Technical Report EL-99-13
November 1999

US Army Corps of Engineers
Engineer Research and Development Center

Water Quality in Richard B. Russell and J. Strom Thurmond Lakes: Interim Report for the Period 1997-1998

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Final report

Prepared for U.S. Army Engineer District, Savannah
Savannah, GA 31402-0889

U.S. Army Engineer Research and Development Center Cataloging-in-Publication Data

Water quality in Richard B. Russell and J. Strom Thurmond Lakes : interim report for the period 1997-1998 / by John J. Hains ... [et al.] ; prepared for U.S. Army Engineer District, Savannah.
117 p. : ill. ; 28 cm. -- (Technical report ; EL-99-13)
Includes bibliographical references.
1. Water quality -- Richard B. Russell Lake (Ga. and S.C.) 2. Water quality -- J. Strom Thurmond Lake (Ga. and S.C.) 3. Richard B. Russell Lake (Ga. and S.C.) 4. J. Strom Thurmond Lake (Ga. and S.C.) 5. Fishes -- Habitat -- Georgia. I. Hains, John J. II. United States. Army. Corps of Engineers. Savannah District. III. U.S. Army Engineer Research and Development Center. IV. Environmental Laboratory (U.S.) V. Series: Technical report EL ; 99-13.
TA7 E8 no.EL-99-13

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Preface

The work reported herein was conducted for the U.S. Army Engineer District, Savannah, by the Environmental Laboratory (EL), U.S. Army Engineer Research and Development Center (ERDC), Vicksburg, MS.

This report was prepared by Dr. John J. Hains, Mr. William E. Jabour, Dr. Robert H. Kennedy, and Mr. William Boyd, Environmental Processes and Effects Division (EPED), EL; Mr. James M. Satterfield, Dyntel; and Dr. Patrick Howle, AScI Corp. Mr. Jeff Cryder provided valuable assistance in collecting field data. Dr. Richard E. Price was Chief, EPED. Dr. John Keeley was Acting Director, EL.

At the time of the publication of this report, Dr. Lewis E. Link was Acting Director of ERDC, and COL Robin R. Cababa, EN, was Commander.

Conversion Factors, Non-SI to SI (Metric) Units of Measurement

Non-SI units of measurement used in this report may be converted to SI units as follows:

Multiply	By	To Obtain
feet	0.3048	meters
meters	3.281	feet
Fahrenheit temperature	5/9 after subtracting 32	Celsius temperature
Celsius temperature	9/5 and add 32	Fahrenheit temperature
cubic feet	0.02831685	cubic meters
cubic meters	35.289	cubic feet
acres	0.405	hectares
hectares	2.47	acres
miles	1.609344	kilometers
kilometers	0.62	miles
square miles	2.59	square kilometers
square kilometers	0.3861	square miles
gallons	3.785	liters
liters	0.264201	gallons
pounds	0.454	kilograms
kilograms	2.2046	pounds

Introduction

Project History

Richard B. Russell (RBR) Dam and Lake was authorized as Trotters Shoals Dam on 7 November 1966 by the Flood Control Act of 1966 (Public Law 89-789, 89th Congress, House Resolution 18233) and was completed in 1983. Originally authorized for flood control, hydroelectric power, and recreation, this original authorization only allowed four 75 MW conventional turbines. The Water Resources Development Act of 1976 (Public Law 94-587) deleted the specific prohibition to pumped storage capability that was written into Public Law 89-789 and the project design was modified to provide for up to four additional reversible pump turbines. Approval for this design change was granted by the Assistant Secretary of the Army for Civil Works on 19 January 1977. The actual installation and operation of these units was contingent on subsequent analyses. The analyses were presented in the Feasibility Report and Final Environmental Impact Statement in 1979.

Feasibility of pumped storage at RBR Dam was justified on an economic basis. Neverthelss there remained environmental concerns, primarily fish entrainment and impingement during pumped storage operation. A final mitigation plan for fish and wildlife losses was completed in April 1981. Although this plan expressed agreement on the anticipated impacts on RBR Lake and on the trout fishery in the HW Dam tailrace, there was no agreement on project effects on the JST Lake fishery. Therefore, a five year study of those effects was planned. In FY 1982 funds were granted by Congress for the fabrication of the necessary equipment for pumped storage at RBR Dam. In April 1982 a fish kill associated with pumped storage operation at the Harry S. Truman Project in Missouri caused comparisons to be drawn to the RBR Dam and Lake Project. A reappraisal of the potential effects of pumped storage on fish resources agreed with earlier conclusions of low potential for impacts. The US Fish and Wildlife Service (FWS), South Carolina Wildlife and Marine Resources Division (SCWMRD), and Georgia Department of Natural Resources (DNR) concurred that additional fishery studies were needed to investigate the potential for impacts at RBR Dam. These studies began in February 1986 with WES as principal investigator and the Georgia Cooperative Fisheries Unit of the FWS conducting the field sampling.

Water quality investigations associated with the construction of RBR Dam had been initiated in 1983. These investigations were designed to identify the effects of the new lake on JST Lake as well as the water quality processes occurring in the new lake. These studies continued through the startup of conventional generation at RBR Dam in January, 1985. The operation of the oxygenation system in RBR

Lake began in April 1985 and the removal of the cofferdike downstream from RBR Dam was completed in August 1985. Following discussions with the resource agencies and public forums (1987-89) on the proposed pumped storage development, one of six public concerns expressed was water quality in RBR and JST Lakes. And one of six opportunities identified by the Corps of Engineers Savannah District (CESAS) was maintenance of good water quality in RBR and JST Lakes. Water quality studies were also needed to support the fishery studies related to other public concerns and Corps opportunities. The primary water quality concerns were related to temperature and dissolved oxygen as determinants of fish habitat as well as to chemical processes potentially affecting dissolved oxygen and patterns of water movement that could affect thermal trends.

Development of pumped storage at RBR Dam proceeded in a phased manner, conforming to the Final Supplement to the Final Environmental Impact Statement (the SEIS; Coleman et al. 1991). While testing of one or two pump-turbines was feasible under any conditions, engineering feasibility studies also showed that pumped storage with more than two units when JST was at low elevations required additional flow conveyance immediately downstream from RBR. Successful Phase II testing with two pumped storage units was a prerequisite for the necessary dredging to increase the conveyance capacity. Dredging, therefore, was also a prerequisite for the initiation of Phase III testing. Dredging for increased conveyance was completed in March 1995. The results of water quality and ecological studies through Phase II (1993-1994) of this effort were reported in Carroll, et al. (1995).

Prior to Phase III studies, another modification to the project was completed to change the flow patterns as water approached the draft tubes during pumped storage operation. This modification consisted of a rock spur built into the channel from the South Carolina shore. Phase III testing and monitoring was initiated in April 1996 in a manner conforming to the draft monitoring plan in the SEIS and the resulting Testing and Monitoring Plan, Pumped Storage Operations Richard B. Russell Dam and Lake (TMP; Coleman et al. 1992). This work was continued through the testing period and ended at the end of October 1996. The results of the Phase III testing and monitoring was reported in technical reports to CESAS (Nestler et al. 1997 and Hains et al. 1997).

Water Quality Concerns

Water quality issues associated with pumped storage operations at RBR Dam were identified through the studies of project operations (Fontane and Bohan 1974, Smith et al 1981), the preparation of the SEIS on pumped storage operation, and the coordination with federal and state resource agencies.

The Phase II and Phase III studies addressed issues raised by the SEIS and other pre-operational studies. Phase III studies specifically addressed the following:

1. Water quality changes in RBR Lake that could occur directly from pumped storage operations.
2. Water quality changes that could occur in the RBR Dam tailrace and tailwater as well as the rest of JST Lake from pumped storage operations.

Following the completion of Phase III studies and reporting, interim studies of water quality were continued for the years 1997 and 1998 in anticipation of the initiation of commercial pumped storage operation. These studies addressed water quality and habitat concerns in RBR and JST Lakes as identified during a series of meetings of a coordination group of scientists and agency representatives and through the examination of the Phase III study results. Principle concerns were related to patterns in the distribution of dissolved oxygen and temperature in the two lakes.

During the testing and monitoring studies, emphasis was placed on the effects of pumped storage on RBR Lake. The effects on JST Lake were not as exhaustively addressed. As a result there was additional interest in fisheries habitat in JST Lake, especially habitat as defined by the habitat suitability index (HSI) for striped bass (Crance 1984). Habitat quality was defined in simple terms of temperature and dissolved oxygen and the limits for the HSI were given as waters with temperatures between 18 and 24°C and dissolved oxygen concentrations greater than 5 mg/l. In addition, the dissolved oxygen limit was relaxed to 3 mg/l as a means of identifying waters with habitat potential. As a result of discussions within the coordination group, additional concern was found for the adverse thermal effect of pumped storage on striped bass habitat in the RBR Dam tailwaters (JST Lake headwaters). The loss of habitat was associated with the warming effect of pumped storage on those waters.

Using the same HSI criteria, the habitat in JST Lake for 1996 was diminished compared to previous years considered for the Phase III studies and reports. As a result, an increased effort was mounted during 1997 and 1998 to more carefully monitor conditions in JST Lake, especially with respect to temperature and dissolved oxygen. The interim studies allowed subsequent comparisons between the water quality and habitat results of the Phase III studies in 1996 and the two non-test years 1997 and 1998.

Site Description

The Savannah River system is located in the southeastern United States and forms most of the border between South Carolina and Georgia. It is approximately 402 km long with a maximum width of 113 km. Its total basin area is 27,400 km2. This system originates on the southern slopes of the Blue Ridge Mountains of North Carolina, South Carolina, and Georgia and then flows into the Atlantic Ocean in the southeast at Savannah, Georgia.

The Savannah River Basin has two major tributary systems, the Tugaloo and Seneca Rivers. Topography of the basin is characterized by gently sloping upland areas cut by gullies and stream valleys. Relief is more rugged in areas adjacent to the Savannah River where well-developed, moderately steep to steep ridges and ravines form the topography. Stream elevation varies from 274 m NGVD above HW Dam to 55 m NGVD below JST Dam.

Soils are derived from geological rock formations of the mountain section and Piedmont Plateau. These formations are primarily composed of igneous or metamorphic materials and include granites, gneisses, schists, basic eruptives, and highly metamorphosed shales, sandstones, and limestones. On most level or gently sloping areas, the rocks are disintegrated to a depth of many meters and the surface is largely formed of residual material. Exposed rock outcrops are mostly confined to summits, steep slopes, and stream channels.

The Savannah River Basin experiences a maritime climate with mild winters, long summers, and moderate to high rainfall (114-152 cm per year). While the basin is subject to Continental climate influences, it is nevertheless protected by the Blue Ridge Mountains from the more rigorous weather found west of the mountains. The average annual air temperature for the basin is 16°C, varying between approximately -7°C and 32°C daily averages. At lower elevations, the average and range is slightly greater.

The three largest reservoirs on this system were constructed by the U.S. Army Corps of Engineers (Figure 1). The major physical characteristics of HW, RBR, and JST Lakes are summarized in Table 1. These lakes were completed in 1952 (JST), 1963 (HW), and 1983 (RBR). Commercial operation of RBR Dam began in 1985. They were authorized for the multiple purposes of flood control, recreation, and power generation. Although they are the largest reservoirs in this system, there are other reservoirs on upstream tributaries to the Savannah River which are operated by Duke Power Company and Georgia

Power Company. Of these, Lake Jocassee and Bad Creek (both Duke Power Company) are pumped storage facilities.

RBR Lake (Figure 2) and JST Lake (Figure 3) were monitored during the interim period for basic water quality variables. The two lakes occur in sequence and form the pumped storage complex of interest for these studies.

The waters of all of these lakes are similar in that they contain low concentrations of dissolved ionic chemicals and therefore have low specific conductance in surface waters. Nutrient concentrations also occur at concentrations that are often near or below the limit of detection for the standard methods of analysis. The pH values are often observed at less than pH 7 and rarely greater than pH 8. Hardness, a function of the concentration of divalent cations, is low.

Few sources of contaminants have been identified for the waters of the Savannah River. Most of the point sources occur upstream of HW Lake. A source of contaminants (polychlorinated biphenyls, PCB's) in the HW Lake watershed was reported by Gaymon (1992) and later the object of a superfund investigation (USEPA 1994).

The chemical characteristics of these waters are indicative of the geologic origin of the soils in the Savannah River watershed. These soils, combined with the terrestrial vegetation, topography, climate, and land use, release waters with few dissolved constituents although clays contribute to non-algal turbidity throughout the system. Because these lakes experience thermal stratification, there is a tendency for the hypolimnia of the larger lakes to experience hypoxia.

In addition to the general characteristics of HW, RBR, and JST Lakes listed in Table 1, the interaction of climate and weather patterns with these characteristics is an important determinant of limnological patterns and processes in these lakes. Figures 4 and 5 illustrate the temporal patterns of monthly precipitation, inflows, outflows, and pool elevations for RBR and JST Lakes for 1996, 1997 and 1998. The monthly average values plotted in these figures show that 1996 and 1997 were similar for surface elevations of both lakes. However, 1998 departed from the 1996 and 1997 in that JST Lake surface elevation did not decline as early in the fall during 1998. In contrast, the RBR Lake surface elevation in summer 1998 declined more rapidly than it did in 1996 and 1997. However the maximum drawdown for RBR Lake is approximately 1.5 m, a design limit not exceeded during any recent year.

Figures 4 and 5 also show the rainfall patterns for the period 1996-1998. While August was, on average, consistently dry and September was, on average consistently wetter than August, there were few other real trends to be seen. If there is a generalization to be found, it is that 1998 precipitation was greater in the spring months than for 1996 and 1997. As a result, both inflows and outflows were also greater during the spring months for 1998. This pattern was more easily observed at JST than at RBR.

Lake elevational changes occurred as a result of the difference between inflows and outflows. For both RBR and JST Lakes the majority of inflowing water is from upstream reservoirs. The patterns of inflows thusly reflect the patterns of operation and lake surface elevation changes for those upstream reservoirs.

Another way to view the hydrologic status of the Savannah River system over the years is to examine the average flows for critical times over many years. Figure 6 provides such a comparison and illustrates that within a 6-year period 1988-1994 the record extremes are found. Figure 6 shows that a storm event (Hurricane Beryl) brought enough precipitation to an otherwise normal season to make that year (1994) the record seasonal high flow. A drought in the late 1980's likewise caused the summer of 1988 to have the record low flow in this comparison. Short-term events may greatly alter the record for any year.

By comparison, the years 1996-1998 were very normal for the average flows for the summer season. In spite of heavy spring rainfall and inflows, 1998 experienced the lowest average summer flows of the years 1996-98. This is indicative of the within-year variation that can occur for these lakes. In Figure 6 it is clear that average summer flows over all the years are approximately 6000 - 7000 cfs. The summers for the three years, 1996-98 all fall within that range of average flows.

Materials and Methods

Lake *In situ* Methods

Temperature, dissolved oxygen, pH and specific conductance were measured *in situ* at designated stations along the main stem and major tributaries in each lake (Figures 2 and 3). Measurements were taken monthly at two-meter intervals from the surface to one-half meter above bottom. From late spring to fall during which the oxygenation system was operated these measurements were taken weekly in the forebay of RBR Dam and mid- to downstream regions of RBR Lake (stations 060B, 100B, 112, 120 and 125). Field limnological survey equipment was employed for these measurements (Hydrolab H20 or Datasonde 3). Instruments were calibrated in a manner which conformed to Standard Methods (APHA 1992). Temperature was calibrated against a standard while dissolved oxygen was calibrated against either air saturation or the result of a Winkler titration. Prepared known chemical standards were used for pH calibrations and for conductivity. Depth was calibrated at the water surface and checked against known depth marks on the cable.

During the early part of 1997 *in situ* data were recorded on standard data forms and returned to Trotters Shoals Limnological Research Facility (TSLRF) for entry into the database. Since then, the data were recorded electronically in the field and downloaded to the database on return. A draft of manually entered data was checked by a third party against the original field sheets in order to detect any entry errors. Once in the database, an error checking program was finally employed to detect any errors that remained. The database was updated with each new data addition. Electronic data collection eliminated the need of proofreading for the purpose of checking accuracy because the data remained in the primary form. Copies of the raw data files were archived.

Continuous Water Quality Monitoring at HW, RBR, and JST Dams

HW, RBR and JST Dam release waters were monitored continuously for temperature, dissolved oxygen, and specific conductance within the piping gallery of RBR Dam and 500 m downstream of HW and JST Dams. Figure 4 illustrates the position of the HW dam monitor. The HW and JST Dam monitors are housed in buildings downstream from the dam and they monitor water pumped to the building on a continuous basis. The pump intakes extend into the channel past which dam releases flow. The monitors employ multiparameter sondes (usually Hydrolab H20 or similar) which measure temperature, dissolved oxygen, conductivity, and other parameters depending on configuration. Output from each sonde is received and stored on disk in a computer also located on site. This computer is equipped with spike protection, a modem for telecommunication, and software which facilitates such communication as well as logging the data.

Monitors were maintained on a weekly basis, including calibration and parameters checking, downloading logged data, and checking that logging operations were functioning properly. Through telecommunication it is possible to access the monitors remotely to download data or reset the parameters of operation.

The RBR Dam monitor is different from the HW and JST Dam monitor designs in that it is located in the dam and monitors water delivered from the penstock tubes for each of the operating turbines. This design was selected because the headwaters of JST Lake extend to the draft tube openings of RBR Dam and any monitor located in the tailwater experiences variable influences of entrained waters from JST Lake. The RBR Dam monitor consists of one multiparameter sonde to which water is delivered from each of the four penstock tubes of the four conventional turbines. Solenoid valves open during generation and allow water from the operating penstock to be delivered to a mixing chamber which holds the sonde. Water from operating units (only those which are operating) is mixed and monitored in an integrated manner. The output from this sonde is logged by a computer in the control room and telecommunication to and from this computer is maintained in a manner similar to monitors at HW and JST Dams. Logged data from the RBR Dam monitor are thus available to operators and can be used to monitor the performance of the oxygenation system and its effect on the release water quality.

Water quality data from the continuous monitors were archived in the "monitor" database. These were then further associated with operational data from the dams prior to 1997. The combined monitor database and operational data composed the "release" database. At the end of Phase III studies, the labor-intensive process of entering operational data manually was terminated. Means of electronic entry were sought from CESAS and from the Southeast Power Authority. Throughout much of 1997 and 1998, these data were not successfully retrieved, affecting the database and the ability to interpret the monitor data.

Analyses of Continuous Monitor Data

Water temperature and dissolved oxygen concentrations during generation periods were normally obtained from the “release” database. These data were not available for the Savannah Lakes during 1997 or 1998, thus a procedure to obtain these values during generation times was needed. A review of release data from previous years (i.e. 1991-96) showed that the beginning of generation is usually associated with an abrupt change in water temperature. This change could be either an increase or decrease in temperature, depending on seasonal conditions. Generation times were also closely related to times of highest dissolved oxygen concentrations.

Water temperature and dissolved oxygen concentrations found in the "monitor" database were used to determined generation times for Richard B. Russell (RBR), J. Strom Thurmond (JST) and Hartwell (HW) Lakes during 1997 and 1998. Monthly and daily profiles were generated for both water temperature and dissolved oxygen levels for each lake. These profiles were examined for patterns that might help identify generation times.

Median release temperatures and dissolved oxygen concentrations were computed to minimize the analytical impact of errant temperatures or those associated with initial startup of generators. This allowed a more realistic assessment of actual release water quality conditions.

A profile for RBR Dam releases showed abrupt decreases in water temperature (i.e. 3 to 4 °C) during the weekday periods while temperatures were higher and relatively constant during weekends. Generation periods for RBR Dam were thus calculated as times when observations for temperature were less than or equal to that day's 10 percentile temperature value. Median temperature and dissolved oxygen concentrations were then taken for these generation periods. Since generation usually only occurred on weekdays, temperature and dissolved oxygen concentrations recorded on weekends were excluded.

Water temperature profiles for JST and HW Dam releases showed no apparent patterns that would help identify generation times. There were often no abrupt changes in daily temperatures that could be associated with generation. Dissolved oxygen concentration profiles, however did show daily peaks for both lakes. Therefore, for both JST and HW Dams generation periods were calculated as times when dissolved oxygen concentrations were greater than or equal to that day's 90 percentile dissolved oxygen value. Median temperature and dissolved oxygen concentrations were then taken for (1) the entire day and (2) the generation period during each day. Again, observations recorded on weekends were not included.

Field Chemical Sampling and Analyses

Chemical analyses were performed on samples from RBR and JST Lakes. Water samples for chemical analysis were collected in RBR and JST Lakes at an interval corresponding to seasonal sampling (quarterly) or more frequently (bimonthly). When possible, the sampling effort was completed in one day for each lake. In 1998 additional effort in JST required the effort to be spread over multiple days. In that case the deeper forebay stations were completed first and shallower upstream stations completed on the following day

Samples were collected either as whole lake water samples or as the product of field filtrations. Additional samples were taken for quality control (QC) purposes. The stations and depths of these QC samples were subjectively distributed throughout the sampling effort to encompass the full time and range of field sampling activity.

Water was collected through a hose marked for depths and connected to a weighted intake in order to maintain an extended configuration and proper depth. Water was pumped using a diaphragm pump through a manifold capable of delivering the samples through attached filter holders. Each sample was taken after the pump had cleared the hose of water remaining from previous depths. This was accomplished by measuring the travel time through the hose and waiting twice that time after repositioning to the subsequent depth.

Depths were determined prior to sampling according to expected stratification conditions. Where the lakes were isothermal and little chemical structure was expected, or where the water was very shallow, as few as three samples were taken (surface, mid-depth and bottom). Where there was stratification or chemical structure expected, up to a total of five depths were specified (surface, top of thermocline, bottom of thermocline, mid-hypolimnion, bottom). Tailwater samples were taken during generation and one sample was taken from the surface. Samples were labeled with waterproof labels which identified the lake, station, depth, date, time and type of analysis.

Chemical Methods

Variously sized sample containers were used to collect field water samples destined for analysis in the laboratory. Samples were transported and stored in coolers to control their thermal conditions as much as possible. Ice was used when necessary. Samples were transported to the laboratory and prepared for analysis within 48 hours of collection.

All samples were collected in acid-washed plastic bottles. Bottle preparation consisted of standard acid cleaning (APHA 1992), except for chlorophyll, alkalinity and biological samples. Samples for nutrient, metal, and carbon analyses were collected in acid-washed, opaque high-density polyethylene (HDPE) bottles. Acid-washed brown HDPE bottles were used for turbidity samples. Chlorophyll, alkalinity and biological samples were collected in tap water rinsed opaque HDPE bottles. Samples analyzed for total suspended solids were collected in both tap water rinse and acid-washed bottles. Care was taken to minimize the shaking of carbon, turbidity and alkalinity samples at all times.

Treatment of samples included filtration and preservation. Dissolved nutrient and metal samples were filtered through a 0.45 μm membrane filter. Dissolved carbon samples were filtered through 1 μm glass fiber filters. All filters were washed sufficiently in the field with sample water prior to collection of the filtrate. Metal samples were preserved in the lab by acidification with nitric acid to pH<2.

Laboratory water used for analyses was produced either by distillation (Model THREE LITER, Corning Glass Works, Corning, NY) or by ultrapurification (E-pure®, Barnstead, Dubuque, IA). E-pure® water provided Type 1 Reagent Grade Water (RGW) per ASTM-D1193, NCCLS-ASC-3 and CAP. All reagents and chemicals were grade certified. Standards were primary standards or traceable to NBS standards. All glassware was acid-washed in 10% hydrochloric acid, followed by three rinses with >8 megohm water (SYBRON/Barnstead, Barnstead, Dubuque, IA).

Analytical QC was maintained in three ways:

1) analysis of split and replicate samples;
2) analysis of spiked samples; and
3) analysis of blind quality assurance (QA) samples.

Split and replicate samples provided a means to estimate intrinsic variation due to laboratory and field sampling errors, respectively. These samples were collected at four selected stations during each bimonthly sampling. A coefficient of variation (CV) was calculated for each parameter at each sampling period. A mean CV across time for each parameter was tabulated (Table 1). These means represent relative sampling precision and provide a way to compare different analytical procedures.

In-house spikes and blind QA samples (Analytical Products Group, Inc., Belpre, OH) provided a measure of laboratory accuracy. Spikes were prepared for each parameter from four selected stations during each bimonthly sampling. The value derived by comparing a spiked to an unspiked sample was used to calculate a percent recovery based on the actual spike addition. Similarly, the results from the blind QA samples were reported as percent recovery. Both are summarized in Table 2.

Analyses

Total (T) and total soluble (TS) nutrient determinations were carried out in the following sequence. All samples were treated with persulfate digestion (APHA 4500-P B, 5) to convert phosphorus (P) containing compounds to orthophosphate. Samples were stored at room temperature until assayed. TP and TSP were determined by the ascorbate method as described in APHA 4500-P E. SRP was measured by reaction with molybdate and antimony ions in the presence of ascorbic acid to form a blue color. This phosphomolybdate complex was read at 880 nm on a Technicon™ AutoAnalyzer™ II.

Following TP and TSP analyses, digested samples also underwent Devarda alloy reduction (Raveh and Avnimelech, 1979) in which available nitrogen (N) is reduced to ammonia. TN and TSN were determined by the salycilate method as described in Technicon™ Industrial Method N. 329-74W/B (revised 11/78). The reaction of ammonia with an alkaline buffered (pH 12.8-13.0) salicylate/nitroprusside/hypochlorite solution produces an emerald-green color. This ammonia-salicylate complex was read at 660 nm on a Technicon™ AutoAnalyzer™ II.

Metals were determined by the direct air-acetylene flame method (APHA 3111 B; APHA 3500-Fe A, B; APHA 3500-Mg A, B) on a Perkin-Elmer 4000 atomic absorption spectrophotometer. Dissolved metals were assayed directly from field sample bottles, while total metals were digested in a CEM MDS-2100 microwave (USEPA, 1986) prior to analysis.

Soluble nutrient (nitrate, nitrite, SRP, and sulfate) concentrations were determined by chromatography on a Dionex DX-300 ion chromatograph with chemical suppression of eluent coductivity (APHA 4110 B).

Pigments were measured on dimethyl formamide extracts (Hains, 1985) using a Shimadzu UV-2101PC UV-VIS scanning spectrophotometer.

Total alkalinity was determined by the titration method (APHA 2320 B) with an Orion 620 pH meter.

Total organic carbon was determined by the combustion infrared method (APHA 5310 B using a Shimadzu TOC 5000 carbon analyzer.

Total suspended solids were measured on glass fiber filter residues dried at 103°-105°C (APHA 2540 D) in a Fisher Isotemp™ Oven Model 501.

Turbidity was determined by the nephelometric method (APHA 2130 B) on a HACH Model 2100A turbidimeter.

Results

Forebay Temperature and Dissolved Oxygen Observations

Near-isothermal conditions were evident during the February sampling in 1997 and 1998. Temperatures averaged 9° C surface to bottom. Surface temperatures were 10° C in March, increased to 17° C in April, and were 21° C by early May for each year. March and April bottom water temperatures were 9° C and 11° C, respectively. Stratification became well established during June within the RBR and JST Lake forebays (Figures 7 and 8) as surface temperatures increased to 29° C. Forebay surface temperatures peaked at 31° C in early July, were 27-28° C in August and September, and 23° C in mid-October. Bottom water temperatures increased through the June-October period, from 12° to 17° C in RBR, from 14° to 17° C in JST. Late fall surface temperatures averaged 18° C in early November and were 12° C and 15° C in mid-December 1997 and 1998, respectively.

In comparison to 1997 and 1998 data, RBR Lake forebay temperatures in 1996 were cooler surface to bottom throughout the first half of the year. Pumped storage testing during the summer months resulted in increased hypolimnetic temperatures in the RBR Lake forebay. RBR Lake 1996 forebay data show a greater range of temperatures than in subsequent years. JST Lake forebay temperatures during the winter months of 1996 were also cooler than during 1997 and 1998. Lake warming processes during summer and fall 1996 periods increased JST Lake forebay temperatures to very closely resemble 1998 data.

Forebay surface dissolved oxygen concentrations were near saturation during February 1996-1998, measuring nearly 11 mg/l on RBR and JST Lakes (Figures 9 and 10). Gradients in forebay dissolved oxygen concentrations developed somewhat earlier during 1997, the first year following pumped storage testing, than during 1998. During May 1997 and June 1998, RBR and JST Lake forebay dissolved oxygen concentrations ranged from 9 mg/l at the surface to less than 5 mg/l on the bottom. Hypolimnetic depletion processes progressively decreased bottom water dissolved oxygen concentrations through the summer and early fall. In the JST Lake forebay, hypolimnetic dissolved oxygen concentrations decreased to less than 3 mg/l during July and to less than 1 mg/l during August. Anoxia was reported from August through early November in the JST Lake forebay during 1997 and 1998.

Initiation of the RBR oxygenation system during June of 1997 and 1998 increased hypolimnetic dissolved oxygen concentrations in the RBR Lake forebay. Dissolved oxygen concentrations throughout the majority of the water column remained greater than 3 mg/l during the critical stratified period (i.e., June through October) although concentrations < 1 mg/l were recorded at depths greater than 46 m during September and October. Autumnal mixing processes resulted in the elimination of anoxic conditions in the JST forebay bottom waters. By late December, the dissolved oxygen concentration in each lake was greater than 7 mg/l.

Cooler temperatures during winter 1996 resulted in greater dissolved oxygen concentrations during February and March in RBR and JST Lakes than in subsequent years. Summer stratification patterns and dissolved oxygen gradients in RBR and JST Lakes were similar for each of the three years. Pumped storage testing resulted in greater hypolimnetic dissolved oxygen concentrations within the RBR Lake forebay during June through October 1996 than observed during the same period in 1997 and 1998. JST Lake summer hypolimnetic dissolved oxygen data for 1996-98 followed near-identical patterns of mid- through late summer oxygen depletion. Concentrations of < 1 mg/l at depths greater than 20 m were recorded during August through October for each of the three years.

RBR Lake Temperature and Dissolved Oxygen Data

Near-isothermal conditions were recorded in early February during 1997 and 1998. Temperatures were 9° C from the surface to bottom. Surface temperatures increased to 17° C in April and 19° C in May, while bottom temperatures averaged 11° C during both years. Surface temperatures were 24° C in early June 1997 and 30° C in late June 1998. Bottom temperatures for the same period ranged from 12° C in the forebay to 15° C in the headwaters (Figure 11). Thermal gradients intensified during July when a maximum surface temperature of 31° C was recorded (Figure 12). Bottom water temperatures during July ranged from 13° C in the forebay (station 060B) to 17° C in the RBR Lake headwaters (station 180) during 1997 and 1998. Surface temperatures lakewide cooled to 28° C and 26° C in August and September, respectively in 1997-1998. Hypolimnetic temperatures increased through the summer months, ranging from 15° to 18° C longitudinally in August (Figure 13) from the dam to the headwaters and from 17° to nearly 20° C in September (Figure 14) of both years. By early October, lakewide seasonal cooling was underway. Surface to bottom temperatures in 1998 ranged from 26° to 17° C in early October to 21° C to 19° C by 28 October (Figure 15). Isothermal conditions were observed during mid-November and mid-December with temperatures of 18° C and 15°C, respectively.

Data for the summer stratification period during 1996 show the disruption of thermal stratification in the RBR Lake forebay resulting primarily from pumped storage testing. The thermocline was much less distinct within RBR Lake during July through October 1996 than in subsequent years, and warmer water extended deeper into the column (Figures 12-15). October data showed that mixing occurred earlier during 1996 than during the same period in 1997-98.

RBR Lake dissolved oxygen concentrations were at saturation levels during early 1997 and 1998. Spring warming during April and May produced the onset of thermal stratification and hypolimnetic oxygen depletion. Gradients intensified during mid- to late summer. Surface dissolved oxygen concentrations averaged 8.5 mg/l June through October. Intensification of vertical gradients during June was evident lakewide. Hypolimnetic dissolved oxygen concentrations ranged from 3 mg/l in the forebay (060B) to 6 mg/l in the headwaters below HW Dam at station 180 (Figure 16). Anoxic conditions were observed in the bottom waters of downstream stations 112B and 120 during July 1997. Dissolved oxygen concentrations of 1 mg/l or less during July 1997 were confined to the area from station 120 to the dam (Figure 17). During July 1998, concentrations of 1 mg/l or less were recorded from station 165 to RBR Dam. Progression of anoxia resulted in bottom water dissolved oxygen concentrations of 0.5 mg/l or less during August and September (Figures 18 and 19) at every station with the exception of 180 which was influenced by HW Lake releases. Cooler temperatures combined with wind mixing during October facilitated increased dissolved oxygen concentrations throughout RBR Lake (Figure 20). Dissolved oxygen concentrations increased coincident with autumnal mixing processes and approached saturation concentrations by mid-December.

Comparison of the 1996-1998 data indicate that mid- to late summer hypolimnetic dissolved oxygen concentrations in RBR Lake were substantially increased during 1996, coincident with pumped storage operation. Anoxia was absent from the deepwater thalweg stations during this year. Improved hypolimnetic dissolved oxygen concentrations were also observed in the Rocky River and Beaverdam Creek embayments.

JST Lake Temperature and Dissolved Oxygen Data

Lake temperatures during February 1997-98 on JST Lake averaged 9°-10° C from the headwaters to the forebay. The onset of spring warming resulted in surface temperatures increasing from 15° to 17° C during March and April, respectively. Bottom water temperatures warmed to 12° C by the end of April. Surface temperatures were 24° C lakewide in early June 1997, and bottom water temperatures averaged 15° C (Figure 21). Data collected during late June 1998 showed an increase in surface temperature to 30° C. Vertical thermal gradients became more pronounced, and the thermocline progressively deepened during the summer months. July surface temperatures were 30° C lakewide during both years (Figure 22). Bottom waters ranged from 15 – 17° C longitudinally from the dam to the headwaters. While surface temperatures cooled slightly to 28° C by late August, bottom water temperatures increased, ranging from 16° C at JST Dam to approximately 20°C at the upstream stations (Figure 23). During September surface temperatures decreased to 27° C, and bottom waters warmed to 17° C in the forebay and 21° C upstream (Figure 24). The onset of autumn and seasonal cooling processes decreased lakewide surface temperatures to 23° and 25° C by early October 1997 and 1998, respectively (Figure 25). Bottom water temperatures averaged 19° C. By November, destratification was nearly complete. JST Lake temperatures decreased to 18° C by early November and to 10° C in mid-December.

JST temperature data for 1996 appear to differ from those of subsequent years in two distinct ways. Greater temperatures in the JST headwaters were recorded June through September 1996 than during 1997-98. This was indicative of the RBR tailwater warming processes that were attributed to pumped storage operation. Secondly, early October data for the three years reveals near isothermal conditions lakewide in 1996 with the exception of the deep forebay station. Data for the same period of early October 1997-98 depicted stratified conditions from the headwaters to the dam.

Concentrations of dissolved oxygen were at or near saturation during February 1997-98 on JST Lake, averaging 10 mg/l. March and April dissolved oxygen averaged 8 mg/l from mid-lake to the headwaters. The onset of hypolimnetic oxygen depletion processes were observed during late April and May in the JST forebay with surface and bottom dissolved oxygen concentrations of 9 and 5 mg/l, respectively. Surface dissolved oxygen concentrations were 8 mg/l or greater during June, July, and August. Hypolimnetic dissolved oxygen concentrations decreased during the summer stratified period. Longitudinal variability in dissolved oxygen concentration was observed during June as bottom waters ranged from 3 mg/l at JST Dam to 6 mg/l in the headwaters (Figure 26). Concentrations declined during July to less than 4 mg/l at station 020 (forebay) at depths greater than 12 m (Figure 27), and at stations 025 and 030 at depths greater than 8 m. Stations farther upstream remained greater than 5 mg/l due to the influence of the oxygenated RBR releases. Anoxia was recorded in the bottom waters of stations 020 and 025 during August. Dissolved oxygen concentrations were 1 mg/l or less at depths greater than 8 m the JST Lake forebay during August 1997 and 1998 (Figure 28). Anoxic conditions persisted during late September and early October at depths greater than 14 m at station 020 (Figure 29) and at depths greater than 22 m at station 025 (Figure 30). On 4 November, anoxia was recorded only at station 020 at depths greater than 40 m. By mid-December 1997-98, mixing was complete in JST as dissolved oxygen concentrations were greater than 9 mg/l surface to bottom from the headwaters to the forebay.

JST dissolved oxygen data for June through September 1996 conforms to the patterns of stratification and hypolimnetic depletion observed during the subsequent years of 1997-98. October 1996 data, however, showed a marked difference. Early mixing resulted in a 7 mg/l or greater dissolved oxygen concentration from mid-lake to the headwaters during the first week of October. In the deepwater areas near the forebay, the thermocline was recorded at 24 m in 1996 and at 13-14 m during 1997 and 1998. Zones of low dissolved oxygen concentrations (< 1 mg/l) occupied a much greater volume during 1997-98 than during 1996. At the forebay, dissolved oxygen concentrations were 1 mg/l or less from 15 m to the bottom in 1997-98. In 1996, these concentrations were recorded only at depths greater than 26 m.

Tailwater Monitor Operational Data

Continuous monitoring data during generation for stations 050 (RBR tailwater), 010 (JST tailwater) and 200 (HW tailwater) for 1997 and 1998 are depicted in Figures 31-33. Table 4 summarizes RBR and JST release data and contains mean, minimum, and maximum temperatures, dissolved oxygen concentrations, and specific conductance values for June through October 1997 and 1998.

RBR release temperatures for the 1997 period ranged from 12.9° to 19.7°C, with an average release temperature of 17° C. 1998 RBR release temperatures ranged from 12.4° to 21.6° C, with an average release temperature of 16.6° C. JST release temperatures were slightly warmer, averaging 19.3° and 19° C during 1997 and 1998, respectively.

Daily average dissolved oxygen concentrations in the RBR Dam release during June through October ranged from 4.1 to 8.6 mg/l with a mean concentration of 6.1 mg/l. RBR release dissolved oxygen concentrations during the same period for 1998 again averaged 6.1, and ranged from 2.7 to 9.0 mg/l. JST dissolved oxygen concentrations averaged 3.1 and 3.6 mg/l during June through October 1997 and 1998, respectively. Minimum concentrations were 0.3 during each year, and maximum concentrations were 6.9 and 6.7 mg/l in 1997 and 1998, respectively.

Specific conductance values exhibited only minimal variability during 1997 and 1998. Averages were 39 and 36 μS in the RBR releases during 1997 and 1998, respectively. JST averages were 40.6 and

39.3 μS for the same periods. Routine maintenance and calibration of the continuous monitors were continued. All monitors are currently in operation.

Performance of the Oxygenation System

Operation of the oxygen injection system was initiated on 11 June 1997 and 19 June 1998. Injection rates averaged 25-35 tons/day during June 1997-98 (Figure 34). Rates ranged from 20 to 60 tons/day during July of both years. August rates ranged from 30 to 90 tons/day during 1997 and from 40 to 110 tons/day during 1998. Oxygen injection rates of greater than 100 tons/day of oxygen were recorded in late September and throughout October for both years. Daily DO injection rates averaged 57 tons/day through the June-October period. Maximum measured rates were 133 tons/day during late October 1998. Autumnal cooling and reaeration during the latter months of 1997 and 1998 reduced oxygen demand. The oxygen injection system ceased operation for the 1997 season on 29 October. During 1998, the system was shut down on 31 October and restarted on 4 November. The final day of system operation was 16 November 1998.

Comparison of oxygenation system performance data for 1996-1998 reveals that the average daily injection rate for the period of 21 June through 8 October was greater in 1997 and 1998 than during 1996. Averages during 1996, 1997, and 1998 were 65.8, 68.7, and 79.2 tons/day, respectively. The total tons injected throughout the season were substantially lower in 1996 as well. Approximately 7111 tons of oxygen were used in 1996, as compared to 8110 and 10343 tons/day in 1997 and 1998, respectively. Lastly, due to the destratification of the RBR Lake forebay and early mixing in October 1996, the system was shut down approximately one month earlier in 1996 than during 1997 and 1998.

Lake Water Chemical Trends

The water chemical characteristics in RBR and JST Lakes are generally similar, owing to the sequential nature of lake systems. Variation within each lake is related to their specific morphometric characteristics as well as to variation among their tributaries.

Winter conditions for RBR and JST Lakes are similar. Once fall and winter mixing has completed the disruption of the thermal structure, chemical structure is virtually absent. For this reason, sampling is minimized and the ability to identify chemical trends is limited to extremes such as major inflows. Spring and the return of thermal structure allows changes in the chemical constituents. These changes are due to spatial (depth) isolation, the decrease of dissolved oxygen, as well as the differences in temperature in stratified lakes. The subsequent summer season produces the most obvious chemical trends for any year. Anoxia in the deeper waters actually changes the chemical form of some compounds and allows others to be formed for the first time. As a result the late summer and early fall are usually the most extreme for certain important chemical characteristics in RBR and JST. The progression of fall mixing produces very transient chemical conditions and the rate of fall cooling and mixing determines the duration of chemical trends in these lakes. In both RBR and JST, this progressed similarly in 1997 and 1998. Because mixing was not complete until late in each year, the fall chemical patterns were indicative of the intensity of processes occurring during the respective previous summers.

Important water chemical characteristics group conveniently into three categories; nutrients, organics, and metals. The major nutrients for RBR and JST include different forms of nitrogen (N) and phosphorus (P), and to a lesser extent, sulfur (S). Although dependent on form and distribution, these nutrients are often encountered in low concentrations and the methods of analyses were adopted to provide adequate sensitivity for their detection in the various forms. The major organics were measured simply as total and dissolved (filtered) organic carbon (TOC and DOC, respectively). No attempt to further identify the forms was made. The major metals included iron (Fe) and manganese (Mn). During the analysis for other constituents, measurement were made of minor alkaline-earth metals, sodium, calcium, and magnesium. The data for these are available but not reported here.

Nutrient Distributions

Phosphorus (P) is often considered a limiting nutrient in surface waters. In RBR and JST, P often occurs at concentrations below detection limits. In RBR this is true for much of the season and measureable concentrations first appear in the summer and extend into fall. The greatest concentrations occur in the deeper waters of RBR in late summer (approximately 0.02 mg/l).

Nitrogen concentrations occur in greater concentrations. This is common for surface waters where P is limiting. Figure 35 illustrates summer N trends in 1997 and 1998. The RBR Lake surface experiences the lowest concentrations and N increases concentration with depth. This is especially true for the deeper waters of RBR near station 120. This indicates the important influence of the adjacent tributaries, Beaverdam Creek and Rocky River. Concentrations of N were as great as 0.75 mg/l in the deepest water at station 120 in June 1998. Late summer concentrations (Figure 36) were greater than 1.0 mg/l in August and were less specific to station 120. This may be due to downstream movement of deeper waters from the station 120 region into the forebay region. Fall and winter N distributions follow similar trends (Figure 36) in RBR as they again tend to increase with depth. In these figures, the absence of plots for certain forms of N or for certain dates indicates that there was no clear trend to be plotted for those times. Hence, figures 35 and 36 depict the major trends that were observed for N concentrations in RBR Lake.

Nutrient distributions in JST Lake are temporally and spatially variable and are influenced by season and the presence of tributary inflows as well as in lake processes and depth. Figure 37 illustrates winter P trends for 1997 and 1998. As can be seen, measureable concentrations occur throughout JST Lake. Furthermore, for 1997 there is an obvious gradient longitudinally in the lake. In 1998 a similar trend exists but is not as clear as in 1997. This gradient is related to a major tributary to JST, Broad River, GA. As noted in Hains, et al (1988), Broad River, GA is the single greatest source of P to JST Lake. This occurs because of the tendency of RBR to trap materials as they arrive in the major flow of the Savannah River. Figure 37 illustrates this clearly for 1997 showing relatively low P concentrations in RBR releases and increasing to approximately 0.03 mg/l total P. This maximum was located near the mouth of Broad River and those tributary stream influences could explain the greater concentrations of P at that location. Downstream from that location the concentrations show a consistent decrease, probably due to dilution with water from RBR releases and other waters of JST Lake. In January 1998, there is also a trend of increase with depth and with distance downstream. This indicates that other processes are also very important for controlling P distributions in JST Lake.

Throughout the remainder of the season for 1997 and 1998, concentrations of P are measureable but low. Clear trends for P are absent in JST for the remaining seasons of both years. There is a sharp gradient in the winter for N concentrations in JST. This gradient is again associated with the Broad River, GA inflow (Figure 38). Concentrations of total N approach 0.7 mg/l in February 1997 at the confluence of that major tributary. At other times or for total soluble N, maximum concentrations attain approximately 0.5 mg/l. There is a tendency to decrease downstream. Again, while uptake and settling can decrease nutient concentrations, dilution probably is also a factor in this region of JST Lake. Summer distributions of N are predictably associated with depth. Concentrations increase with depth for August 1997 as well as June 1998 (Figure 39). August 1997 concentrations, however are generally greater than June 1998. This pattern is reflected at other times. For some reason JST Lake had greater concentrations of N in 1997 than 1998. Figure 40 shows that although both years again displayed the depth dependent increase of N concentrations, 1997 consistently had greater concentrations of forms of N than 1998. In general there was approximately twice the N in JST in 1997 than in 1998.

Metals Distributions

The predominant metals in these lakes are Fe and Mn and their dynamics depend on processes in RBR Lake. The interaction of the oxygenation system in RBR Lake with their chemical forms of these metals alters the form in which they are released to JST Lake. The most abundant metal is Fe which has its source in the submerged soils and allochthonous sediments. Under reducing conditions this metal becomes soluble and can enter the overlying waters. In the summer (Figure 41) Fe occurs in a depth-dependent manner. Figure 41 shows that for 1997 and 1998, there is an observable trend in RBR Lake in which Fe is undetectable in surface waters but increases to greater than 2 mg/l in the deepest region of the RBR forebay. June of each year contains a depth-dependent trend although June 1997 is displayed only for comparison to June 1998. Clearly there is great year-to-year variation. In contrast, August 1997 was the time in which oxygen conditions were most extreme and this is reflected in the distribution and concentration of Fe in the deep forebay region.

In November 1997, Fe was distributed in RBR Lake with greatest concentrations upstream (Figure 42). Most of the Fe was in the form of filterable particulates probably due to oxidized Fe released from Hartwell Dam or subsequent oxidation in RBR. This is not uncommon for this season. Concentrations for November 1997 and October 1998 were quite different and distributed differently as well. As can be seen in Figure 42, the concentrations in RBR Lake in October 1998 were as much as 2.5 mg/l while in November 1997 they were less than 1.0 mg/l. This difference cannot be explained with the available data. However the greatest concentrations of Fe in RBR Lake in 1998 were confined to the deepest areas of the lake in the RBR forebay (Figure 42). Concentrations increased from undetectably low concentrations to greater than 2.5 mg/l near the bottom of the lake at station 60. The similarity between the total and dissolved concentrations indicates that most of the Fe was dissolved.

Concentrations of Mn in RBR Lake were similar for 1997 and 1998 in early summer. As commonly observed, Mn occurred in greatest concentrations at the deepest depths in the RBR forebay for both years (Figure 43). In late summer Mn did not occur in a discernable pattern for 1998 and in 1997 seemed to attain maximum concentration in the deepest water throughout much of the lake (Figure 44). Again, this did not depart from normal or expected distributions.

Fall trends of Mn in RBR Lake were discernable but not as strong as observed for the summer distributions. There was a trend of increase in concentration with depth for both years (Figure 45). There was also a trend in November 1997 with decreasing dissolved Mn concentration downstream. However, in November 1997 most of the Mn occurred in a particulate (oxidized) form while in October 1998 Mn occurred mostly as dissolved (reduced). This difference is indicative of this highly dynamic time of the limnological year.

Although Fe and Mn distributions tend to be in oxidized form during aerated, mixed, cooler seasons, there was nevertheless an observable trend in JST Lake for dissolved Fe in February 1997 (Figure 46). Total Fe did not exhibit a discernable trend. In February 1997 the greatest concentrations seemed to be related to Broad River, GA inflows. The only other identifiable trends for Fe in JST were for November 1997 and October 1998 and only for the dissolved Fe distributions (Figure 46). In November 1997 there again was an association between the greatest concentrations and the confluence of the Broad River, GA. Other contributing processes such as anaerobic chemical processes or microbial activity may have influenced metals distributions in mid-lake locations. In October 1998, dissolved Fe was simply confined to the greatest depths in the JST forebay and only in the deepest waters less affected by the oxygenation system.

The only consistent identifiable trends for Mn in JST Lake were increases with depth for dissolved Mn during November 1997, June 1998, and again in October 1998 (Figure 47). The fall concentrations attained seasonal maxima of approximately 3 - 5 mg/l in the JST Dam forebay (station 20).

Organic Carbon Distributions

There is increasing interest in organic carbon as a water quality factor. As a naturally occurring substance and as a contaminant it supports microbial growth and affects the cost of treatment for drinking water supplies. In excess, organic carbon can interact with common water treatment processes to form precursors to potential carcinogens (Stepczuk 1997).

In undisturbed aquatic systems organic carbon can originate in the watershed as the product of organic leaching, decomposition, or other processes. In the lake it can be produced by biota which excrete it during metabolism or lose it in the decomposition process (Stepczuk 1997).

Organic carbon, both TOC and DOC occur in concentrations ranging from approximately 1 - 5 mg/l in RBR and JST Lakes as well as in other lakes in the region. In RBR Lake winter concentrations had a discernable trend only for 1997 (Figure 48). This trend was identified as a TOC and DOC increase with distance downstream from Hartwell Dam. This indicated that the source for the difference was autochthonous, produced in the lake. Concentrations were approximately 1.0 mg/l. Moreover, TOC and DOC concentrations were approximately equivalent indicating that most of the organic carbon occurred in dissolved form (DOC).

Depth-dependent trends were identifiable in RBR Lake for June 1997 and 1998 (Figure 49). These late spring concentrations varied from approximately 2.0 - 4.0 mg/l. There were no other discernable trends for organic carbon in RBR Lake.

Winter TOC and DOC trends were observed in JST Lake in 1997 and not identifiable in 1998 (Figure 50). Concentrations were approximately 2 mg/l, were almost entirely dissolved, and had a trend of increase from upstream to downstream in the lake.

TOC and DOC trends for late spring and early summer were very similar for 1997 and 1998 (Figure 51). Concentrations of organic carbon were also similar, varying between approximately 2.0 - 4.0 mg/l. There tended to be greater concentrations of dissolved organic carbon nearer the surface.

In August 1997 there was a trend similar to June with the greatest concentrations of TOC and DOC near the surface and declining concentrations with depth (Figure 52). There was approximately 1.0 mg/l greater TOC than DOC and this may be interpreted as organic carbon in the form of particles. There was not an identifiable trend in 1998.

The trends of TOC and DOC in JST Lake for November 1997 were reversed from October 1998 (Figure 53). In 1997 fall organic carbon concentrations increased with depth to a maximum of approximately 3.5 mg/l. In 1998 fall organic carbon concentrations tended to increase nearer the surface to approximately 3.5 mg/l. Furthermore the November 1997 concentrations were maximum near the bottom of the lake at station 30, approximately mid-lake. In October 1998 the maximum occurred throughout the water column in the JST forebay, station 20.

The processes controlling organic carbon production and distribution have not been investigated for the Savannah River system. Nevertheless, the observed distributions in RBR and JST Lakes allow informed hypotheses about the seasonality and sources of carbon in those two lakes. Organic carbon usually occurs in the dissolved form and is temporally and spatially dynamic. If this limnological parameter becomes important in the future, its study will require adequate sampling design and intensity to accurately characterize this variation.

Habitat in RBR and JST Determined by Habitat Suitability Index

The concept of habitat is sometimes confusing, poorly understood, or misapplied. Nevertheless it is possible to create simplistic guidelines which describe approximate habitat limits for certain environmental characteristics. One example of this is the habitat suitability index (HSI) as applied here to RBR and JST Lakes. This index was created for a variety of fish species but has been applied to RBR and JST Lakes for striped bass (Morone saxatilis). The limits associated with the HSI for these lakes were: < 24° C and >18° C; >5 mg/l dissolved oxygen (Crance 1984). An additional delimiter (>3 mg/l) was used in order to provide information on potential habitat under that criterion.

Routine field water quality data were used to graphically describe the extent to which habitat existed in RBR and JST Lakes at different times. In RBR Lake, three years, 1996-1998, were compared to illustrate the differences between pumped storage conditions and normal conditions. Particular interest existed for JST Lake and for that lake additional comparison years were included. Five years including 1988, 1994, and 1996 - 1998 were employed for those comparisons. These included the record low flow and high flow seasons as well as the Phase III testing season and subsequent years, 1997 and 1998.

The habitat effect of Phase III testing was discussed in the Phase III report but here the comparisons included the two subsequent years, 1997 and 1998. Habitat as described using the striped bass HSI is determined simply from temperature and dissolved oxygen criteria selected on a species- and size-specific basis. For this reason, the winter and spring months are rarely examined for habitat limitation. Instead, most interest is in the summer stratified period during which dissolved oxygen demand and increased temperatures pose potential obstacles to habitat maintenance. For this reason this analysis includes only the months July - October for each year of the comparison.

Based on the HSI criteria and considering only July for the years 1996-1998 in RBR Lake, figure 54 illustrates what was obvious in the Phase III report. Simulated pumped storage operation during July 1996 warmed extensive regions of RBR Lake. This process also contributed to the extensive distribution of dissolved oxygen throughout RBR Lake. This caused an increase of available habitat based on the HSI. In the subsequent years of 1997 and 1998 this habitat was restricted to a thin layer associated with the thermocline. This habitat layer was limited by temperature in shallower depths and by both temperature and dissolved oxygen availability in deeper depths. In 1997 there was less habitat than in 1996 and in 1998 habitat was even more restricted than in 1997. Indeed in July 1998, following the strict HSI guidelines (i.e., D.O.>5 mg/l), habitat was eliminated from approximately the downstream half of RBR Lake.

In August 1996, potential habitat was variable, existing upstream and downstream but was potentially impacted in the mid-RBR Lake region by the influence of the two tributaries, Beaverdam Creek and Rocky River (Figure 55). Relaxing the oxygen concentration limit to 3 mg/l, however, increased some of the potential habitat space. It also illustrated the importance of small differences in processes controlling dissolved oxygen distributions. In 1997 and 1998, August habitat assumed similar distributions as in July 1997 and 1998 but was even more restricted in extent in August. The late summer conditions are typically the most extreme in these lakes.

September 1996 habitat extended to the surface in RBR Lake (Figure 56). Otherwise habitat during September was similar to August for 1996. And again in 1997 and 1998 habitat was greatly diminished in comparison to September 1996 (Figure 56). However, there was habitat present near the dam in the RBR forebay during September of both 1997 and 1998 where it had been absent during July and August. Although the oxygenation system had been supplying adequate oxygen supplements for habitat needs, the temperatures during the earlier months were less than the stated habitat limit of 18° C. By September, the deeper depths had warmed to temperatures acceptable as habitat. In 1996, pumped storage accomplished this early in the season.

In October, the comparison of the three years offers additional insight to habitat trends. Virtually the entire RBR Lake qualified as habitat in October 1996 (Figure 57). However, although conditions had improved in 1998 in the absence of pumped storage, both temperature and dissolved oxygen still placed limits and habitat was not as extensive as in 1996. For additional comparison, November 1997 is included in figure 57 because October data were not available. There is an obvious thermal limit in November 1997 associated with fall cooling and the progressive mixing that occurs earlier in the shallower regions of these lakes. On a thermal basis habitat is lost from these regions each fall due to natural cooling.

The habitat trends were very clear for RBR Lake. However, evidence of tailwater warming and the effect of this on habitat in JST Lake remained a source of concern after the Phase III studies and report. The interim studies included additional monitoring sites in JST Lake in order to address those concerns. Accordingly, in order to provide a broader basis for comparison, the results from previous years, 1988 and 1994, were included with 1996 - 1998 for this discussion of results. As shown in figure 6, 1988 was a record low flow year and 1994 was a record high flow year. Although other factors influence the distribution and duration of conditions that determine habitat, hydrology is clearly one of the most important factors. Inclusion of the extreme years, 1988 and 1994, reasonably express the likely range of conditions for JST Lake in which the years 1996-1998 fall.

The importance of a multi-year comparison such as this is apparent in figure 58 which depicts HSI habitat for July. It is important to note that the 24° C criterion excluded the upper epilimnion as habitat for all years. In this graphical analysis the high flow year had the least habitat as described with greater than 5 mg/l dissolved oxygen. The years 1988, 1997 and 1998 were similar in habitat development. The Phase III testing year, 1996, not only had more habitat based on the HSI, a thin region of habitat extended farther down the lake than any other year, possibly to JST Dam. Relaxing the dissolved oxygen requirement to 3 mg/l produced greater habitat in all years. Only in 1998 was there severe degradation near JST Dam.

The distribution of habitat for the five comparison years was different in August (Figure 59). The month of August for 1988, 1994, and 1998 were similar in most respects. In these three years a small region of habitat remained in the JST headwaters (RBR tailwaters). Waters containing >3 mg/l dissolved oxygen extended significantly downstream into JST Lake. In 1988 a small amount of this region extended to JST Dam. Figure 59 also showed that although the habitat in 1996 was distributed somewhat differently, it existed to approximately the same extent as 1988, 1994, and 1998. There was a small region of habitat loss in the immediate area of RBR Dam but it extended farther downstream than 1988, 1994, or 1998. Figure 59 also showed that the worst conditions for August occurred in 1997. In 1997 habitat existed only in a small headwater region and it was almost non-existent elsewhere in JST Lake.

September data were not available for 1997. Among the remaining years, the greatest amount of habitat existed in the low flow year, 1988 (Figure 60). The high flow year, 1994, and the Phase III year, 1996, were similar in their extent of habitat. However, the amount of habitat >3 mg/l was more extensive in 1994 than in 1996, due to the extreme high flows of 1994. The least amount of habitat occurred in

1998. Importantly, the extent of habitat for September in the comparison years was usually the result of processes controlling dissolved oxygen distributions. Although the upper thermal limit was important to habitat in at shallower depths during September of the Phase III year, 1996, habitat was available in deeper waters.

By October, fall cooling and surface mixing increased habitat in most regions of the lakes. In spite of this there was still an interesting comparison between the three years, 1996-1998, for the month of October (Figure 61). The greatest amount of habitat for the three years was clearly observed in 1996. October 1997 had somewhat less habitat. October for 1996 and 1997 had sufficient surface cooling to allow habitat to the lake surface. However, in 1998, the remaining warm waters limited the extent of habitat as described by the HSI. If a small amount of additional cooling had occurred in October 1998 the amount of habitat available would have been similar to 1997.

Conclusions and Recommendations

Conclusions drawn from the interim studies must rely on comparison to other years, notably the Phase III year, 1996. It was fortunate, then, that the three years, 1996-1998, were similar in most respects except the Phase III testing. This allowed some important comparisons and conclusions regarding the impact of the Phase III pumped storage operation.

Thermal trends for RBR and JST Lakes were similar in almost all respects except for the Phase III testing period. As noted prominently in the Phase III report, temperatures increased significantly in the deeper waters of RBR as a result of pumped storage operation. The same entrainment, mixing, and displacement processes important to the thermal alterations also contributed to increased dissolved oxygen in widespread areas of RBR Lake. These changes as a result of pumped storage operation during the Phase III testing were made very clear by comparison with the interim years, 1997 and 1998.

Both lakes experienced hypolimnetic hypoxia in the deeper waters for the years, 1997 and 1998. While thermal trends were comparable, 1997 had dissolved oxygen concentrations that were worse than any year since 1984, the pre-operation first year of impoundment. While 1998 was not as extreme it nevertheless was similar. Hydrologically, the years 1996 - 1998 were similar (factoring out pumped storage) and there is no reason to suspect that other major differences exist that would make such comparisons invalid.

One important consequence of this is that the amount of oxygen necessary to achieve target concentrations in the RBR releases was less for 1996 than 1997 or 1998. This was primarily due to the decreased duration of operation necessary which was, in turn, due to the entrainment and mixing processes observed during pumped storage.

Results acquired from continuous monitors at RBR, JST, and HW Dams were similar to previous non-pumped storage years. An important difference was the initial modification at Hartwell Dam which contributes to increased aeration of releases during operation. Such increases in dissolved oxygen in dam releases will benefit downstream habitats. Two remaining concerns are non-generation releases and potential need to monitor total dissolved gases (TDG).

Non-generation releases are any dam release while turbines are not operating. During the summer and early fall such releases can result in water quality that is less desirable than turbine releases. The reason for this is that they may not be aerated and they can originate deep in the upstream lake. If downstream habitats are the concern for turbine release water quality, then clearly the majority of the day during which there is no turbine release is also important and receipt of non-generation releases is then important for those times. Additional efforts to address the magnitude of this impact are needed.

Another issue important as dams are modified to allow greater aeration is the potential for excessive (TDG). This issue is similar to that observed in the Northwest but the source is different. Simply put, if waters depleted of oxygen but not nitrogen gas are aerated to force more air into solution for the purpose of increasing oxygen, then increases of nitrogen are also likely, possibly to excess. This is a serious potential problem and should be addressed as part of a plan to operate the projects in a manner that balances the improvements for dissolved oxygen against the potential impact of nitrogen supersaturation.

Future efforts must keep in mind the important trends identified during these studies. Tributaries to the lakes are important sources (perhaps the most important) of nutrients that contribute to or control fertility. These tributaries also therefore affect the processes important to oxygen demanding processes downstream. The nature of their influence depends on watershed processes and they are therefore independent of lake management measures.

Metals are interesting aspects of the water quality in these systems and they are relatively easy to measure. But they do not at present exhibit trends that would be considered in need of further study.

Organic carbon is potentially important for two reasons. First there is growing interest as a factor in the formation of precursors to potential carcinogens in water supply treatment systems. As such their concentration and form are important. At present, organic carbon occurs in RBR and JST Lakes primarily as dissolved organic carbon. Concentrations are less than 5 mg/l and usually in the range of approximately 2 - 3 mg/l. However, there is evidence that autochthonous sources are important in these lakes in addition to inflows from the watershed. If this water quality parameter becomes important in the future, the in-lake sources versus watershed sources must be addressed in order to understand distributions and to identify potential management measures.

The proposed construction of an in-lake oxygenation system in JST Lake is an important development in this system. The existence of an oxygenation system in RBR Lake and its interaction with pumped storage has been shown to greatly enhance the water quality in RBR Dam releases as well as in RBR Lake. However the maintenance of dissolved oxygen concentrations in the RBR Dam releases is insufficient to overcome oxygen demanding processes in JST Lake. Another oxygenation system in JST Lake can enhance habitat in that lake as well.

A current proposal to establish such a system in a region approximately 2/3 of the distance downstream from RBR Dam places it in position to potentially accomplish several benefits. First, the area is downstream from the largest tributary on JST Lake (Broad River, GA) and its effect on water quality. The site is also deep enough to affect deeper waters in a potentially large region of JST Lake. Second, the site is far enough upstream to greatly increase the potential habitat through increased dissolved oxygen concentrations. The effect of the system may diminish with distance downstream but appropriate design and operation can maximize the benefit. Once the design for this new oxygenation system is established additional monitoring will be needed to establish a baseline for comparison after the oxygenation system begins operation. In this manner its effectiveness can be adequately described.

A potential factor in the effectiveness of the oxygenation system proposed for JST Lake is the interaction with the Little River, GA tributary arm of the lake. This unknown factor is important and needs to be addressed either through additional field monitoring or through application of available numerical models.

The effect of the proposed oxygenation system in JST Lake on JST Dam releases is also important to this system. Assuming that proposed goals are met and dissolved oxygen conditions are improved for JST Lake from the location of the oxygenation system to JST Dam, some benefit may be realized for subsequent hydropower releases. Changes to lake dissolved oxygen distributions will be an important consideration for the proposed modifications to the turbines at JST Dam because of the interaction with aeration capabilities proposed in the modifications. Additional monitoring is needed to adequately describe the effects and potential interactions of these changes.

The continuous monitors at each dam have performed well over the past years. However, the proposed and current modifications of the projects indicate additional interest in the release water quality that was not present during the installation of present monitoring systems. If monitoring needs change, then the design and placement of the monitoring systems must be studied for possible revision as well. In this manner their operation will best characterize release waters to fit the changing data needs.

For the interim studies, the most important issue was habitat. The fortunate similarity between the years 1996 - 1998 allowed further identification of the potential effects of pumped storage on these lakes and their habitats. Employment of the striped bass HSI allowed direct comparison when applied to field data. The years 1997 and 1998 experienced important degradation of habitat in the absence of pumped storage. This degradation was similar between the two years and remarkably greater than observed in 1996. It occurred in both RBR and JST Lakes.

Habitat was affected by processes important to both thermal and dissolved oxygen trends. Obviously pumped storage altered these in RBR and to a lesser extent in JST Lake. The alterations were observed to have a positive effect for most of the season. An exception to this was during the late summer (August) in the region immediately downstream from RBR Dam. As identified during the Phase III studies, this resulted from warming the tailwaters to temperatures greater than 24° C. In these comparisons pumped storage was observed to have a positive effect on habitat based on the HSI for nearly all locations and times in RBR Lake.

Temperature is an important physiological determinant of habitat for any fish species. The fact could not be ignored, however, that the lower habitat limit of 18° C is significantly violated throughout both lakes for the period of December into April every year. During this time waters are nearly uniformly mixed and contain adequate dissolved oxygen at all depths. Temperatures decrease to a minimum of approximately 9 - 12° C throughout the lakes during the winter season.

The absence of concern for the lower temperature limit and existing concern for the upper temperature limit are confusing and difficult to understand. This is merely indicative of the uncertain nature of habitat issues. A key to resolving this obvious conflict is recognition of the temporal variability of real habitat needs for populations or cohorts as well as the variability of available habitat. Additional objective examination of this variability, the ability of species to adapt, and the frequency and intensity of variability of water quality characteristics important to habitat is needed to provide a realistic framework for the management of these systems.

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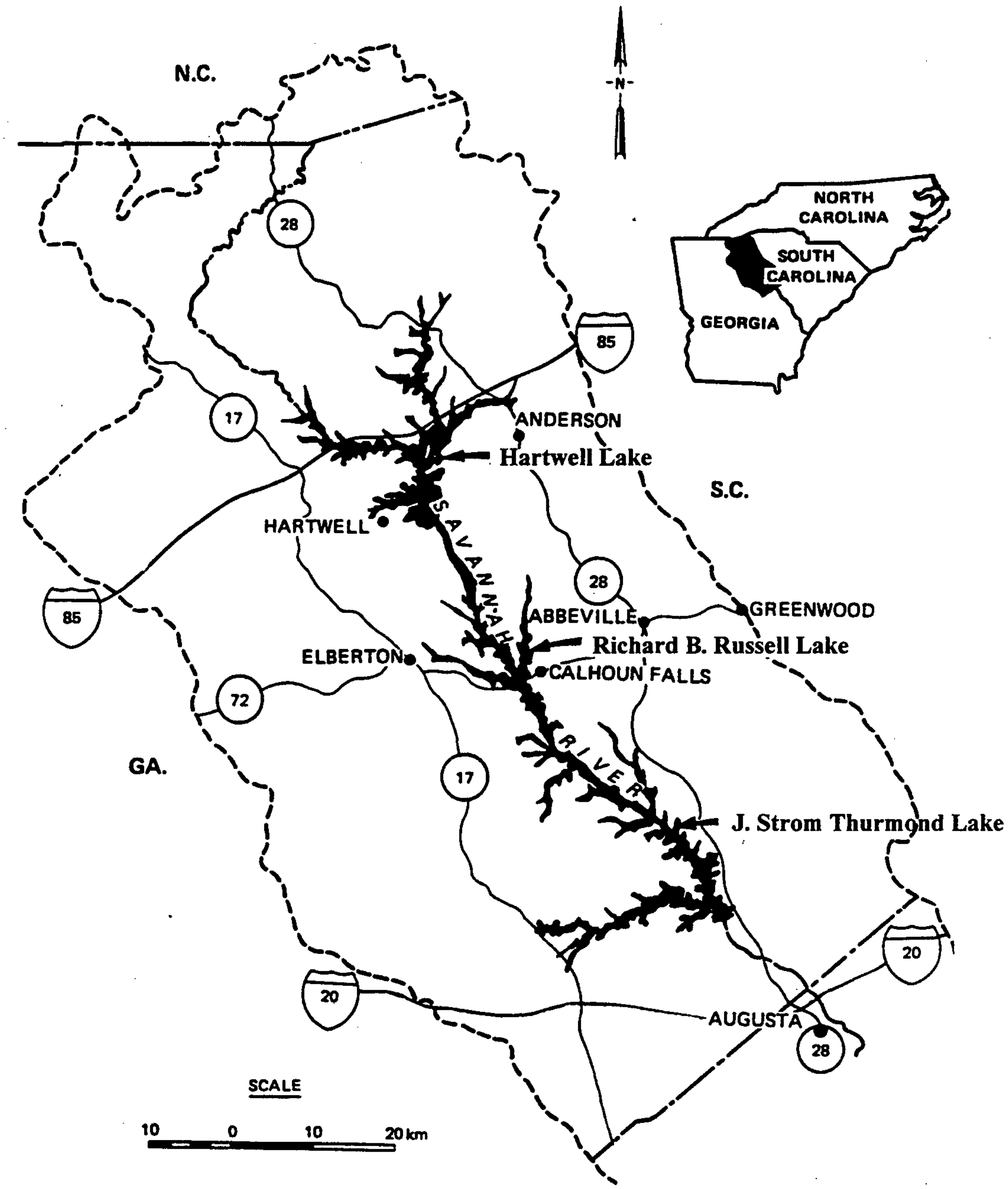


Figure 1. Map of the upper Savannah River basin indicating the locations of Hartwell Lake, Richard B. Russell Lake, and J. Strom Thurmond Lake.

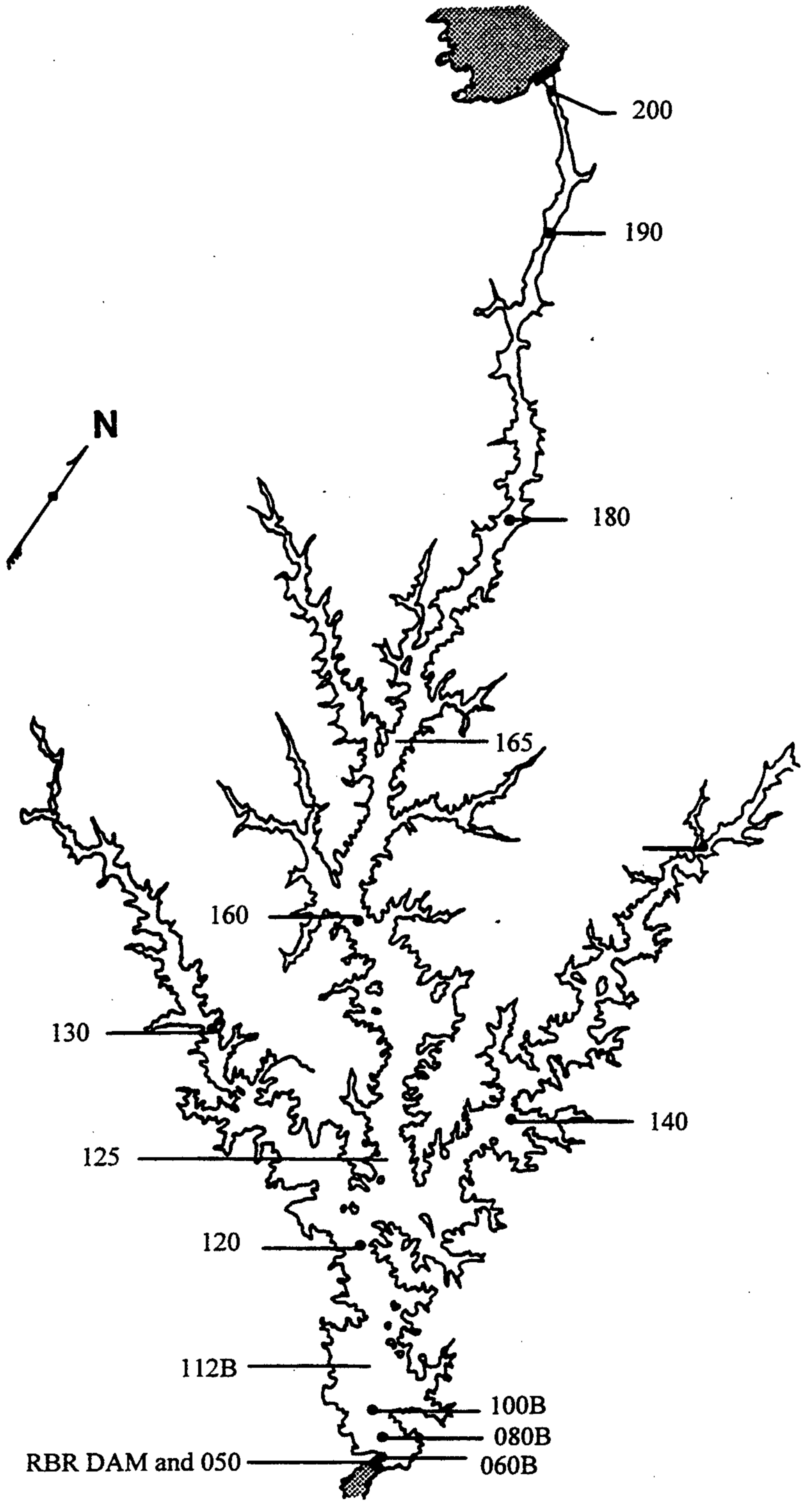


Figure 2. Location of routine sample stations in Richard B. Russell Lake.

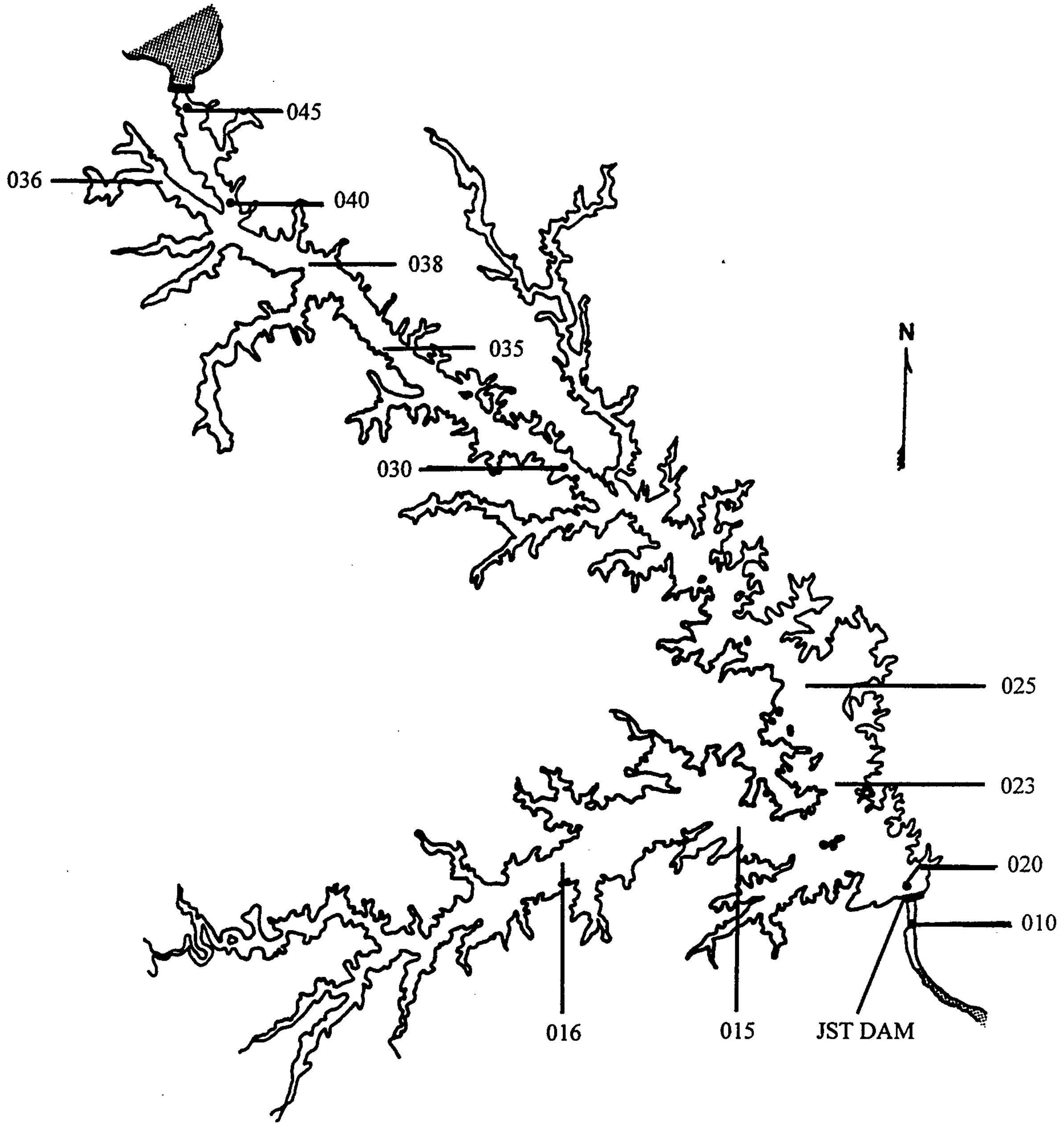


Figure 3. Location of routine sampling stations in J. Strom Thurmond Lake.

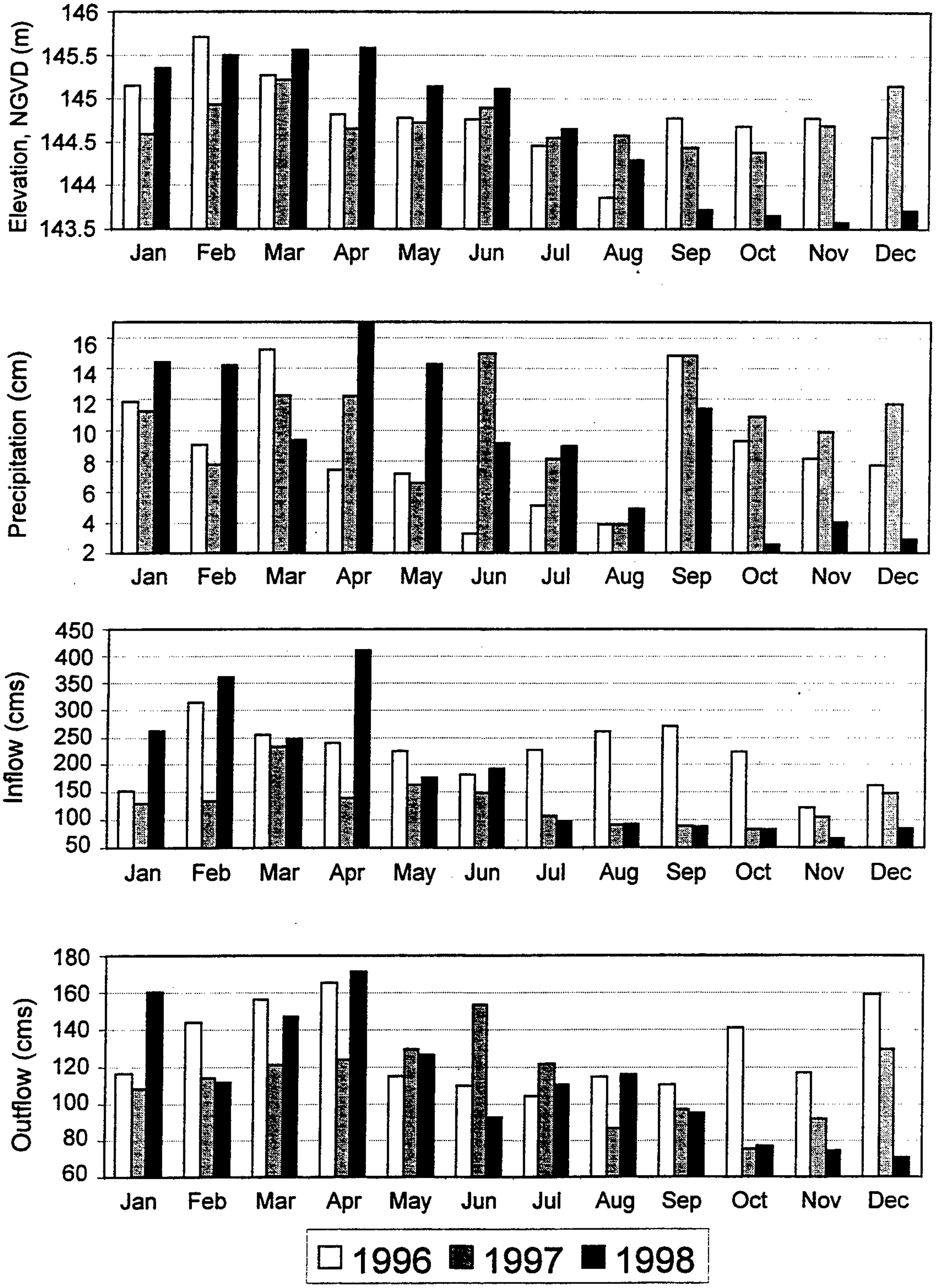


Figure 4. Monthly hydrologic features of Richard B. Russell Lake for the years 1996-1998.

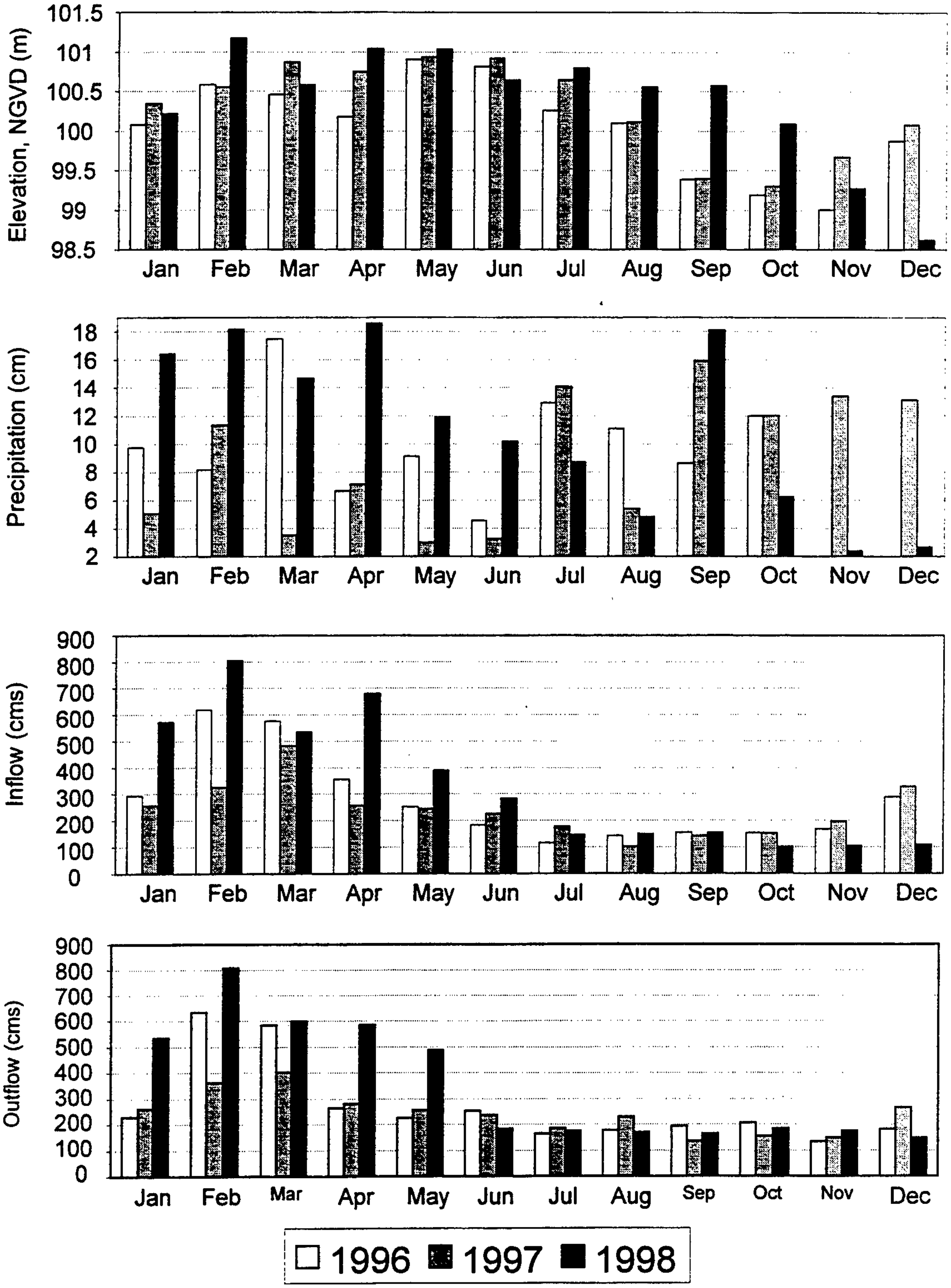


Figure 5. Monthly hydrologic features of J. Strom Thurmond Lake for the years 1996-1998.

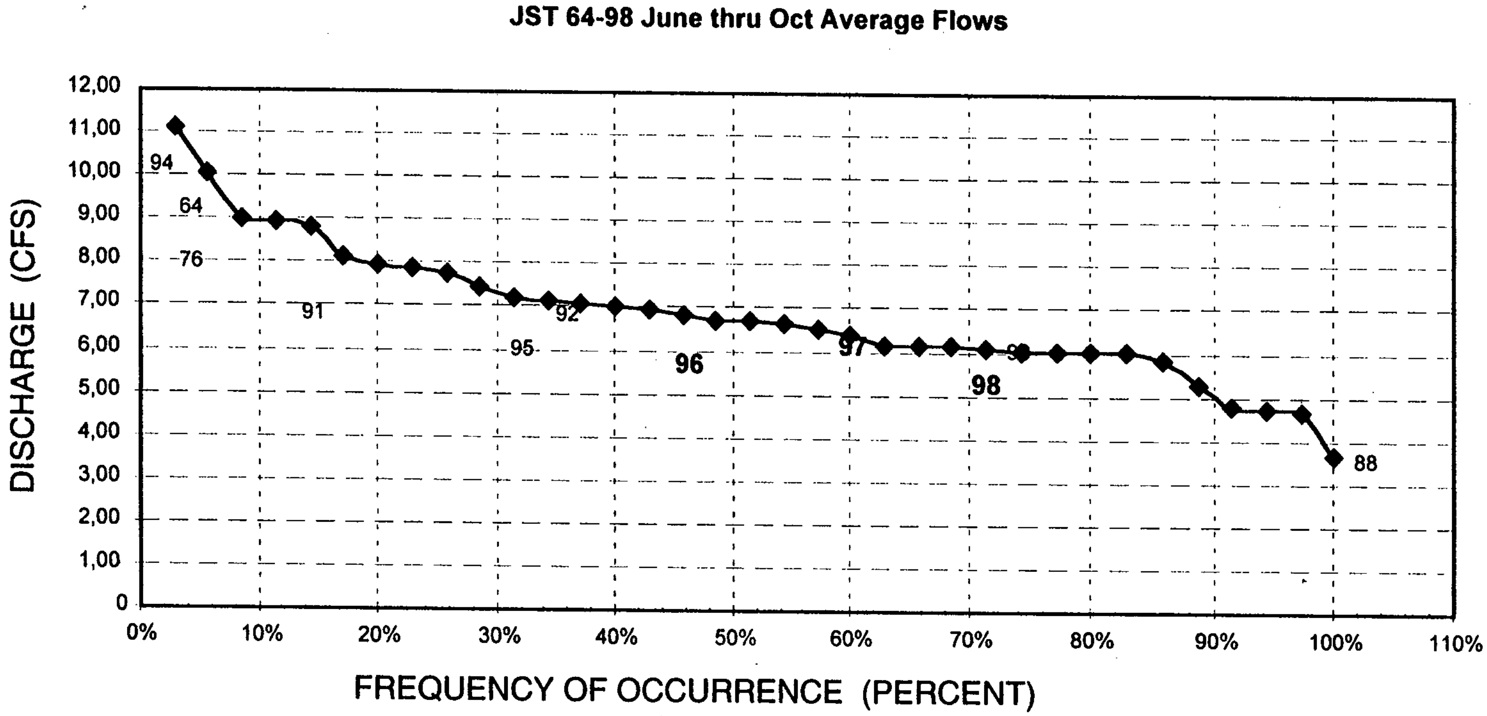


Figure 6. Average flows for the period June through October at JST Dam for years 1964-1998. The years 1996-1998 are similar and fall approximately within the 50-70% occurrence range (6000-7000 cfs) for the years considered. The record for RBR is not as long but the flows for the Savannah River at RBR Dam would reflect similar trends. (Plot prepared by Mark Mobley, TVA)

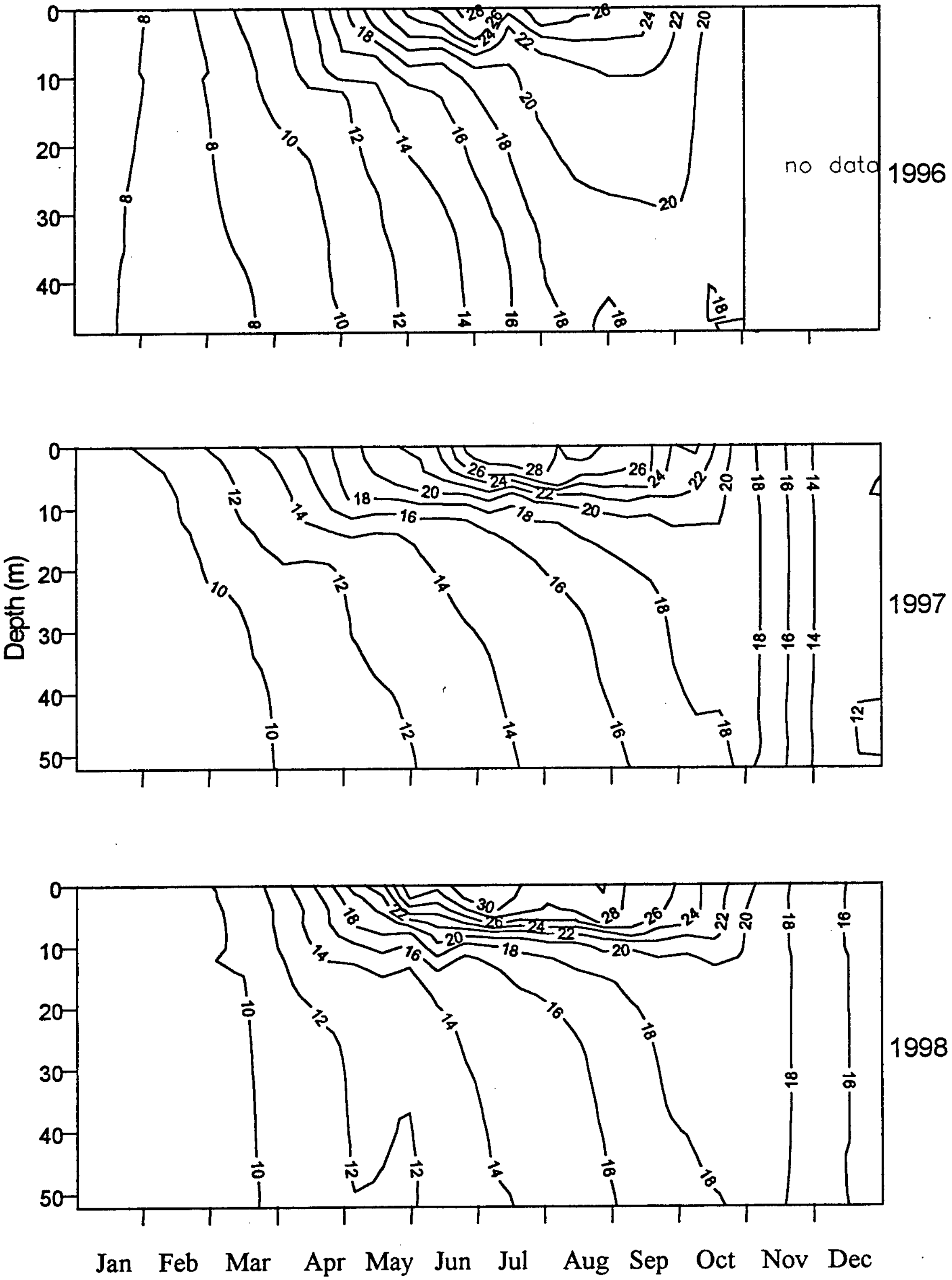


Figure 7. Vertical changes in water temperature (C) at station 060B in Richard B. Russell Lake during the period 1996-1998.

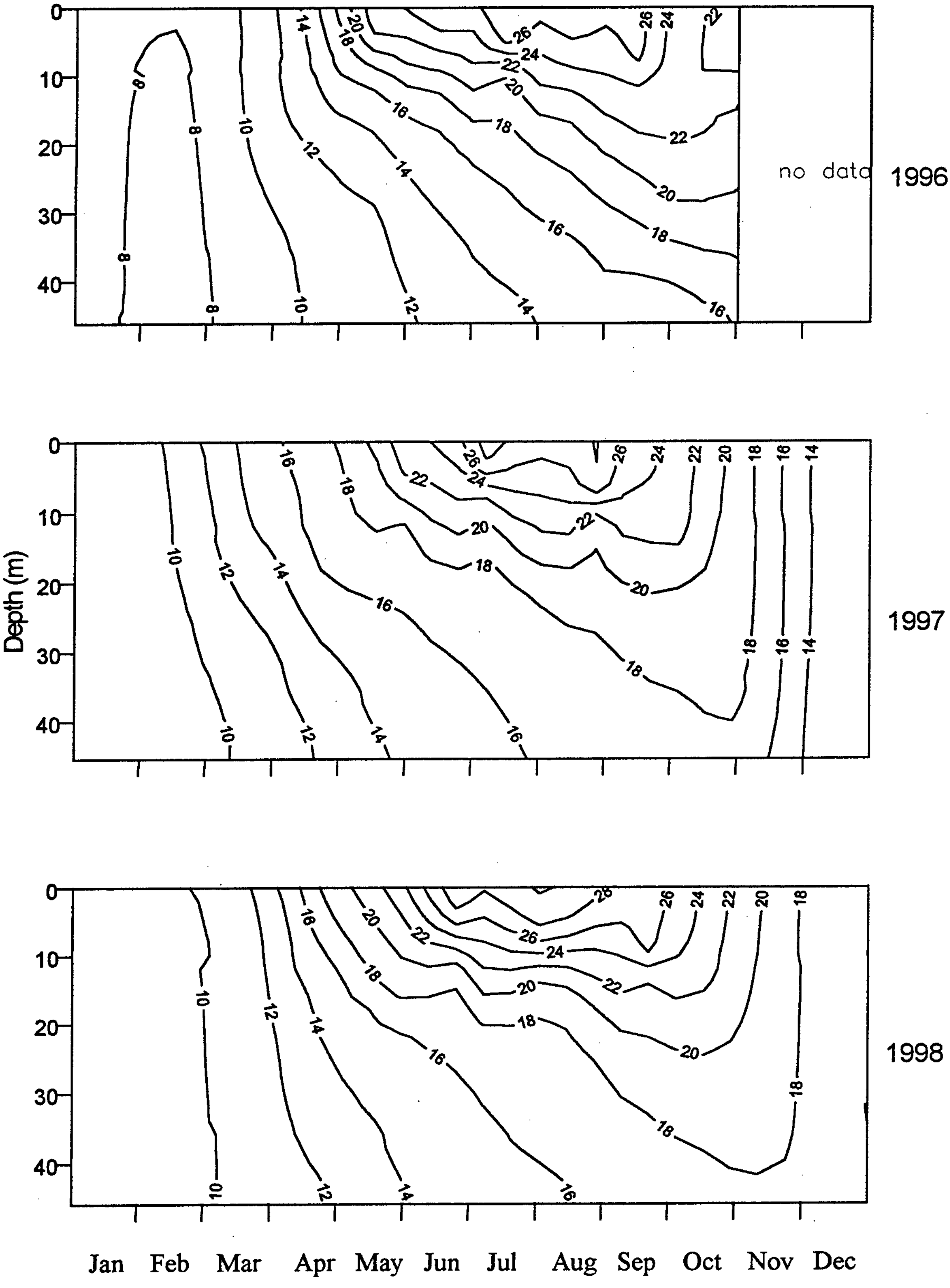


Figure 8. Vertical changes in water temperature (C) at station 020 in J. Strom Thurmond Lake during the period 1996-1998.

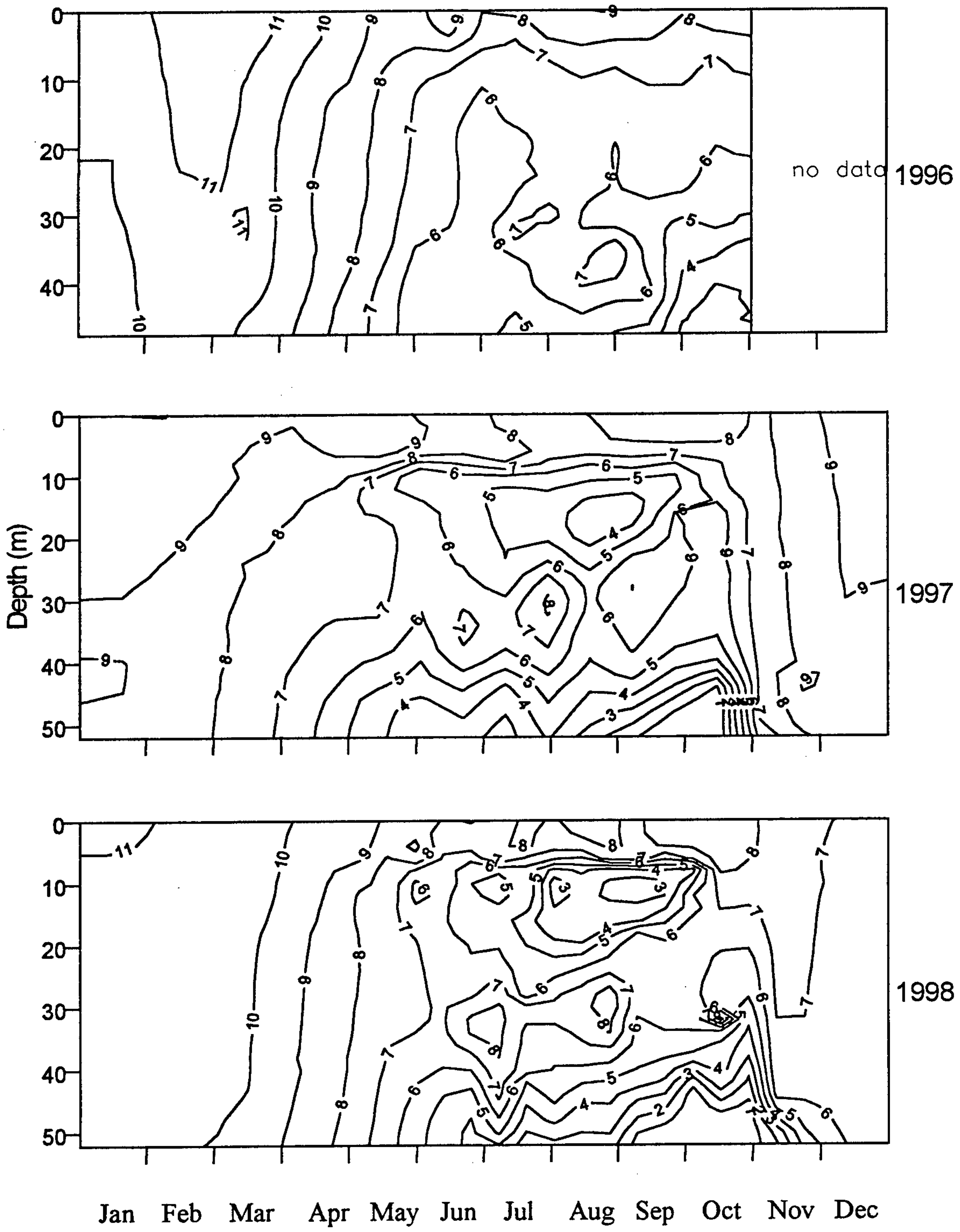


Figure 9. Vertical changes in dissolved oxygen concentration (mg/l) at station 060B in Richard B. Russell Lake during the period 1996-1998.

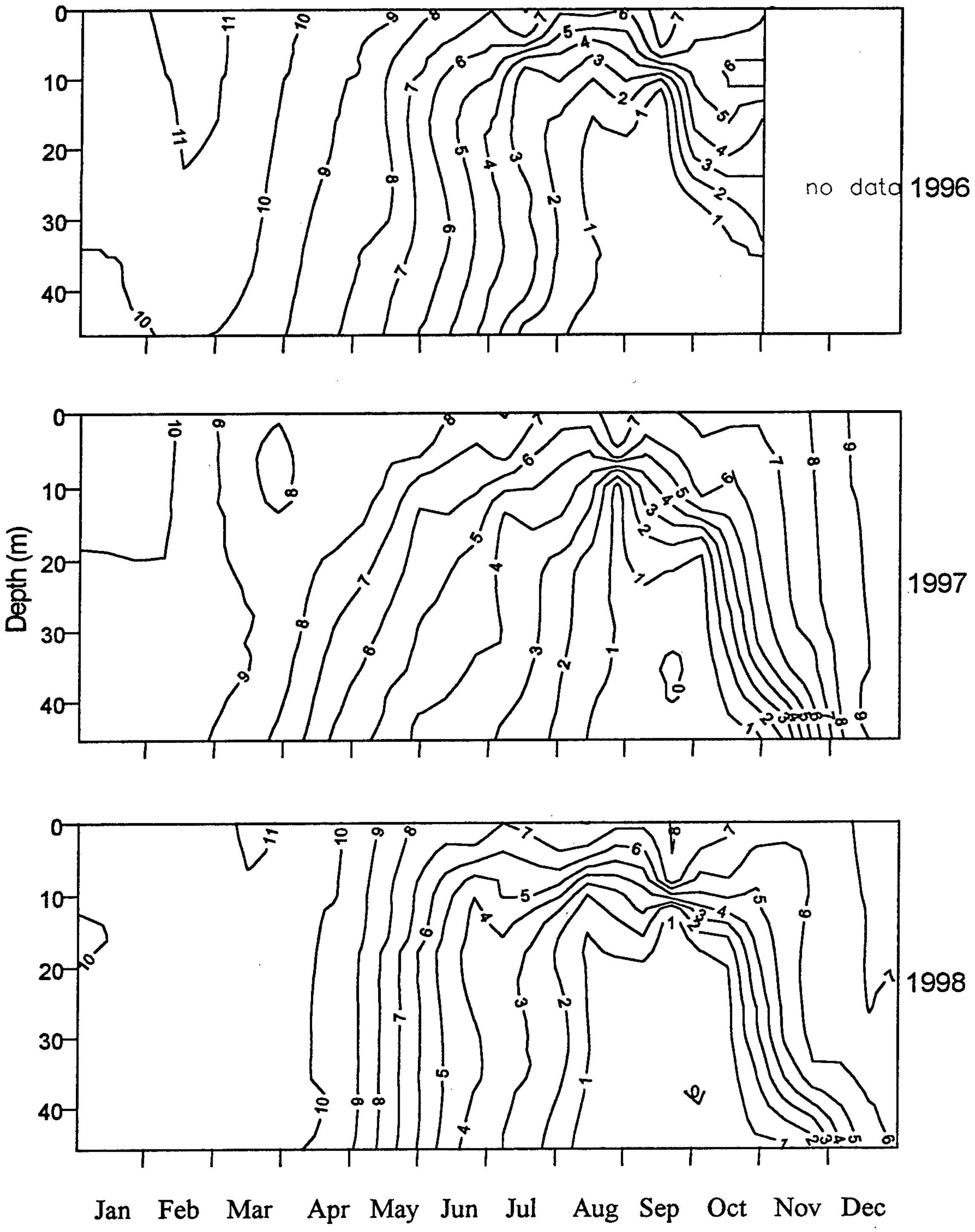


Figure 10. Vertical changes in dissolved oxygen concentration (mg/l) at station 020 in J. Strom Thurmond Lake during the period 1996-1998.

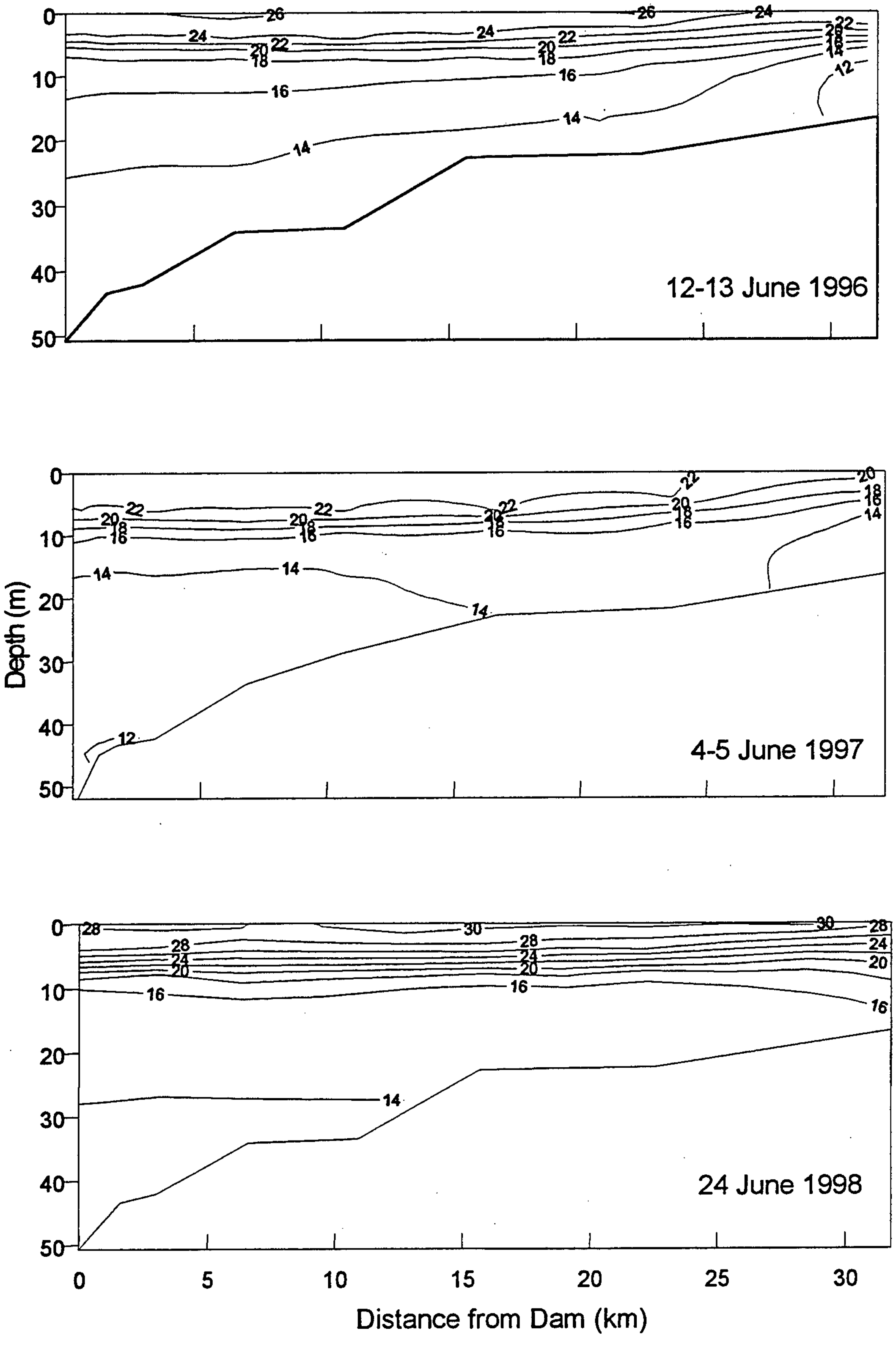


Figure 11. Longitudinal and vertical changes in temperature for Richard B. Russell Lake during June 1996-1998.

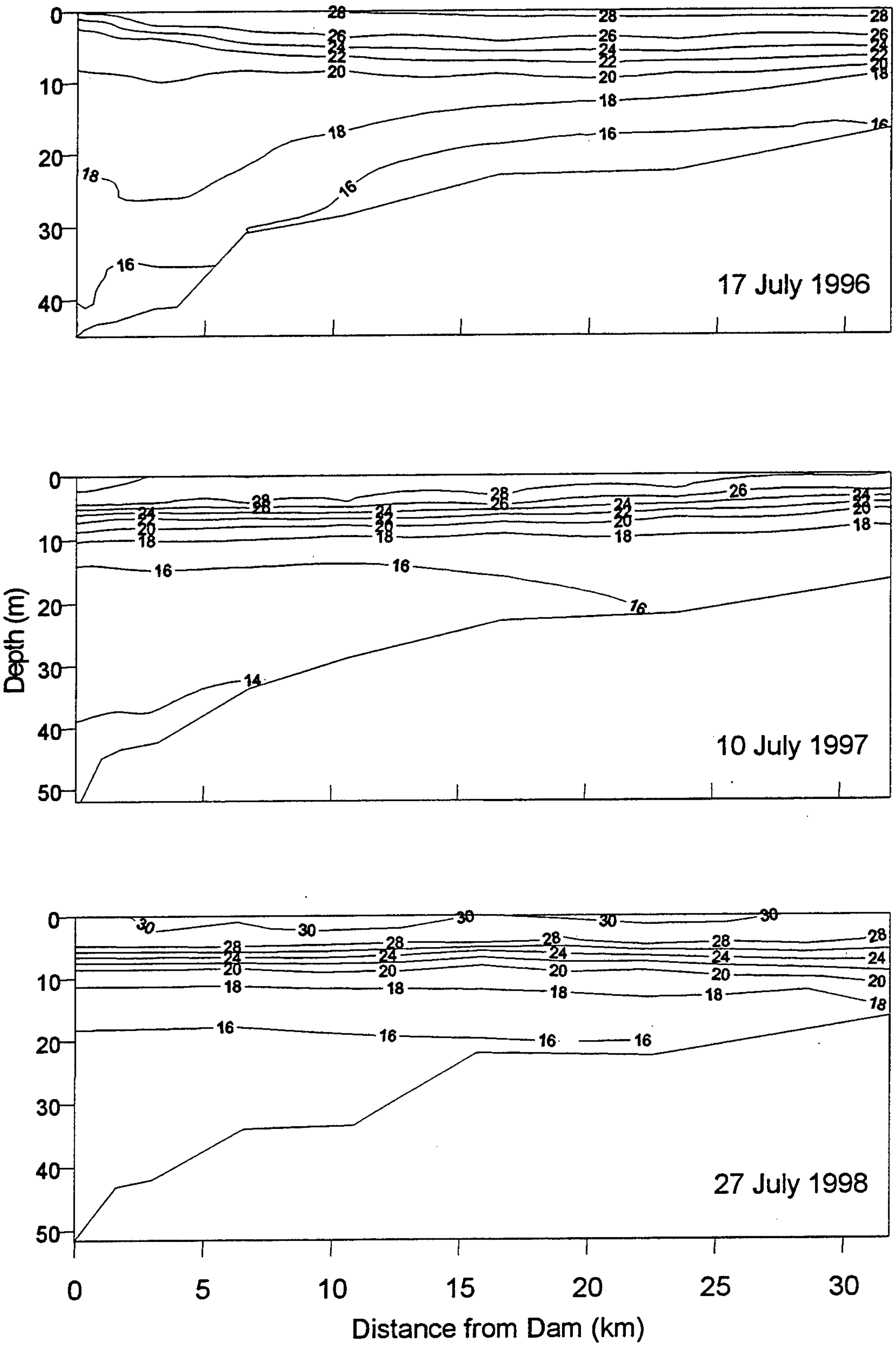


Figure 12. Longitudinal and vertical changes in temperature for Richard B. Russell Lake during July 1996-1998.

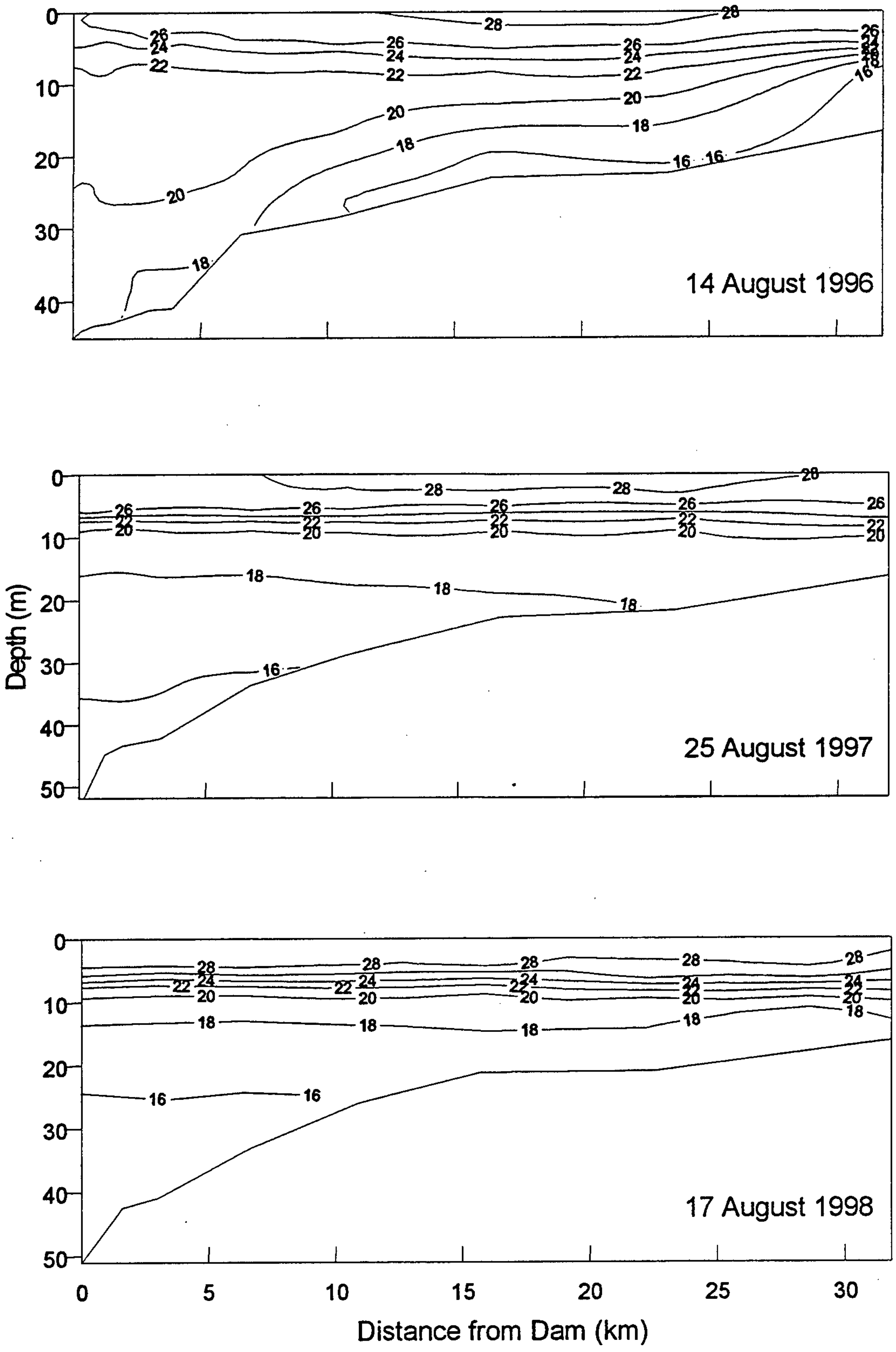


Figure 13. Longitudinal and vertical changes in temperature for Richard B. Russell Lake during August 1996-1998.

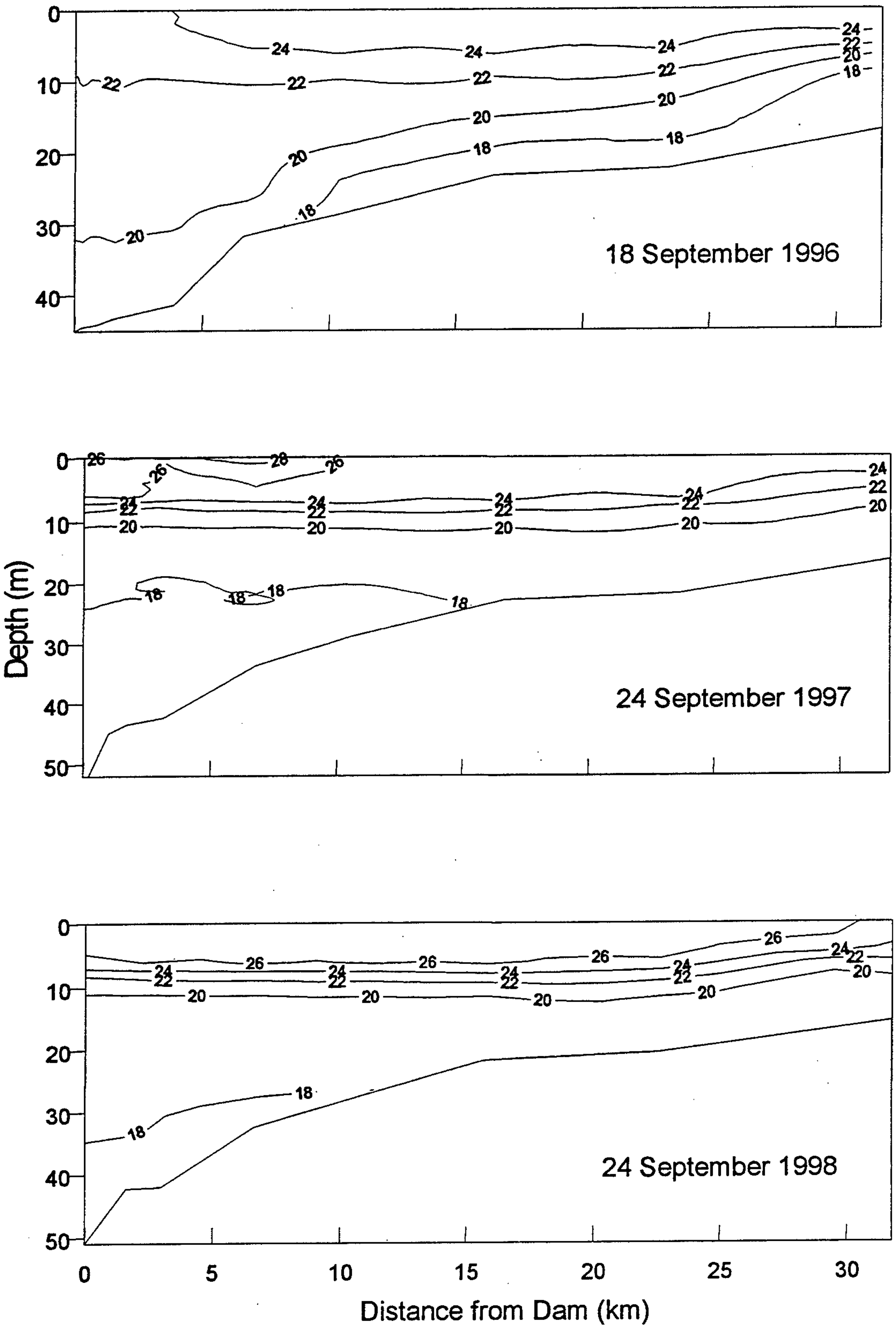


Figure 14. Longitudinal and vertical changes in temperature for Richard B. Russell Lake during September 1996-1998.

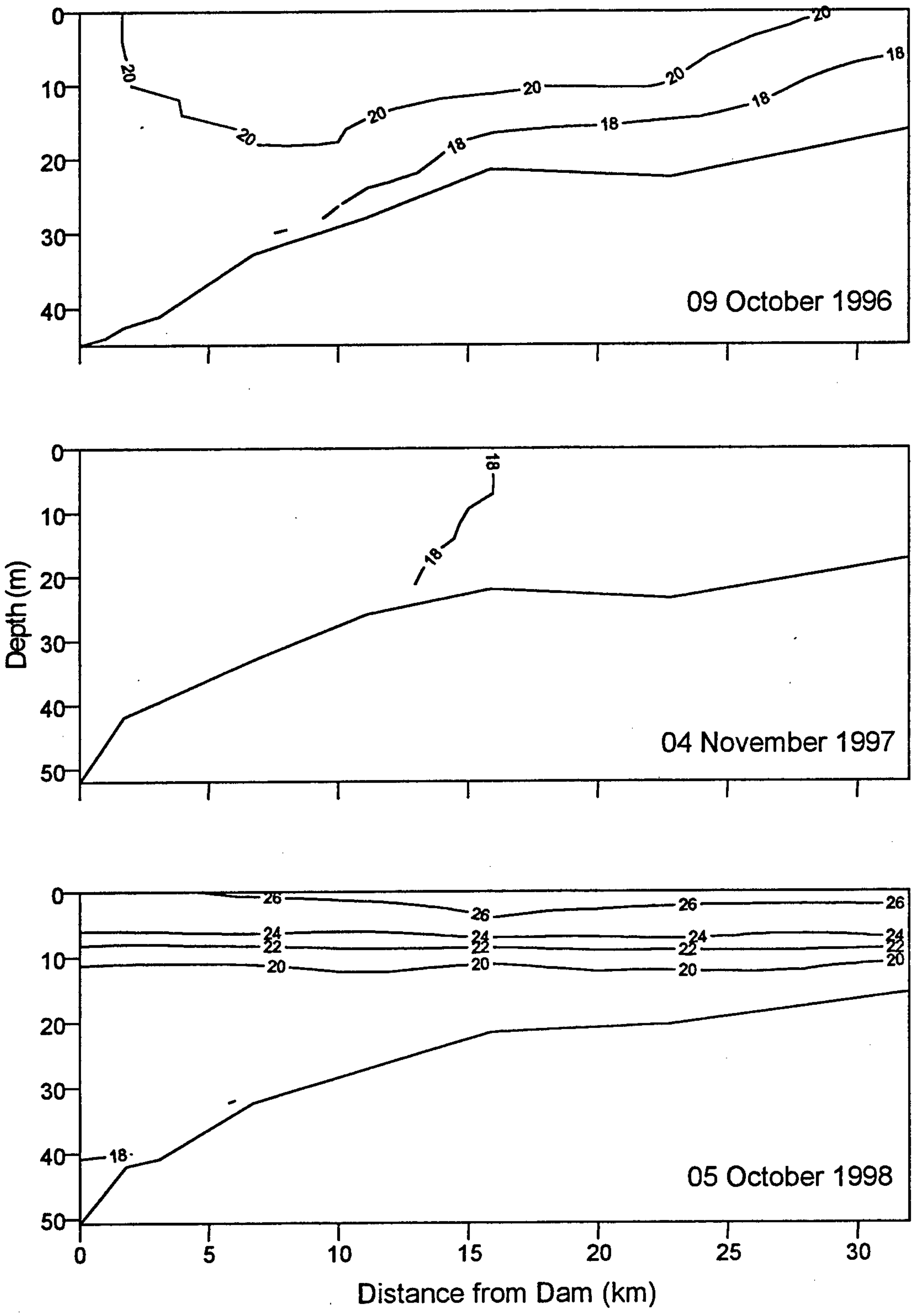


Figure15. Longitudinal and vertical changes in temperature for Richard B. Russell Lake during October 1996, 1998 and November 1997.

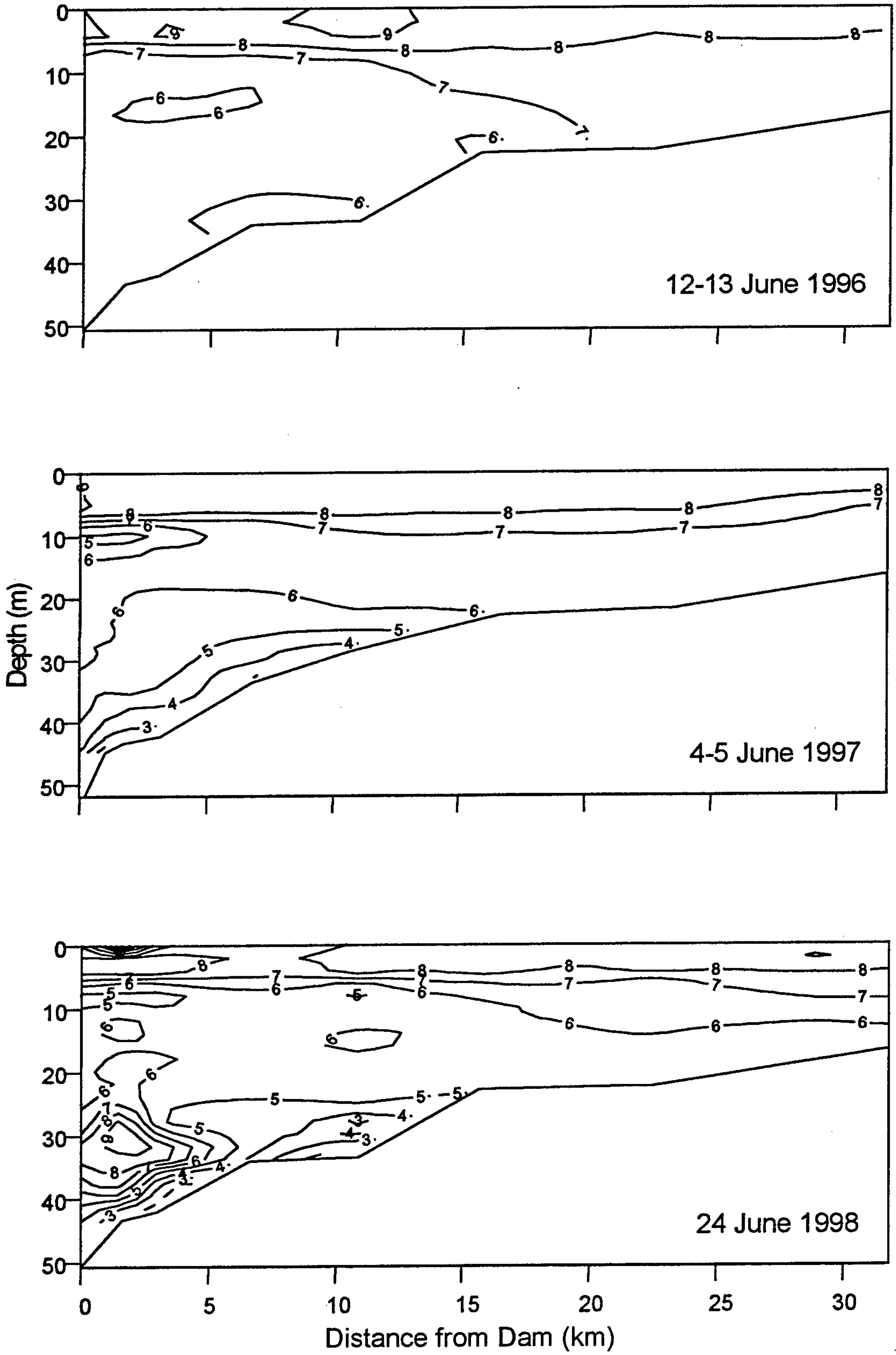


Figure 16. Longitudinal and vertical changes in dissolved oxygen concentration for Richard B. Russell Lake during June 1996-1998.

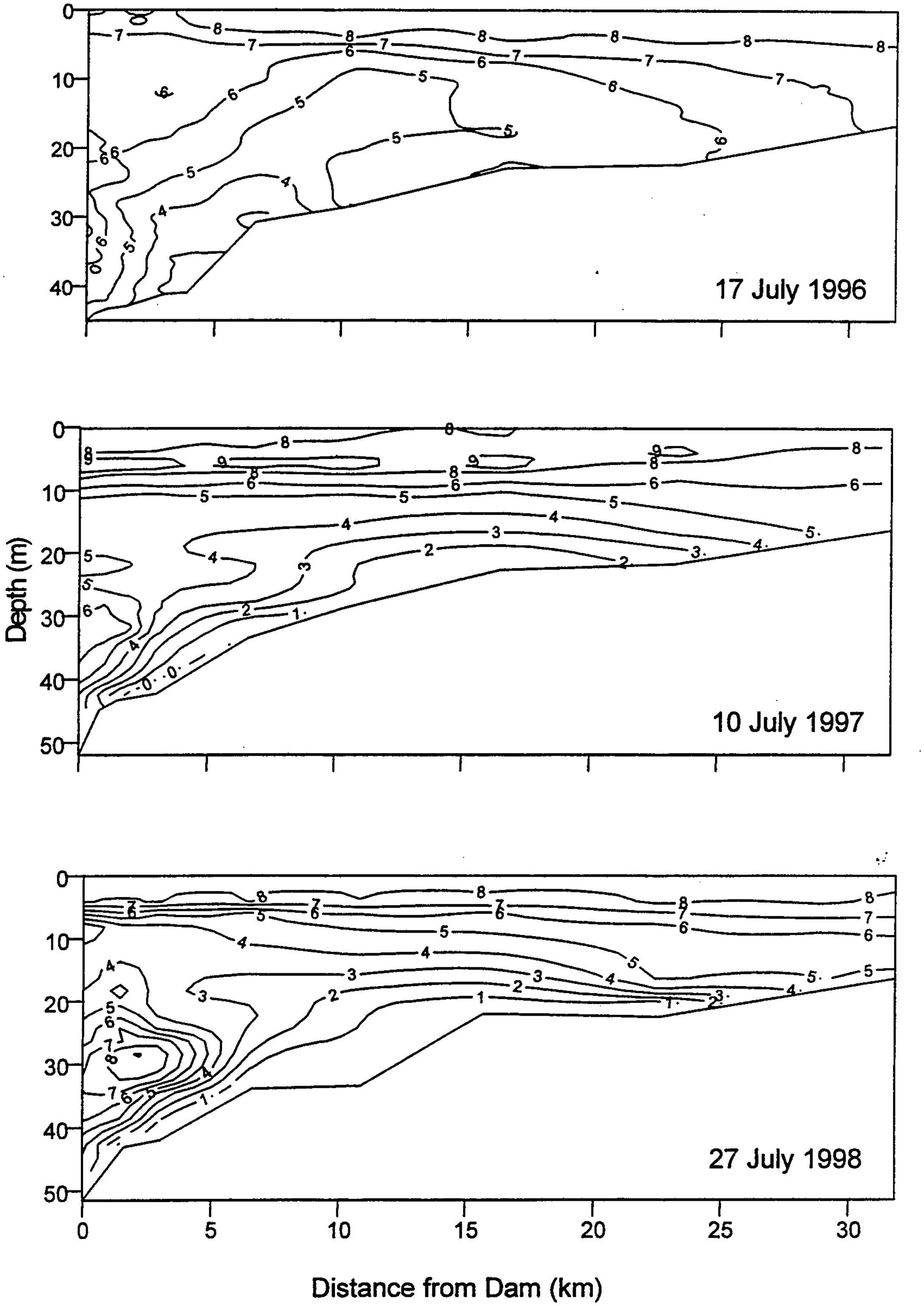


Figure 17. Longitudinal and vertical changes in dissolved oxygen concentration for Richard B. Russell Lake during July 1996-1998.

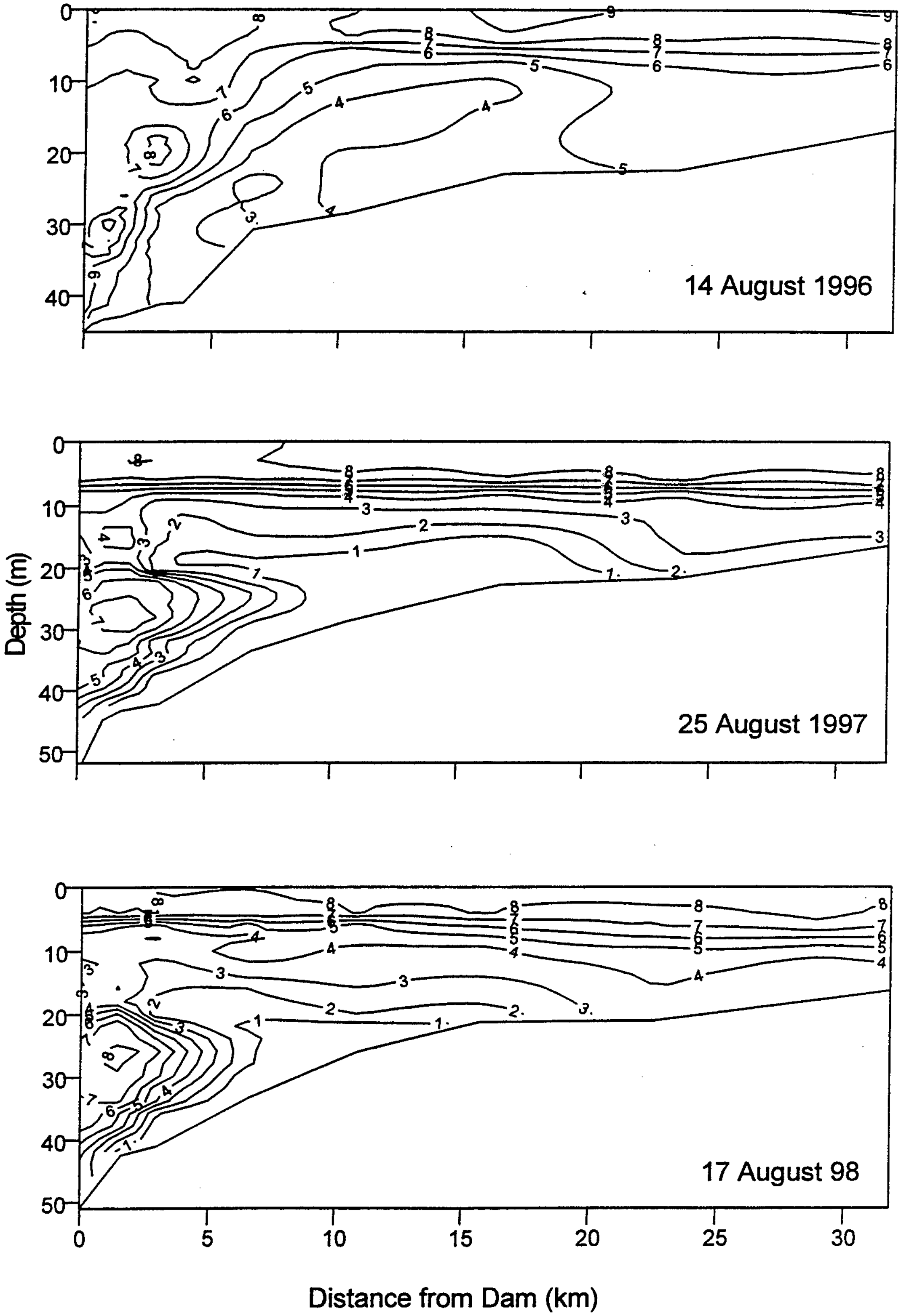


Figure 18. Longitudinal and vertical changes in dissolved oxygen concentration for Richard B. Russell Lake during August 1996-1998.

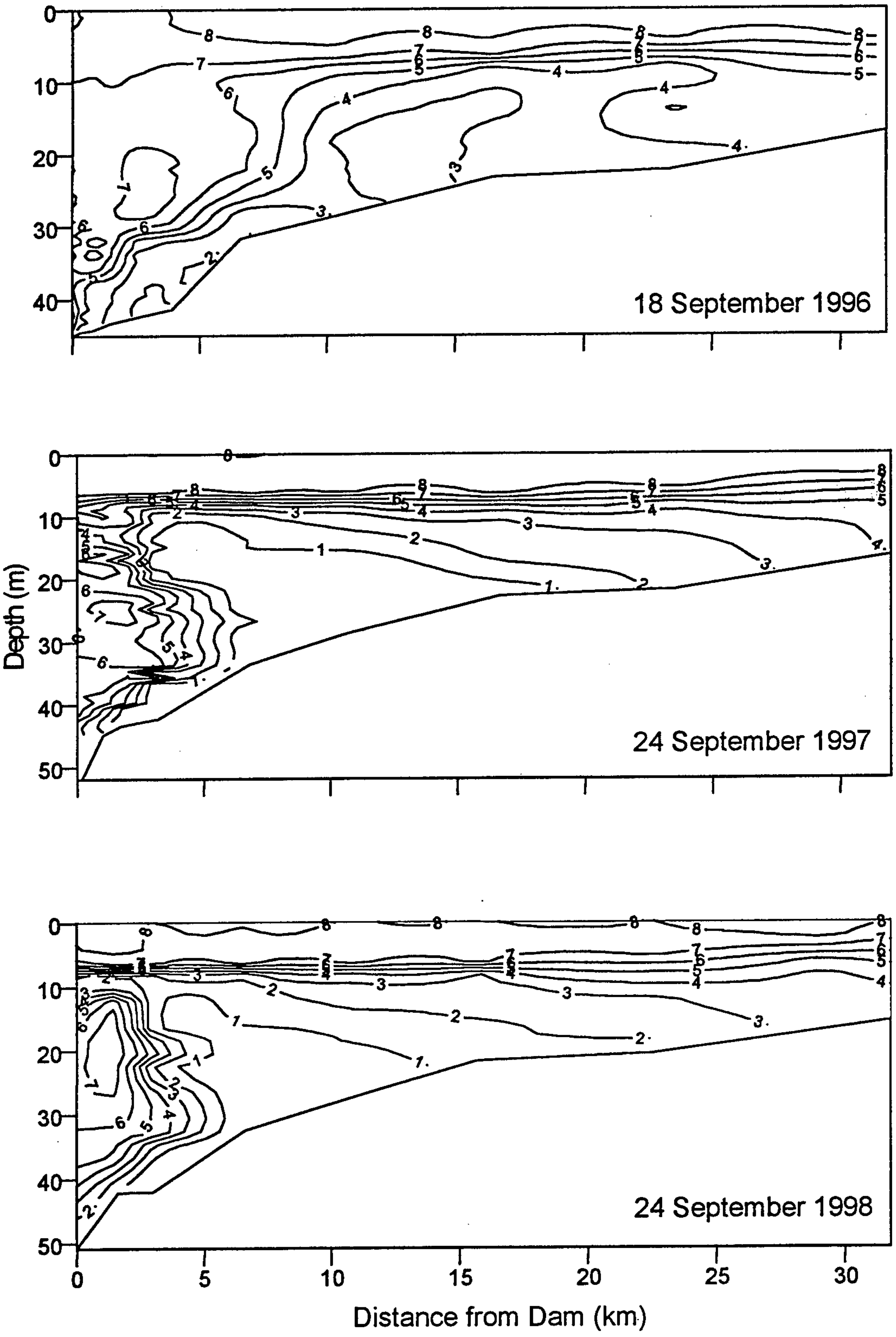


Figure 19. Longitudinal and vertical changes in dissolved oxygen concentration for Richard B. Russell Lake during September 1996-1998.

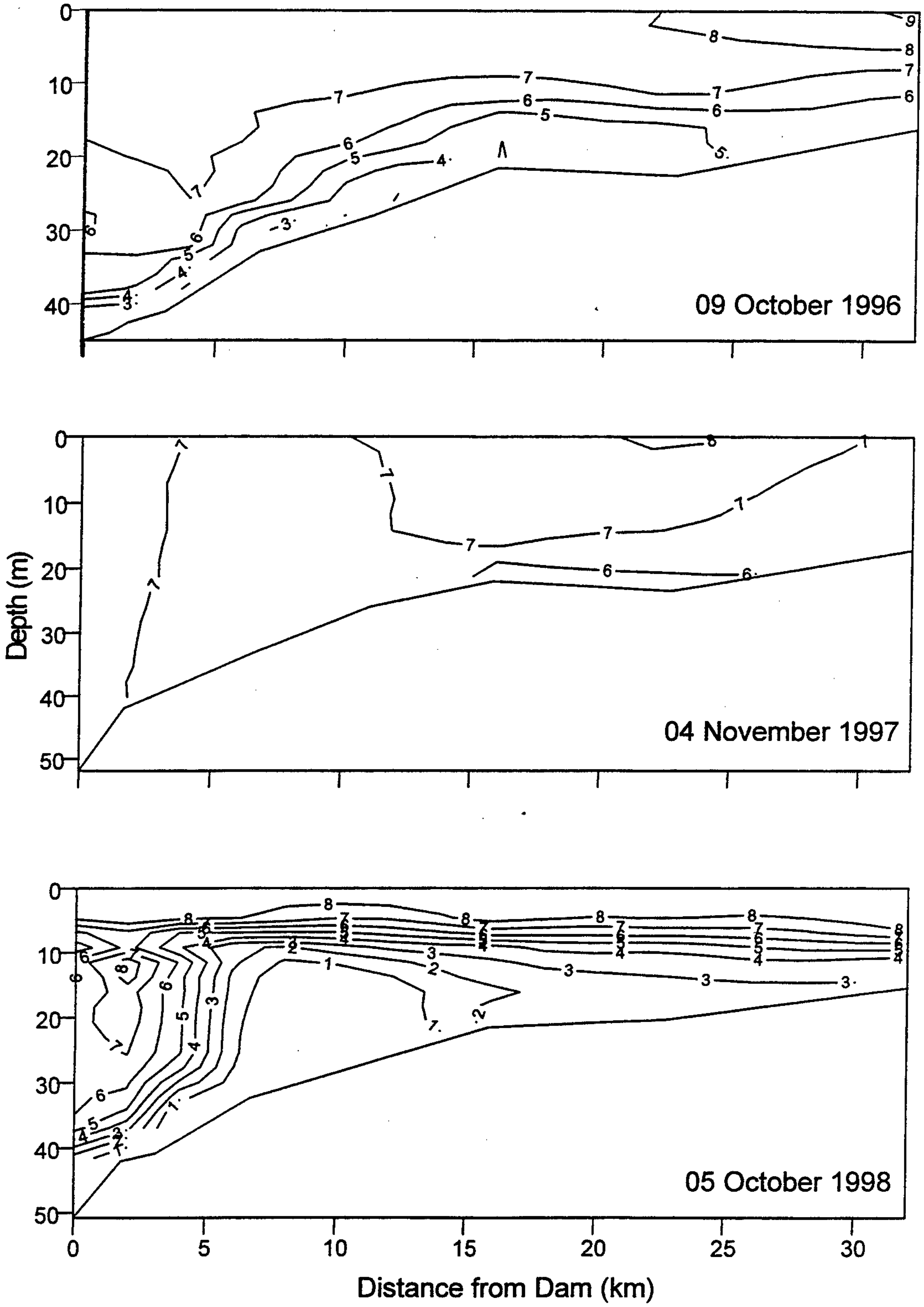


Figure 20. Longitudinal and vertical changes in dissolved oxygen concentration for Richard B. Russell Lake during October 1996-1998.

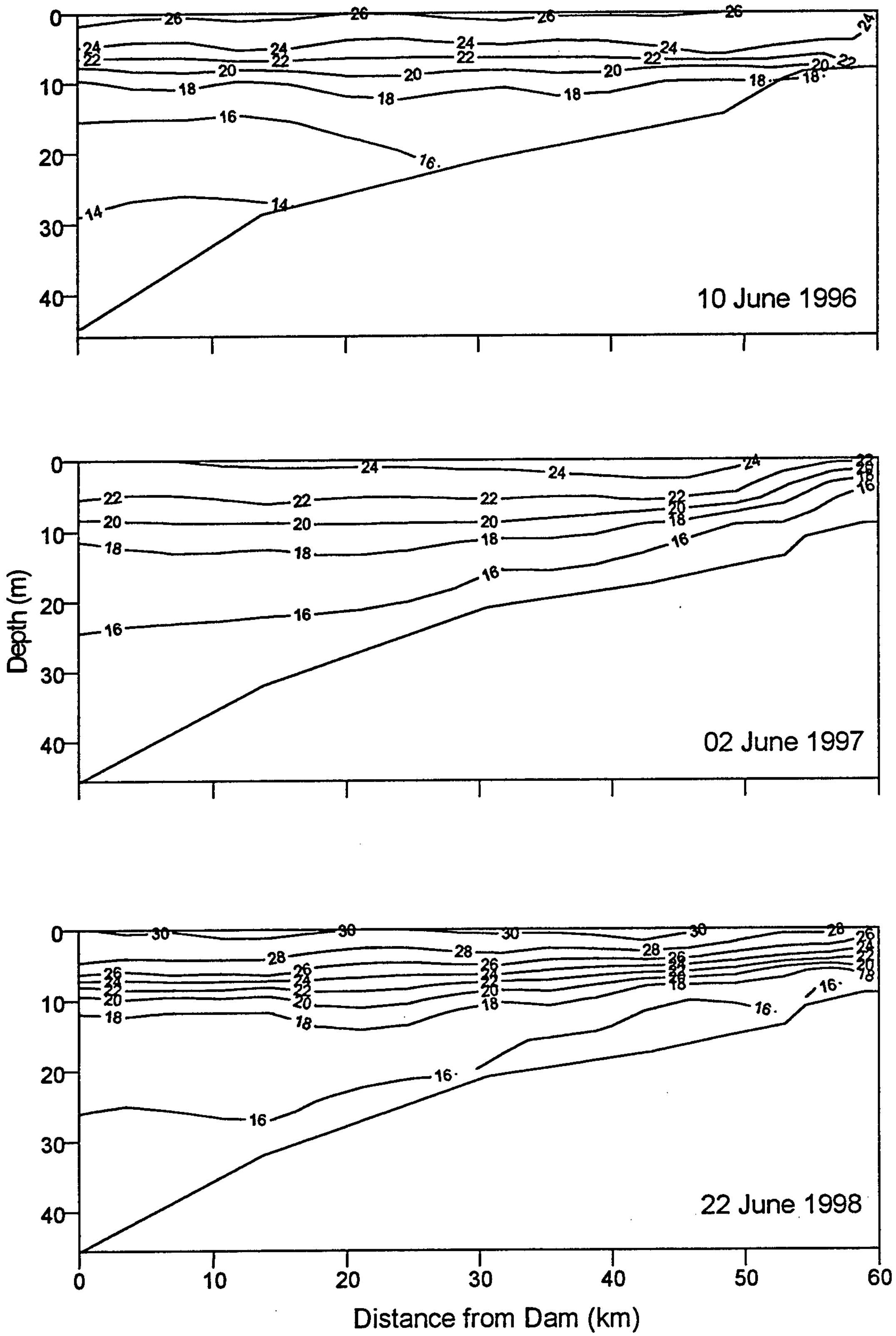


Figure 21. Longitudinal and vertical changes in temperature for J.Strom Thurmond Lake during June 1996-1998.

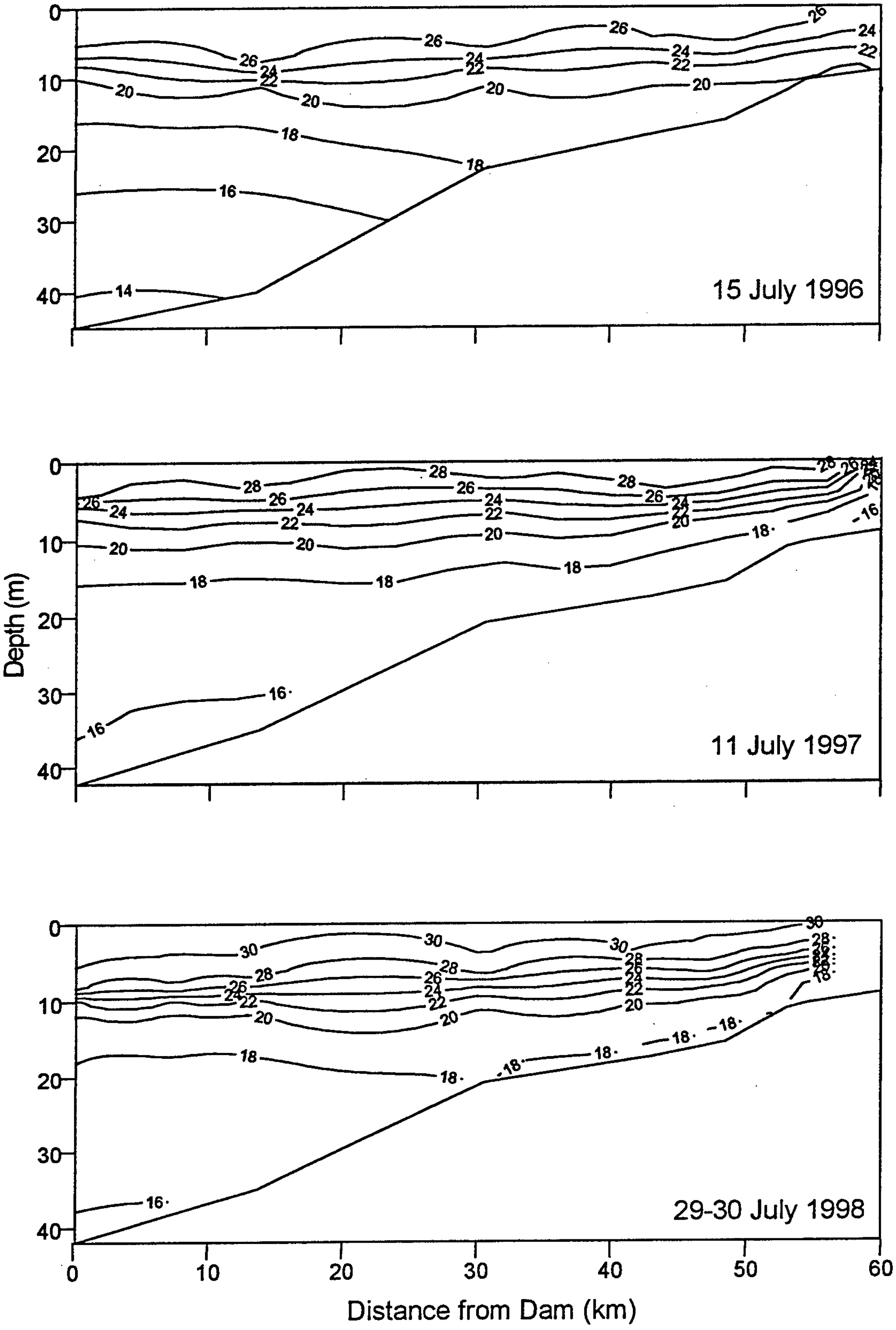


Figure 22. Longitudinal and vertical changes in temperature for J.Strom Thurmond Lake during July 1996-1998.

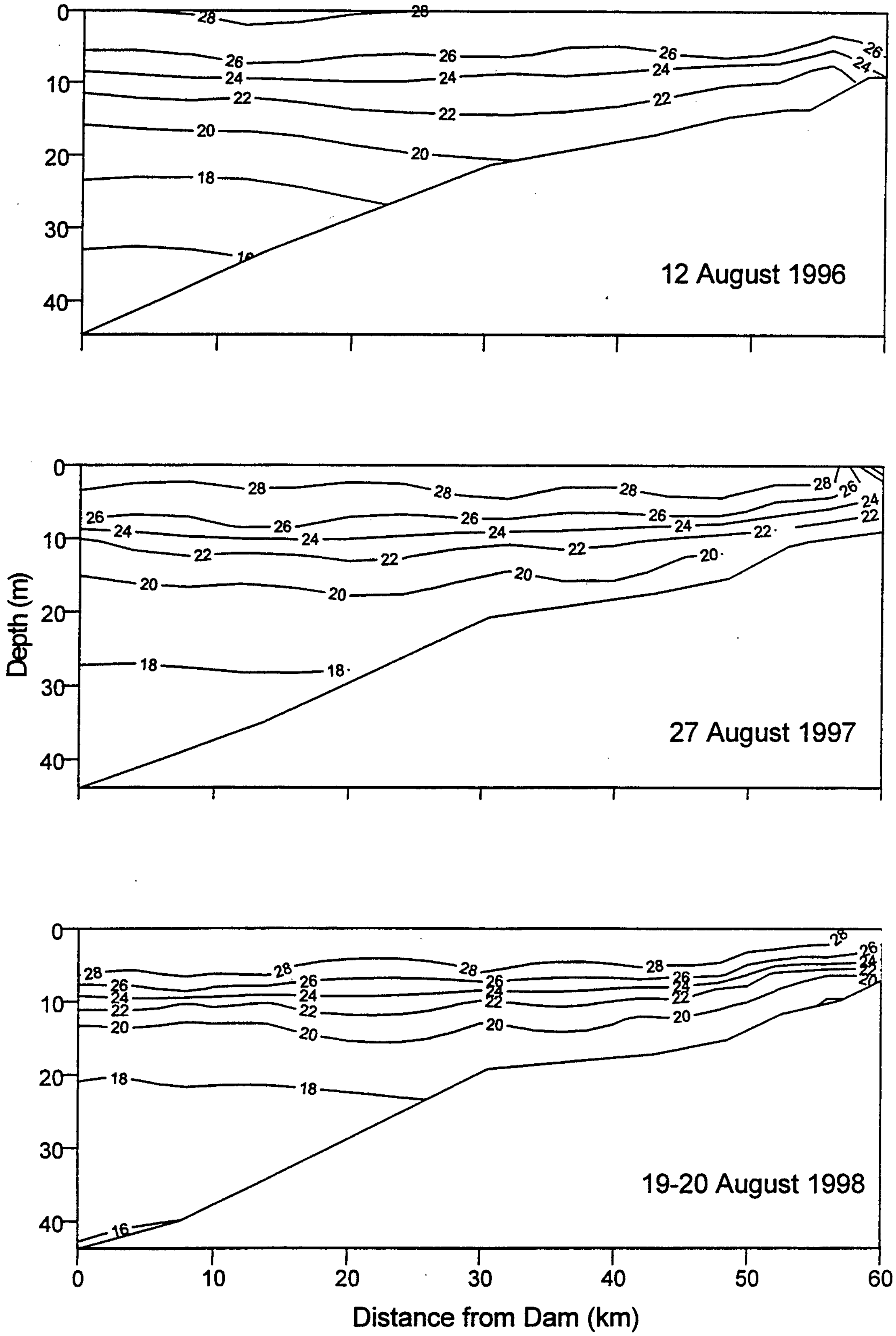


Figure 23. Longitudinal and vertical changes in temperature for J.Strom Thurmond Lake during August 1996-1998.

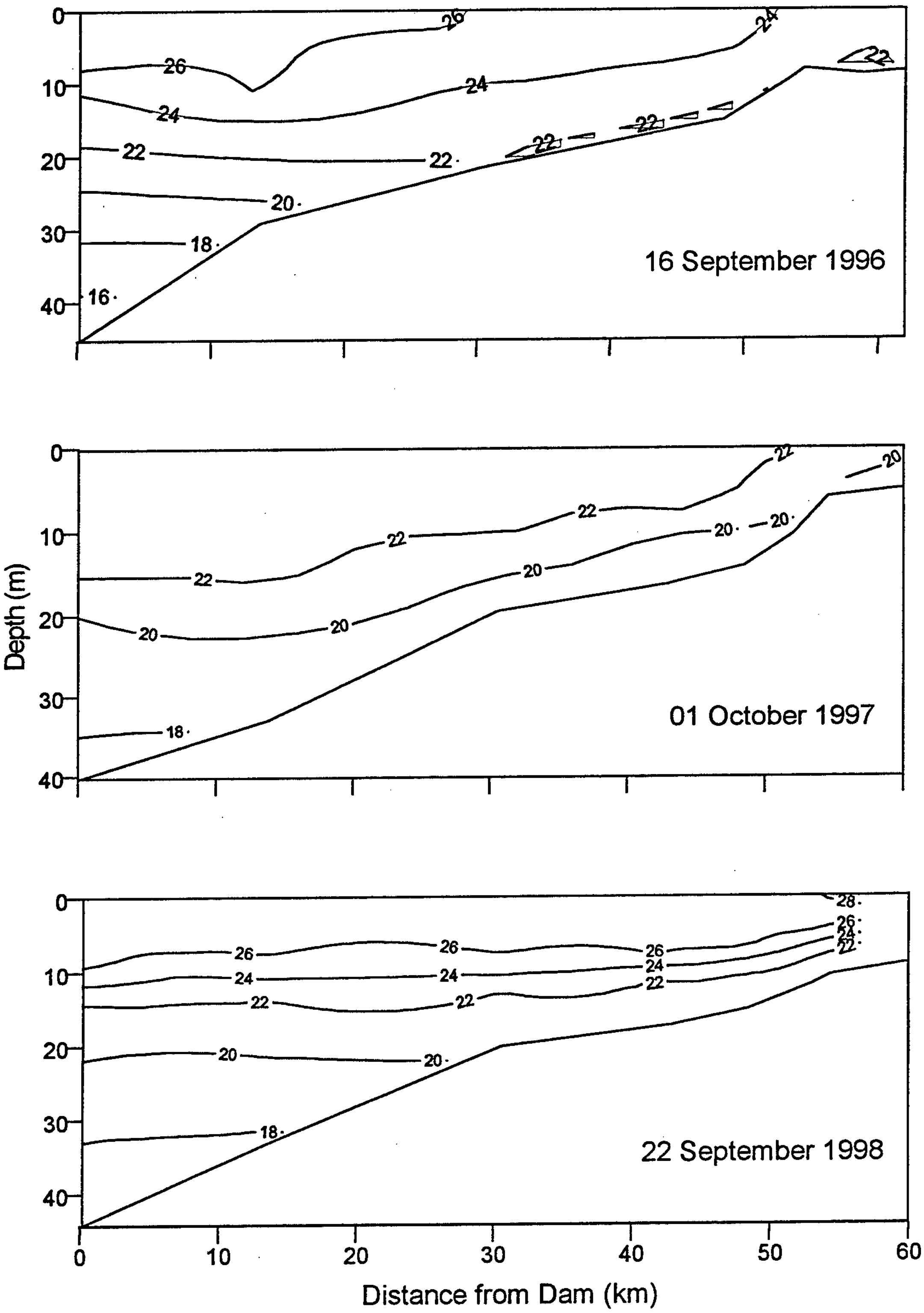


Figure 24. Longitudinal and vertical changes in temperature for J.Strom Thurmond Lake during September 1996-1998.

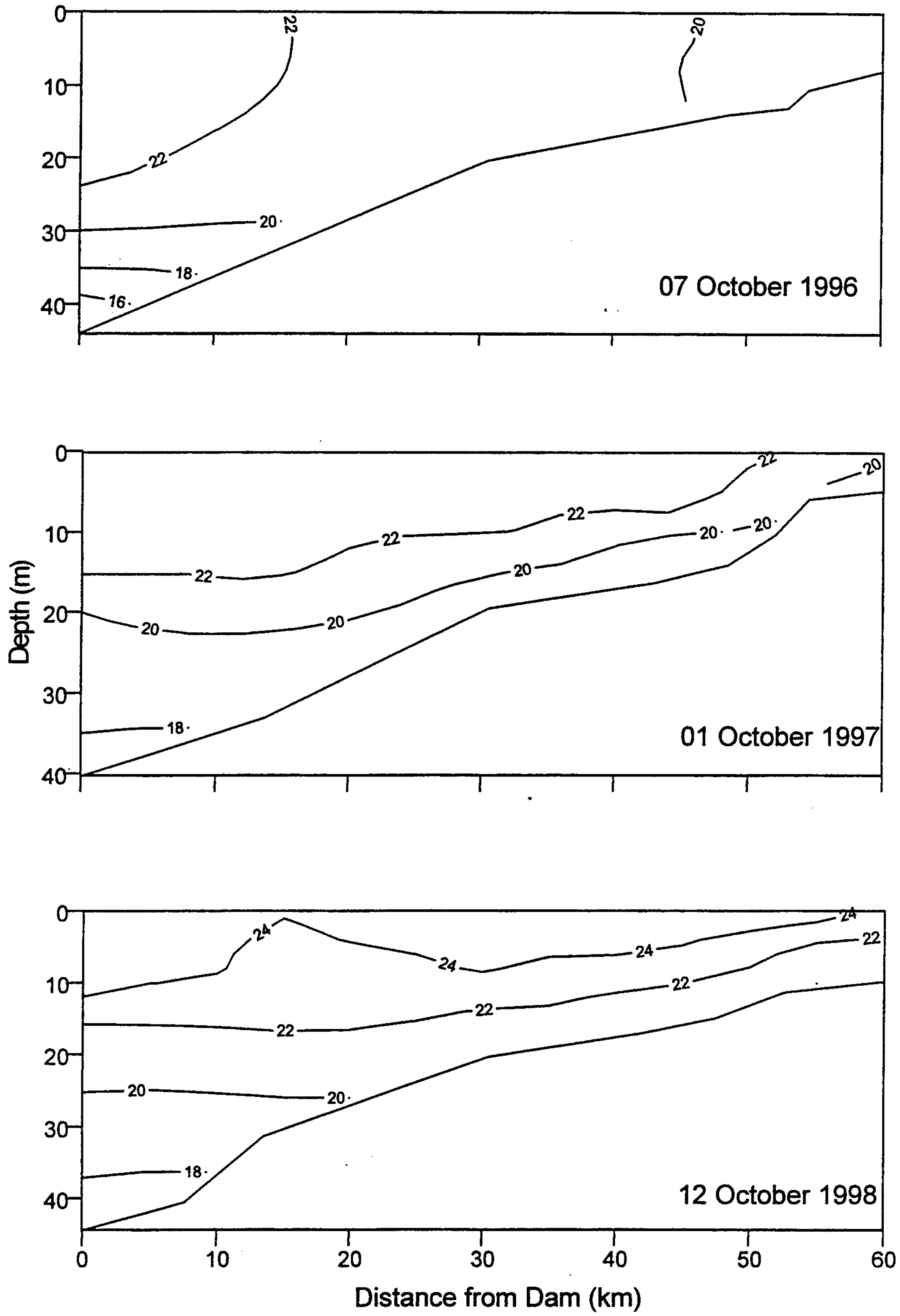


Figure 25. Longitudinal and vertical changes in temperature for J.Strom Thurmond Lake during October 1996-1998.

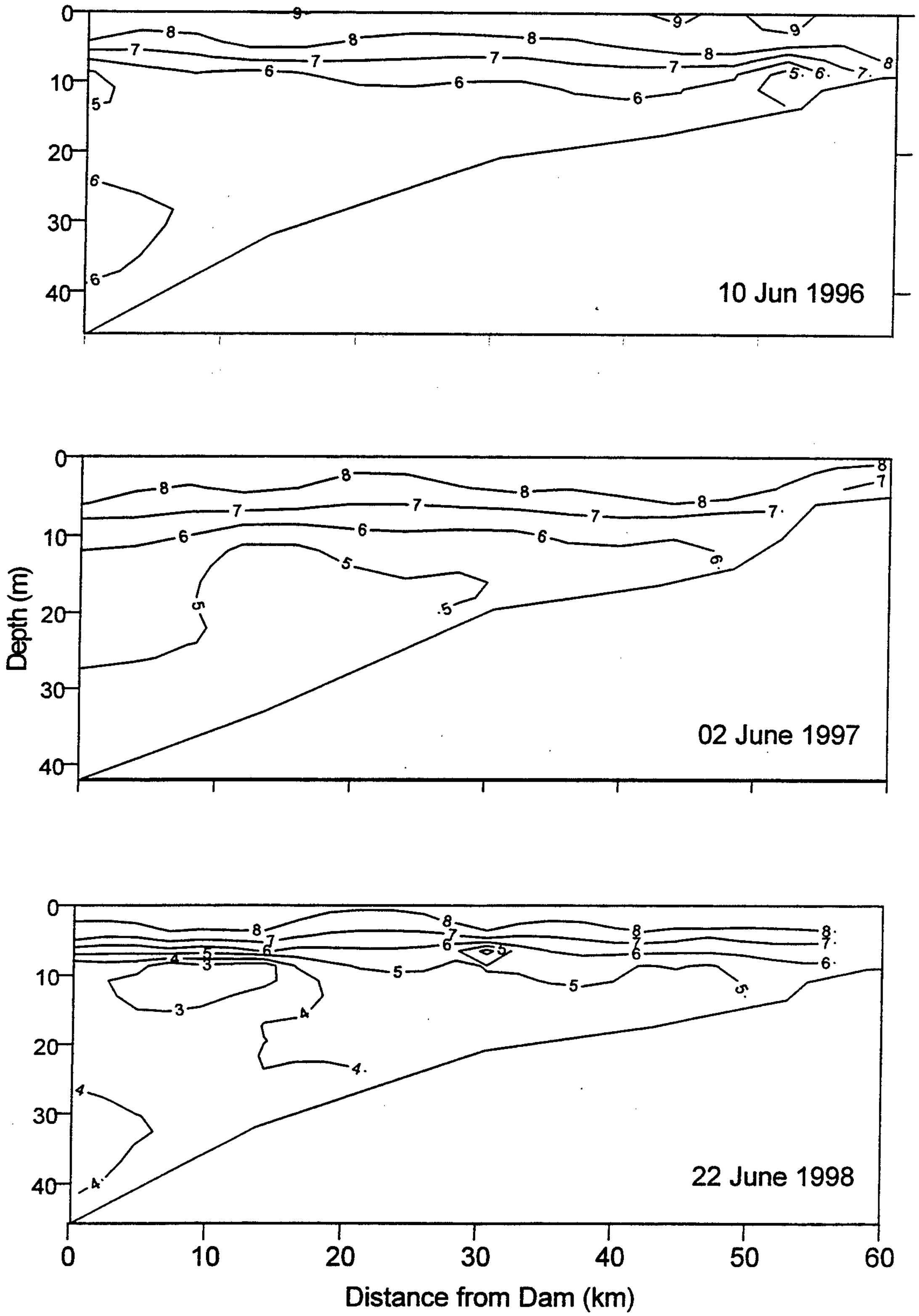


Figure 26. Longitudinal and vertical changes in dissolved oxygen concentration for J.Strom Thurmond Lake during June 1996-1998.

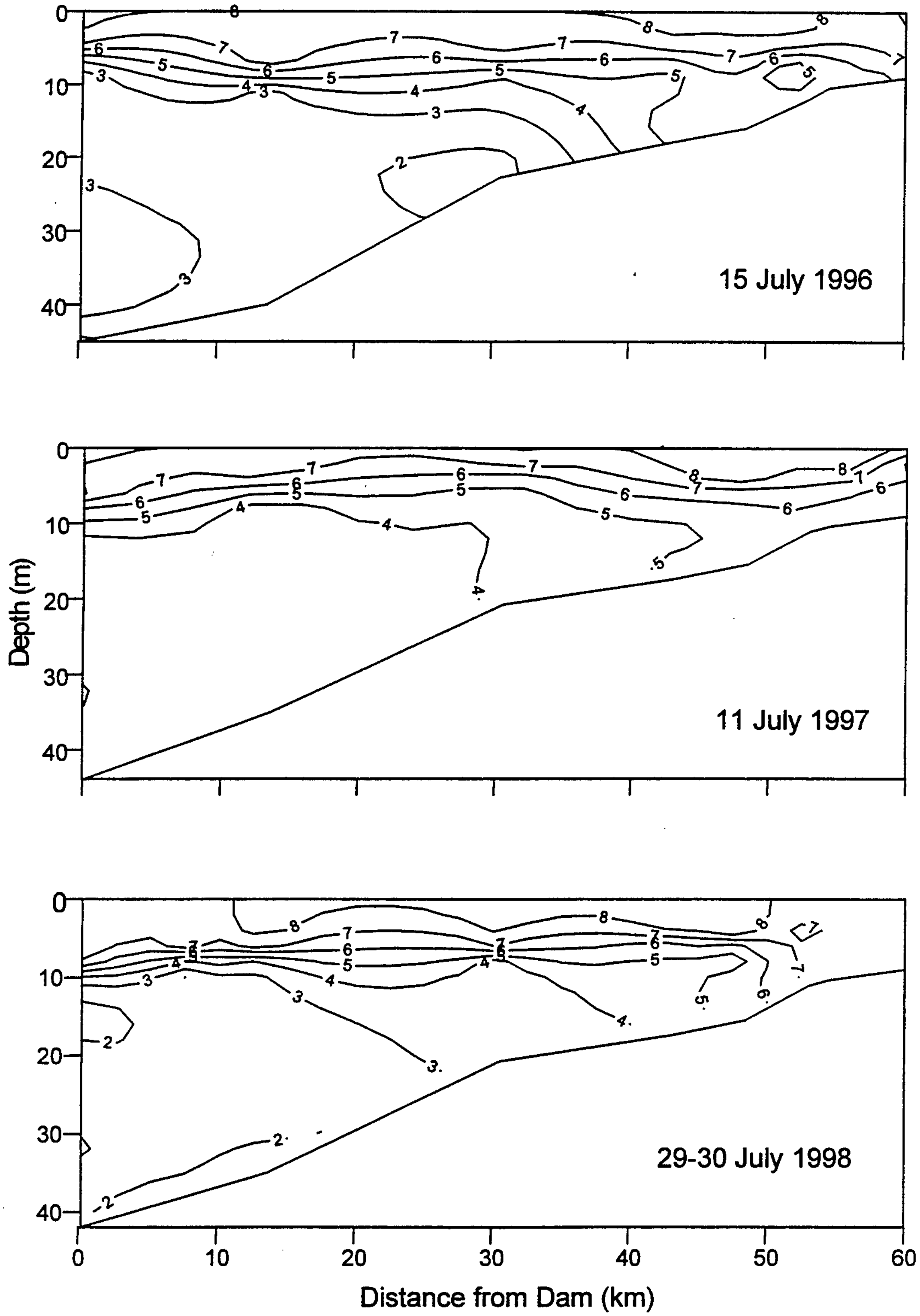


Figure 27. Longitudinal and vertical changes in dissolved oxygen concentration for J.Strom Thurmond Lake during July 1996-1998.

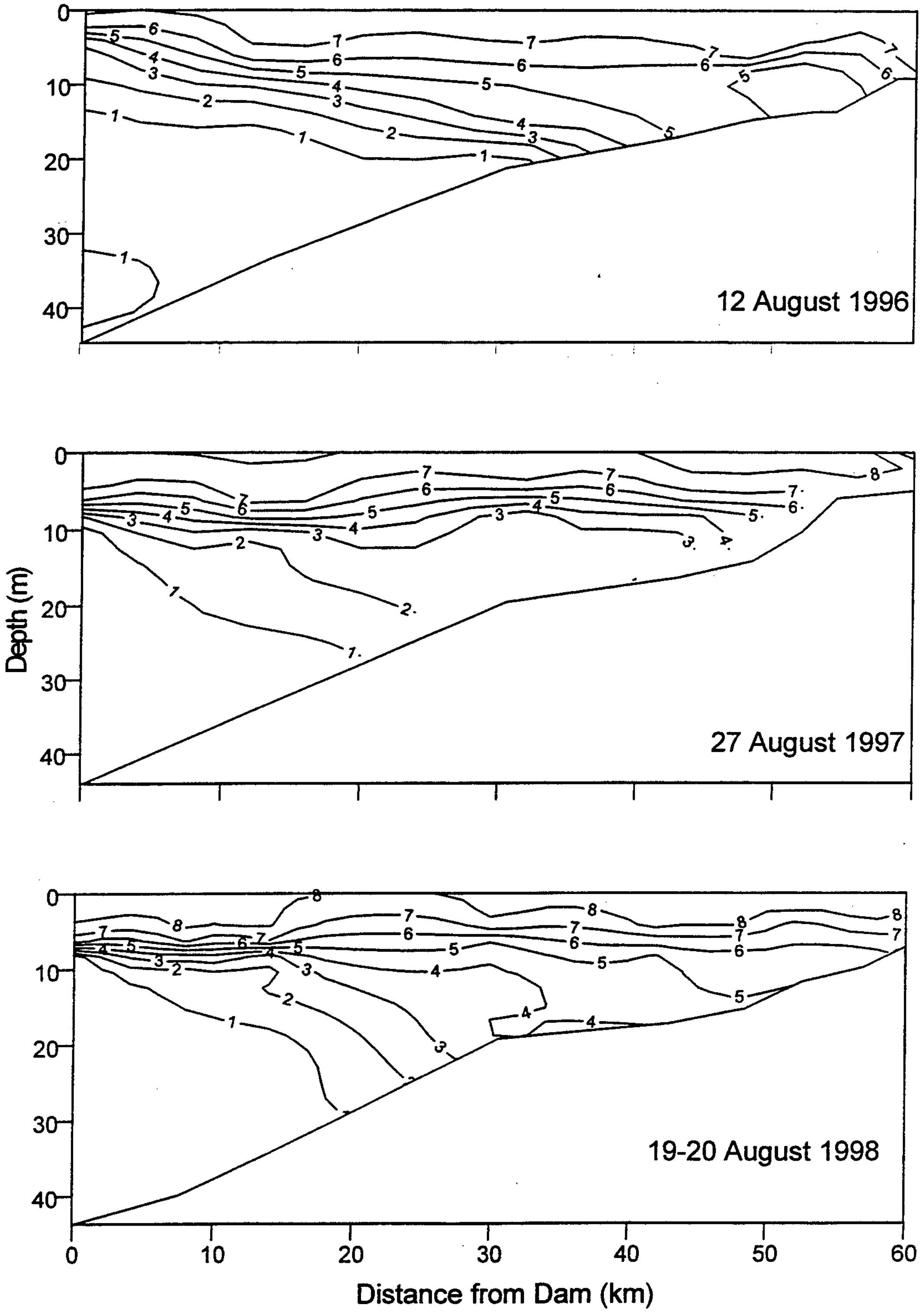


Figure 28. Longitudinal and vertical changes in dissolved oxygen concentration for J.Strom Thurmond Lake during August 1996-1998.

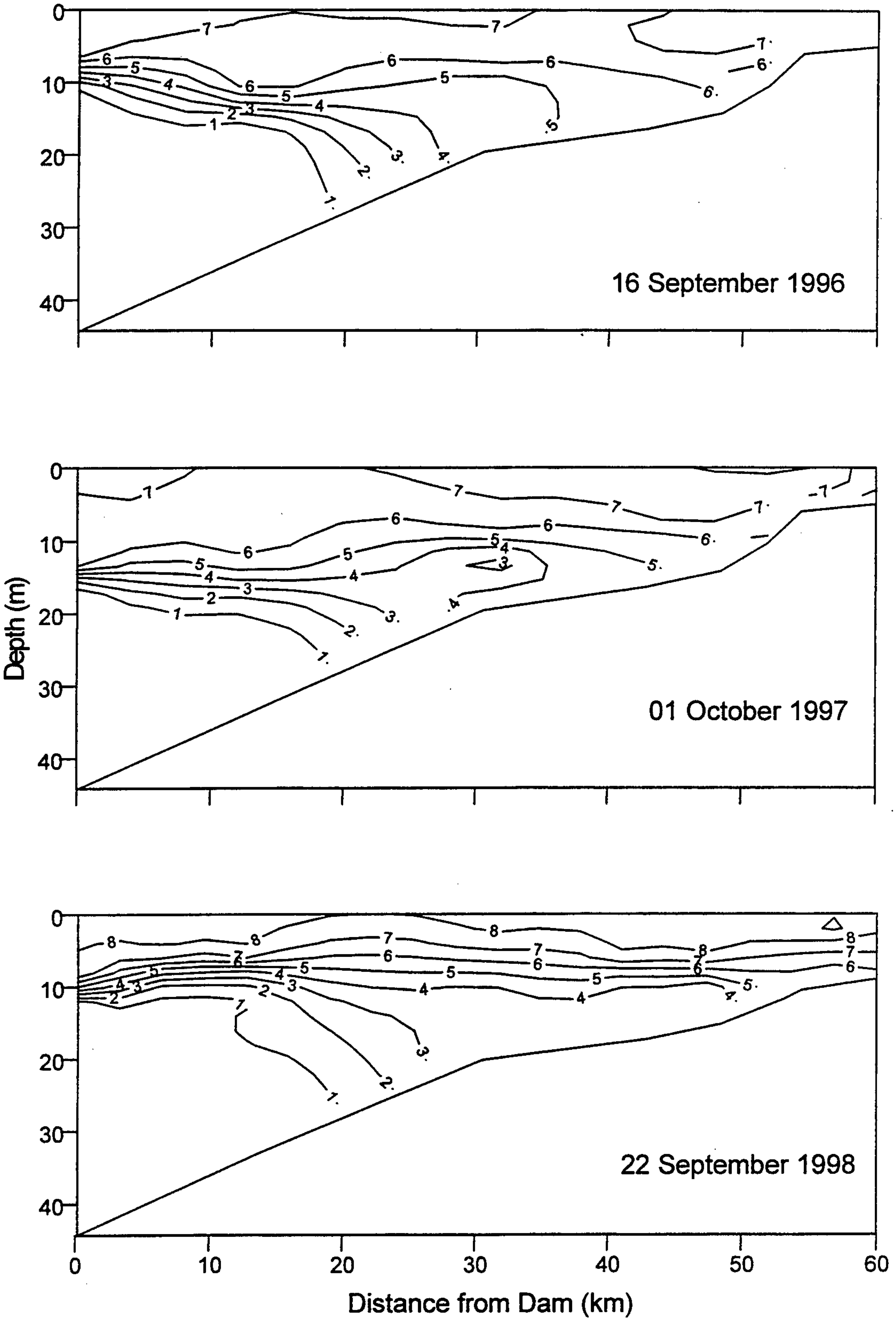


Figure 29. Longitudinal and vertical changes in dissolved oxygen concentration for J.Strom Thurmond Lake during September 1996-1998.

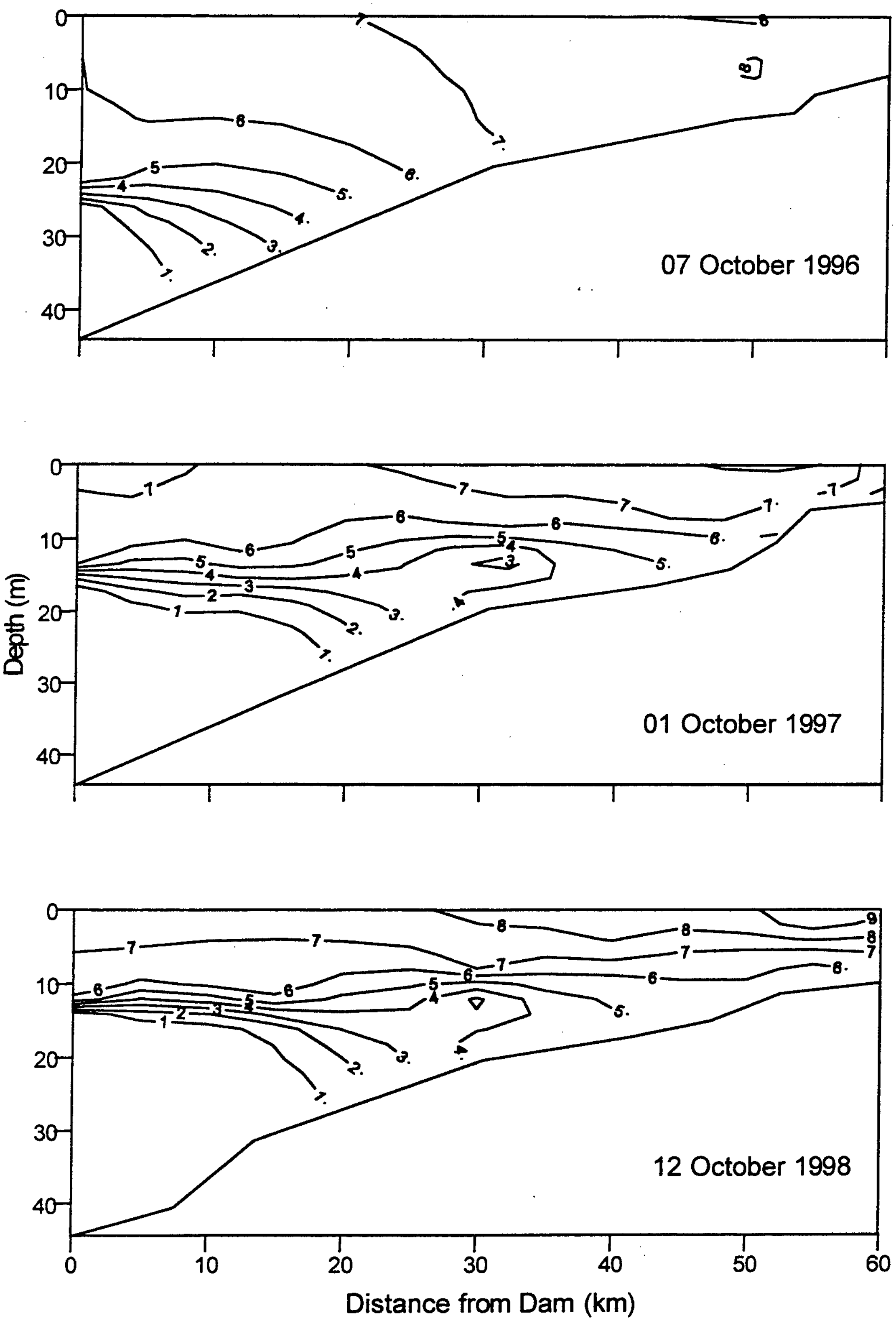


Figure 30. Longitudinal and vertical changes in dissolved oxygen concentration for J.Strom Thurmond Lake during October 1996-1998.

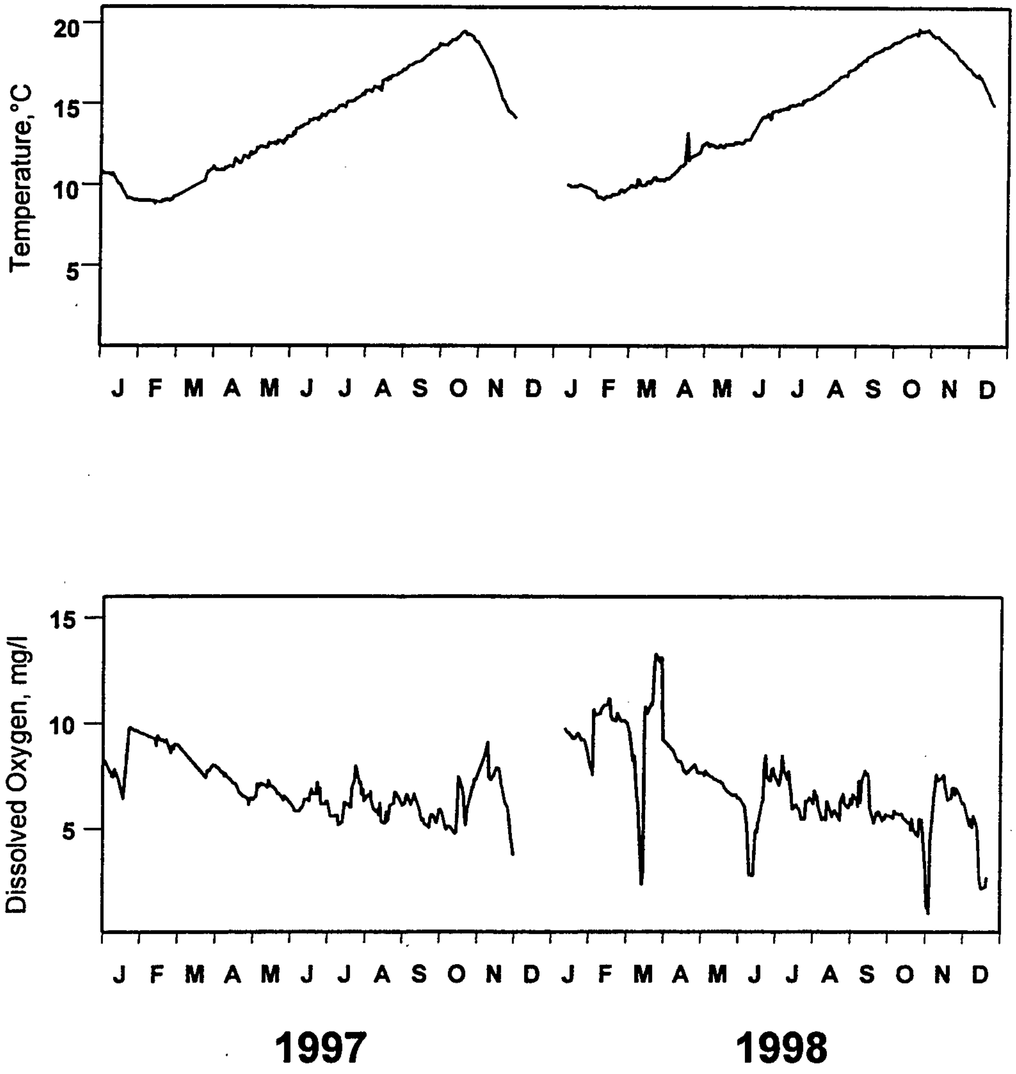


Figure 31. Richard B. Russell tailrace continuous release data for temperature (top) and dissolved oxygen concentration (bottom) for 1997 and 1998.

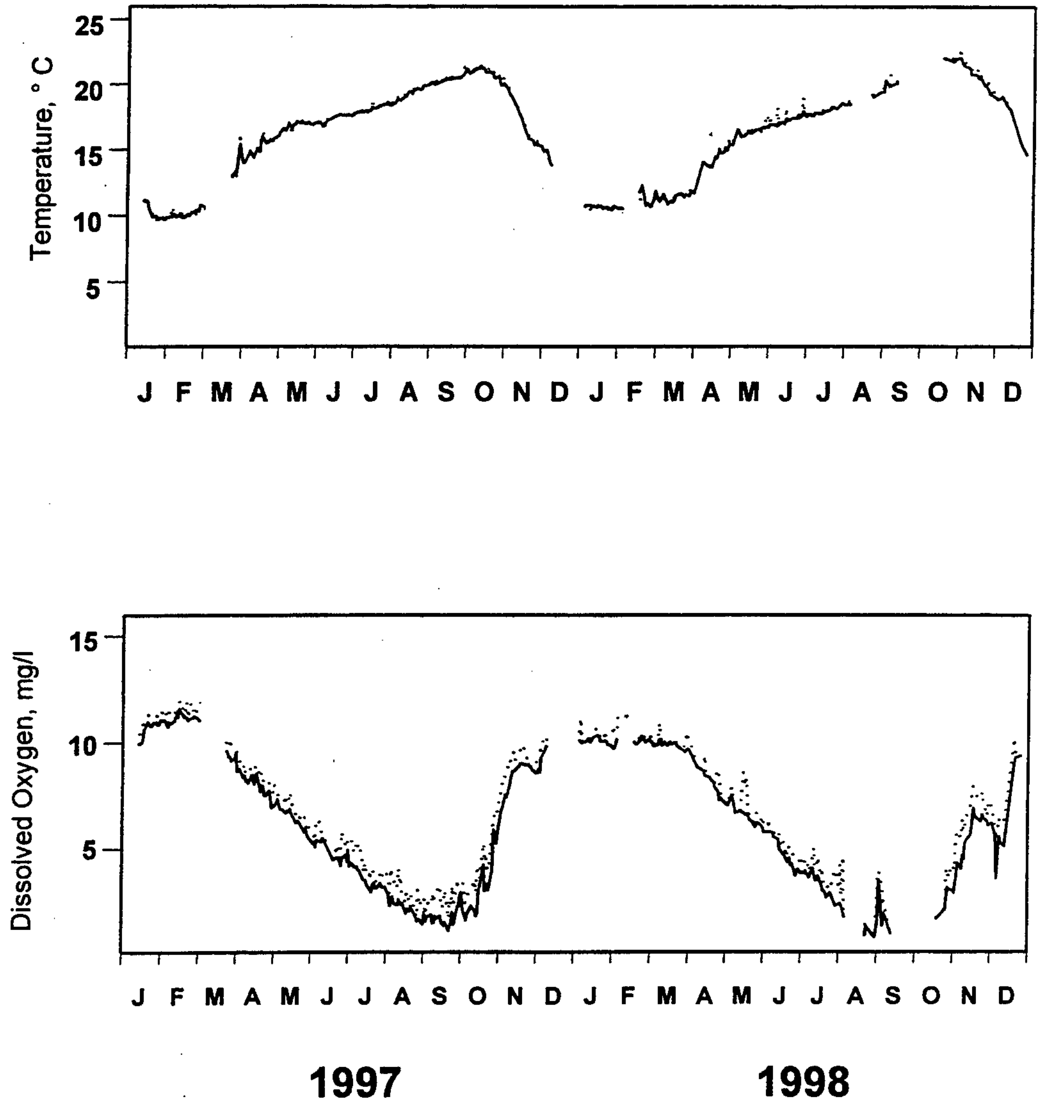


Figure 32. J. Strom Thurmond tailrace continuous release data for temperature (top) and dissolved oxygen concentration (bottom) for 1997 and 1998.

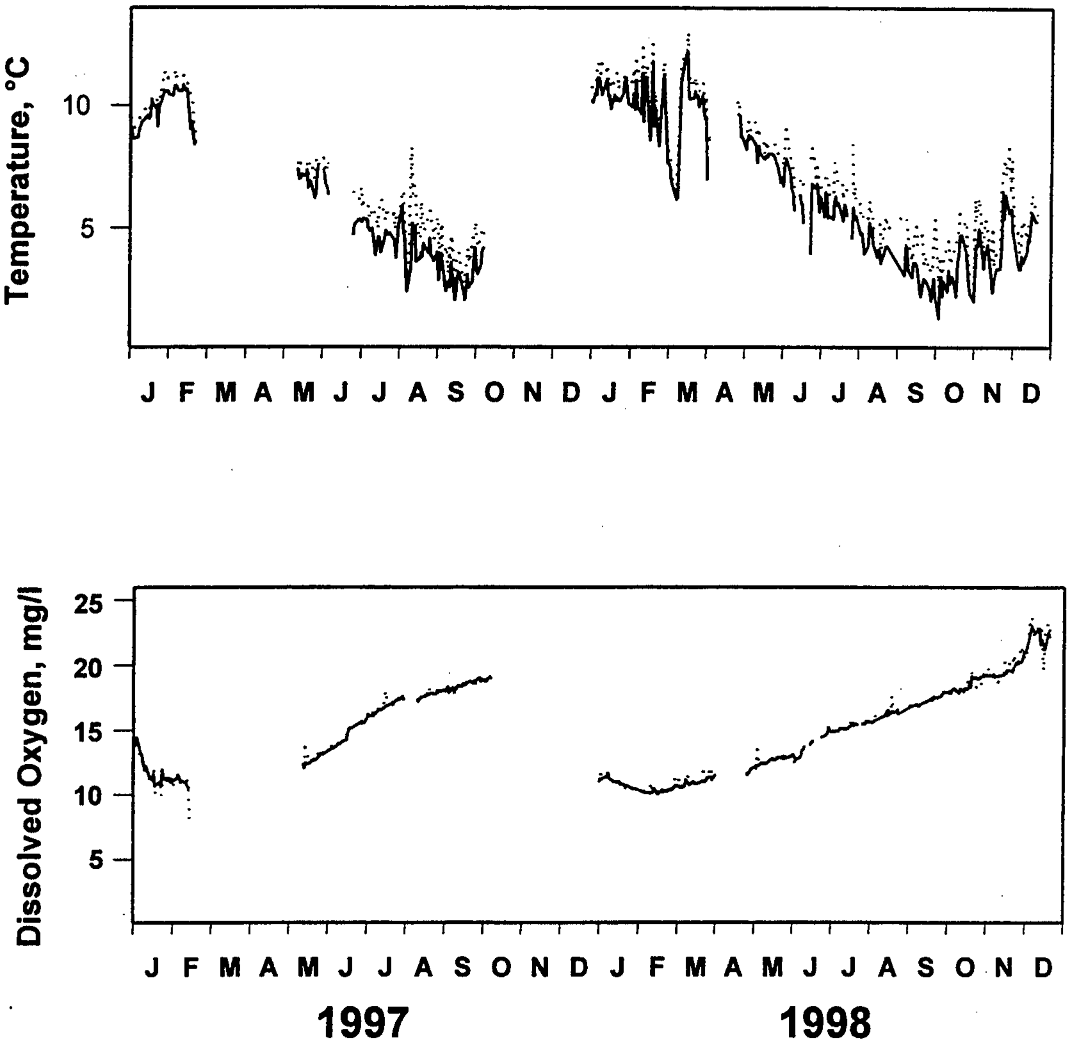


Figure 33. Hartwell tailrace continuous release data for temperature (top) and dissolved oxygen concentration (bottom) for 1997 and 1998.

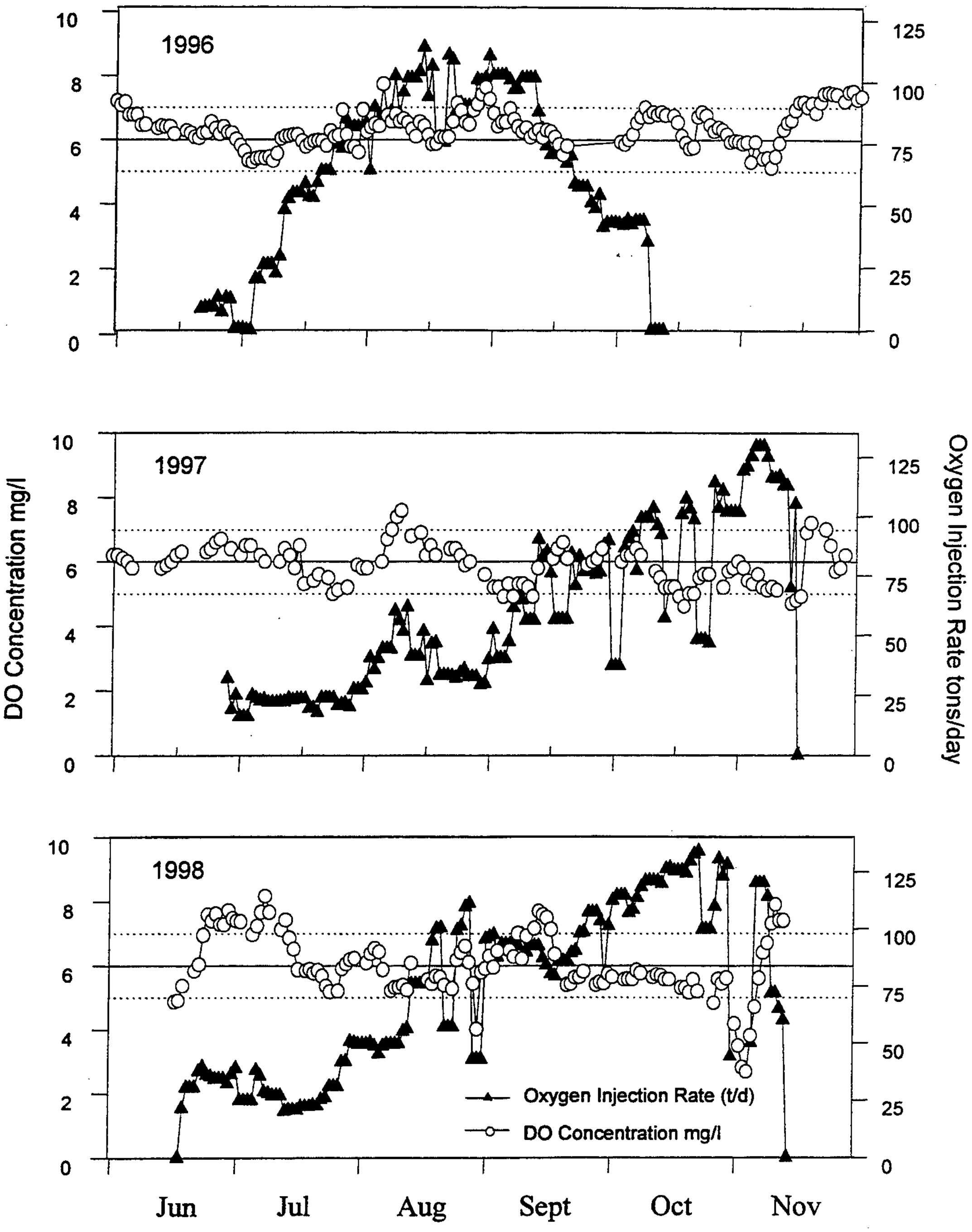


Figure 34. Oxygen injection rate (metric tons/day) and dissolved oxygen (DO) concentration (mg/l) during the period 1996-1998.

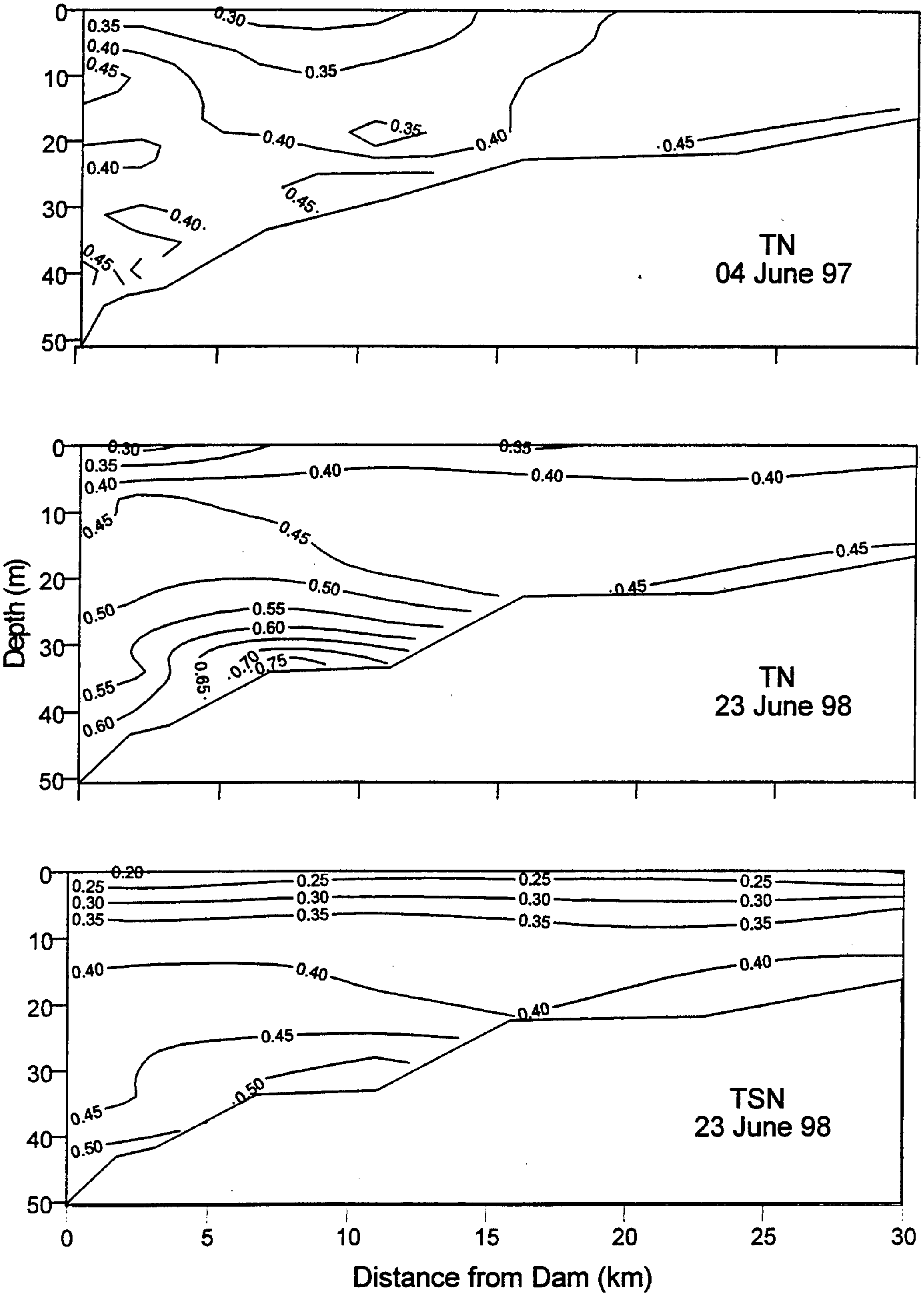


Figure 35. Spatial distribution of total and total soluble nitrogen in Richard B. Russell Lake during June 1997 and 1998.

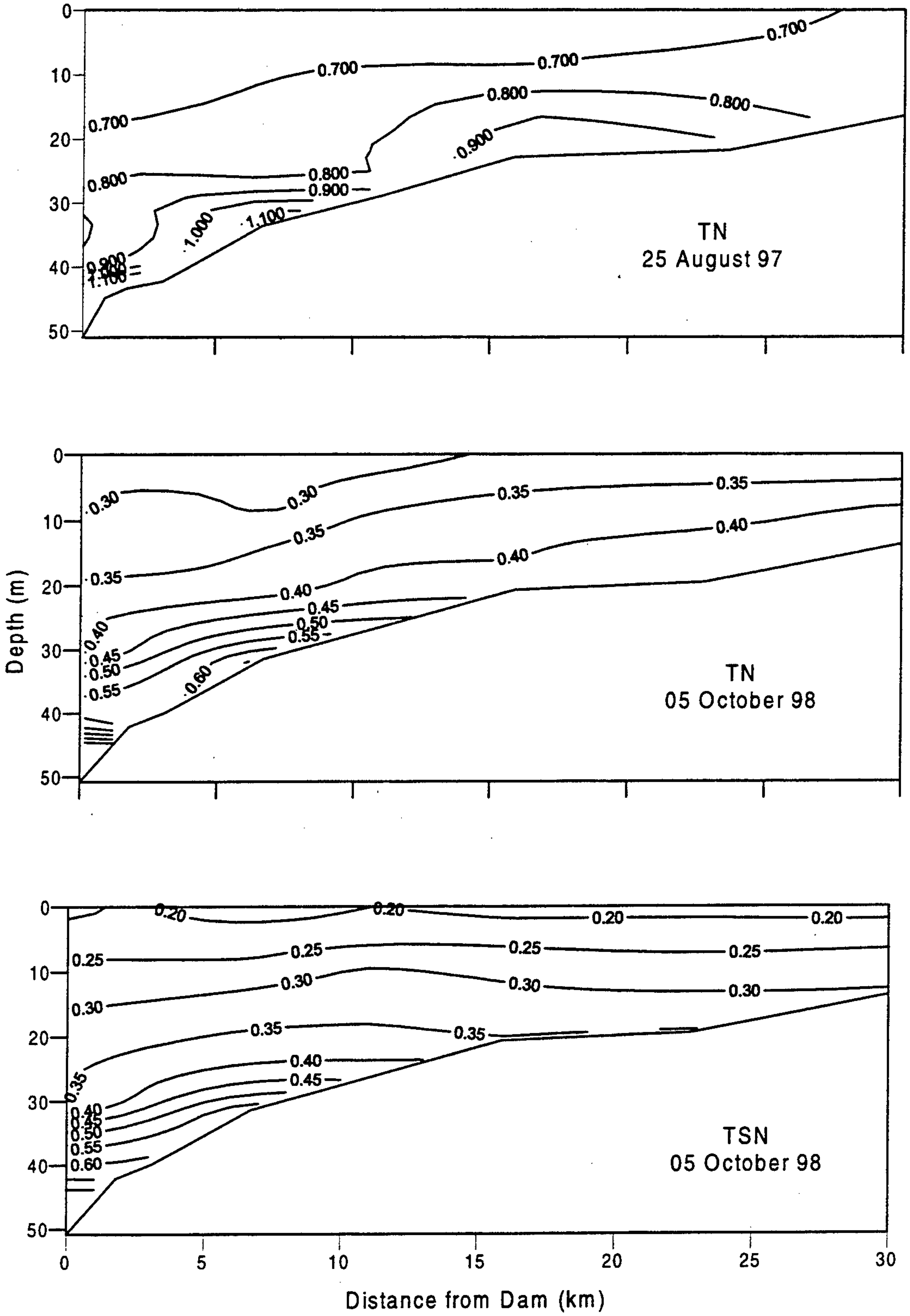


Figure 36. Spatial distribution of total and total soluble nitrogen in Richard B. Russell Lake during August 1997 and October 1998.

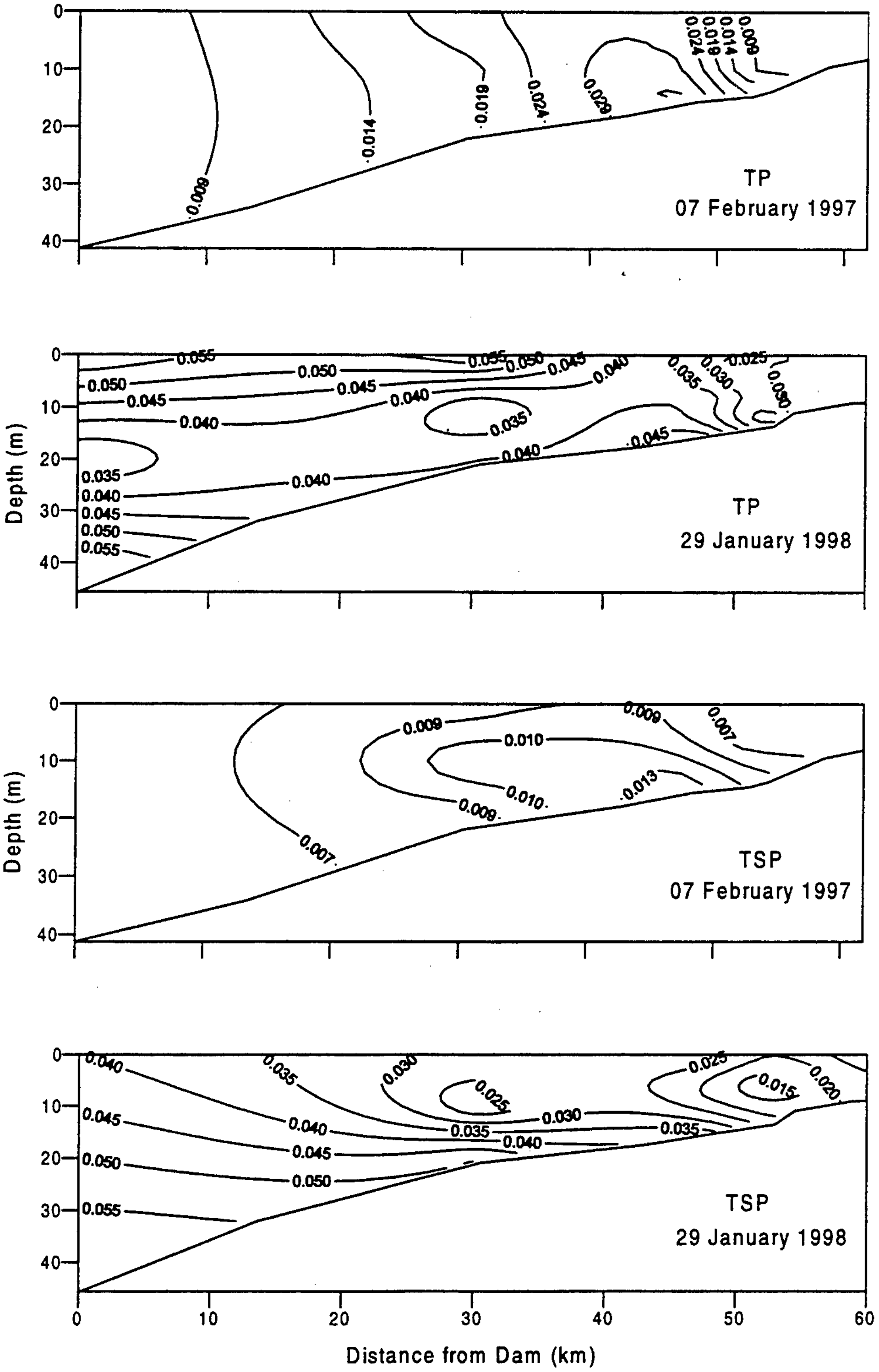


Figure 37. Spatial distribution of total and total soluble phosphorus in J. Strom Thurmond Lake during February 1997 and January 1998.

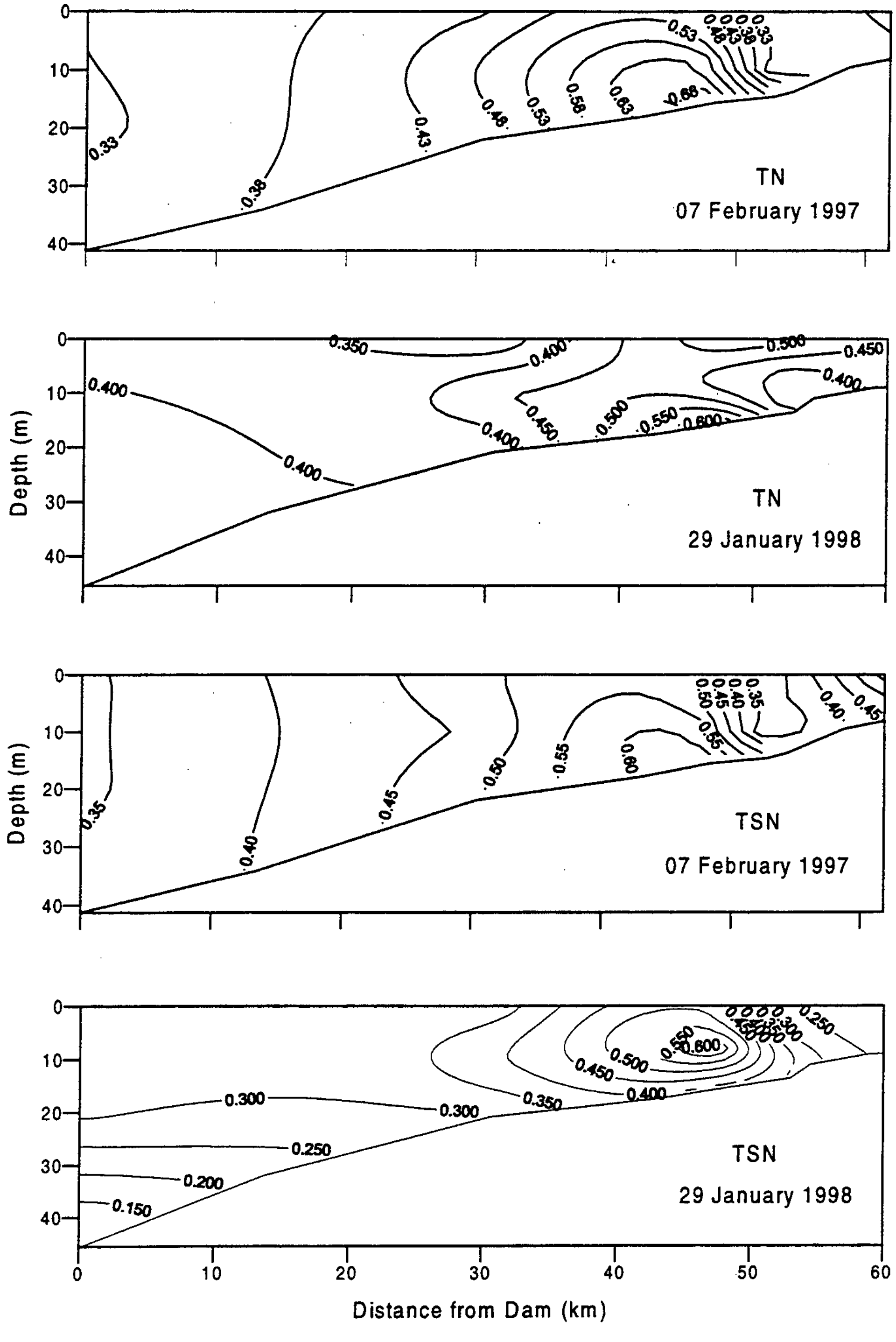


Figure 38. Spatial distribution of total and total soluble nitrogen in J. Strom Thurmond Lake during February 1997 and January 1998.

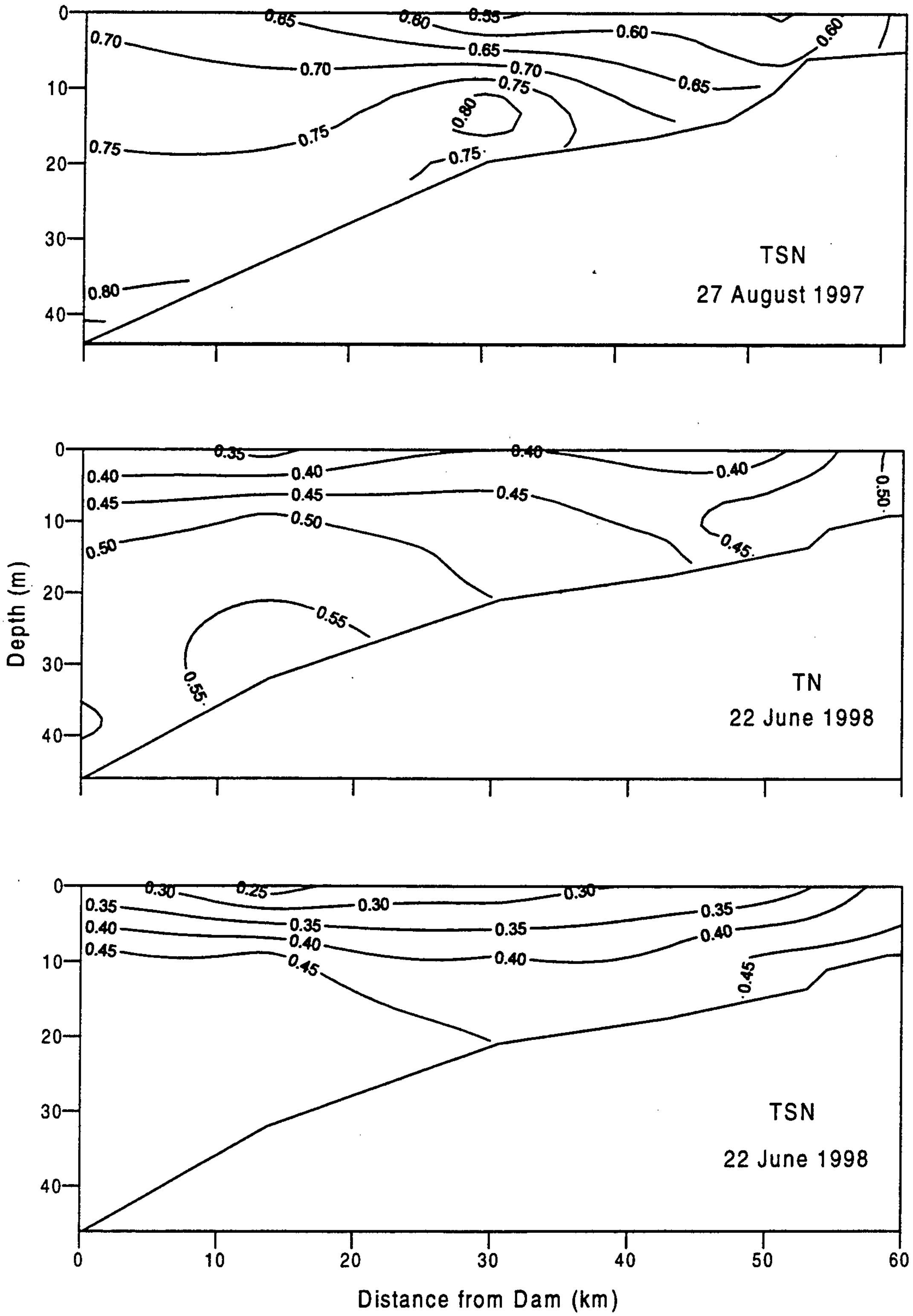


Figure 39. Spatial distribution of total and total soluble nitrogen in J. Strom Thurmond Lake during August 1997 and June 1998.

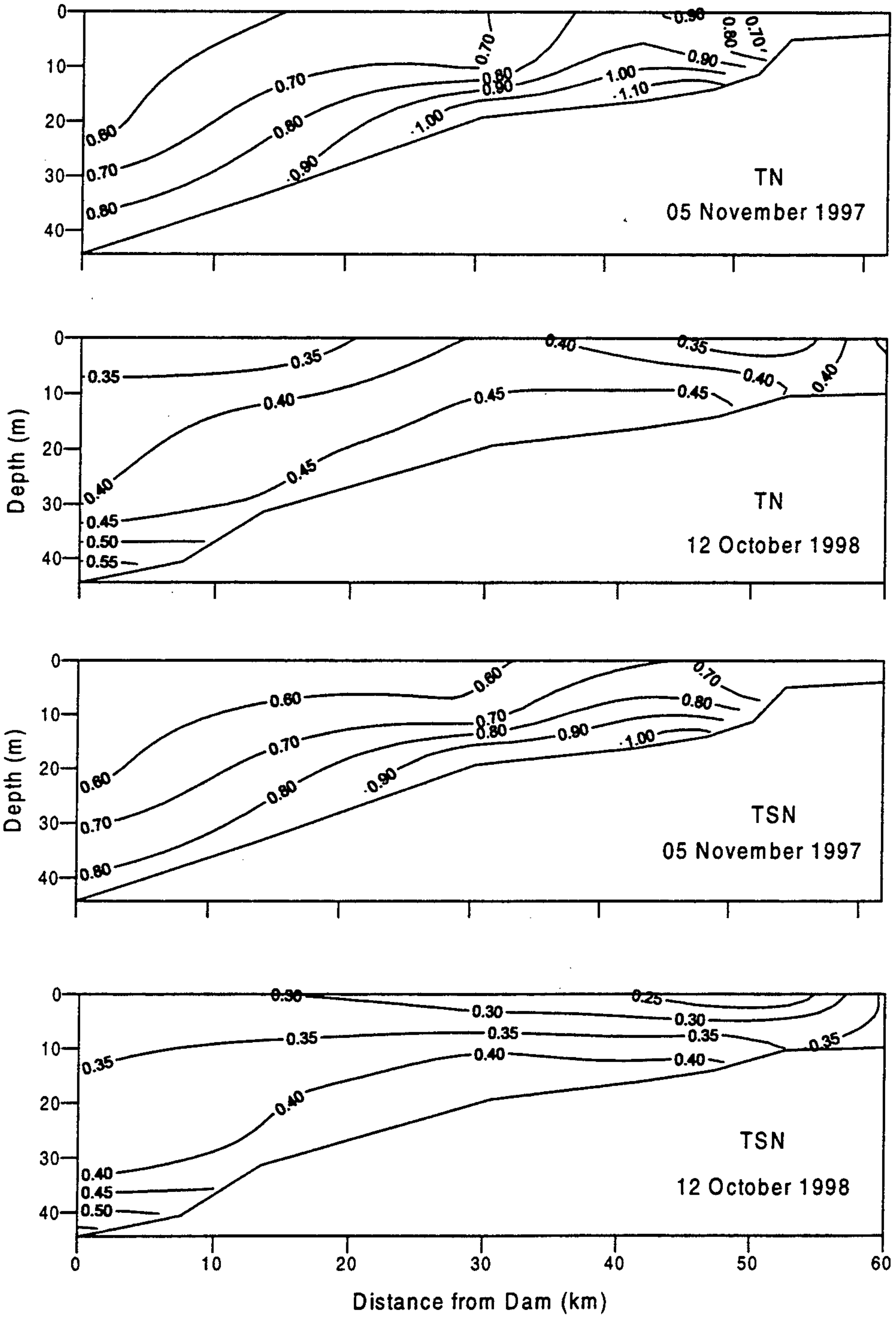


Figure 40. Spatial distribution of total and total soluble nitrogen in J. Strom Thurmond Lake during November 1997 and October 1998.

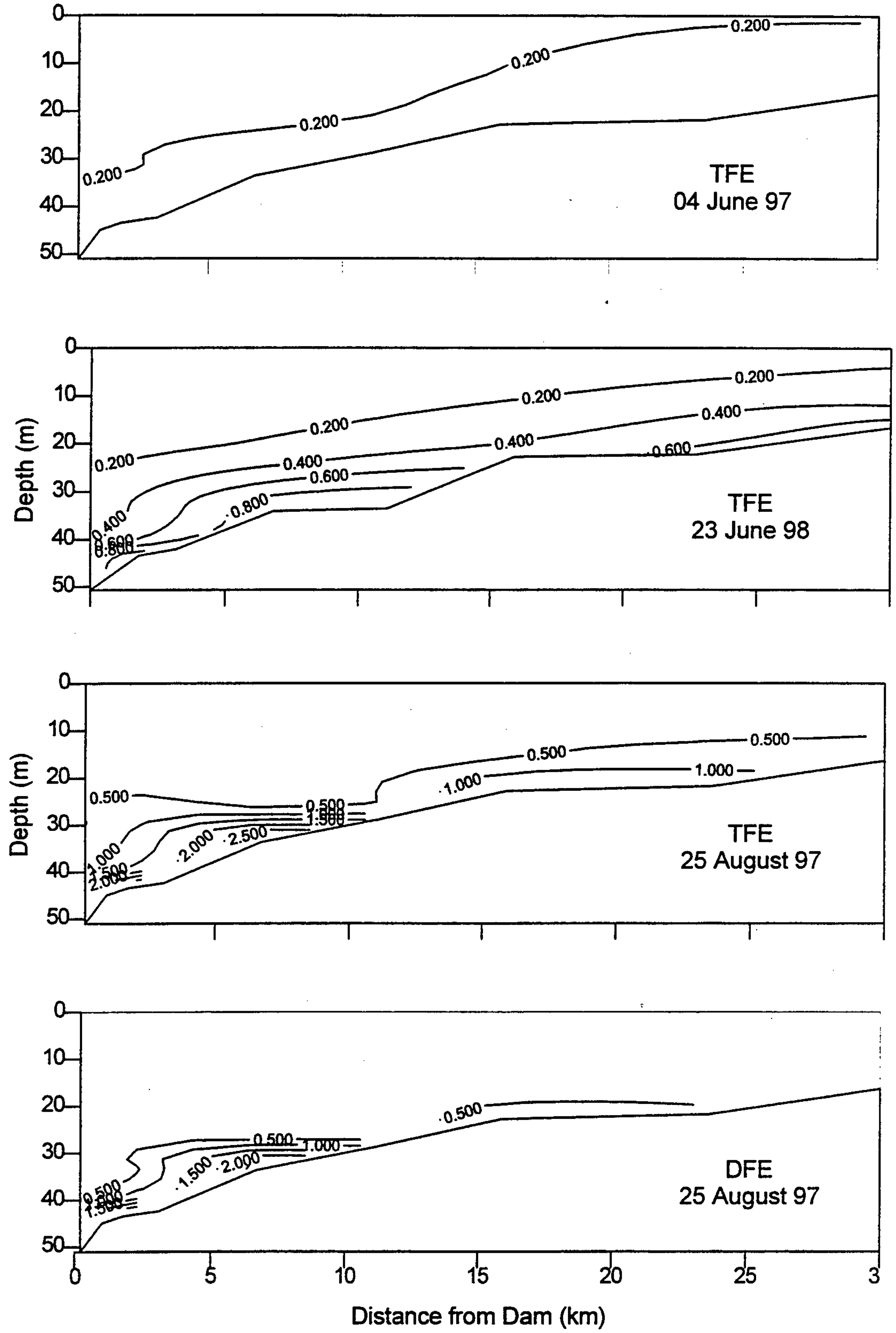


Figure 41. Spatial distribution of total and dissolved iron in Richard B. Russell Lake during June and August 1997 and June 1998.

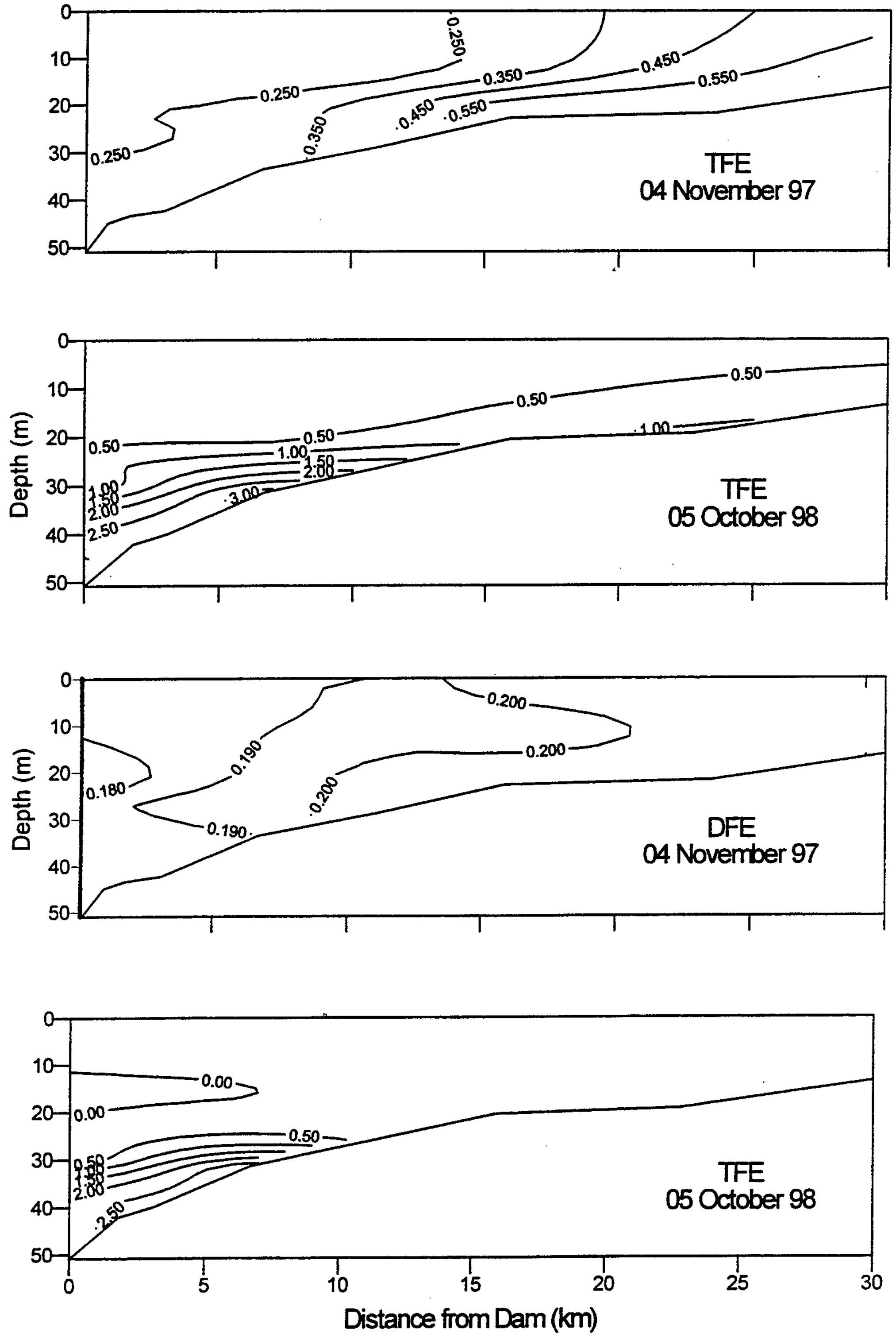


Figure 42. Spatial distribution of total and dissolved iron in Richard B. Russell Lake during November 1997 and October 1998.

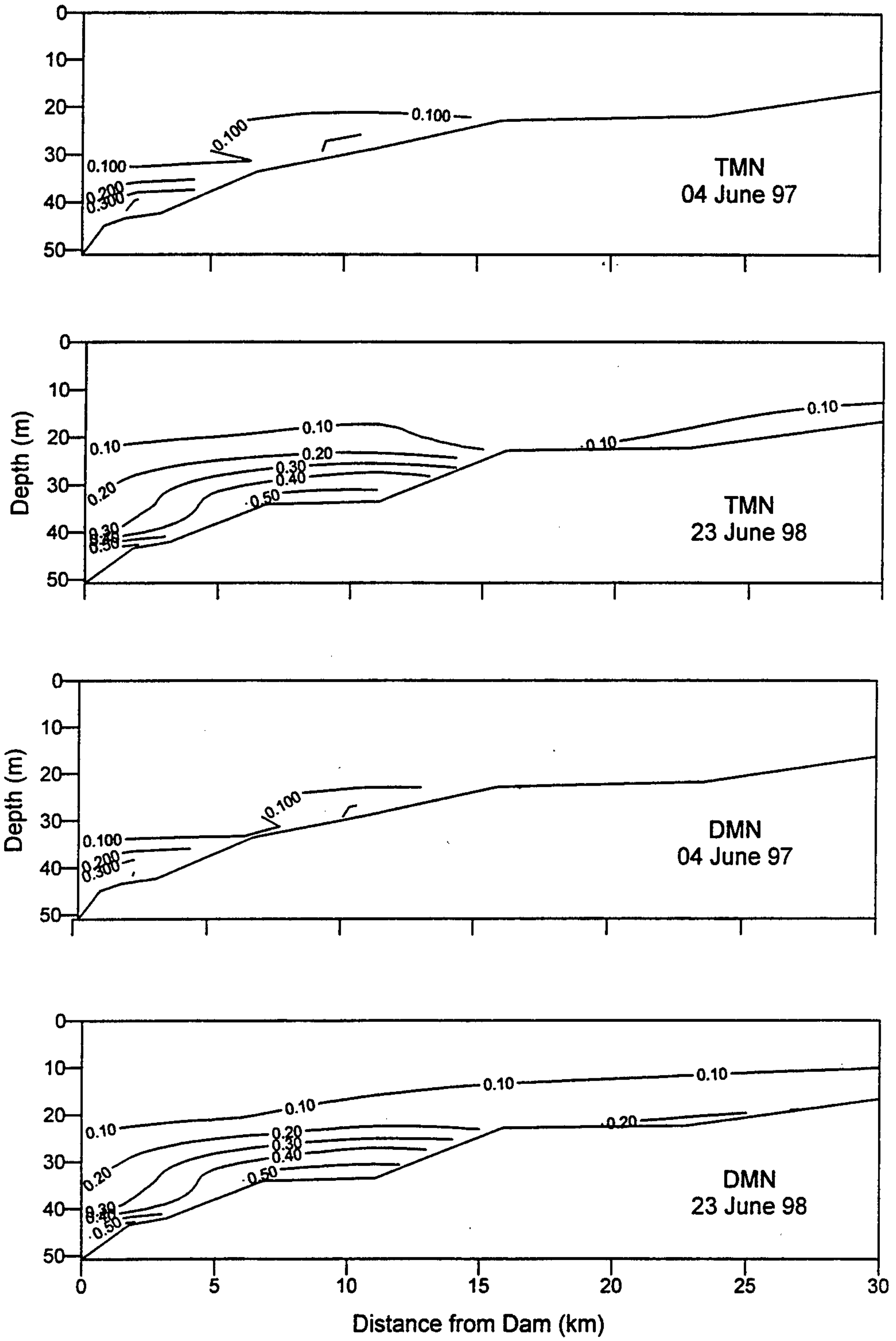


Figure 43. Spatial distribution of total and dissolved manganese in Richard B. Russell Lake during June 1997 and 1998.

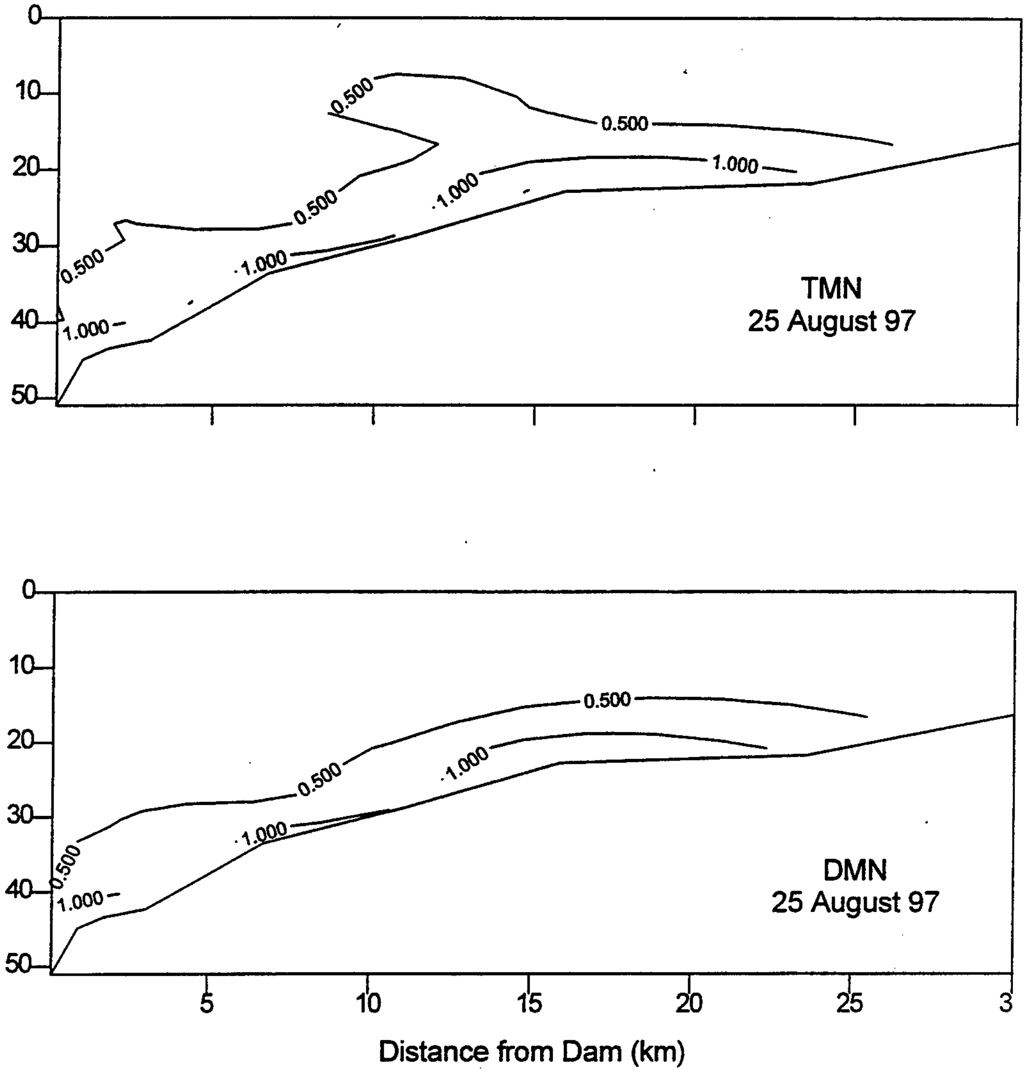


Figure 44. Spatial distribution of total and dissolved manganese in Richard B. Russell Lake during August 1997.

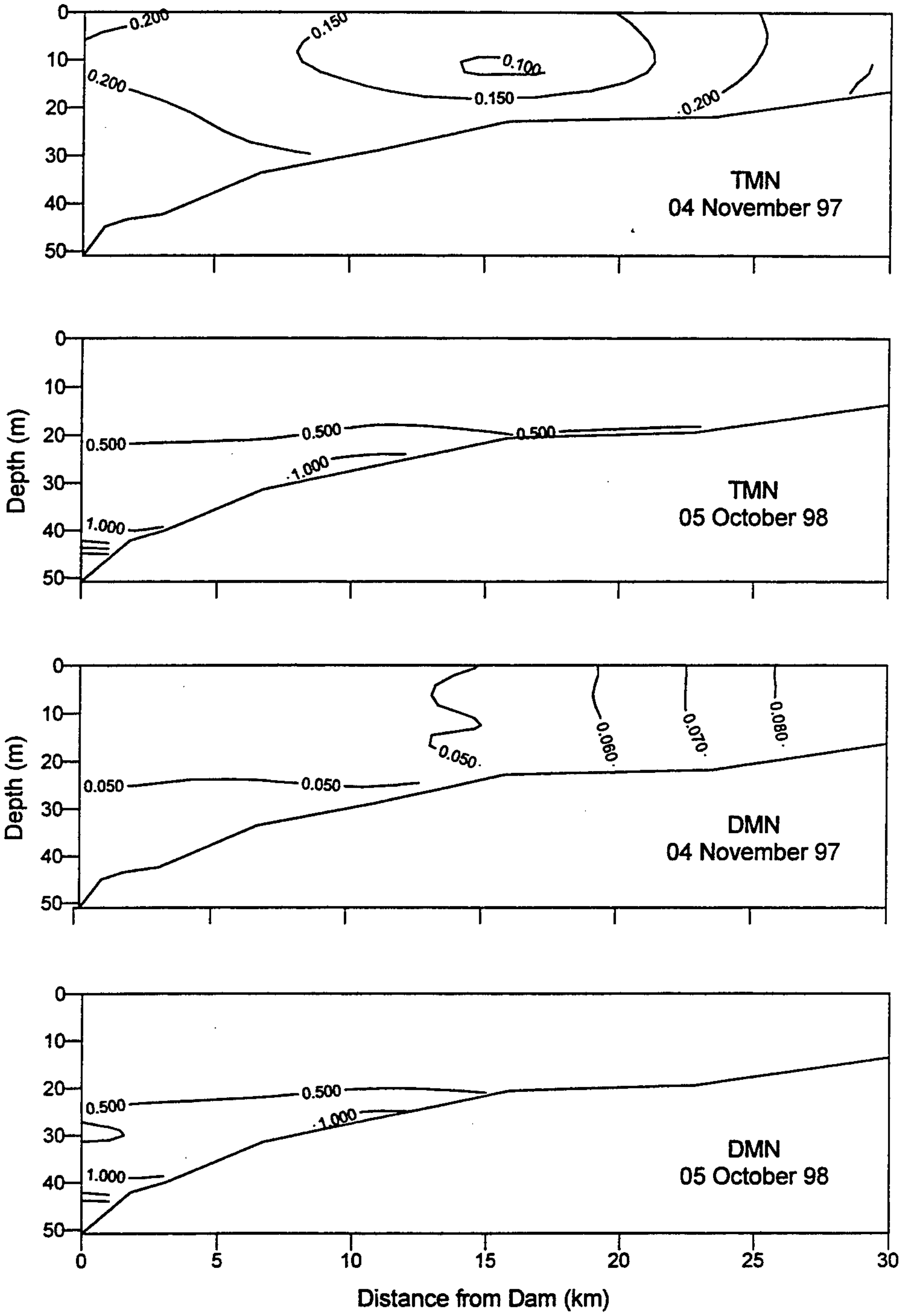


Figure 45. Spatial distribution of total and dissolved manganese in Richard B. Russell Lake during November 1997 and October 1998.

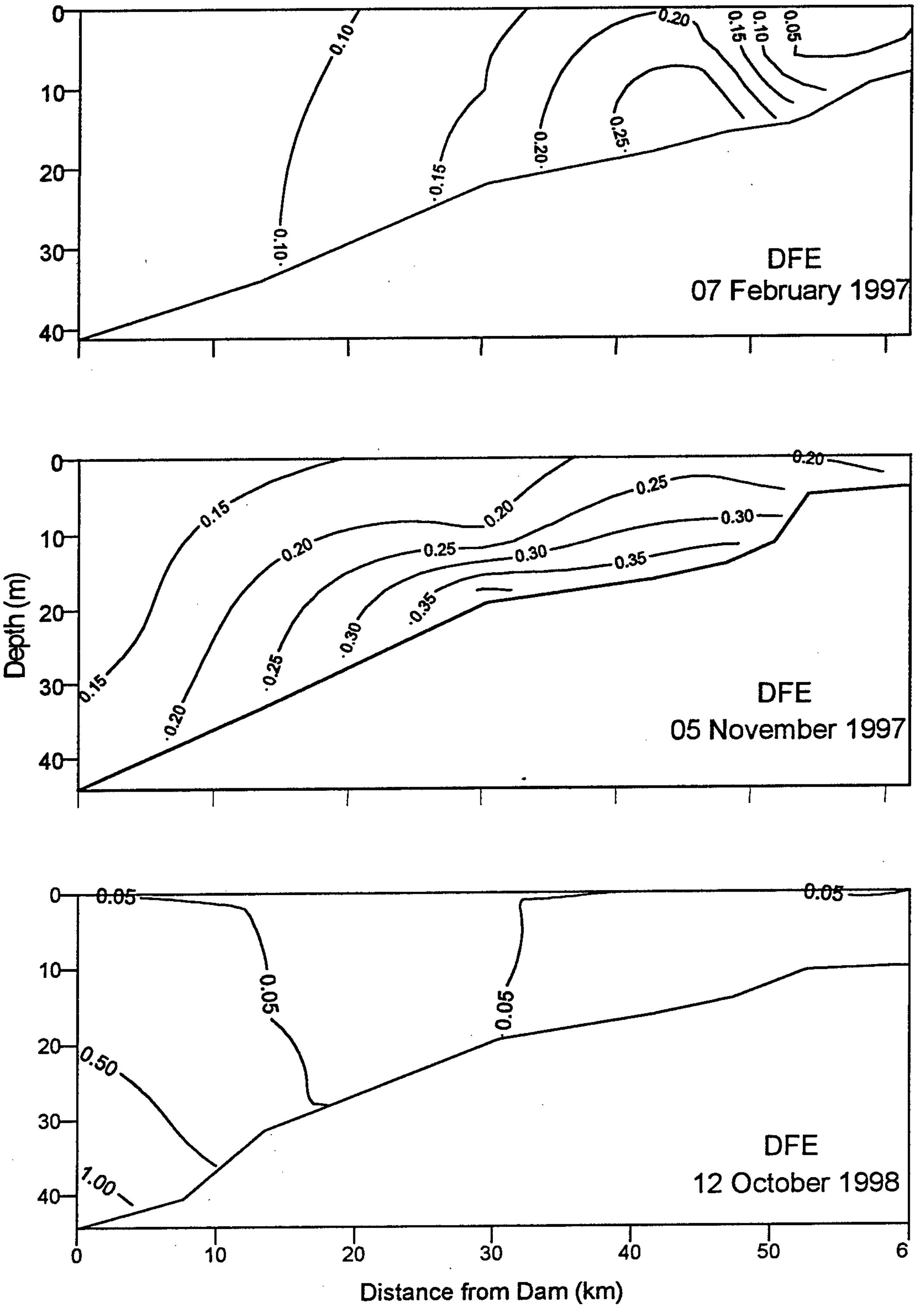


Figure 46. Spatial distribution of dissolved iron in J. Strom Thurmond Lake during February and November 1997 and October 1998.

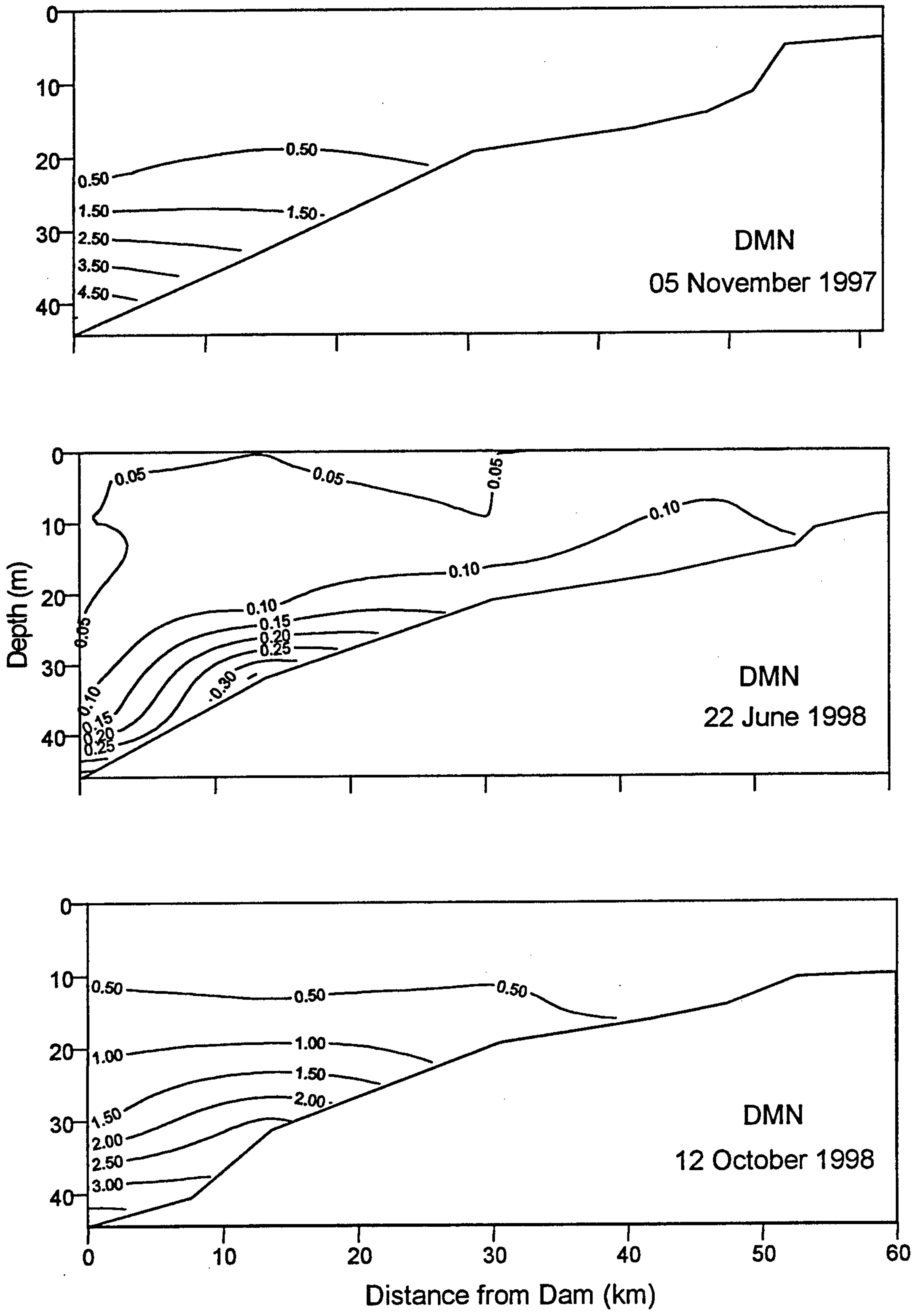


Figure 47. Spatial distribution of dissolved manganese in J. Strom Thurmond Lake during November 1997 and June and October 1998.

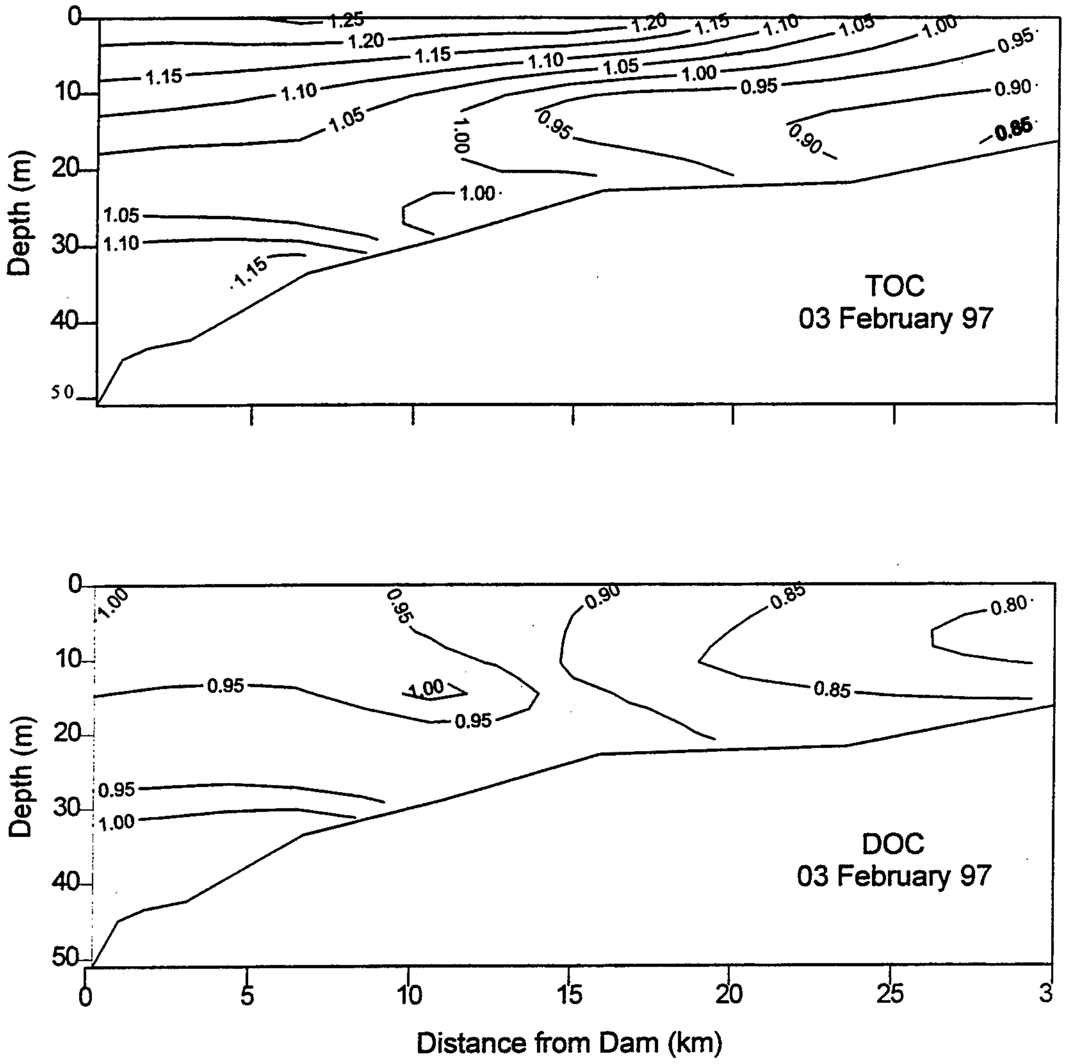


Figure 48. Spatial distribution of total and dissolved organic carbon in Richard B. Russell Lake during February 1997.

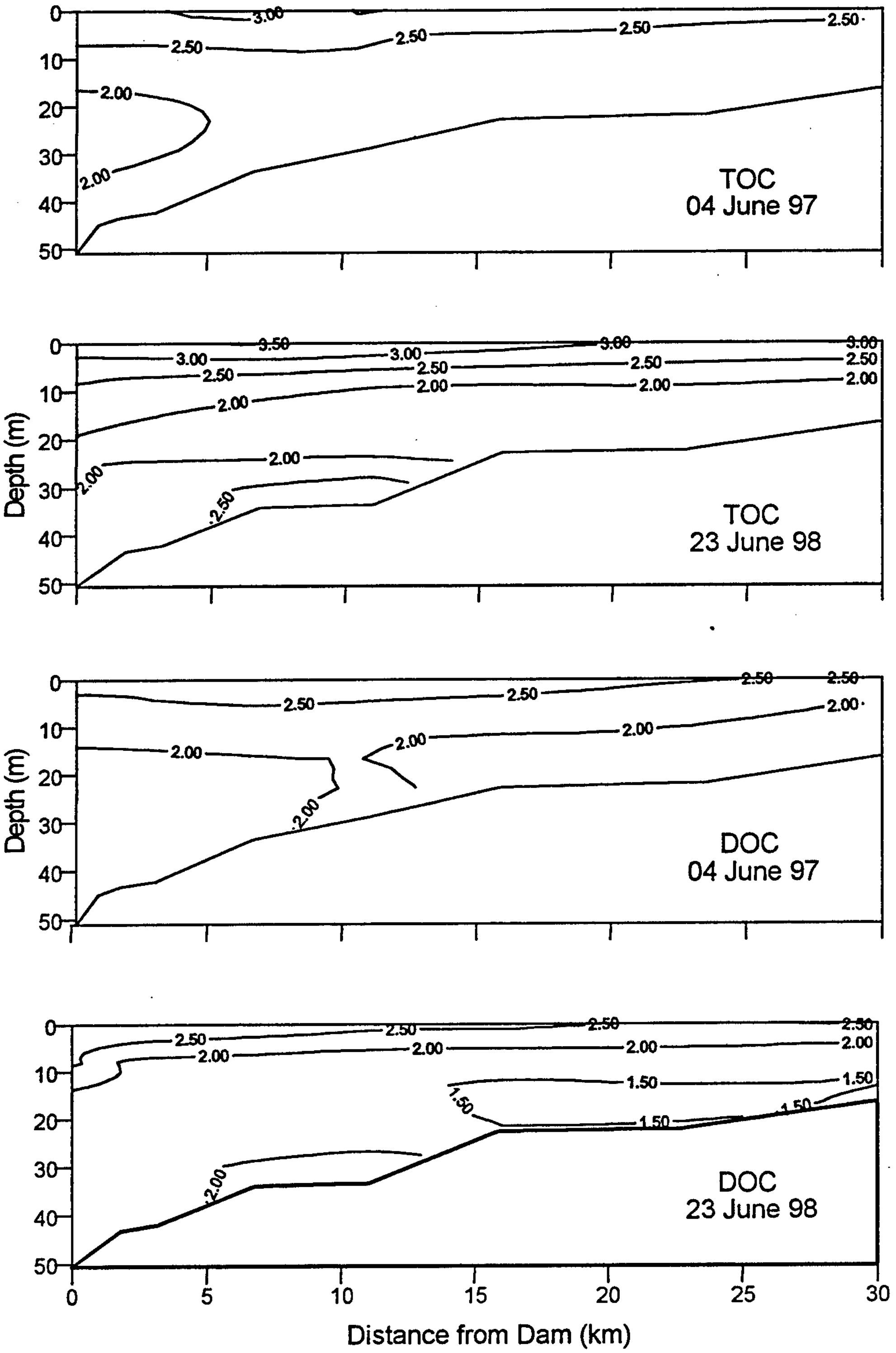


Figure 49. Spatial distribution of total and dissolved organic carbon in Richard B. Russell Lake during June 1997 and 1998.

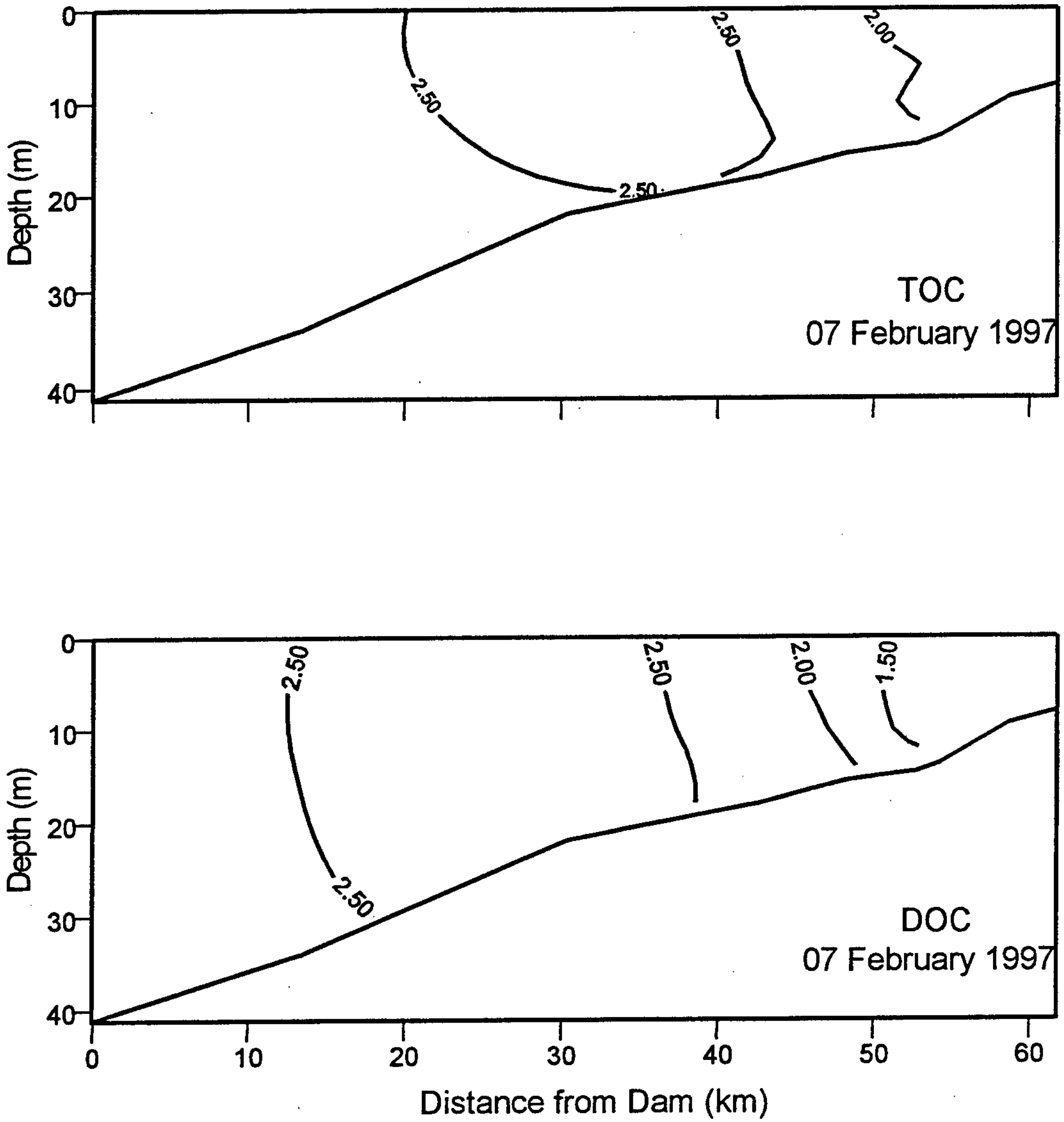


Figure 50. Spatial distribution of total and dissolved organic carbon in J. Strom Thurmond Lake during February 1997.

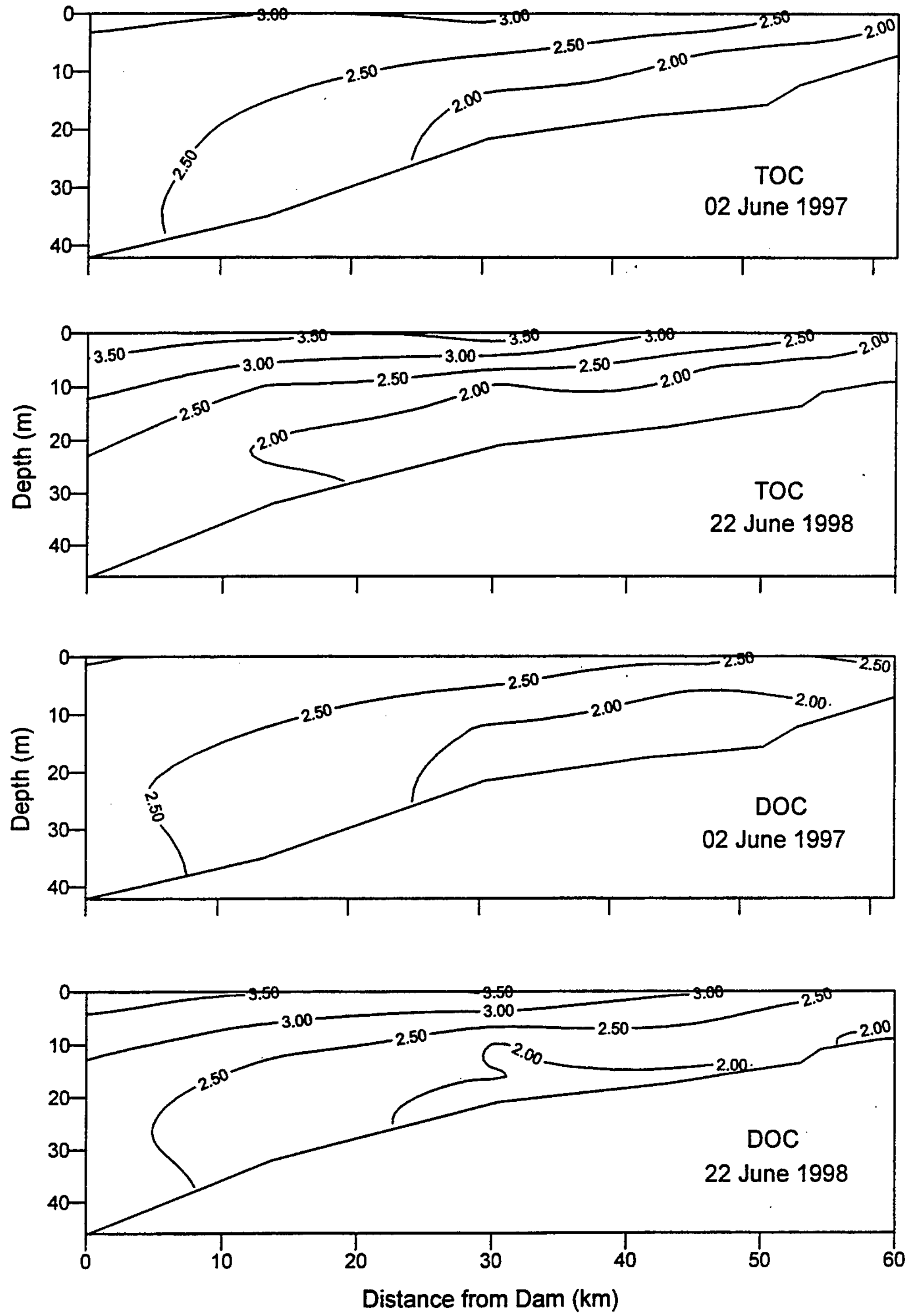


Figure 51. Spatial distribution of total and dissolved organic carbon in J. Strom Thurmond Lake during June 1997 and 1998.

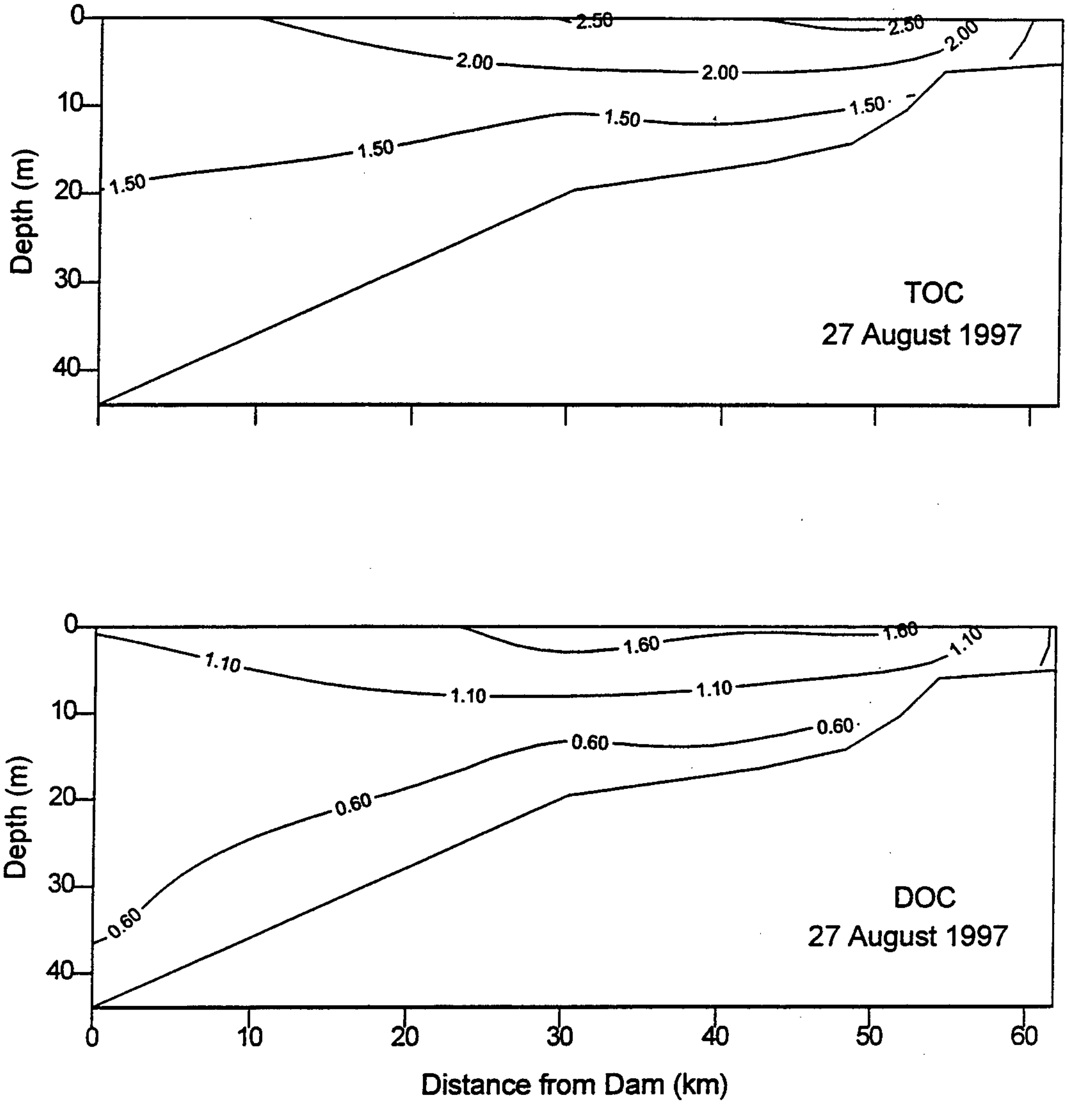


Figure 52. Spatial distribution of total and dissolved organic carbon in J. Strom Thurmond Lake during August 1997.

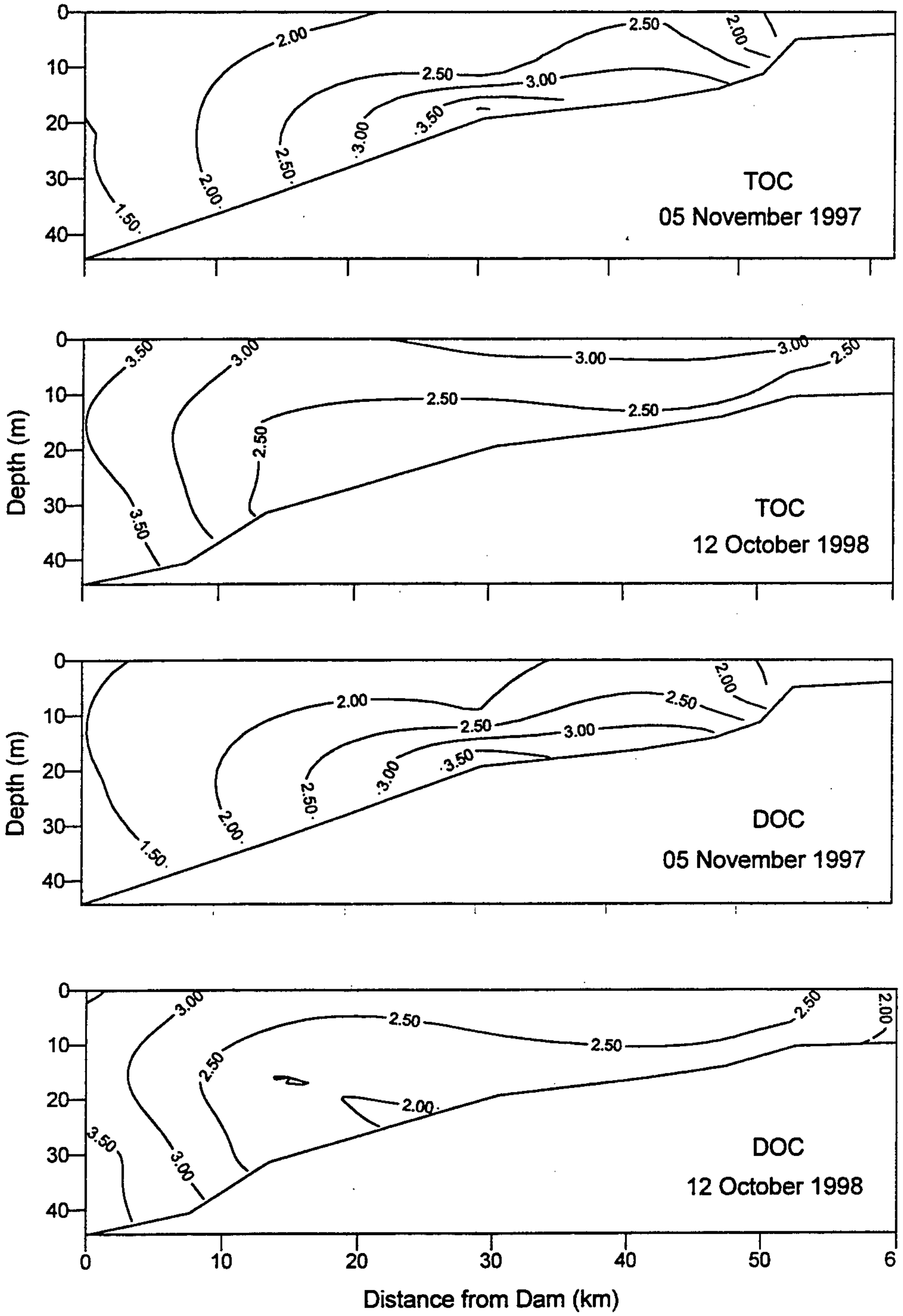


Figure 53. Spatial distribution of total and dissolved organic carbon in J. Strom Thurmond Lake during November 1997 and October 1998.

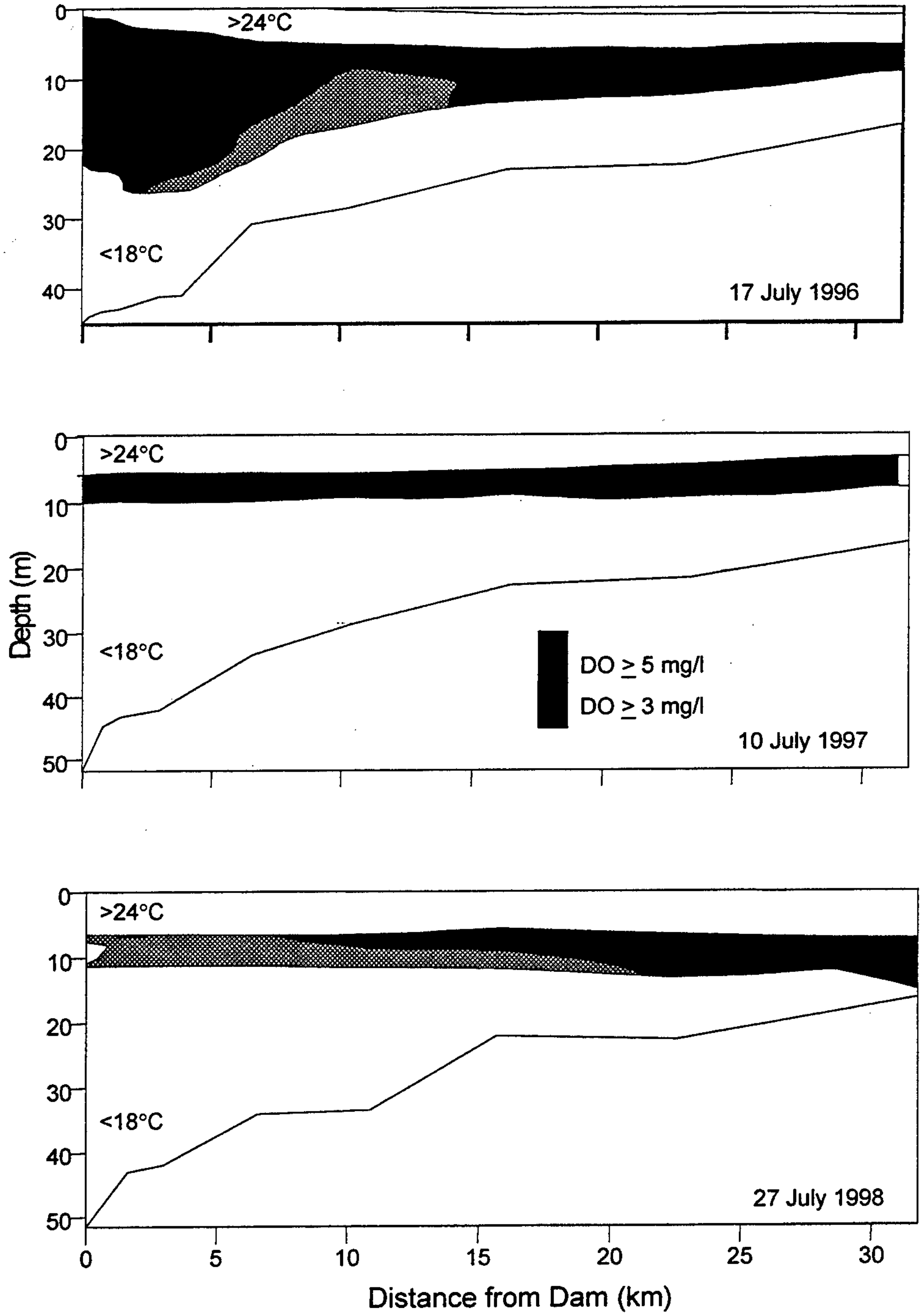


Figure 54. Habitat availability for striped bass (based on HSI) in Richard B. Russell Lake during July 1996, 1997, and 1998.

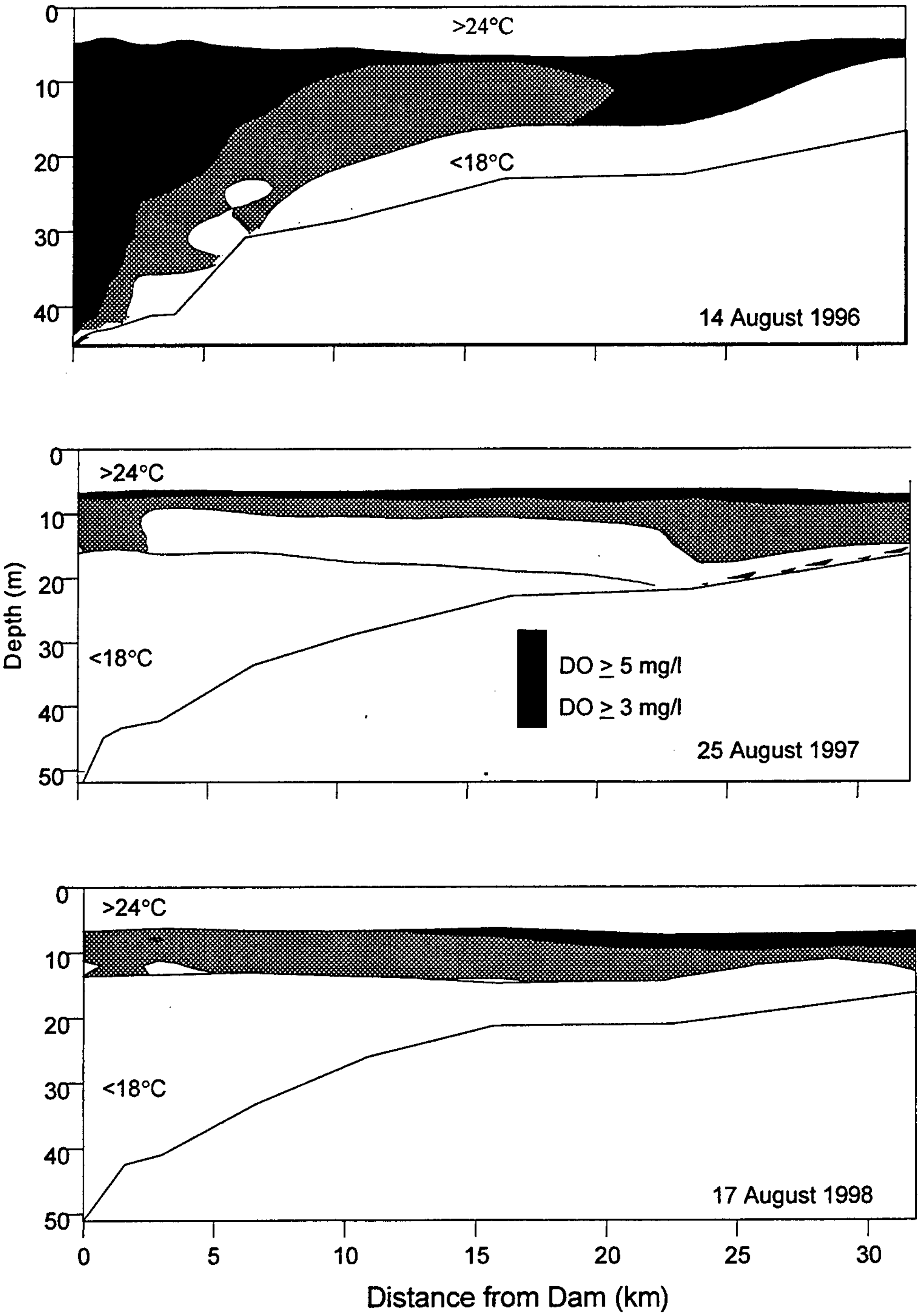


Figure 55. Habitat availability for striped bass (based on HSI) in Richard B. Russell Lake during August 1996, 1997, and 1998.

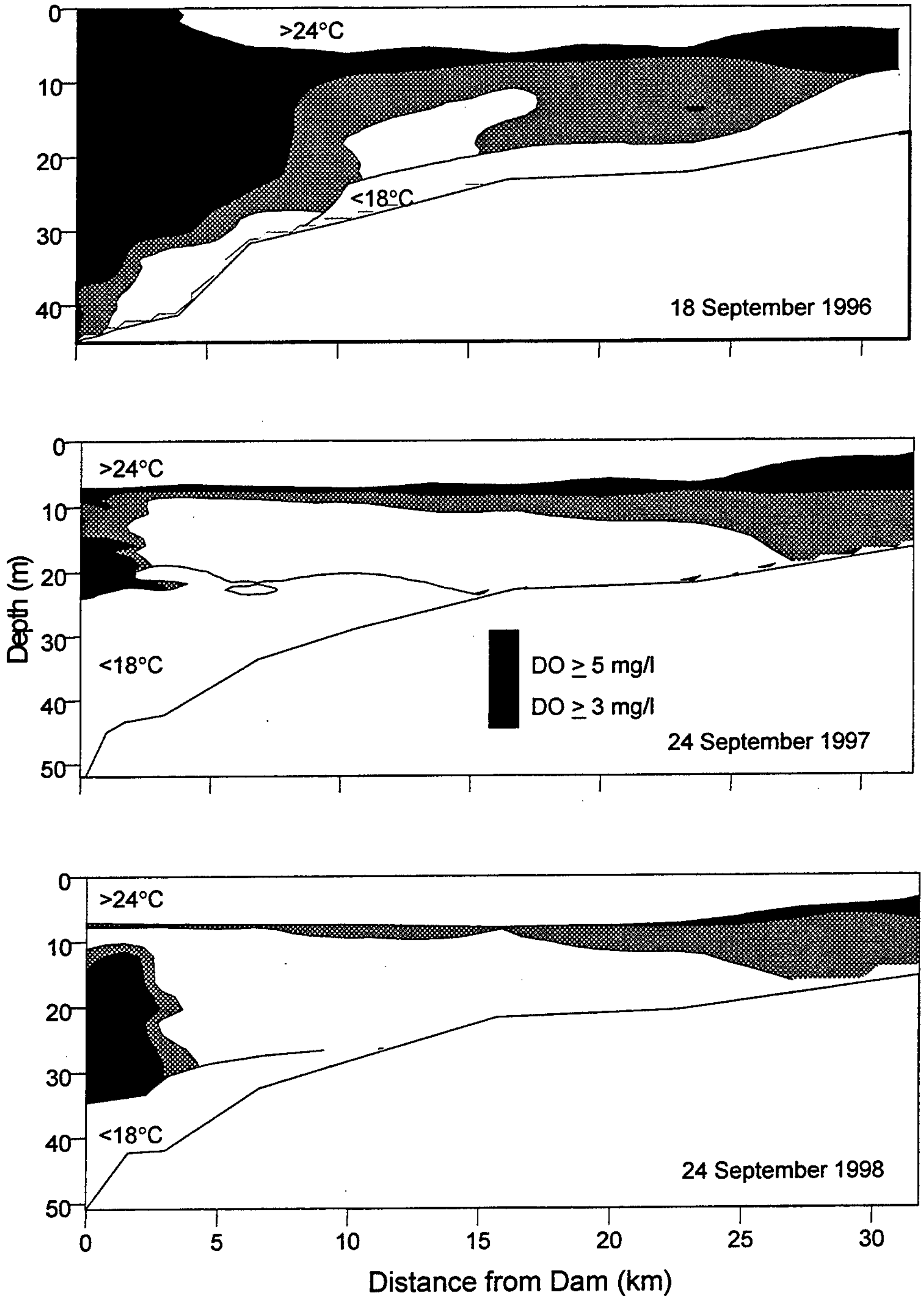


Figure 56. Habitat availability for striped bass (based on HSI) in Richard B. Russell Lake during September 1996, 1997, and 1998.

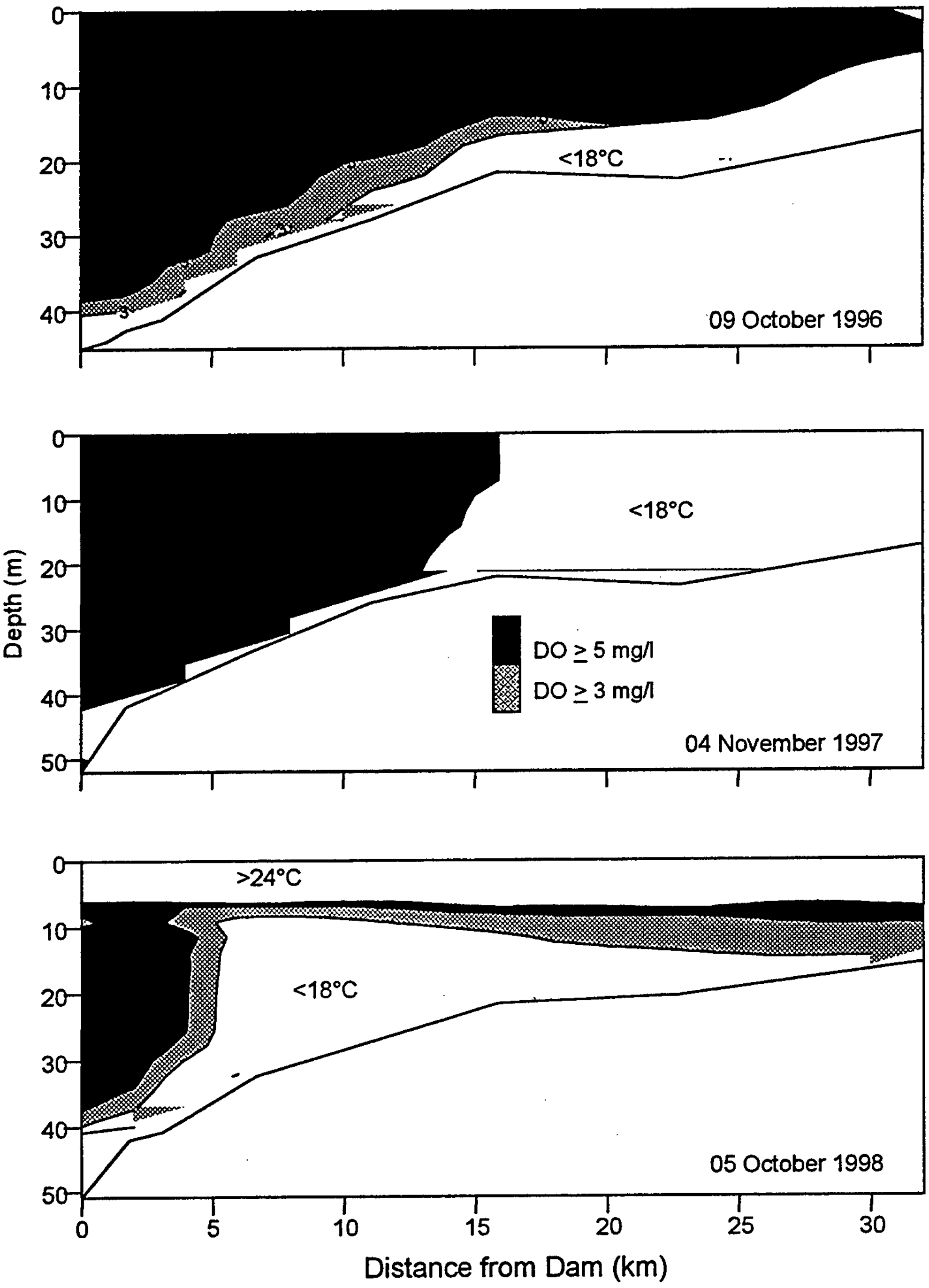


Figure 57. Habitat availability for striped bass (based on HSI) in Richard B. Russell Lake during October 1996, November 1997, and October 1998.

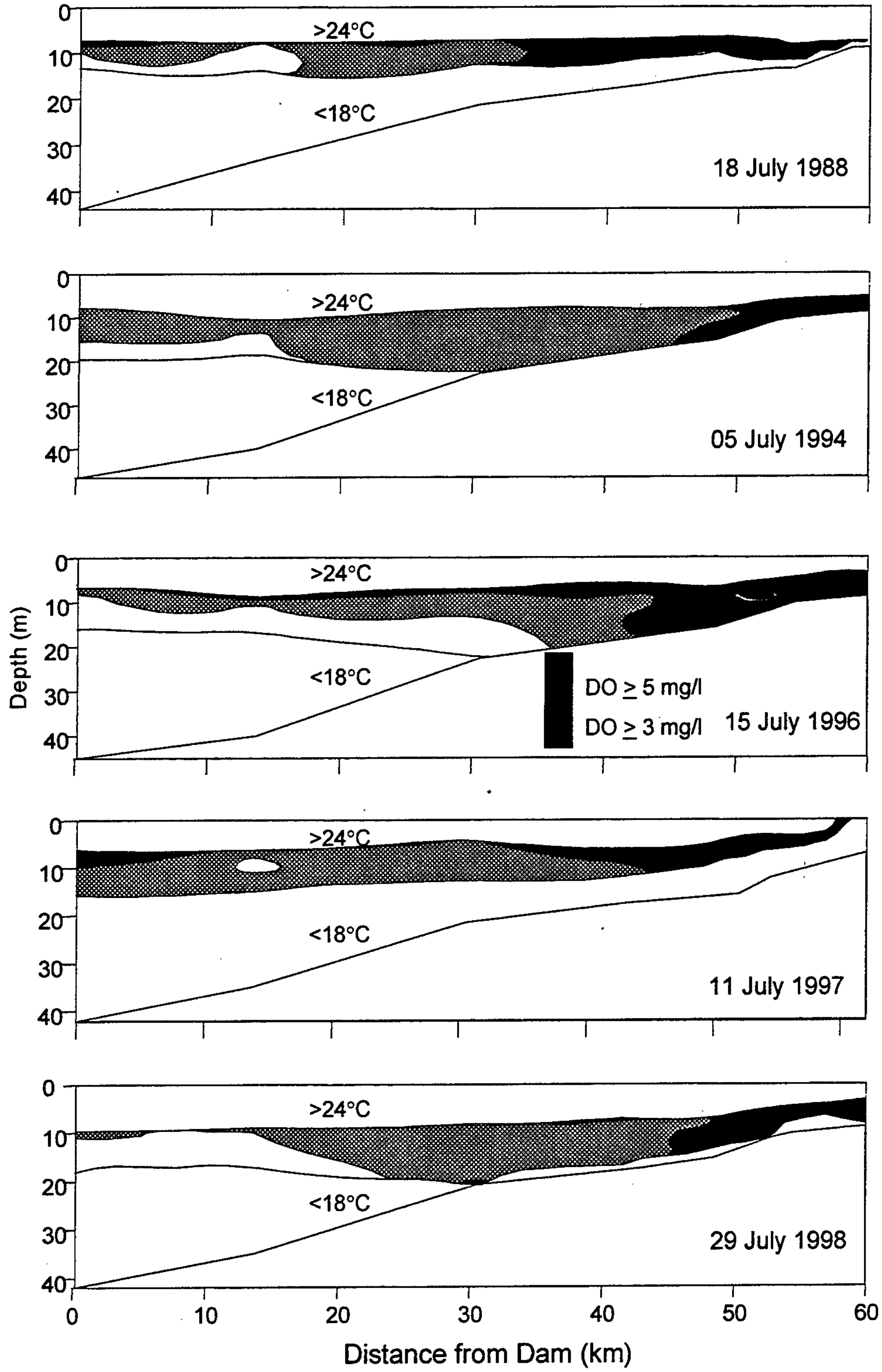


Figure 58. Habitat availability for striped bass (based on HSI) in J. Strom Thurmond Lake during July 1988, 1994, 1996, 1997, and 1998.

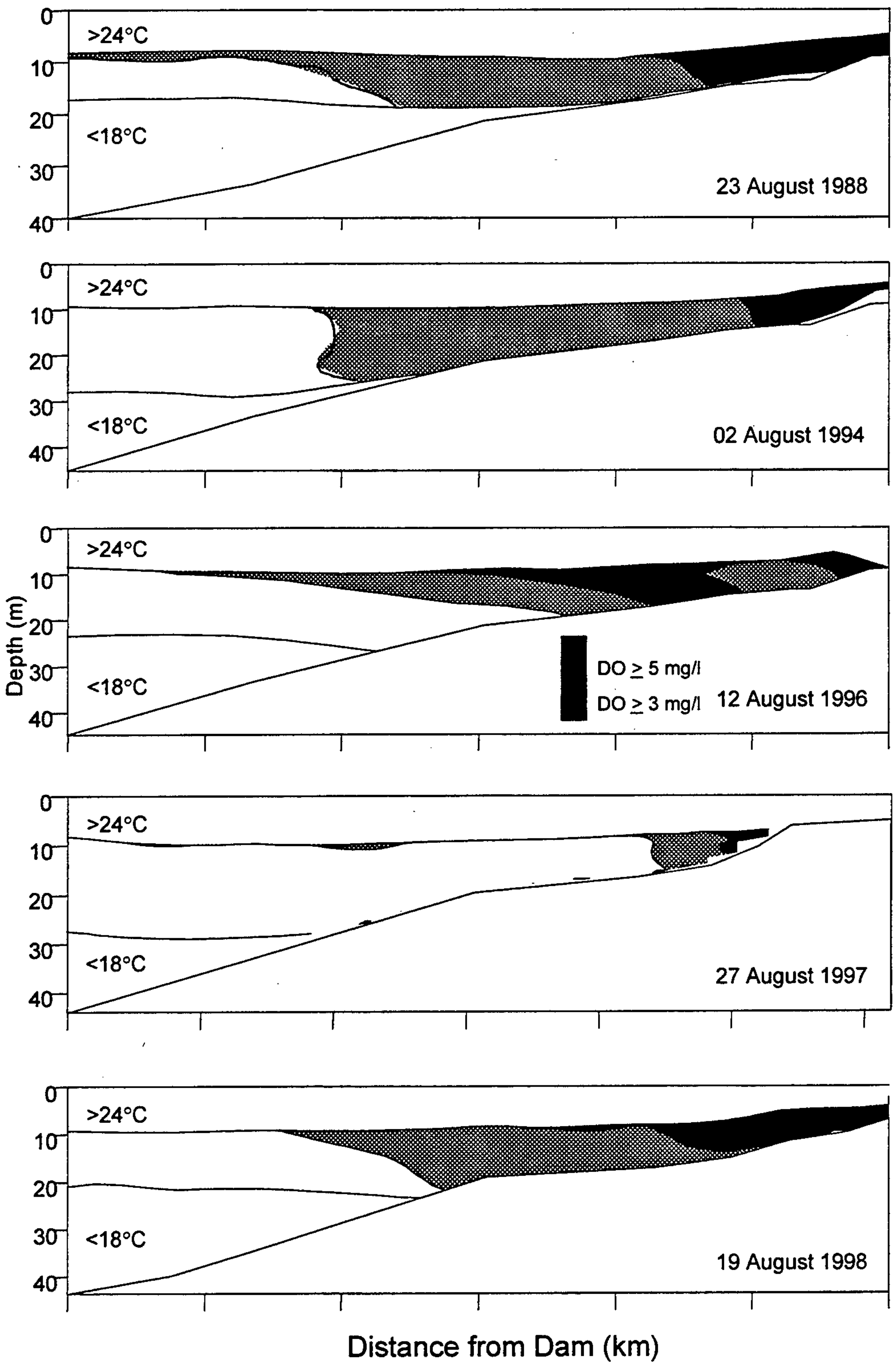
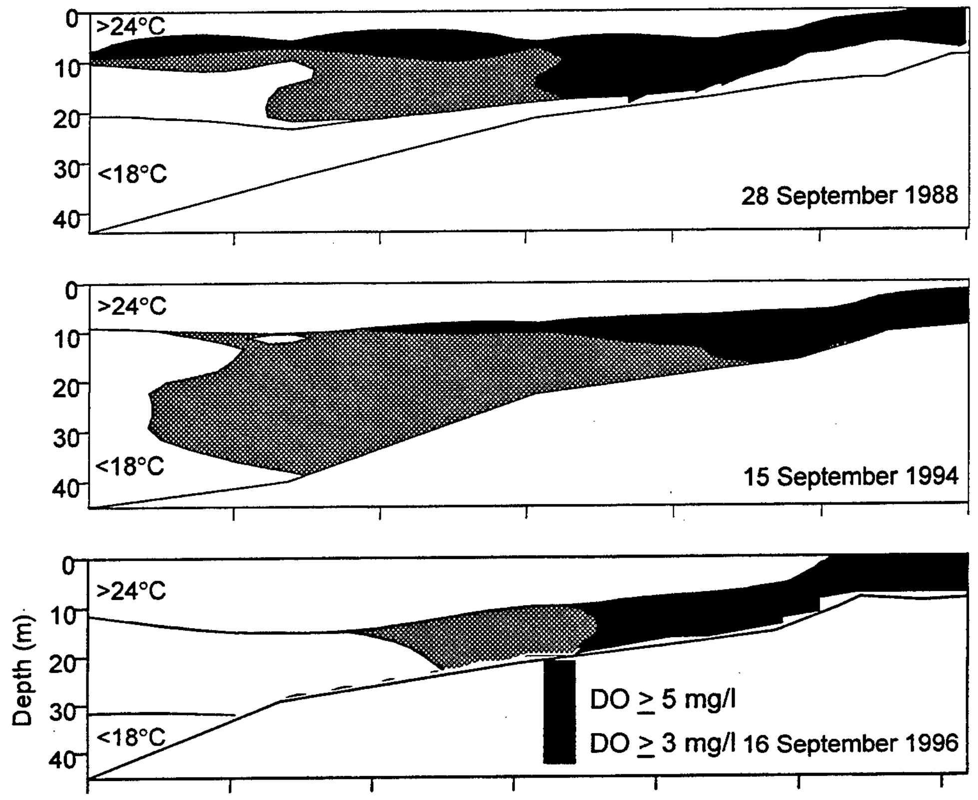


Figure 59. Habitat availability for striped bass (based on HSI) in J. Strom Thurmond Lake during August 1988, 1994, 1996, 1997, and 1998.



No September 1997 Data

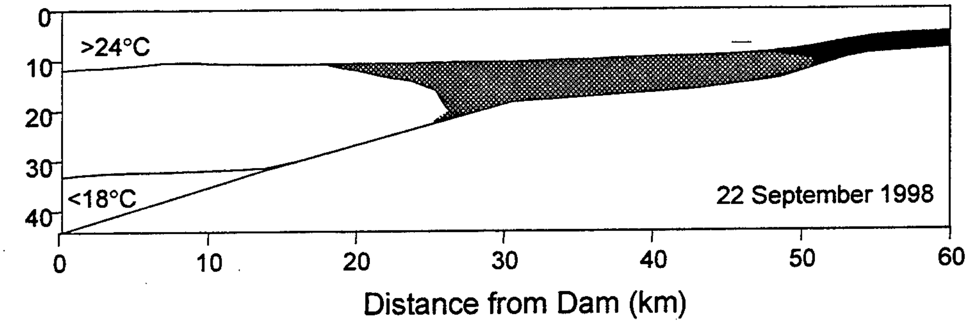


Figure 60. Habitat availability for striped bass (based on HSI) in J. Strom Thurmond Lake during September 1988, 1994, 1996, 1997, and 1998.

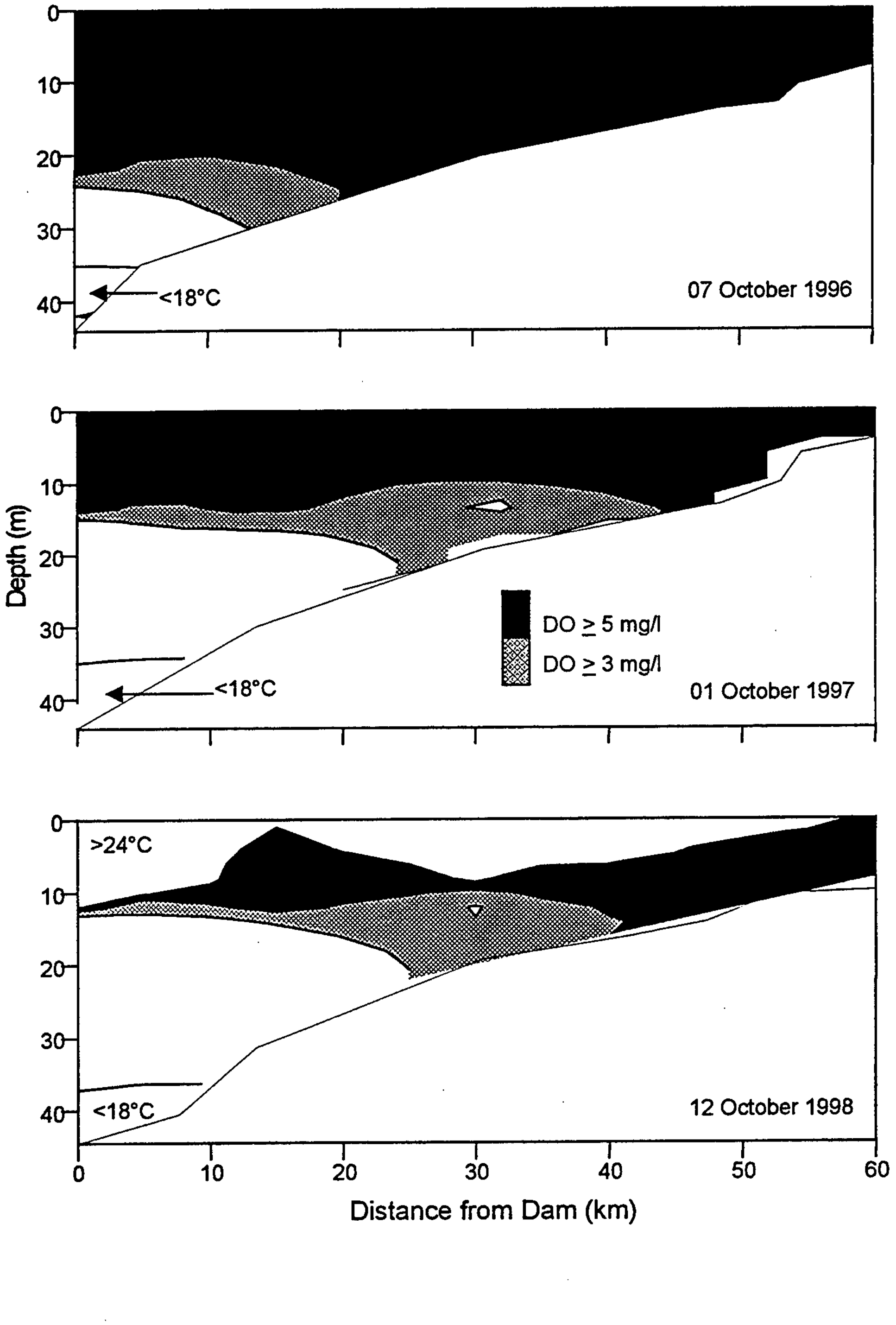


Figure 61. Habitat availability for striped bass (based on HSI) in J. Strom Thurmond Lake during October 1996, 1997, and 1998.

Characteristics	HW	RBR	JST
Maximum power pool elevation, m ngvd	201.2	144.8	100.6
Minimum power pool elevation, m ngvd	190.5	143.2	95.1
Flood control pool, m ngvd	202.7	146.3	102.1
Surface area, km^2, at max. power pool	226.6	107.9	283.2
Volume, m^3 (10^6), at max. power pool	3146.7	1271	3023.3
Maximum depth, m, at max. power pool	55	47	45
Mean depth, m, at max. power pool	14	12	11
Reservoir length , km, at max. power pool	79 Tugaloo R. 72 Seneca R.	45	63
Shoreline length, km. at max. power pool	1548	885	1930
Shoreline development ratio at max. power pool	29.0	24.5	32.0
Drainage area, km^2	5406	7508	15,912
Theoretical residence time, days at max. power pool	306	102	144
Mean discharge, cms,	119.0 31yr average	143.8 31yr average	243.6 1925-73
Elevation, top of penstocks, m ngvd	181.4	133.2	88.4
Elevation, bottom of penstocks, m ngvd	160.9	110	69.5

Table 1. Characteristics of Richard B. Russell (RBR), Hartwell (HW), and J.Strom Thurmond (JST) Lakes

Parameter	Replicate	Split
Total phosphorous	5.68	2.54
Total dissolved phosphorous	12.11	1.81
Total nitrogen	7.28	8.38
Total dissolved nitrogen	10.86	9.84
Ammonia nitrogen	8.90	4.51
Nitrate nitrogen	8.45	1.11
Sulfate	0.85	1.06
Total organic carbon	3.94	2.06
Total dissolved organic carbon	3.50	2.50
Total manganese	13.95	3.03
Total dissolved manganese	7.37	0.58
Total iron	7.70	2.62
Total dissolved iron	7.73	2.43
Total alkalinity	2.16	1.67
Total suspended solids	26.95	28.19
Turbidity	7.90	5.75

Table 2. Mean coefficient of variation of replicate and split samples.

Parameter	Spike	QA
Total phosphorous	101.1±5.1	105.5±0.9
Total dissolved phosphorous	102.6±3.4	-
Soluble reactive phosphorous	95.2±5.0	104.2±3.4
Total nitrogen	112.2±27.8	-
Total dissolved nitrogen	95.4±28.8	-
Ammonia nitrogen	105.7±16.3	104.7±3.2
Nitrate nitrogen	96.9±4.6	101.2±3.6
Sulfate	99.6±5.1	-
Total organic carbon	106.0±9.9	96.6±6.7
Total dissolved organic carbon	106.3±17.3	-
Total manganese	100.9±4.4	-
Total dissolved manganese	103.0±2.3	100.8±2.2
Total iron	105.6±19.7	-
Total dissolved iron	99.4±3.5	93.4±8.6
Total alkalinity	88.5±7.2	96.5±1.2
Turbidity	104.7±17.1	-
Total suspended solids	-	99.2±3.5

Table 3. Mean percent recovery and standard deviation of spike and quality assurance (QA) samples.

Variable	Mean	Min	Max	n
Richard B. Russell 1997				
Dissolved Oxygen, mg/l	6.1	4.1	8.6	1751
Temperature, ^{0}C	17.0	12.9	19.5	1751
Specific Conductance, µS	39.0	35.3	41.8	1751
Richard B. Russell 1998				
Dissolved Oxygen, mg/l	6.1	2.7	9.0	1879
Temperature, ^{0}C	16.6	12.4	21.6	1879
Specific Conductance, µS	36.2	32.8	39.3	1879
J. Strom Thurmond 1997				
Dissolved Oxygen, mg/l	3.1	0.3	6.9	2546
Temperature, ^{0}C	19.3	16.6	21.8	2546
Specific Conductance, µS	40.6	37.7	44.9	2546
J. Strom Thurmond 1998				
Dissolved Oxygen, mg/l	3.6	0.3	6.7	1744
Temperature, ^{0}C	19.0	16.4	22.5	1744
Specific Conductance, µS	39.3	35.7	46.1	1744

n Number of observations on which calculations are based.

Table 4. Summary of continuous monitor data during generation for Richard B. Russell and J. Strom Thurmond tailwaters for June through October 1997 -1998.

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY ***(Leave blank)***

2. REPORT DATE
November 1999

3. REPORT TYPE AND DATES COVERED
Final report

4. TITLE AND SUBTITLE
Water Quality in Richard B. Russell and J. Strom Thurmond Lakes: Interim Report for the Period 1997-1998

5. FUNDING NUMBERS

6. AUTHOR(S)
John J. Hains, William E. Jabour, Robert H. Kennedy, William Boyd, J. M. Satterfield, Patrick K. Howle

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Environmental Laboratory
U.S. Army Engineer Research and Development Center
3909 Halls Ferry Road, Vicksburg, MS 39180-6199

8. PERFORMING ORGANIZATION REPORT NUMBER
Technical Report EL-99-13

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
U.S. Army Engineer District, Savannah
Savannah, GA 31402-0889

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT ***(Maximum 200 words)***

After completion of phase III of the Richard B. Russell Pumped Storage Testing and Monitoring studies an interim period of water quality studies was continued to provide additional baseline information and to maintain continuity in the water quality database. These studies continued through 1997 and 1998 and are reported here.

Phase III results detailed the effect of simulated commercial operation of pumped storage on Richard B. Russell Lake (RBR) and J. Strom Thurmond Lake (JST) in terms of water quality and fisheries habitat. Although there were observable changes in RBR and JST as a result of pumped storage, the subsequent comparisons of adjacent years of conventional operation without pumped storage were important for identification of additional trends in water quality and fisheries habitat.

The interim studies continued in a similar manner to baseline studies during the phase III period. As a result, it was shown that although the years 1996-1998 were similar in many respects, weather for example, and the resulting thermal conditions were similar to many years on these lakes, increased dissolved oxygen demand greatly affected the extent of habitat as defined by the habitat suitability index. During 1997, in the absence of pumped storage, there was greatly diminished habitat in JST in comparison to other years and, in particular, to the phase III operational year - 1996. Although 1998 conditions

(Continued)

14. SUBJECT TERMS

15. NUMBER OF PAGES
117

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT
UNCLASSIFIED

18. SECURITY CLASSIFICATION OF THIS PAGE
UNCLASSIFIED

19. SECURITY CLASSIFICATION OF ABSTRACT

20. LIMITATION OF ABSTRACT

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. Z39-18
298-102

13. (Concluded).

were not as severe, they also had greatly diminished habitat in JST. Habitat RBR was maintained through the operation of an oxygenation system in the forebay of RBR.

The observations of the two interim years of study show extremes of variation in water quality in these lakes in the absence of pumped storage. The studies provide a valuable source of information for prediction and management of these systems in the future. The recent observations also may indicate a trend of increasing oxygen demand in the lakes, and this potential trend must be considered carefully in the future.