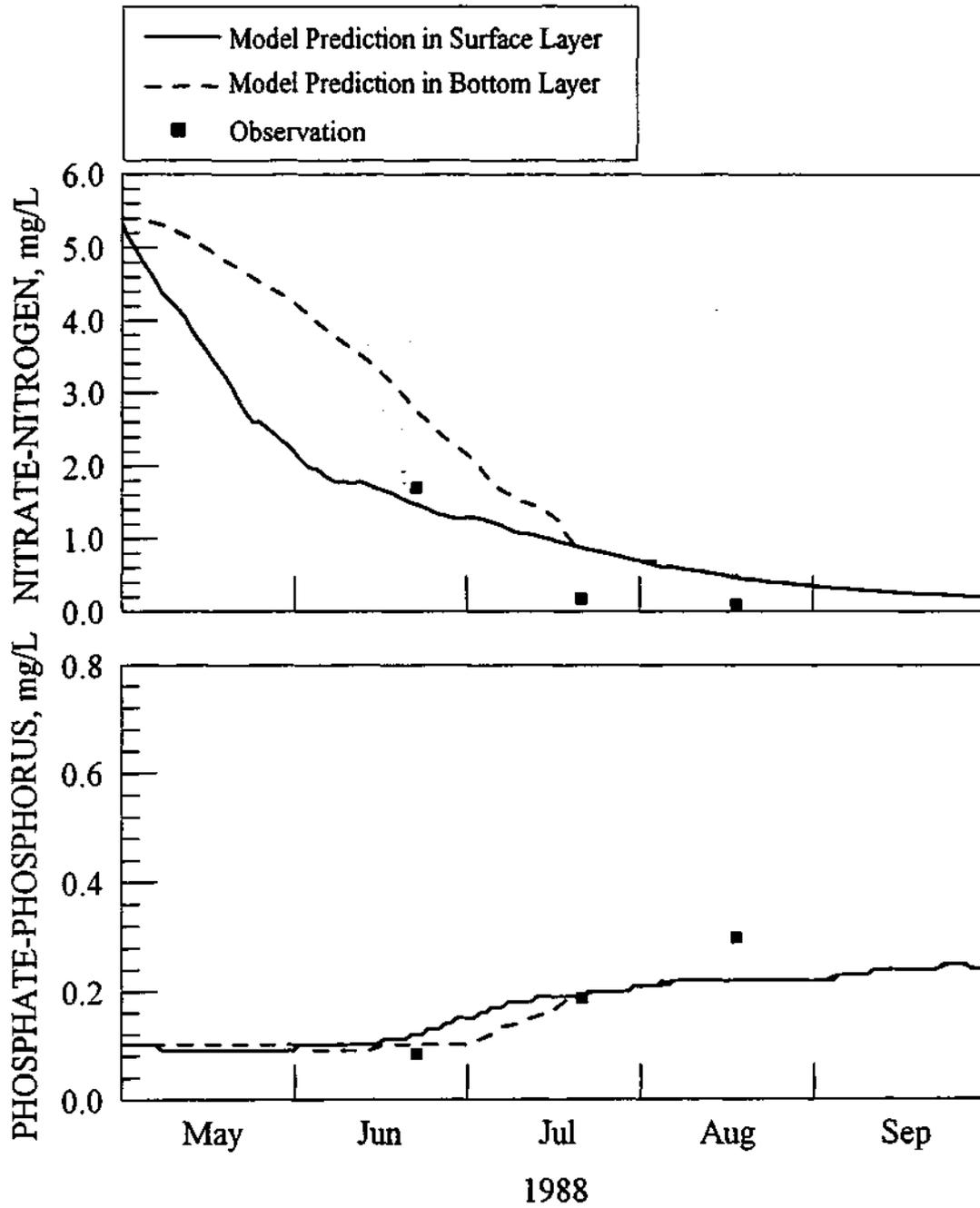
Figure 11. Nitrate-nitrogen and phosphate-phosphorus in Lake Springfield:
comparisons of model predictions and observations
while verifying HEC-5Q model

Verification with 1953-1954 Data

A 20-month period, May 1, 1953-December 31, 1954, was chosen for model verification. As discussed earlier, the annual simulation mode of the HEC-5Q model where the daily time step can be used is limited to a simulation period of maximum one calendar year per run. Therefore, the model was run twice, once for the 1953 period and again for the complete 1954 year. Monitored data for the above periods were available only on lake levels and daily water supply withdrawal rates. No constituent data were recorded at that time, and therefore, although the constituents were simulated, the results were not presented or discussed for verification purposes.

Similar to the 1988 run, daily inflows to the lake from all sources, and monthly net evaporation were estimated using the ISWS watershed simulation model (Knapp, 1997). The South Fork pump station was not built at that time; therefore, there was no additional inflow of water. The observed lake levels were used to estimate initial lake volumes, and to compare predicted levels for verification. Based on the monitored data, the daily average water supply withdrawal rate was 26 cfs (17 mgd) during the eight-month period of 1953, and 24 cfs (15.4 mgd) during the calendar year of 1954. Based on discussion with Springfield CWLP staff, rates of power plant withdrawal, ash pond diversion, and loss due to forced evaporation were revised because of much lower power generation in those days. Instead of a 15 cfs loss due to diversion and evaporation, one third (5 cfs) was assumed for the losses during the 1953-1954 period. The purpose of this 1953-1954 verification run was to evaluate the performance of the model in estimating reservoir volume during drawdown. There was no attempt to evaluate the thermal and water quality characteristics of Lake Springfield during the 1953-1954 drought. Therefore, an accurate estimation of water recycled through the power plant was not critical. The power plant withdrawal rate was always kept 5 cfs higher than the return flow rate to the lake.

Similar to the previous simulation periods, meteorological data for the entire years of 1953 and 1954 were acquired from the Midwestern Climate Center, ISWS, and model inputs were prepared. The remaining inputs and model parameters were kept the same as for the 1986 calibration and 1988 verification runs. Figure 12 presents comparisons of predicted water surface elevations of the lake with the observed elevations during the 1953 and 1954 simulation periods. The model predicted the 1953 elevations almost perfectly. The model also predicted the 1954 elevations reasonably well for the entire year in general (overall), although there were some departures during the spring and early winter months. The departures may be due to use of average withdrawal rates for the entire year and differences in inflow estimates and actual values, which are unknown.
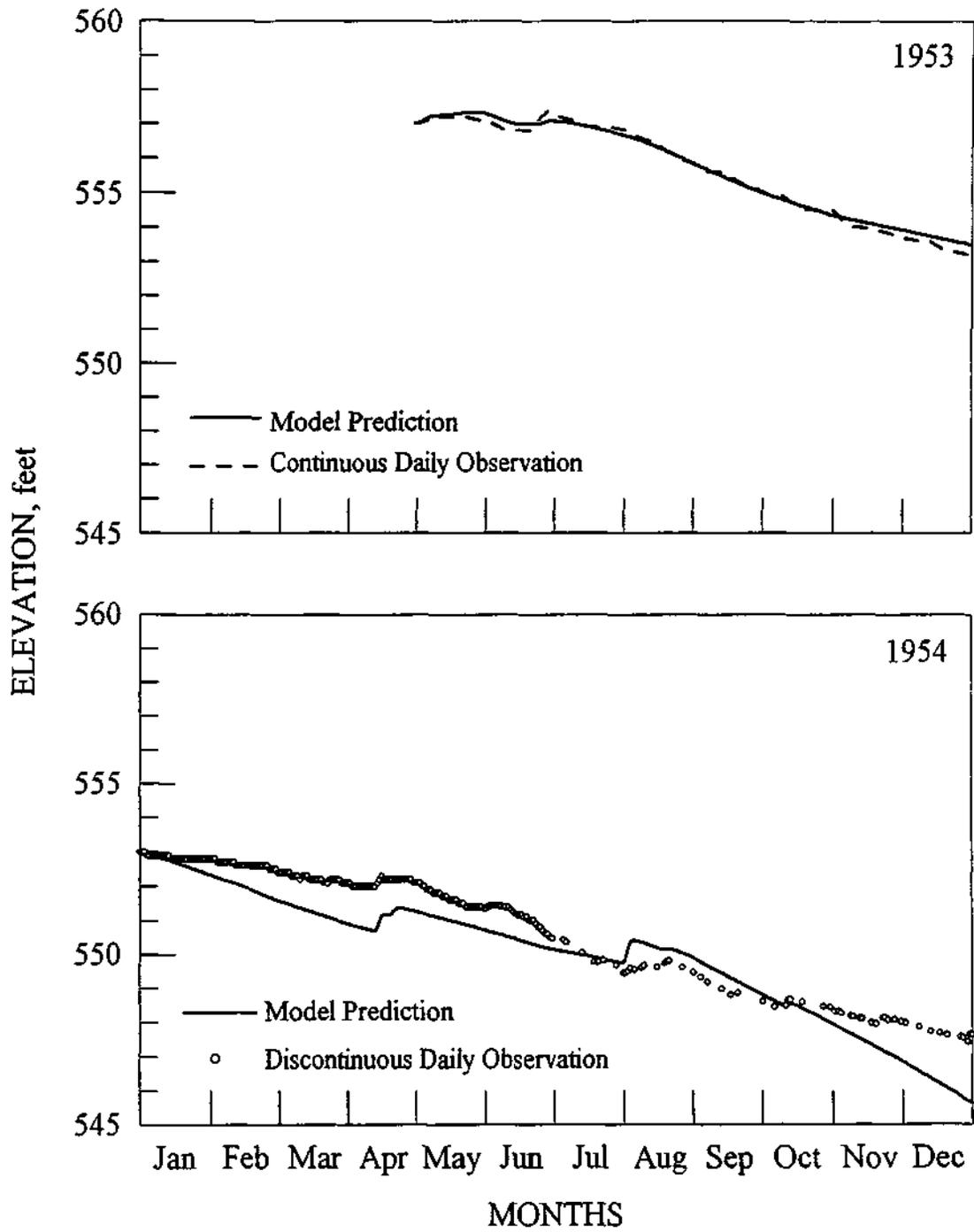
Figure 12. Water surface elevation in Lake Springfield: comparison of model
predictions and observations while verifying HEC-5Q model

LAKE WATER QUALITY DURING SEVERE DROUGHT AND DRAWDOWN

The purpose of this modeling study was to examine the potential for water quality problems in Lake Springfield, Hunter Lake, and the Lick Creek Reservoir during prolonged drought and severe drawdown conditions, and within a practical range of present-day and future operating conditions. For each lake, the water quality conditions at three specific levels of drawdown were addressed in the analysis: 2 feet, 2 meters (6.6 feet), and 6 meters (19.8 feet). These three draw-down levels were identified in the HEP study (Hunter Lake HEP Team, 1992) as the levels at which water quality and aquatic habitat concerns in the lakes were most apt to occur. A drawdown of 6 meters was not expected to occur on Lake Springfield because the minimum operating level of the lake, as defined by the water supply intake levels, occurs at a drawdown of 13 feet (roughly 4 meters). Therefore the lowest level of water quality evaluation for Lake Springfield was at this minimum operating level.

Springfield's public water supply use during average years has increased approximately 1 mgd over the last ten years to the present level of approximately 21.5 mgd. During a severe drought year, the average water use is expected to increase by almost 8 percent, much as it did during the 1988 drought. Additional increases in power generation and water circulation during that time may also contribute to a slight increase in evaporation losses. For the purpose of simulating the present-day water use conditions during a severe drought, an overall increase of 2.5 mgd (4 cfs) in the total consumptive losses from 1988 conditions was assumed.

Four factors were identified as having the potential to cause future changes in the water quality conditions in the lakes: (1) an increase in the overall consumptive use of the Springfield public water supply, (2) a change in the evaporative loss associated with either thermal loading from the power plant or the addition of cooling towers, (3) a change in the operating scheme that might cause a greater drawdown in one of the lakes, and (4) potential changes in thermal loading to Lake Springfield. The impact of the first two factors is identical in that they both cause a volumetric change in Lake Springfield and can thus be combined for modeling purposes.

This study does not attempt to predict the growth of water use, changes in the evaporative rate, or the change in thermal loading for future years. Rather, hypothetical changes in the overall loss rate or release rate from the reservoir are used that produce the desired volumetric changes in each lake that cause the drawdown levels identified above. In a roundabout manner these changes represent future conditions at an unspecified date, because in most cases they represent conditions of increased water consumption, such as are likely to occur in the future. Thermal loading impacts are represented by a selected set of hypothetical increases in the water temperature being returned to the lake from the power plant.

The basic assumption used in these simulations is that water quality problems in the lakes will be most evident during periods of an extended and sizable lake drawdown,

such as receding of the Lake Springfield level during the drought of 1953-1954 with a maximum drawdown of 12.6 feet below the spillway crest on December 29, 1954. Hydrologic and meteorological conditions during the 1953-1954 drought of record were used as the base conditions for analysis. Water use rates used in the simulations were increased to more accurately represent present-day and potential conditions. To avoid confusion with actual 1953-1954 conditions on Lake Springfield, this severe drought will be referred to here as a 2-year drought, with the 1953 conditions denoted as the First Drought Year or Year 1, and 1954 as the Second Drought Year or Year 2.

Water quantity and quality simulations in Lake Springfield, alone and in combination with Hunter Lake and Lick Creek Reservoir, for the above drought period are discussed separately. Also presented are water quality (temperature and DO) predictions in the three lakes under different drawdown levels, identified above. Finally, the impact of increased thermal discharges from the power plant on Lake Springfield is discussed.

Lake Springfield during Severe Drought

The calibrated and verified HEC-5Q model was run for Lake Springfield with the same tributary inflows and meteorological data of the 20-month drought period of 1953-1954, used in model verification. As indicated above, this severe drought will be referred here as a 2-year drought, with the 1953 conditions denoted as the First Drought Year or Year 1, and 1954 as the Second Drought Year or Year 2.

Lake Springfield, and the current water supply and power plant demands have changed significantly since the severe drought of 1953-1954. Also, the addition of the South Fork pump station has given some relief to Lake Springfield's demands. Flows from the South Fork pump station were estimated based on available flows in the South Fork Sangamon River, recorded by the U.S. Geological Survey, using a withdrawal scenario similar to that conducted in present times. Water supply withdrawal rates were varied from month to month. These values (Table 4) were obtained from daily records of CWLP during May 1988-April 1989 and varied from 29.45 mgd in June to 17.15 mgd in February with an annual average of 21 mgd (33 cfs). As discussed earlier, the total consumptive losses, including forced evaporation, were increased by 4 cfs for a total of 8 cfs. Diversion to the ash pond was kept the same at 11 cfs. The power plant recycled water was kept the same (595 cfs) as the 1988 simulation (verification) run. Including consumptive losses and ash pond diversion (19 cfs), the total power plant withdrawal was 614 cfs. This was added to the monthly average water supply withdrawal rates (Table 4, unit converted from mgd to cfs) for model inputs as total daily withdrawal rates.

Table 4. Average Monthly Water Supply Withdrawal from Lake Springfield

Year	Month	Withdrawal rate (mgd)
1988	May	25.10
	June	29.45
	July	28.56
	August	25.44
	September	20.49
	October	19.41
	November	17.17
	December	17.82
1989	January	17.27
	February	17.15
	March	17.18
	April	17.91

Meteorological data and input parameters for the entire years of 1953 and 1954 were kept the same as for the 1953-1954 verification run. The starting date of simulation was May 1, Year 1, and the finishing date was December 31, Year 2. These simulations assumed an initial full pool level of 560 feet. Initial constituent concentrations on May 1, Year 1, were taken from 1986 observations. As discussed earlier, with the 1953-1954 verification runs, the model was run separately for Year 1 and Year 2. Initial lake level (volume), and constituent concentrations for January 1, Year 2, were taken from results on December 31, Year 1. Remaining inputs, such as concentrations of constituents in upstream inflows and model parameters were kept the same as the 1986 calibration and 1988 verification runs. Because of unavailable observation records, the model was not calibrated and verified for the winter months. Although water quality simulations were conducted for the winter months with assumed inflow constituents, the results are not included here. Constituent results of only the late spring, summer and early fall months (May-September) are reported. However, lake levels for the entire year are reported.

With the above inputs, the model was run for each of the drought years. Figures 13-16 show results from these runs. Figure 13 shows daily temperatures in the surface and bottom layers of Lake Springfield during May-September of both drought years, and water surface elevations for the entire 20-month period. The beginning of the first drought year period and then early summer months of the second year show some temperature gradient, and during the remaining periods, temperatures at those layers were almost the same, which must be due to extreme weather conditions and shallow water depths. Dissolved oxygen (DO) results, shown in Figure 14, also reflect the shallow water depth, high wind, and severe weather conditions of 1954 by recovering bottom DO in the second year more quickly than the first year (1953), and also more quickly than 1986 and 1988 (Figures 6 and 10). Meteorological data for 1953 and 1954 indicate that mean wind velocities were significantly higher than during the years 1986 and 1988.

The predicted nitrate-nitrogen levels (Figure 15) and the predicted phosphate-phosphorus levels (Figure 16) followed the patterns and magnitudes of the calibration and verification runs (Figures 9 and 11). This was expected because the same inflow constituent concentrations were used as for the calibration and verification runs, and also because of model sensitivity to upstream contributions in predicting nitrate-nitrogen and phosphate-phosphorus concentrations in the lake. The predicted nitrate-nitrogen levels (Figure 15) were all well below the limits of 10 mg/L for drinking water standards.

Results were searched for the lowest DO in the entire water column during both years and found on July 10 of Year 1 and June 21 of Year 2. Figure 17 indicates vertical temperature and DO profiles on these two days as "Lake Springfield Only." The figure also shows the influence of proposed Hunter Lake and proposed Lick Creek Reservoir, which will be discussed in subsequent subsections. As shown in this figure, due to a lower maximum temperature in Year 1, DO in the water column was much higher (6-7 mg/L in the upper 13 feet of depth) than in Year 2 (5-7 mg/L in the upper 9 feet).

Figure 13. Predicted temperature and surface elevation in Lake Springfield during a 2-year drought under a selected operating scenario

Figure 14. Predicted dissolved oxygen and surface elevation in Lake Springfield during a 2-year drought under a selected operating scenario

Figure 15. Predicted nitrate-nitrogen and surface elevation in Lake Springfield during a 2-year drought under a selected operating scenario
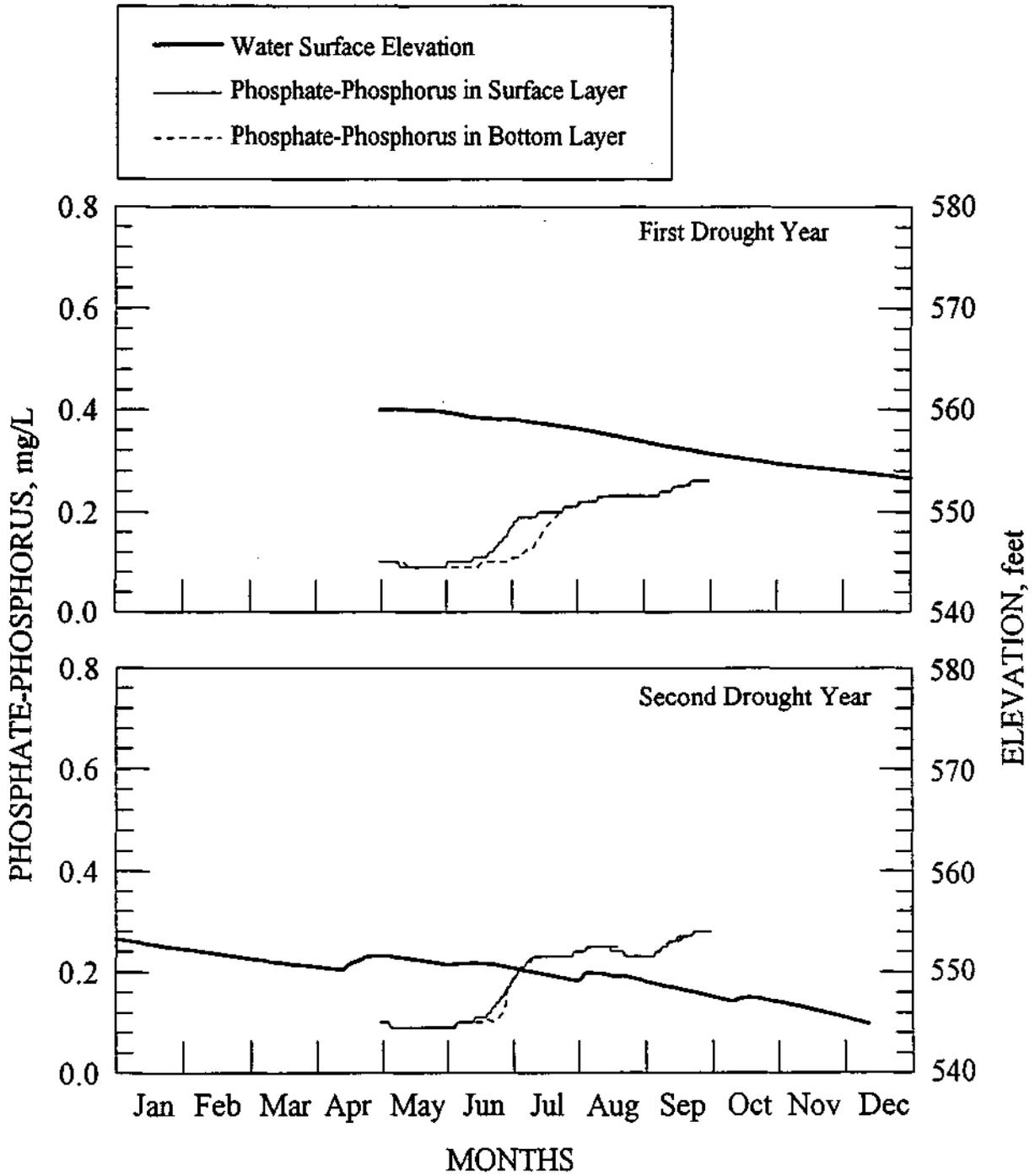
Figure 16. Predicted phosphate-phosphorus and surface elevation in Lake Springfield
during a 2-year drought under a selected operating scenario
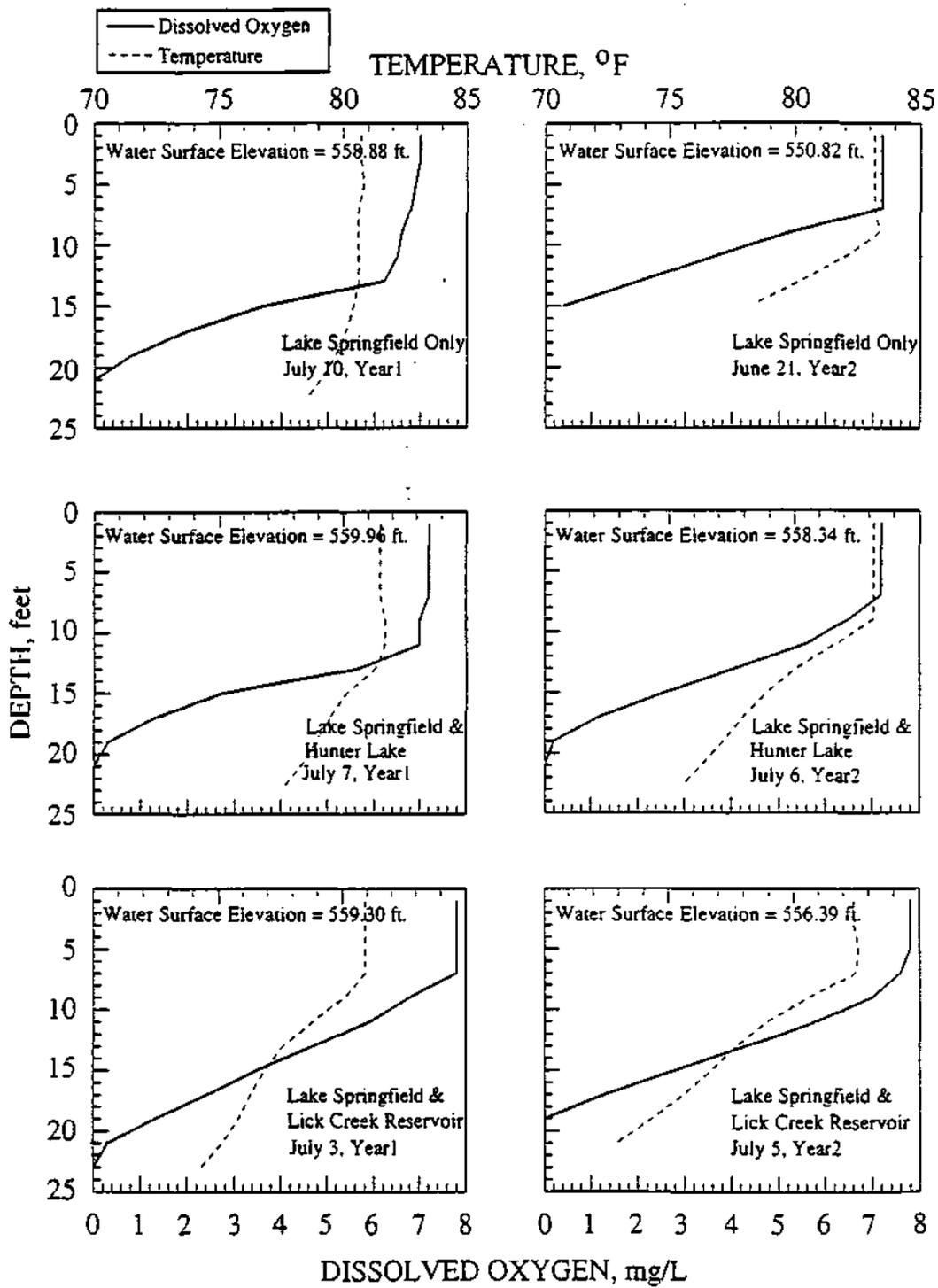
Figure 17. Predicted vertical profiles of temperature and dissolved oxygen in Lake Springfield on most critical days (lowest DO) in each year of a 2-year drought under selected operating scenarios

The above results agree with findings of Raman and Schnepper (1987) who reported the results of their investigation to discern the underlying functional relationship between the stream discharges during low flow (drought) periods and the concomitant water quality characteristics. There were no discernible relationships between low-flow conditions in the stream and the concomitant stream quality characteristics. Also, the above investigators concluded that the values for conductivity, total hardness, chloride, sulfate, ammonia-nitrogen, nitrate-nitrogen, and DO met the Illinois water quality standards during the droughts. Only phosphorus was found to exceed the stipulated limit of 0.05 mg/L. The investigators also noted that news media (radio, television, newspaper, etc.) stories about drought impacts were all about water quantities, not water quality. The latter was never a public concern during times of water crisis or scarcity.

Hunter Lake and Lake Springfield during Severe Drought

The proposed Hunter Lake was simulated for the two drought years in combination with Lake Springfield using the network described earlier and shown in Figure 3. Physical dimensions and model inputs of Hunter Lake were described earlier. Daily inflows from all sources, including Brush Creek and Horse Creek, and monthly net evaporation rates from Hunter Lake during the 1953-1954 drought period were estimated using the ISWS watershed simulation model (Knapp, 1997).

An operating scenario was selected for supplementing Lake Springfield water with Hunter Lake water via the South Fork pump station. In this hypothetical scenario, a discharge of 50 cfs was released from Hunter Lake and added to Lake Springfield whenever the following conditions were met:

1. the water level of Lake Springfield was at least 2 feet below normal pool, and

2. the natural flow at the South Fork pump station was less than 50 cfs.

Using this scenario, a discharge of 50 cfs was released from Hunter Lake and added to Lake Springfield in the following periods: August 5-December 31 of Year 1; and March 1-April 14, May 15-June 2, June 27-August 2, August 24-October 10, and November 1-December 31 of Year 2. This scenario produced a significant drawdown in Hunter Lake while keeping Lake Springfield near its normal pool.

Meteorological data and inputs were the same as for Lake Springfield during the 1953-1954 drought. As described earlier, constituent concentrations with inflow water were estimated based on observations made by CMT (1994) on Horse Creek and Brush Creek during 1990-1991. These observations include constituent contributions from all point and nonpoint sources within the upstream sub-watersheds, including the Pawnee wastewater treatment facility. Initial lake level or volume was assumed to be full at 571 feet. Initial constituent concentrations in lake waters on May 1, Year 1, were assumed to be the same as for Lake Springfield. Similar to Lake Springfield, initial constitutions on January 1, Year 2, were taken from the results of the Year 1 run on December 31.

All inputs to Lake Springfield except inflows were kept the same as described in the previous section. With all the inputs described here, the model was run, and both Lake Springfield and Hunter Lake were simulated for the 20-month drought period. Figures 18-21 present model results on water surface elevations and constituent concentration in Hunter Lake. Figure 22 shows the impact of Hunter Lake on Lake Springfield in supplementing its water.
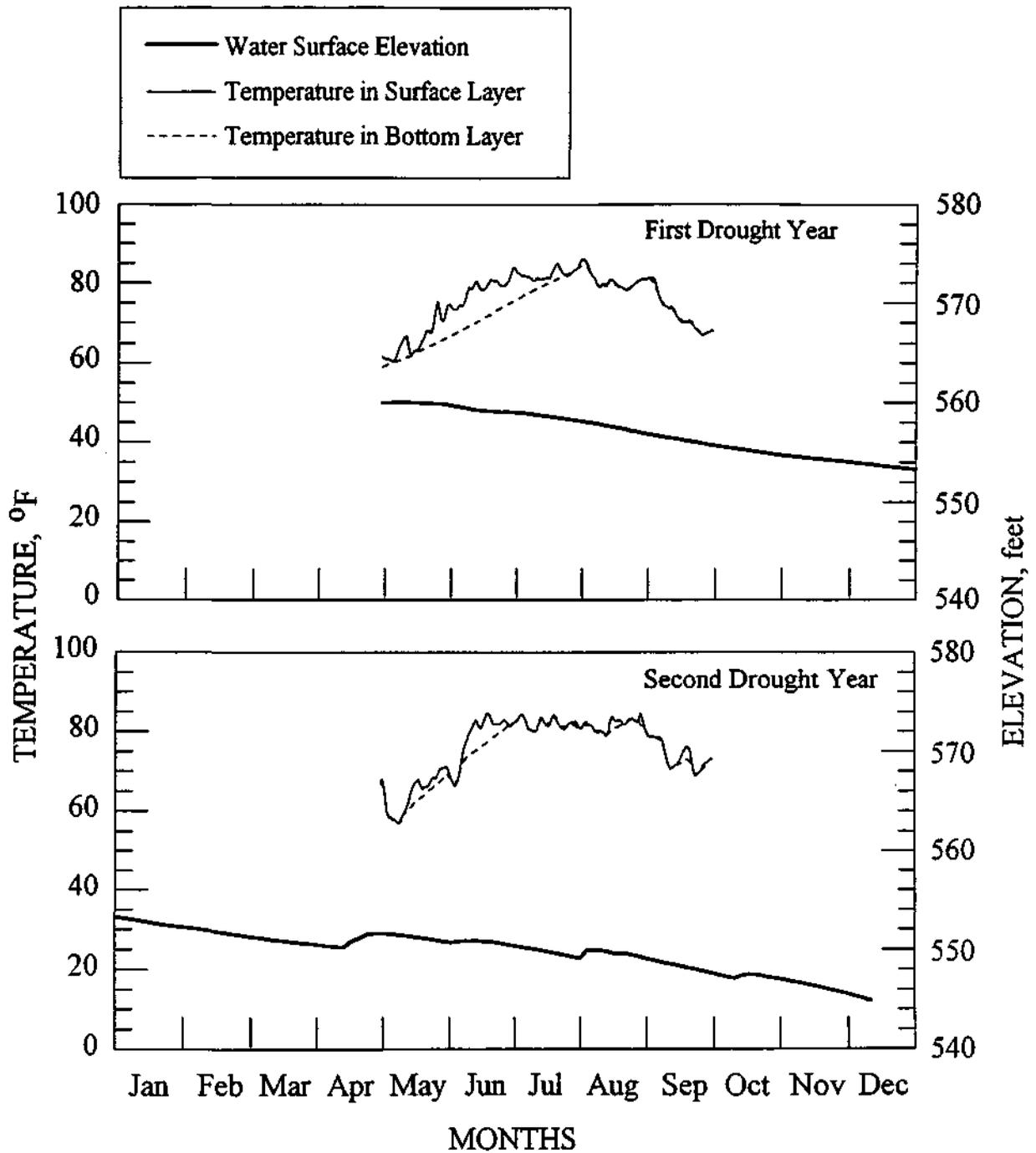
Figure 18. Predicted temperature and surface elevation in proposed Hunter Lake during a 2-year drought under a selected operating scenario with Lake Springfield
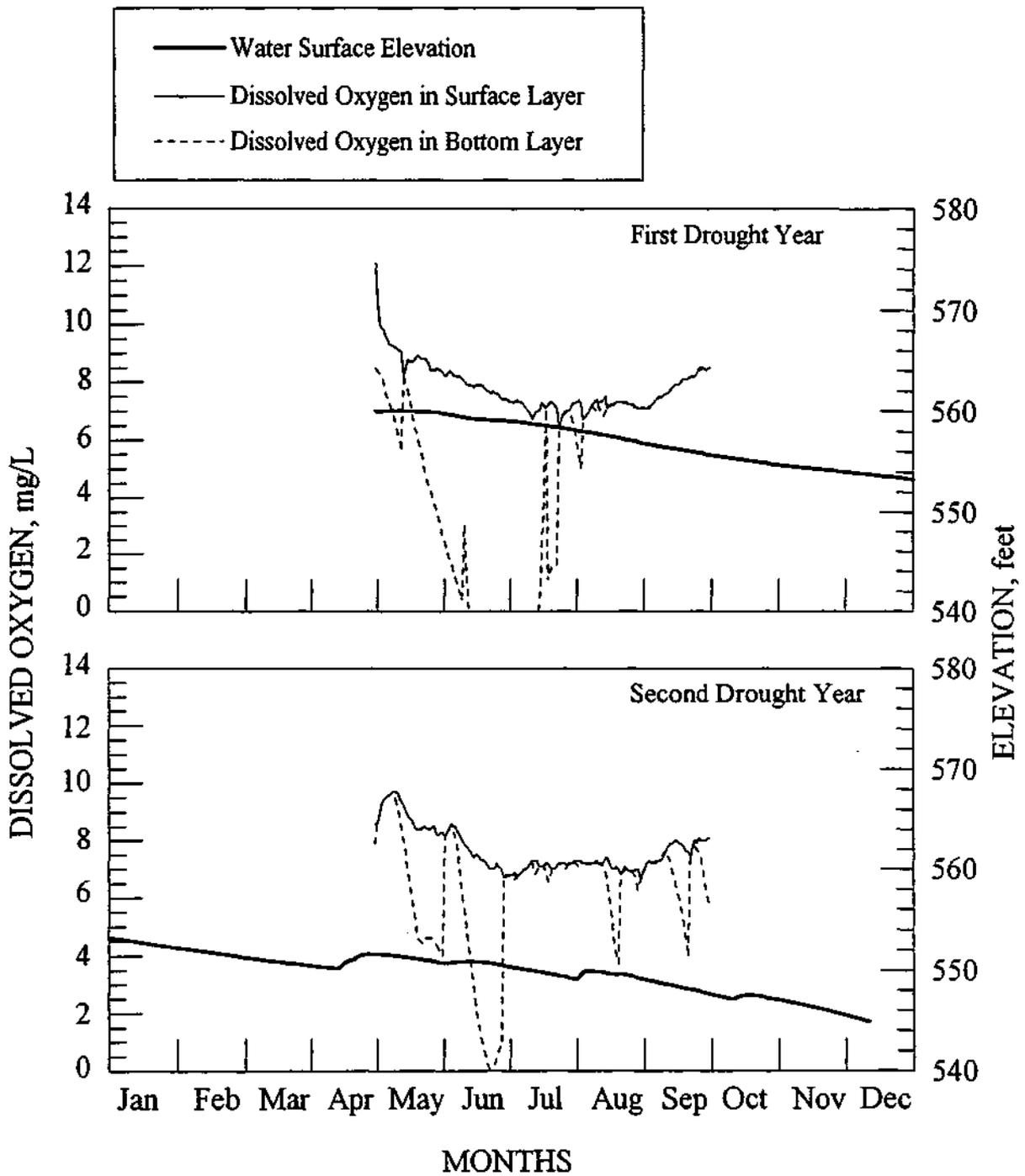
Figure 19. Predicted dissolved oxygen and surface elevation in proposed Hunter Lake during a 2-year drought under a selected operating scenario with Lake Springfield
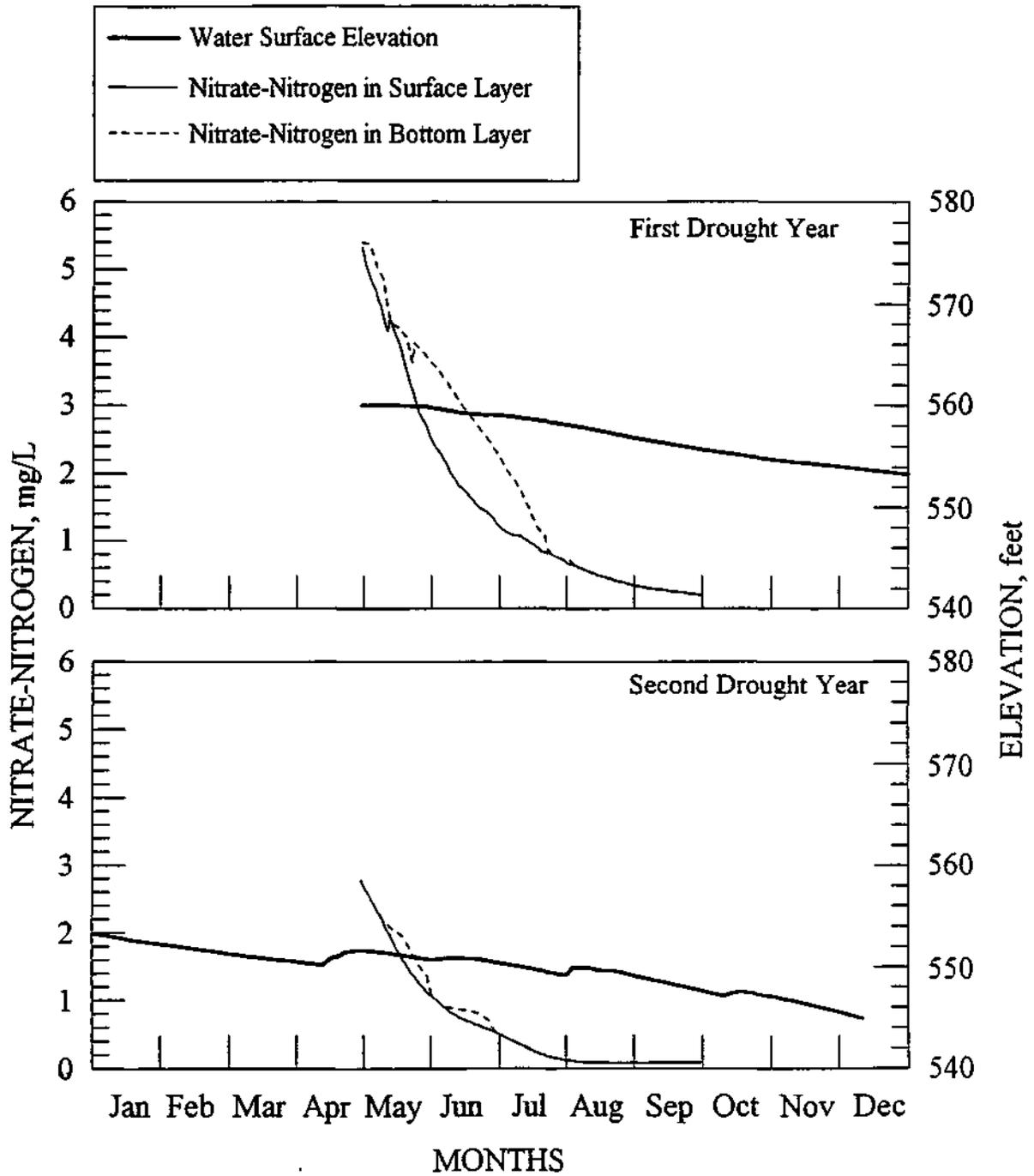
Figure 20. Predicted nitrate-nitrogen and surface elevation in proposed Hunter Lake during a 2-year drought under a selected operating scenario with Lake Springfield
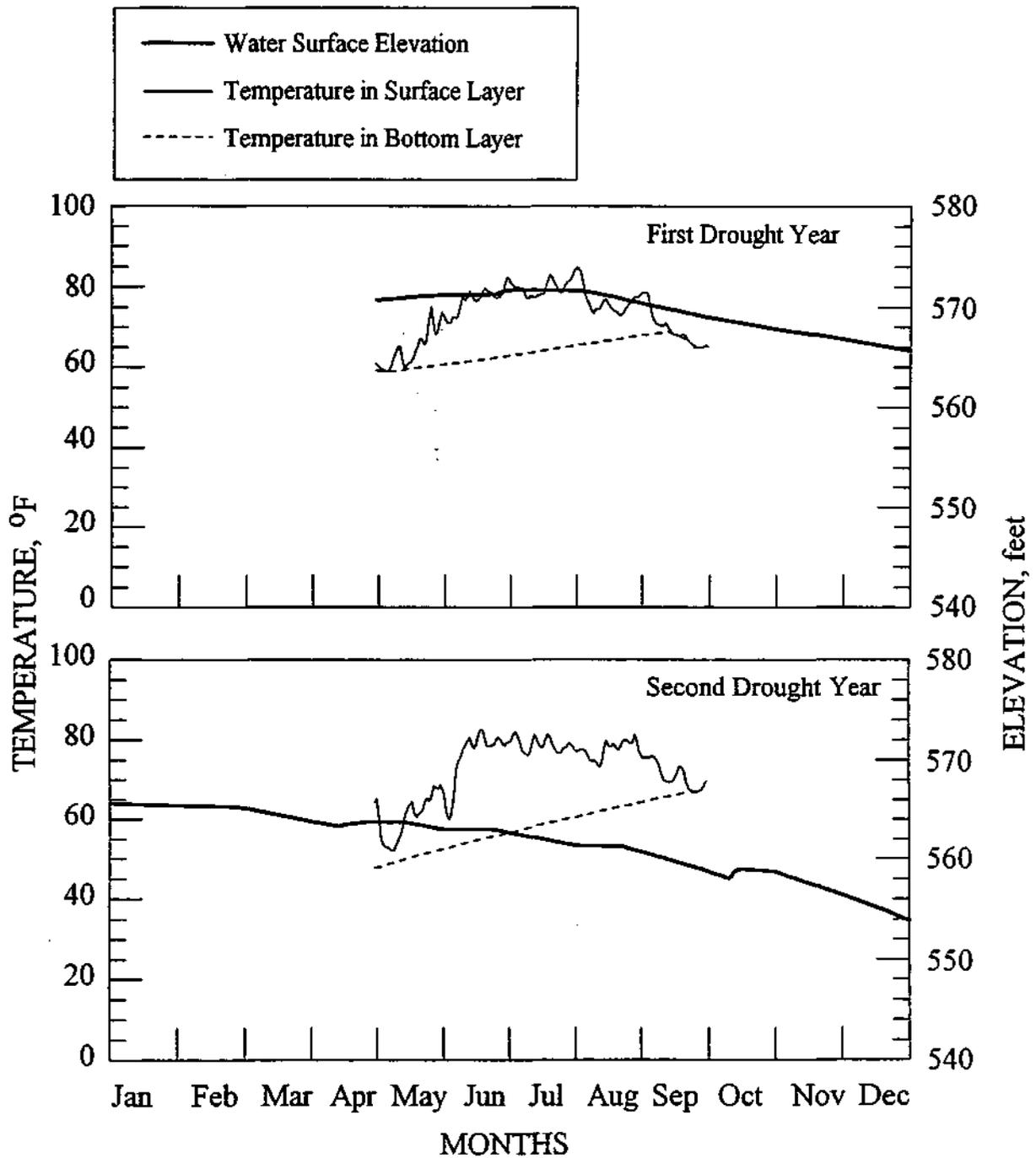
49

Figure 21. Predicted phosphate-phosphorus and surface elevation in proposed Hunter
Lake during a 2-year drought under a selected operating
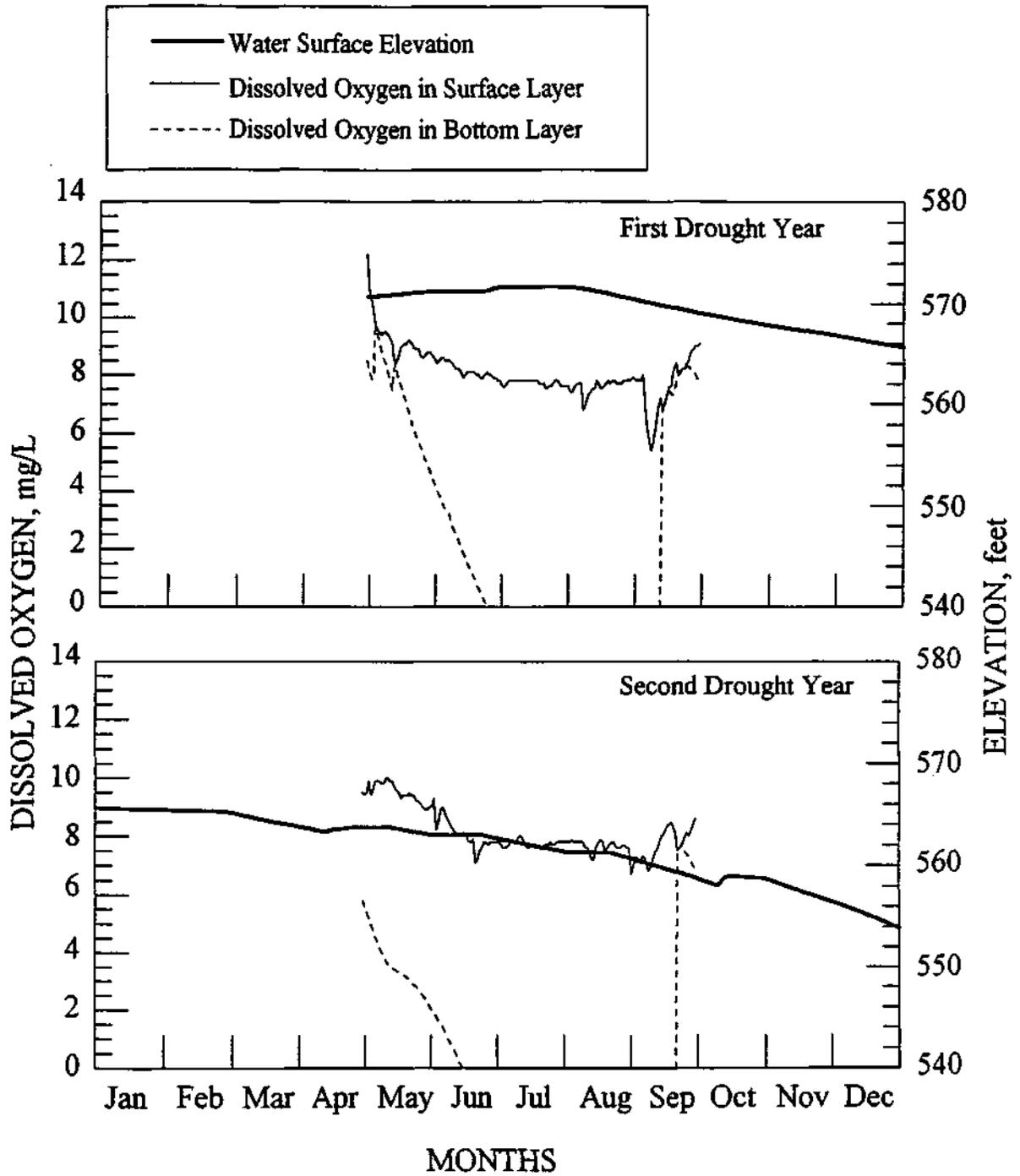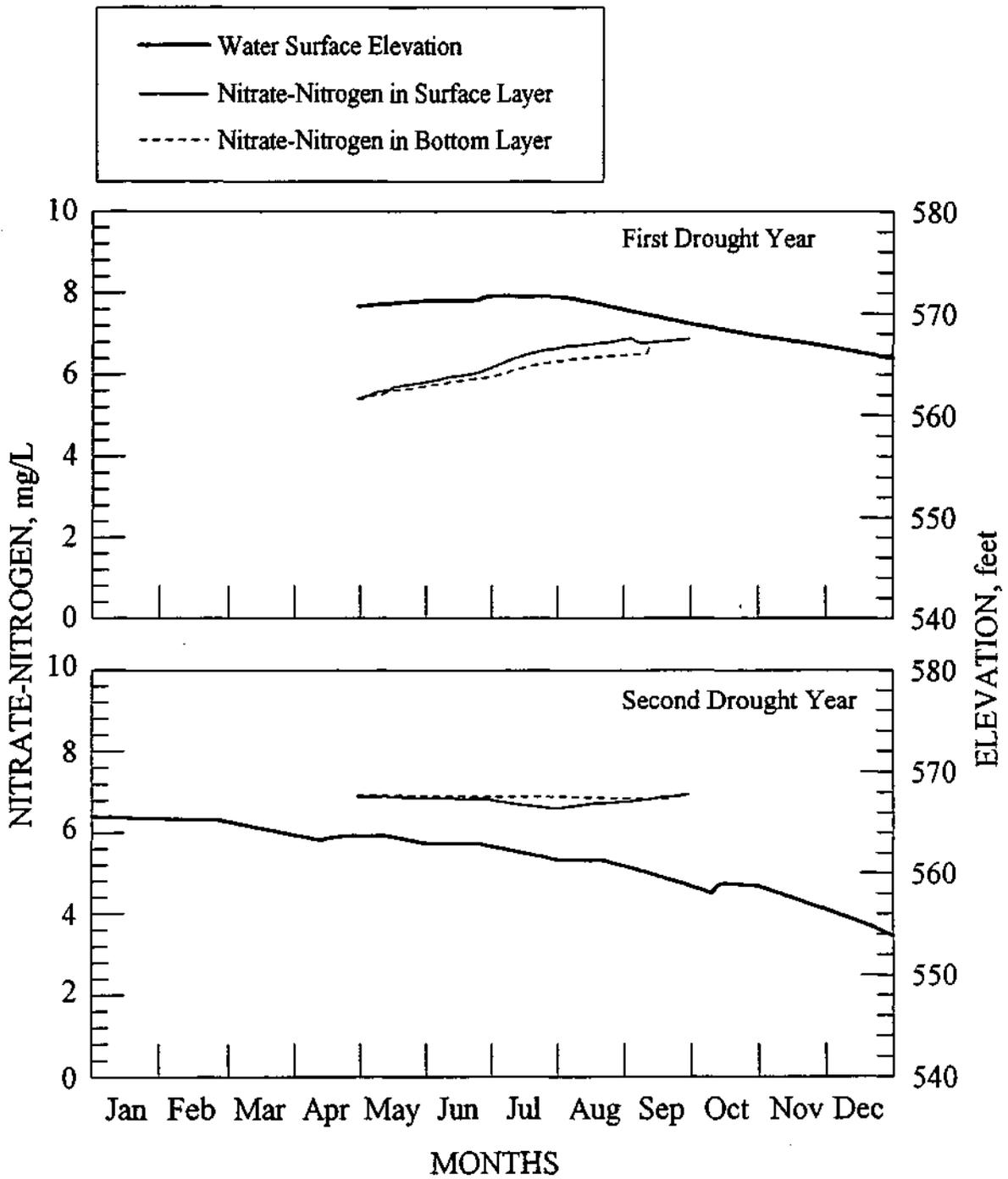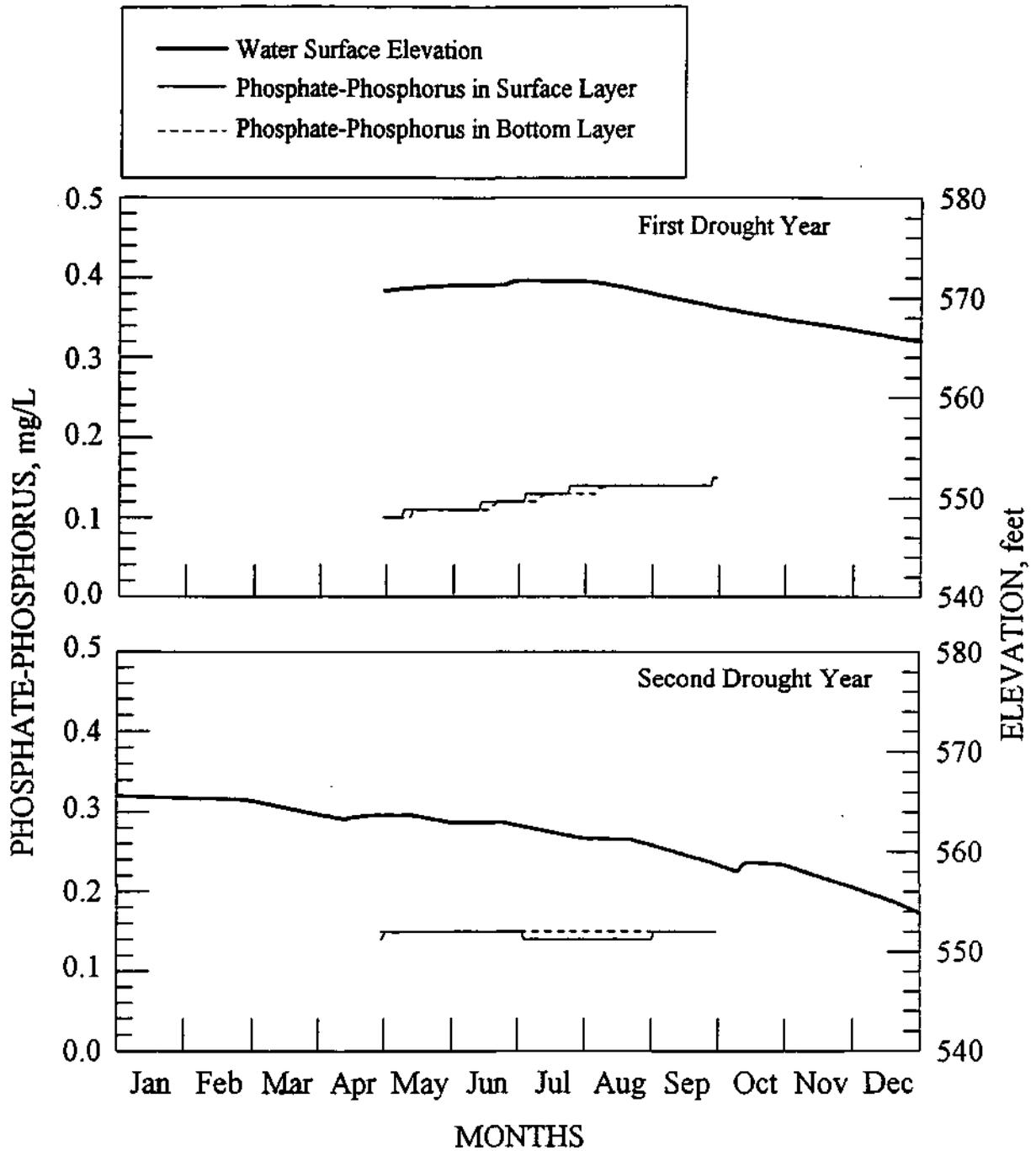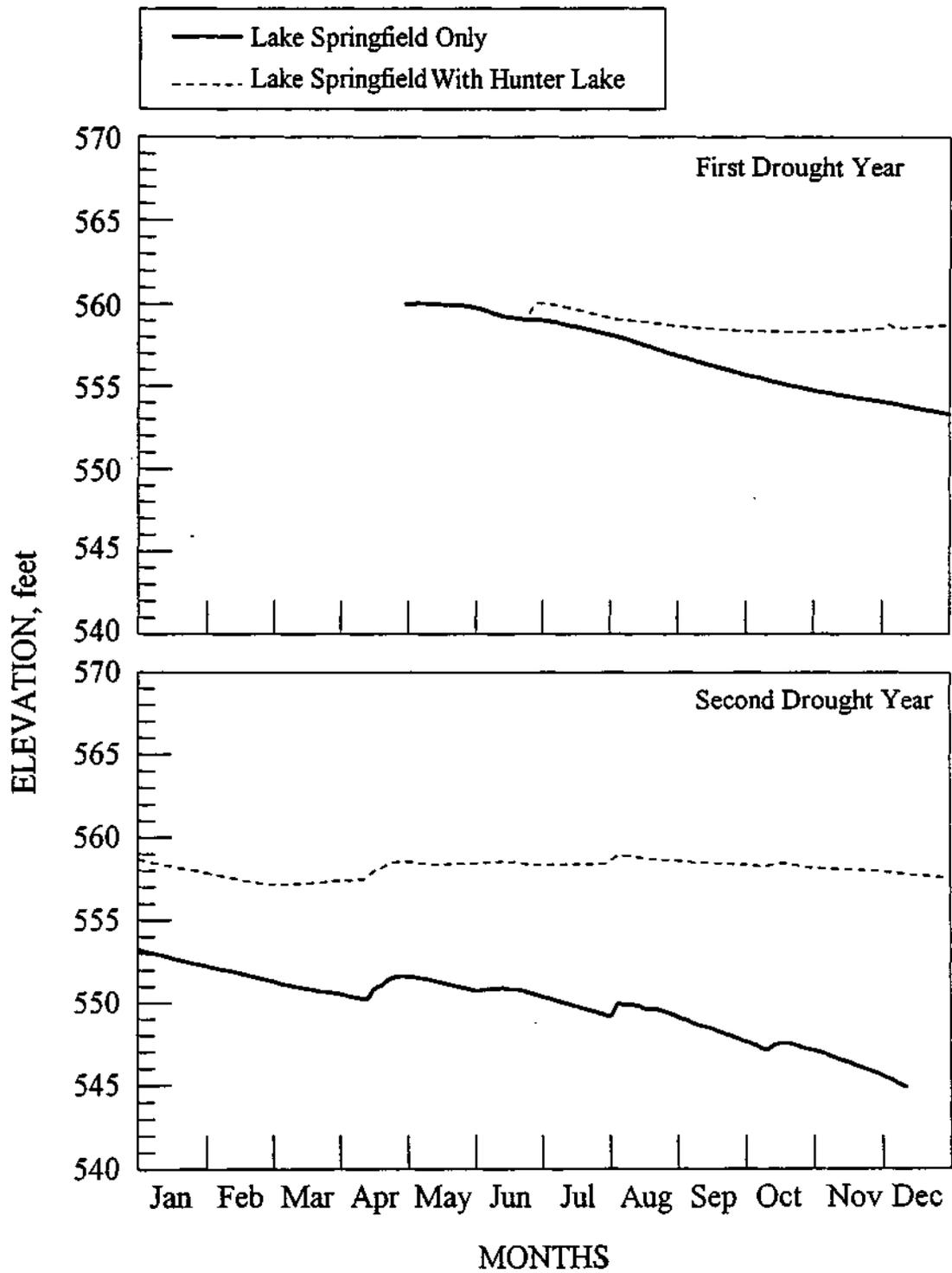scenario with Lake Springfield

Figure 22. Predicted water surface elevations in Lake Springfield during a 2-year drought showing impact of proposed Hunter Lake

As shown in Figures 18-21, Hunter Lake suffered a total drawdown of 17 feet during this drought period. On the other hand, it helped restore 13 feet of water in Lake Springfield at the end of the 20-month drought period, as shown in Figure 22. Since Hunter Lake is very deep, 46 feet at full pool, and even 29 feet deep at the end of the 20-month drought, there is a sharp gradient and substantial difference of temperature from surface layer to bottom layer, as shown in Figure 18. Due to the depth of Hunter Lake, the sharp gradient of DO and zero values at the lower layers of water remained for the entire summer months, as shown in Figure 19. Surface DO always remained above 6 mg/L, except for a very short period in Year 1.

The pattern and magnitudes of nitrate-nitrogen concentration in Hunter Lake (Figure 20) are quite different from Lake Springfield (Figure 15). This is mainly because of different inflow concentrations of nitrate-nitrogen to the lakes. Unlike Lake Springfield, inflow concentrations of nitrate-nitrogen and phosphate-phosphorus were not adjusted (reduced) for calibration, these were estimated based on the limited data collected by CMT (1994), and were considered conservative. Although the conservative nitrate-nitrogen predictions for Hunter Lake (Figure 20) are higher than the predictions for Lake Springfield (Figure 15), they are below drinking water standards. Phosphate-phosphorus predictions for Hunter Lake (Figure 21) are slightly lower than the predictions for Lake Springfield (Figure 16); however follow a similar pattern.

The lowest DO in the water columns of Hunter Lake during each year was on July 22 of Year 1 and July 5 of Year 2. Figure 23 shows DO and temperature profiles for Hunter Lake on these two days. As shown in this figure, DO was above zero only in the upper 20 feet on July 22, Year 1, and above 14 feet on July 5, Year 2. Depletion of DO in the hypolimnetic zone during the summer months is a common phenomenon in central Illinois deep-water lakes, and the model predicted this phenomenon reasonably well for the proposed Hunter Lake.

The lowest DO in Lake Springfield under the influence of Hunter Lake was on July 7 in Year 1 and July 6 in Year 2. Figure 17 shows profiles on these days and may be compared with the lowest DO without the influence of Hunter Lake shown in the same figure as "Lake Springfield Only." As shown in Figure 17, in addition to adding significant water depth (volume), Hunter Lake provided improved DO levels in Lake Springfield on the most critical days, especially the second year of the drought during which there was an additional 4-5 feet of water with higher DO.

The addition of supplemental water from Hunter Lake may impact the water temperature toward the bottom of Lake Springfield, including at the normal power plant intake elevation of 547 feet, by creating a greater water depth. For example, the temperature at an elevation of 547 feet on June 21, Year 2 was 83.2°F (Figure 17), which was reduced to 76.1°F (not shown in Figure 17) on the same day with supplemental water from Hunter Lake. However, on the critical day for Hunter Lake, (July 6, Year 2), the temperature was reduced from 84.0°F (not shown in Figure 17) to only 81.7°F (Figure 17), approximately a 2°F reduction. Except for these critical days, temperature differences
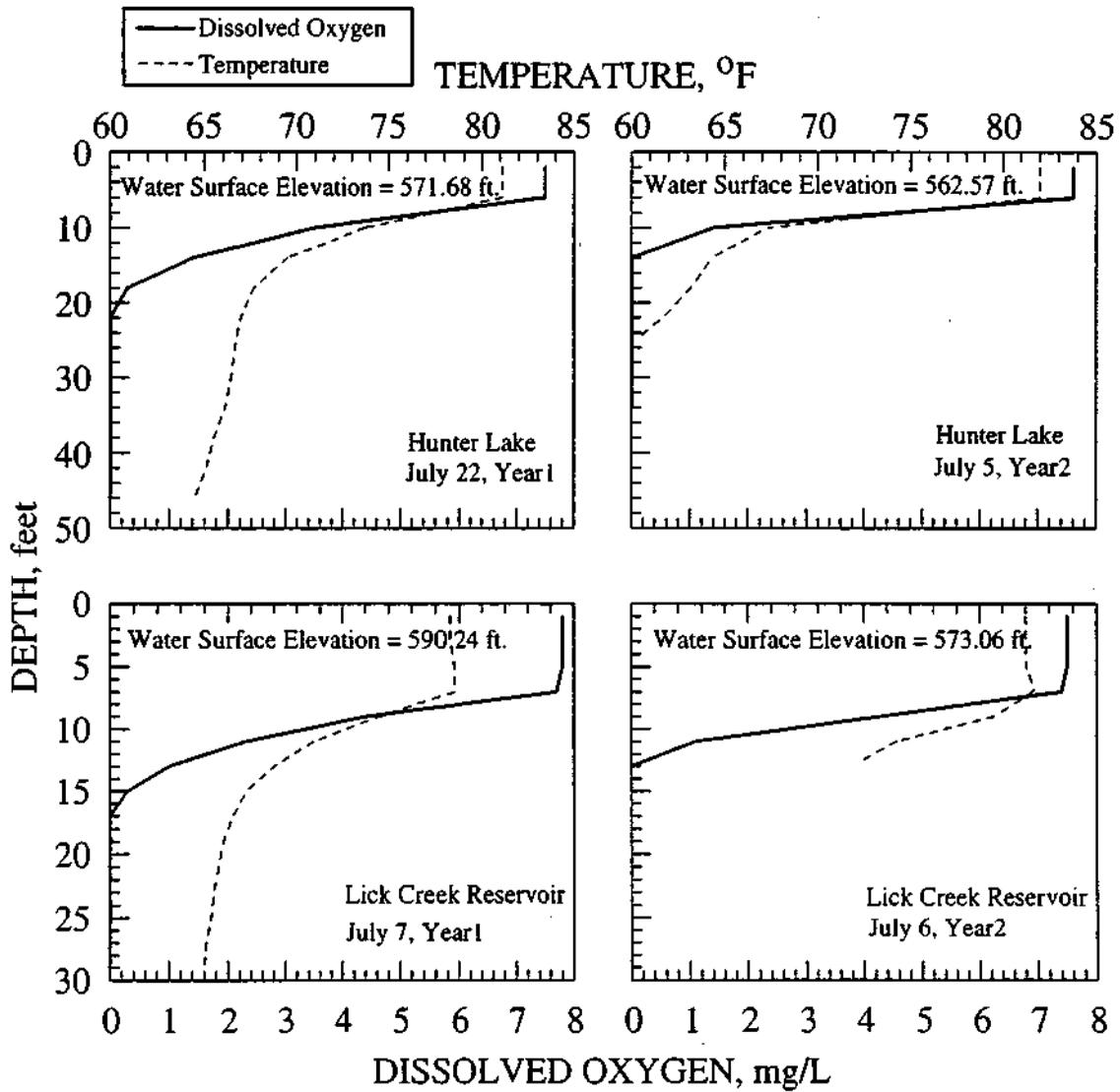
Figure 23. Predicted vertical profiles of temperature and dissolved oxygen in proposed
Hunter Lake and Lick Creek Reservoir on most critical days (lowest DO) in
each year of a 2-year drought under selected operating scenarios

in the water transferred from Hunter Lake do not appear to have significant thermal impact on Lake Springfield and account for only a small component of the lake's heat budget. The impact of lake depths on water temperatures at the intake are discussed further in the section: "Lake Springfield, Hunter Lake, and Lick Creek Reservoir under Severe Drawdown."

In general, water quality in Lake Springfield with supplemental water from Hunter Lake remained practically unchanged (same as shown in Figures 13-16) with some, mostly minor, differences during certain days of Year 2.

Lick Creek Reservoir and Lake Springfield during Severe Drought

Similar to what was done for Hunter Lake, the proposed Lick Creek Reservoir was simulated for the two drought years in combination with Lake Springfield using the network described earlier and shown in Figure 4. Physical dimensions and model inputs for Lick Creek Reservoir were also described earlier. Daily tributary and direct inflows from all sources into Lick Creek Reservoir and Lake Springfield, and monthly net evaporation rates from these two impoundments during the 1953-1954 drought period were estimated separately using the ISWS watershed simulation model (Knapp, 1997). As described before, based on flow records for the South Fork Sangamon River during this period, pumping contributions from the South Fork pump station were determined and added to the inflows for Lake Springfield.

An operating scenario was selected for supplementing Lake Springfield with water from Lick Creek Reservoir. In this scenario, a discharge of 50 cfs was released from the Lick Creek Reservoir when Lake Springfield was at least 2 feet below normal levels. During the winter and early spring, the level in Lake Springfield was allowed to fall to as much as 5 feet below full pool. A release of 100 cfs was begun in mid-spring when water levels in Lake Springfield failed to recover. The release was discontinued when the water level in the Lick Creek Reservoir was 6 meters below normal. The rationale for selecting this operating scenario was to produce a substantial transfer of water from Lick Creek Reservoir to Lake Springfield within the range of expected operating conditions, thus producing the most favorable water quality impact to Lake Springfield. As shown below, this scenario produced a significant drawdown in the Lick Creek Reservoir and moderate drawdown in Lake Springfield.

Meteorological data and inputs were the same as described above. Constituent concentrations with inflow water were estimated based on water quality observations on Lick Creek near Loami (Figure 1), data available in ISWS open file records. Initial lake level or volume was assumed to be full at 590 feet. Initial constituent concentrations in the lake waters on May 1, Year 1 were assumed to be the same as for Lake Springfield. Similar to Lake Springfield and Hunter Lake simulations, initial constituent concentrations on January 1, Year 2, were taken from the results of the Year 1 run on December 31.

Except the inflows, all other inputs to Lake Springfield were kept the same as described above. The model was run, and both Lake Springfield and Lick Creek Reservoir were simulated for the 20-month drought period. Figures 24-27 present model results on water surface elevations and constituent concentrations in Lick Creek Reservoir. Figure 28 shows the impact of Lick Creek Reservoir on Lake Springfield in supplementing its water.

Figure 24. Predicted temperature and surface elevation in proposed Lick Creek
Reservoir during a 2-year drought under a selected
operating scenario with Lake Springfield

56

Figure 25. Predicted dissolved oxygen and surface elevation in proposed Lick Creek Reservoir during a 2-year drought under a selected operating scenario with Lake Springfield

Figure 26. Predicted nitrate-nitrogen and surface elevation in proposed Lick Creek
Reservoir during a 2-year drought under a selected
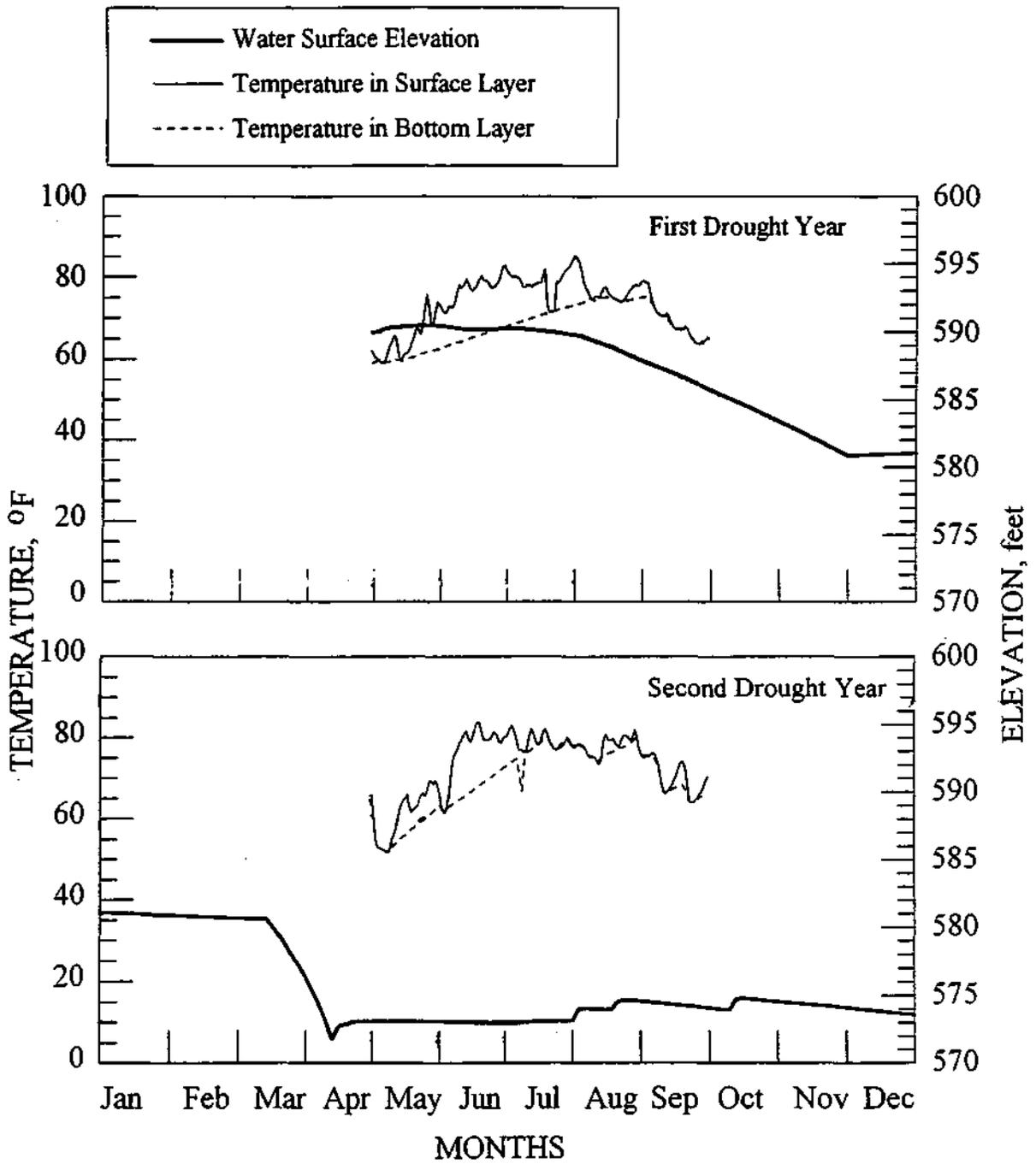operating scenario with Lake Springfield

Figure 27. Predicted phosphate-phosphorus and surface elevation in proposed Lick
Creek Reservoir during a 2-year drought under a selected
operating scenario with Lake Springfield

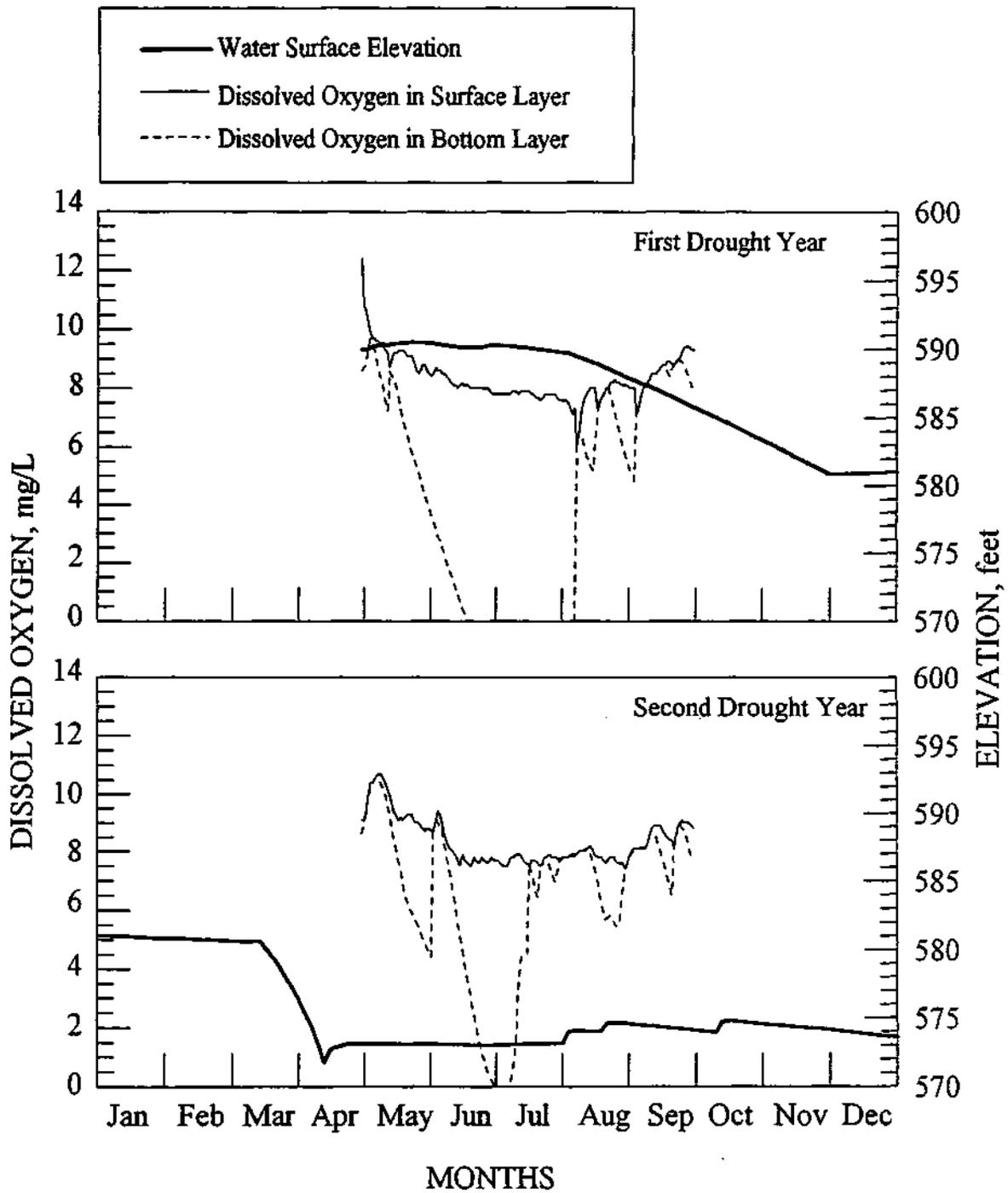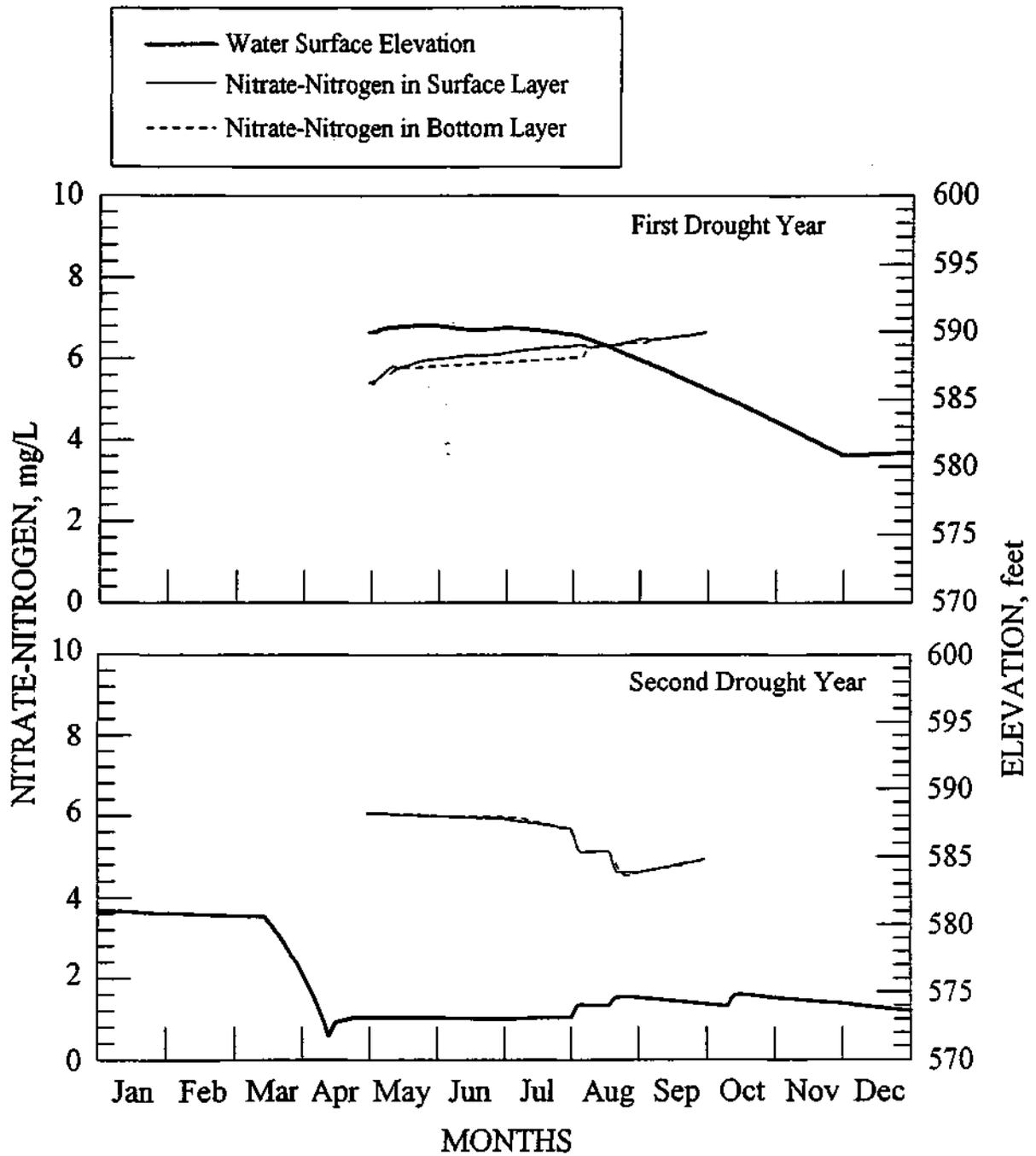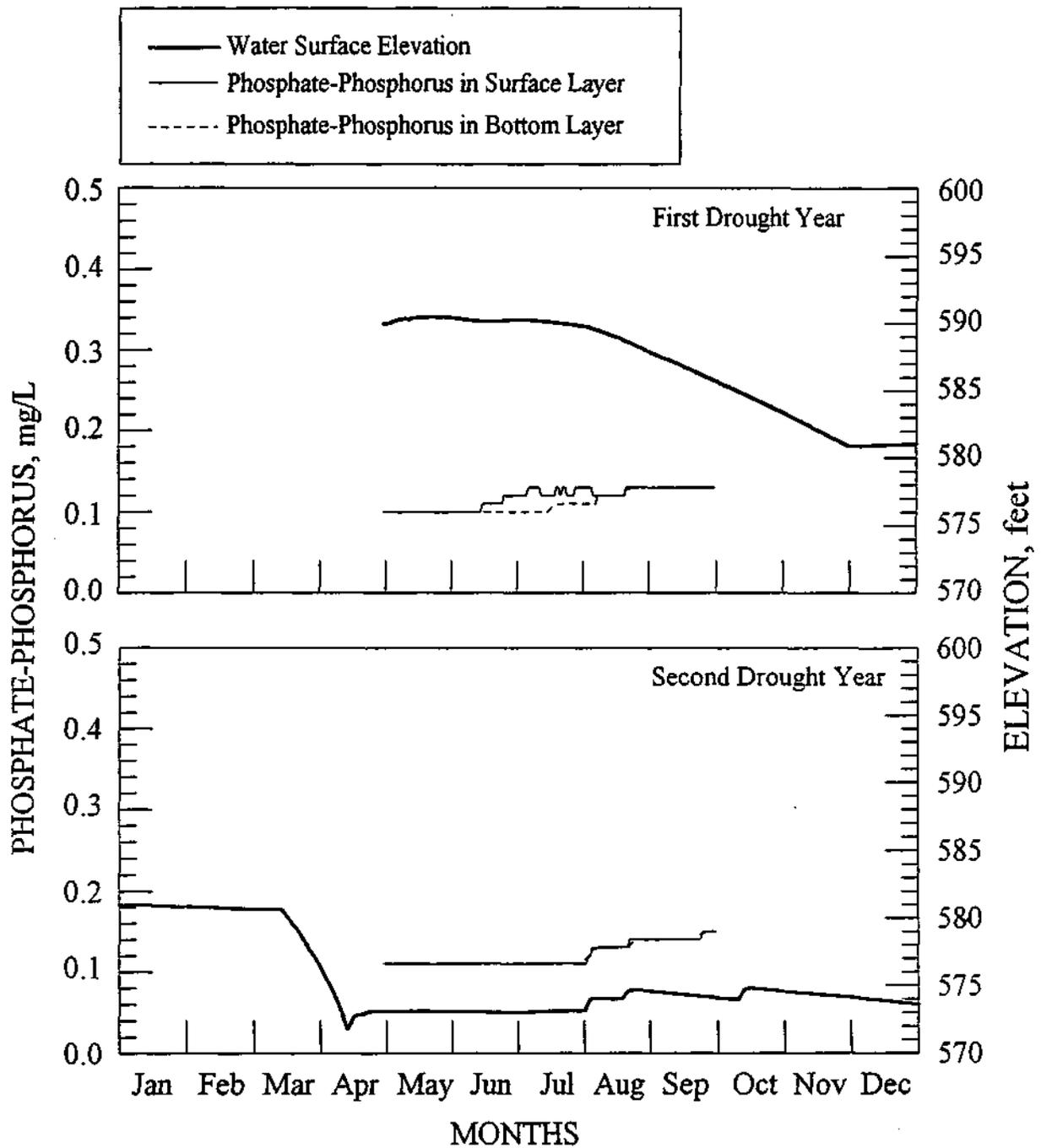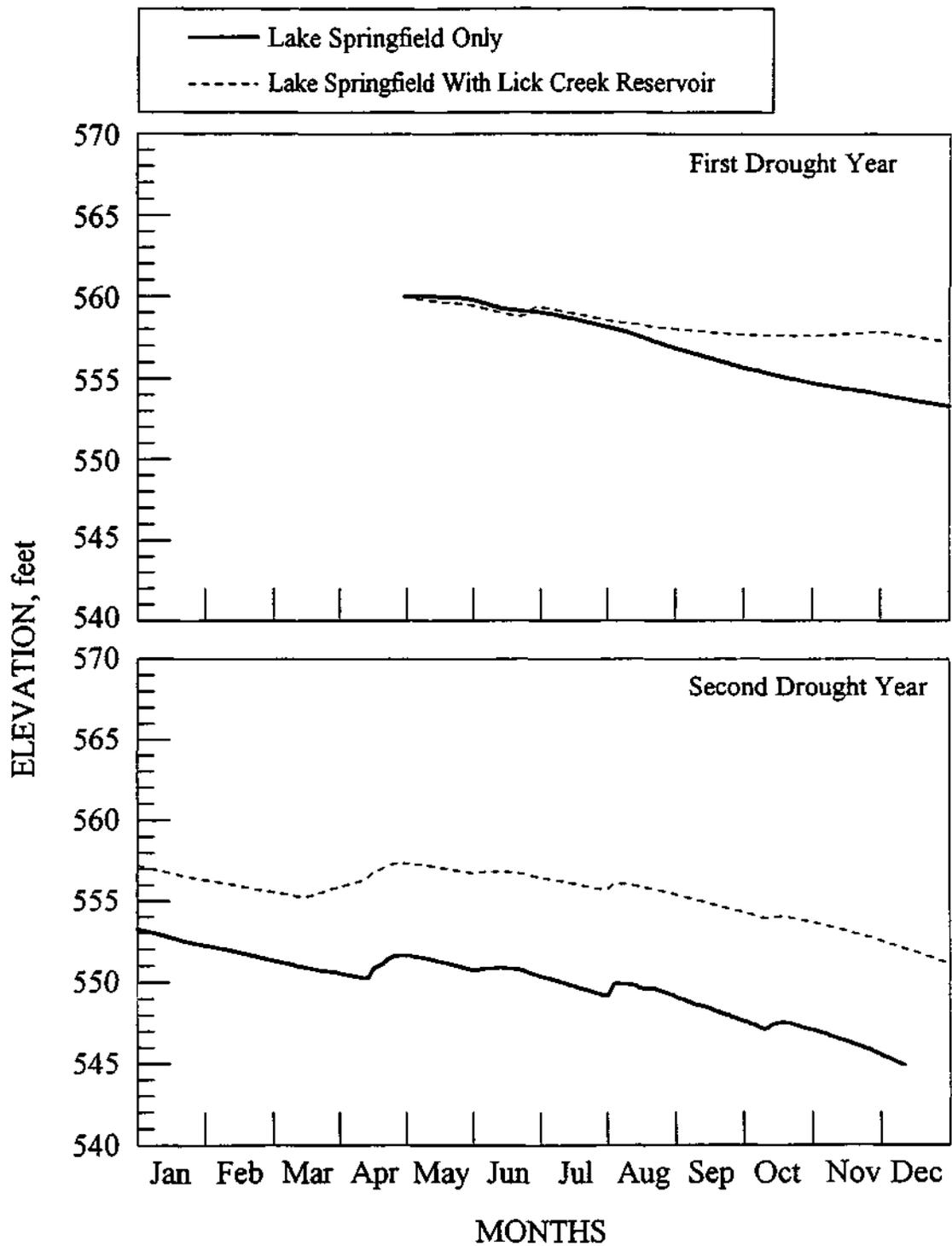Figure 28. Predicted water surface elevations in Lake Springfield during a 2-year drought showing impact of proposed Lick Creek Reservoir

As shown in Figures 24-27, Lick Creek Reservoir suffered a total drawdown of 16 feet during this drought period. On the other hand, it helped restore about 7 feet of water in Lake Springfield at the end of the 20-month drought period, as shown in Figure 28. Since Lick Creek Reservoir is 5 feet deeper than Lake Springfield, the model shows some temperature gradient from surface layer to bottom layer, as shown in Figure 24. Due to its shallow depth, similar to Lake Springfield, vertical gradient of DO and zero DO values at the bottom layer of Lick Creek Reservoir water remained for short periods during summer months, as shown in Figure 25. Surface DO remained above 6 mg/L during Year 1 and approximately above 8mg/L during Year 2.

The lowest DO in the water columns of Lick Creek Reservoir during each year was on July 7 of Year 1 and July 6 of Year 2. Figure 23 shows DO and temperature profiles on these two days. As shown in this figure, DO was above zero in the upper 17 feet on July 7 (Year 1) and above 13 feet on July 6 (Year 2). The lowest DO in Lake Springfield under the influence of Lick Creek Reservoir was on July 3 in Year 1 and July 5 in Year 2. Profiles on these days (Figure 17) may be compared with the lowest DO without the influence of this new reservoir, shown in the same figure as "Lake Springfield Only." As may be seen in Figure 17, in addition to adding some water depth (volume), Lick Creek Reservoir provided improved DO levels in Lake Springfield in terms of concentration and volume in both years. Similar improvements in DO levels and slight reductions in temperature in Lake Springfield due to the influence of Lick Creek Reservoir, as shown in Figure 17, were fairly uniform throughout the simulation period; however, the patterns remain the same as shown in Figures 13 and 14.

Improvements in DO levels in Lake Springfield due to the influence of Lick Creek Reservoir were expected partly because the model included a one-mile free-flowing stream reach conveying releases from the Lick Creek Reservoir to Lake Springfield (Figures 1 and 4). Within this reach, the re-oxygenation potential of the water with low initial DO content is high. Similar improvements in DO concentrations in Lake Springfield due to the influence of Hunter Lake (Figure 17) were not noticed partly because the model did not include any free-flowing stream between these two reservoirs. Water released from Hunter Lake was simply added to Lake Springfield. In reality, Hunter Lake release water will likely be conveyed through a nearly 4-mile-long free-flowing stream reach before diversion to South Fork pump station and pumping into Lake Springfield (Figures 1 and 3). Modeling of this free-flowing stream reach would likely result in improved DO concentrations in Lake Springfield.

Similar to Hunter Lake, although the nitrate-nitrogen values, as shown in Figure 26, were higher than values in Lake Springfield (Figure 15), those values were below the limits of the drinking water standard. Phosphate-phosphorus values, shown in Figure 27, were slightly lower than values in Lake Springfield (Figure 16).

Due to the substantial supplement of Lake Springfield water from Lick Creek Reservoir during the drought period, higher nitrate-nitrogen and lower phosphate-phosphorus contents of Lick Creek Reservoir (Figures 26 and 27) had an influence on

Lake Springfield by raising its nitrate-nitrogen concentration and lowering its phosphate-phosphorus concentration, however, both were below the limits of drinking water standards. It must be noted that concentrations of these two constituents in inflows to Lake Springfield and Lick Creek Reservoir were based on the limited observations at Loami. Concentrations to Lake Springfield were adjusted during calibration since Loami was located further upstream from Lake Springfield and, more importantly, there were data for Lake Springfield to help make such adjustments. Because Loami will be close to Lick Creek Reservoir, and there are no data for Lick Creek Reservoir (nonexistent reservoir), no adjustment of concentrations to this reservoir were made. This resulted in higher nitrate-nitrogen and lower phosphate-phosphorus values in Lick Creek Reservoir and, subsequently, in Lake Springfield compared to Lake Springfield under existing conditions.

Lake Springfield, Hunter Lake, and Lick Creek Reservoir under Severe Drawdown

One of the objectives of the modeling exercise was to examine water quality conditions, especially temperature and DO, in Lake Springfield and in the proposed lakes under certain drawdown levels, as discussed earlier, and shown in Table 5.

As seen in the above simulations, temperature and DO levels in a lake were very much dependent on meteorological conditions varying with time of the year. Severe drawdown levels did not coincide with the worst water quality conditions. Therefore, hypothetical simulations were made on the three lakes using the 1954 flow and meteorological data. In these simulations, release rates from each of the lakes were determined using trial and error so that the lowest DO in the water column coincided with each of the desired drawdown levels. The date on which the above condition was met was noted in each case. In order to be able to simulate severe drawdown at the worst time of the year, the summer months, without using unrealistically high release rates, full pool was assumed to be on January 1 in each run.

Table 6 presents results of the model runs made to examine water quality conditions (temperature and DO) in each of the lakes at drawdown levels specified in Table 5.

Table 5. Drawdown Levels at Which Water Quality Is Evaluated

Lake/Reservoir	Drawdown (ft/m)	Drawdown level (ft)
Lake Springfield	2 ft	558
	2 m	553
	10 ft	550
	13 ft	547
Hunter Lake	2 ft	569
	2 m	564
	6 m	551
Lick Creek Reservoir	2 ft	588
	2 m	583
	6 m	570

**Table 6. Water Quality Predictions for Lake Springfield and Proposed Hunter Lake
and Lick Creek Reservoir during Specific Drawdown Levels
Using 1954 Flow and Meteorological Data and Initial Full Pool on January 1**

Drawdown level (ft)	Release rate(cfs)	Date	Surface temperature		Bottom temperature		Dissolved oxygen	
			(°F)	Increase over full pool (°F)	(°F)	Increase over full pool (°F)	Surface (mg/L)	Bottom (mg/L)
			Lake Springfield					
560*	0	June 22	81.2	0.0	71.0	0.0	7.5	1.2
560*	0	June 29	80.9	0.0	73.2	0.0	7.4	0.0
560*	0	July 8	80.1	0.0	76.3	0.0	7.1	0.0
560*	0	July 11	79.3	0.0	77.3	0.0	6.9	0.0
558	52	July 8	80.2	0.1	77.7	1.4	6.8	0.0
558	52	July 11	79.4	0.1	78.7	1.4	6.9	0.0
553	95	June 29	81.5	0.6	77.8	4.6	7.0	0.0
553	95	July 11	79.7	0.4	79.7	2.4	7.2	7.2
550	125	June 22	81.7	0.5	78.8	7.8	7.0	0.2
548	125	July 11	79.6	0.3	79.6	2.3	7.2	7.2
547	145	June 22	81.6	0.4	78.8	7.8	7.2	0.6
545	145	July 11	79.5	0.2	79.5	2.2	7.3	7.3
			Hunter Lake					
571*	0	July 5	82.0	0.0	55.9	0.0	7.7	0.0(22)**
569	15	July 5	82.0	0.0	55.9	0.0	7.7	0.0(22)
564	45	July 5	82.1	0.1	56.5	0.6	7.7	0.0(18)
551	100	July 5	82.5	0.5	58.1	2.2	7.4	0.0(14)
			Lick Creek Reservoir					
590*	0	July 7	79.2	0.0	64.0	0.0	7.9	0.0(17)
590*	0	July 8	76.7	0.0	64.2	0.0	7.6	0.0(17)
588	12	July 8	76.8	0.1	65.4	1.2	7.5	0.0(15)
583	30	July 7	78.9	-0.3	67.3	3.3	7.3	0.0(11)
583	30	July 8	76.4	-0.3	67.5	3.3	7.6	0.0(11)
570	53	July 7	79.2	0.0	74.3	10.3	7.3	0.0
570	53	July 8	76.4	-0.3	74.7	10.5	7.6	0.0

Note: *Full pool. Bottom elevations: Lake Springfield 535 ft, Hunter Lake 525 ft, and Lick Creek Reservoir 560 ft.

**Number in parentheses indicates depth where zero DO begins.

Table 6 presents the dates and release rates, determined by trial and error, required to achieve the desired drawdown level on the lowest DO in the water column. In order to compare the results with a control situation, a base run was made for each of the lakes with no release, and stage or volume remained at full pool during the entire year. Under certain (normal to extreme) weather conditions DO may be very low, up to zero, in several bottom layers of a lake, especially if the lake is deep. Therefore, the last column of Table 6 provides the depth at which zero DO begins in parentheses for cases where zero DO was not limited to only the bottom layer.

As shown in Table 6, except for Hunter Lake and one level in Lick Creek Reservoir, the lowest DO for the desired levels occurred on a date different than the base run. In all cases, the date was advanced: when the reservoir was lowered by releasing water, the worst condition occurred a few days earlier. For Lake Springfield, the date advanced by almost 20 days (July 11 to June 22) for the two severe drawdown levels (550 feet and 547 feet). For the base run, the lowest DO occurred on July 11. Although the lowest DO occurred on different dates for the drawdown levels, temperatures and DO on July 11 are also given in Table 6 for comparison. Similarly, base (full pool) values on all the relevant dates are also shown for comparison. Increases in temperatures are also given in Table 6. It must be noted that these increases in temperatures were from the same days when the lake level was constantly at full pool with no release (the base run). Except for the bottom temperatures, changes in water quality due to the drawdowns were minor. Bottom temperatures were raised up to 7.8°F in Lake Springfield for the two severe drawdown levels (550 feet and 547 feet). On the other hand, although the drawdowns were even severe on July 11 (545 feet), DO improved substantially in terms of total DO in the water column (surface and bottom values were the same as 7.3 mg/L). For the July 11 simulation, the temperature gradient in the lakes was less, an increase in bottom temperatures of only 2.2 °F.

The modeling results and monitoring data indicate that the temperatures at the normal power plant intake elevation of 547 feet are usually within 3°F of the surface temperature. Model results indicate that as the lake heats up during early summer, a greater gradient can be established with temperature differences of up to 7°F. But during late July and August, when the temperature of the lower levels has increased, the gradient becomes low and the temperatures at 547 feet are generally only 1 or 2°F below the surface temperature. Thus, a severe lake drawdown may create a significant temperature difference for the power plant intake during June and early July but have a relatively small impact in late July and August.

Hunter Lake appeared to be quite unique having the same date of lowest DO for all the levels (Table 6), but minor differences in temperature and DO values. This may be due to its depth, which remained much deeper than the other two lakes all the time. Lick Creek Reservoir behaved in a similar fashion to Lake Springfield, except the date advanced only by one day for the last two levels. Bottom temperature rose by 10.5°F under 6-meter drawdown on July 8.

Examination of the nitrate-nitrogen and phosphate-phosphorus results in the three lakes revealed that these constituents were practically unaffected by the drawdowns and showed only minor differences.

During severe or prolonged drawdown periods, the model indicates that the DO levels in the epilimnetic zones of Lake Springfield and the proposed Hunter Lake and Lick Creek Reservoir are about 7-8 mg/L, which is greater than the Illinois general use water quality minimum standard of 5 mg/L. The fish in the lakes will tend to congregate in the lake's epilimnetic zone and in the thermocline zone. In the recent (1988-1989) drought episode experienced by Lake Bloomington and Evergreen Lake, no fish kill was reported. Consequently, no serious adverse impacts on fisheries are anticipated in Lake Springfield, as well as in the proposed Hunter Lake and Lick Creek Reservoir.

Since Lake Springfield and the proposed sites for Hunter Lake and Lick Creek Reservoir are not in the waterfowl flyway corridor, there is no anticipated impact of lake operations on waterfowl.

Impact of Thermal Discharges from the Power Plant on Lake Springfield

In a normal situation, temperature of the power plant discharge is 15-20°F warmer than water temperature in Lake Springfield. For example, on July 2, 1986, the lake temperature varied from 71.6°F at the bottom to 78.8°F at the surface, with a depth average of 77°F. Average water temperatures from the three Dallman units on the same day were 89.6°F, 93.6°F, and 95.7°F, with an overall average of 93°F, 16°F warmer than average lake temperature. Similarly, on July 16, 1986, the depth average lake temperature was 84°F, and the average temperature from the Dallman units was 102°F. That day, the Lakeside power plant, which re-circulates 20% of the water, was also active with a discharge temperature of 95.9°F. The weighted average temperature from all units was 101°F, 17°F warmer than the lake water. On both days the lake levels were almost full, 559.84 feet on July 2, and 559.70 feet on July 16.

There are two regulatory limits on the discharge temperatures from the Dallman units. The absolute maximum discharge temperature from any unit shall not exceed 109°F at any time. The temperatures may also not exceed 99 °F for more than 8% of the operational hours over a 12-month period. Discharges from the Lakeside unit may not exceed 99 °F for more than 5% of the operational hours. The possibility of increased levels of thermal loading in the future and the potential for power plant shutdown in these circumstances is thus a primary concern. The future amount of thermal loading on Lake Springfield and the associated discharge temperatures will depend upon: (1) increases in power loads, (2) the volume of water being recycled, and (3) the use of cooling towers and/or new cooling technologies.

It may ordinarily be expected that highest water temperatures occur during periods of severe lake drawdown. During such drawdown periods when the lake volume is relatively small, it may also be expected that the thermal loading from the power plant would also have the greatest impact on lake temperatures. Figures 6, 10, and 13 present the available observed and simulated water temperatures for 1986, 1988, and 1953-1954, respectively. Note that the highest simulated water temperatures were in the mid-summers of 1986 and 1988, periods when there was relatively less drawdown in Lake Springfield. This suggests that lake drawdown, by itself, may not be a good predictor of high temperatures. Meteorological factors may still play the dominant role in the energy budget of the lake and its water temperatures.

Although the simulations of Lake Springfield, presented earlier in this report, included the thermal loading of the power plant, further examination was made on the influence of the power plant on Lake Springfield water during severe drawdown. In such a period, when the lake stage or water volume is small, the water can easily become warmer with discharge from the power plant. It is believed that if that warmer water is drawn again for cooling purposes, the power plant discharge can be even warmer, and the lake water will gradually be warmer.

The HEC-5Q model was used to simulate the increase of lake temperature due to an increase of temperature in power plant discharge. Three additional simulation runs were made with the second drought year (1954) data by raising the temperatures of power plant discharges to Lake Springfield by 3°F, 6°F, and 9°F. The rate of recycled water was kept at 595 cfs. Temperature profiles on June 21 from these runs were compared with the profile of earlier simulation, referred to as normal temperatures. This date was chosen for the comparisons because the worst water quality (DO) occurred that day in that earlier simulation (Figure 17). Also, the lake level on June 21 was predicted to be 550.82 feet, a desired level to show the impacts of a low lake level on thermal loading. Comparisons shown in Figure 29 indicate that, on an average, depth average water temperature in the lake was raised by approximately 0.5°F for every 3.0°F rise in power plant discharge.

Similar rises of temperature, as shown in Figure 29, were found uniformly throughout the simulation period. The remaining three water quality constituents were practically unaffected by the temperature rise in power plant discharge, except for some minor changes in DO. DO depletion of 0.1-0.2 mg/L in surface and bottom layers at 9°F temperature rise was observed uniformly throughout the simulation period. For the same temperature rise, improvements of bottom DO up to 4 mg/L were also found on rare days having sharp gradients in vertical profiles under normal temperature.
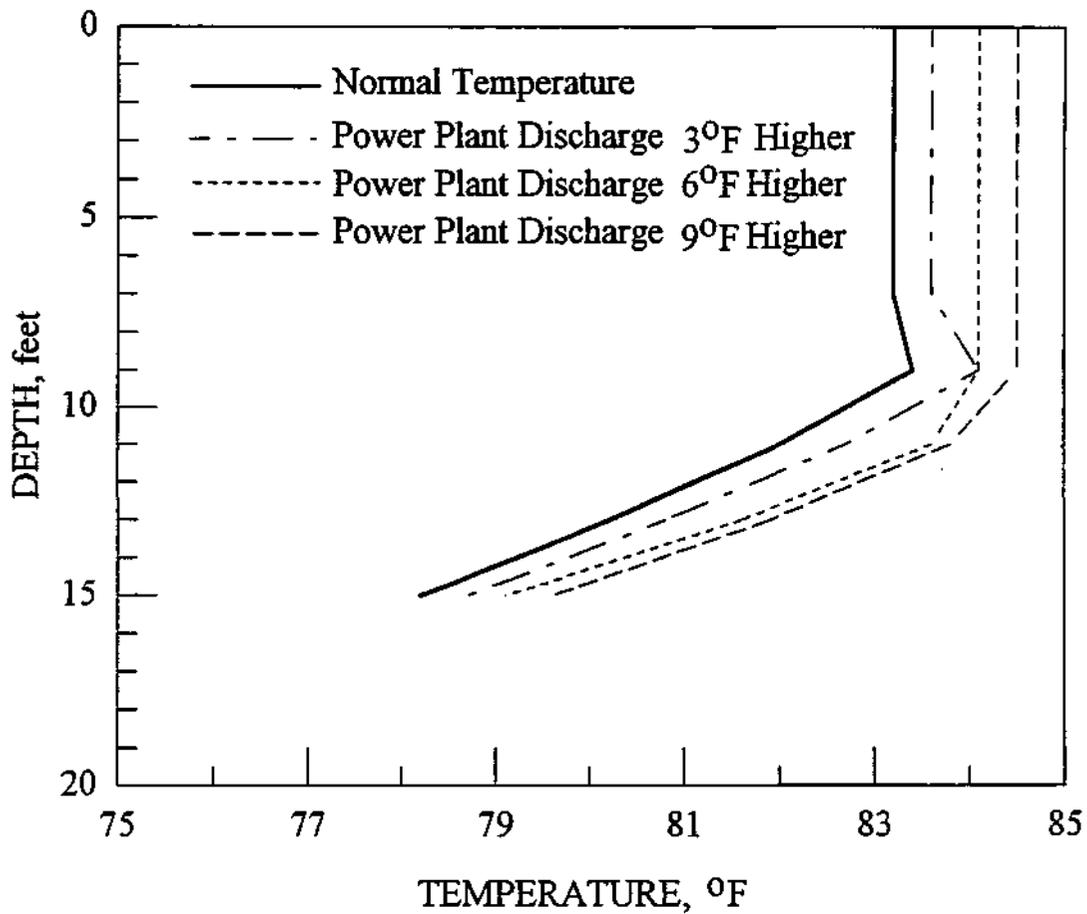
Figure 29. Vertical profiles of temperature in Lake Springfield predicted on June 21, Year 2 with increasing temperatures in power plant discharge

SUMMARY AND CONCLUSIONS

The U.S. Army Corps of Engineers HEC-5Q model for Simulation of Flood Control and Conservation Systems with Water Quality Analysis was calibrated and reasonably verified for Lake Springfield using monitored data in 1986 and 1988, respectively. Year 1986 was an average year, and 1988 a recent drought year. Water quantity predictions of the model were also verified with monitored data during 1953-1954, a severe recorded drought period. The calibrated and verified model was used to predict water surface elevations and constituent concentrations in Lake Springfield and the proposed Hunter Lake and proposed Lick Creek Reservoir, individually and in combination, during a 20-month drought, represented by meteorological data and estimated flows in 1953-1954, and current water supply and power plant withdrawal rates. The model was also used to evaluate, hypothetically, water quality in the three lakes for certain draw-down levels, including severe conditions, and the impact of additional thermal discharges from the power plant on Lake Springfield, expected during severe droughts.

It must be noted that the HEC-5Q model was designed to estimate changes in overall water quality of each lake, assuming normal horizontal mixing of temperature and other water quality properties. Therefore, the water quality of unique locations in the lakes were not estimated. From the model results, the following conclusions may be drawn:

- The HEC-5Q model provided a useful tool in water quality evaluations of Lake Springfield and the proposed Hunter Lake and proposed Lick Creek Reservoir, including thermal loading effects in Lake Springfield.

- Water temperature and DO concentrations were highly dependent on meteorological conditions, i.e., time of the year.

- Concentrations of nitrate-nitrogen and phosphate-phosphorus in lake waters were highly dependent on upstream contributions.

- Lake Springfield would experience a drawdown of 15 feet during the 20-month drought.

- Proposed Hunter Lake would experience a drawdown of 17 feet, but would help restore 13 feet of water in Lake Springfield during the 20-month drought.

- Proposed Lick Creek Reservoir would experience a drawdown of 16 feet, but would help restore 7 feet of water in Lake Springfield during the 20-month drought.

- There was no significant difference in the overall water quality conditions in Lake Springfield during drought and nondrought years.

- Although there were no significant changes in DO concentrations in Lake Springfield as a result of supplemental storage from proposed Hunter Lake or proposed Lick Creek Reservoir, total DO amounts improved (higher concentration for deeper water) due to the supplemental storage.

- Supplemental storage from proposed Hunter Lake or proposed Lick Creek Reservoir may favorably affect the water temperature at the power plant intake elevation of 547 feet by creating a greater water depth in Lake Springfield but does not have much additional impact on lake temperatures.

- Due to greater water depth, proposed Hunter Lake and proposed Lick Creek Reservoir had distinct and prolonged gradients of water temperature and DO concentration in comparison to Lake Springfield.

- Nitrate-nitrogen levels in the proposed lakes were predicted to be higher than for Lake Springfield but below the drinking water limit.

- Phosphate-phosphorus levels in the proposed lakes were similar to Lake Springfield with minor differences.

- Temperatures of the lake surface are virtually unaffected by severe drawdown in the lakes, but bottom temperatures may rise.

- Temperatures at the normal power plant intake elevation of 547 feet may increase significantly with drawdown during early summer, but may increase by only 1 or 2°F in late summer.

- Drawdown does not appear to significantly impact water quality characteristics other than temperature.

- The impact of thermal discharges on Lake Springfield during severe drought periods may be expected to increase water temperature by 0.5°F for every 3.0°F temperature rise in discharge from the power plant, and have practically no impact on other constituents, except minor changes in DO.

REFERENCES

Bohan, J.P. and J.L. Grace, Jr. 1973. *Selective Withdrawal from Man-made Lakes: Hydraulic Laboratory Lnvestigation.* Technical Report H-73-4, U.S. Army Engineer Waterways Experiment Station, CE, Vicksburg, MS.

City Water, Light and Power. 1987. *Clean Lakes Program Phase I Diagnostic/Feasibility Study for the Lake Springfield Restoration Plan.* City Water, Light and Power, Springfield, IL.

City Water, Light and Power. 1992a. *Phase II Project Report for Lake Springfield.* EPA Clean Lakes Program. City Water, Light and Power, Springfield, IL.

City Water, Light and Power. 1992b. *Lake Springfield Ecology and Management: A Leaseholder and Community Guide* City Water, Light and Power, Springfield, IL.

Crawford, Murphy & Tilly, Inc. 1965. *Water Supply, Treatment and Storage Facilities for the City of Springfield, Illinois.* Springfield, IL.

Crawford, Murphy & Tilly, Inc. 1980. *Update Study of Water Supply Needs.* Springfield, IL.

Crawford, Murphy & Tilly, Inc. 1983. *City of Springfield, Illinois: Technical Report on Emergency Water Supply Plan.* Prepared for city of Springfield, IL.

Crawford, Murphy & Tilly, Inc. 1993. *Draft Report on Point Source Discharges in the Watershed of Proposed Hunter Lake, Springfield, Illinois.* Prepared for City Water Light and Power Department, City of Springfield, IL.

Crawford, Murphy & Tilly, Inc. 1994. *Water, Sediment and Nutrient Budgets of the John H Hunter Lake.* Prepared for City Water Light and Power Department, City of Springfield, IL.

Debler, W.R. 1959. Stratified Flow into a Line Sink. *ASCE Journal of Engineering Mechanics Division,* Vol. 85, EM3.

Department of Public Utilities. 1988. *The Construction of Lake Springfield II in the City of Springfield, Illinois.* A Report to the City Council, City of Springfield, *IL.*

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

Durgunoglu, A., H.V. Knapp, and S.A. Changnon. 1987. *PACE Watershed Model (PWM): Volume 1, Model Development.* ISWS Contract Report 437, Illinois State Water Survey, Champaign, IL.

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

Fitzpatrick, W.P., and L.L. Keefer. 1988. *Water, Sediment, and Nutrient Budgets of Lake Springfield, Springfield, Illinois.* ISWS Contract Report 444. Illinois State Water Survey, Champaign, IL.

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

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

Illinois State Water Survey Water Quality Section. 1975. *An Assessment of the Probable Water Quality Characteristics in the Proposed Middle Fork-Vermilion Reservoir.* Water Quality Section, Illinois State Water Survey, Peoria, IL.

Knapp, H.V. 1996. *Preliminary Report on the Yield of the Proposed Lick Creek Reservoir.* Letter Report to CWLP Springfield IL, Illinois State Water Survey, Champaign, IL.

Knapp, H.V. 1997. *Operation Strategies for the Springfield Water Supply System and Impacts on Drought Yield.* Report in preparation. Illinois State Water Survey, Champaign, IL.

Kothandaraman, V., and R.L. Evans. 1970. Annual Temperature Variations in an Impoundment in Central Illinois. *Journal of American Water Works Association* 62(10): 639-642.

Kothandaraman, V., and R.L. Evans. 1971. Analysis of Variations in Dissolved Oxygen in an Impoundment in Central Illinois. *Water Resources Research* 7(4): 1037-1044.

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, IL.

Raman, R.K., and D.H. Schnepper. 1987. *Water Quality under Drought and Low Flow Conditions.* Drought in Illinois - Their Physical and Social Dimensions, Assembled by S.A. Changnon, Unpublished SWS Report, various pages.

U.S. Army Corps of Engineers. 1982. *HEC-5: Simulation of Flood Control and Conservation Systems: User's Manual.* Hydrologic Engineering Center, U.S. Army Corps of Engineers, Davis, CA.

U.S. Army Corps of Engineers. 1986a. *HEC-5: Simulation of Flood Control and Conservation Systems: Appendix on Water Quality Analysis.* Hydrologic Engineering Center, U.S. Army Corps of Engineers, Davis, CA.

U.S. Army Corps of Engineers. 1986b. *Kanawha River Basin Water Quality Modeling.* Hydrologic Engineering Center, U.S. Army Corps of Engineers, Davis, CA.

U.S. Army Corps of Engineers. 1989. *HEC-5: Simulation of Flood Control and Conservation Systems: Exhibit 8 of User's Manual: Input Description.* Hydrologic Engineering Center, U.S. Army Corps of Engineers, Davis, CA.

ILLINOIS

DEPARTMENT OF

NATURAL
RESOURCES