This is to certify that the

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The Limnology of Sessions Lake,
Ionia County, Michigan

presented by

Timothy James Feist

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Niles R. Kevern
Major professor

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THE LIMNOLOGY OF SESSIONS LAKE,
IONIA COUNTY, MICHIGAN

By

Timothy James Feist

A THESIS

Submitted to
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ABSTRACT

THE LIMNOLOGY OF SESSIONS LAKE, IONIA COUNTY, MICHIGAN

By

Timothy James Feist

The objective of this study was to examine watershed nutrient input into Sessions Lake over the 1986 summer stratification period, the effect of this input on the reservoir, and the effect of the reservoir on Sessions Creek.

Sessions Creek and groundwater/overland flow discharged the most water to the reservoir, although Sessions Creek and Inlet E supplied the largest amount of nutrients. Stream discharge and nutrient loads were heavily influenced by storm events.

Sessions Lake was a eutrophic, phosphorus limited reservoir. High productivity led to surface algal films and an anaerobic hypolimnion.

A mid-level outlet discharged well-oxygenated water and prevented downstream warming of Sessions Creek. The reservoir had little effect on nutrient amounts in Sessions Creek, although chemical forms of nitrogen were affected.

Implementing best management practices in the watershed will improve reservoir water quality, but may not reduce lake total phosphorus concentrations enough to bring the reservoir to a mesotrophic condition.

ACKNOWLEDGEMENTS

I would like to thank my major professor, Dr. Niles Kevern, and the members of my graduate committee, Dr. Clarence McNabb and Dr. Eckhart Dersch, for their guidance during this project. Dr. Ted Batterson also provided much appreciated help and advice. I would especially like to thank Dr. McNabb and Dr. Batterson for allowing me to use the facilities and equipment of the MSU Limnological Laboratory for this study. Katherine Feist and Ralph Beebe provided much needed assistance with field and laboratory work. I would also like to thank my wife Kathy for editorial assistance and for support throughout my graduate studies. Funding for this project was provided by the Michigan Agricultural Experiment Station.

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INTRODUCTION

The long range objective of this study was to examine the development of a newly created reservoir over the first few years of its existence. The reservoir selected for this study was Sessions Lake, located in south-central Michigan between the cities of Ionia and Saranac (Ionia County, Berlin Township, T6N, R7W, Section 3, and T7N, R7W, Section 34). The lake was managed for recreational use by the Michigan Department of Natural Resources (MDNR) as part of the Ionia State Recreation Area. The present study contributed baseline limnological data for the second year of the reservoir's existence. The short term objective was to study the amount of watershed nutrient input into the reservoir over the summer stratification period, the retention of these nutrients in the lake, the effect of the nutrients on the productivity, and the amount of nutrients released downstream. The changes in temperature and dissolved oxygen within the reservoir, and the effect of the reservoir discharge on these parameters in Sessions Creek downstream of the reservoir were also examined.

Studies of similar watershed management projects were examined to predict the possible effectiveness of a watershed management plan for the lake if it were to be implemented. Predictions were based on examination of the nutrient concentrations and inputs into the reservoir and review of the results of previously studied lakes with similar conditions.

Study Site

Sessions Lake was created by the construction of a 430-meter-long earthen dam across Sessions Creek. The dam was closed December 1, 1984 and the lake finished filling March 28, 1985. The reservoir had a surface area of 53 hectares (131 acres) and a volume of 3.23×10^6 cubic meters (2610 acre-feet) (Figure 1). The design elevation of the lake surface was 222.5 meters (730 feet) above sea level. The average depth of the reservoir was 6.1 meters (20 feet), and the maximum depth was 17 meters (55 feet) at the base of the dam.

The reservoir discharged water into a control structure from a mid-level outlet 10 meters below the lake surface. A weir in the control structure maintained the lake level. The lake water was oxygenated as it passed over the weir and fell 17 meters to the outlet to Sessions Creek. This system was designed to return water to the creek with an oxygen level and temperature similar to that of the stream above the reservoir. An emergency overflow at 222.8 meters (731 feet) above sea level allowed flood waters to pass through the reservoir more quickly.

The Sessions Creek watershed contained 4545 hectares (11,230 acres). Ninety-five percent of the watershed formed the headwaters of Sessions Lake (Figure 2). Sessions Creek entered the Grand River 1.6 kilometers downstream from the reservoir. The area draining directly into the reservoir comprised 5% of the watershed, and was primarily forest and rangeland. Nineteen percent of the watershed consisted of forest and rangeland. Less than one percent of the watershed was residential or commercial. Seventy-eight percent of the watershed was

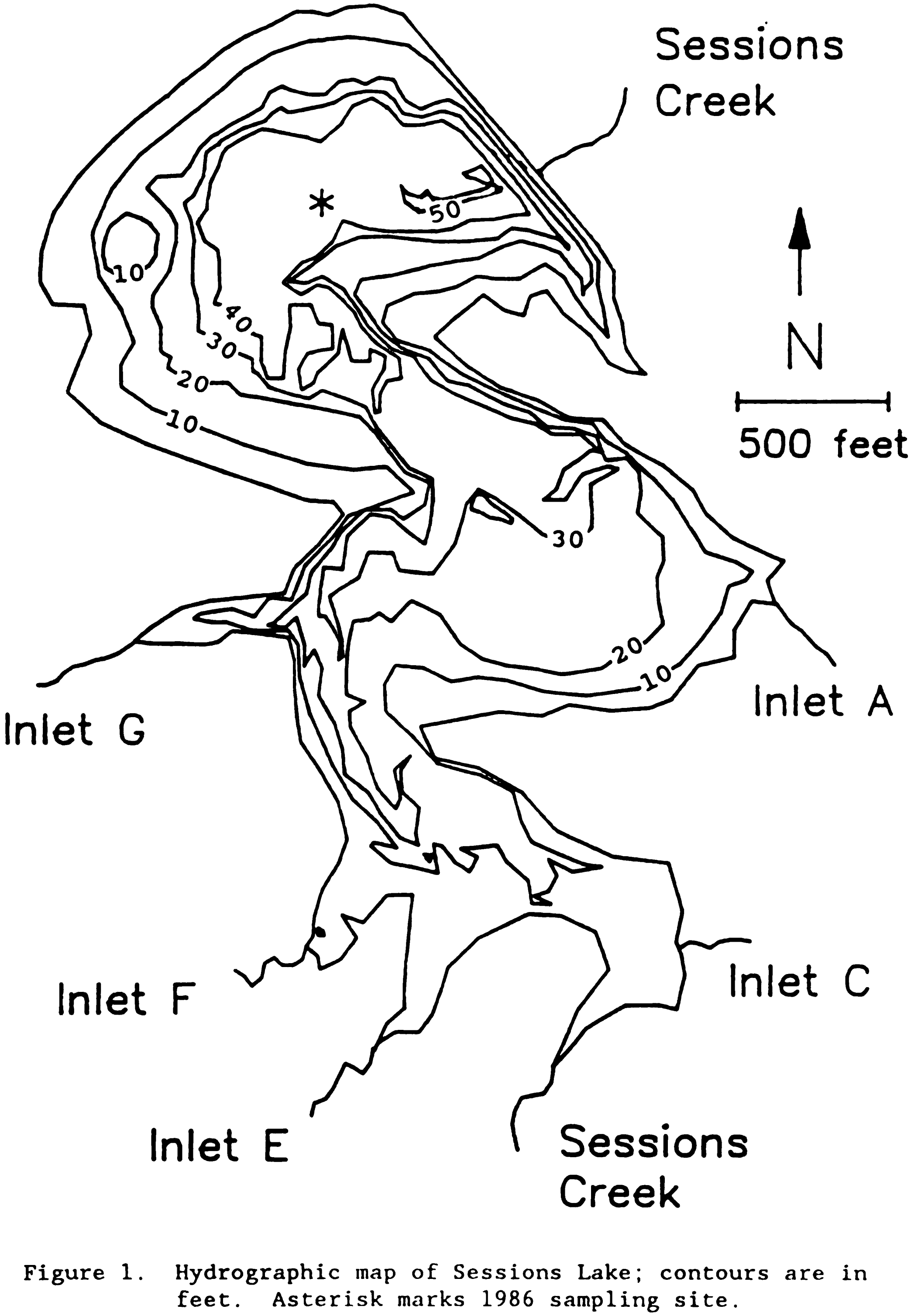

Figure 1. Hydrographic map of Sessions Lake; contours are in feet. Asterisk marks 1986 sampling site.

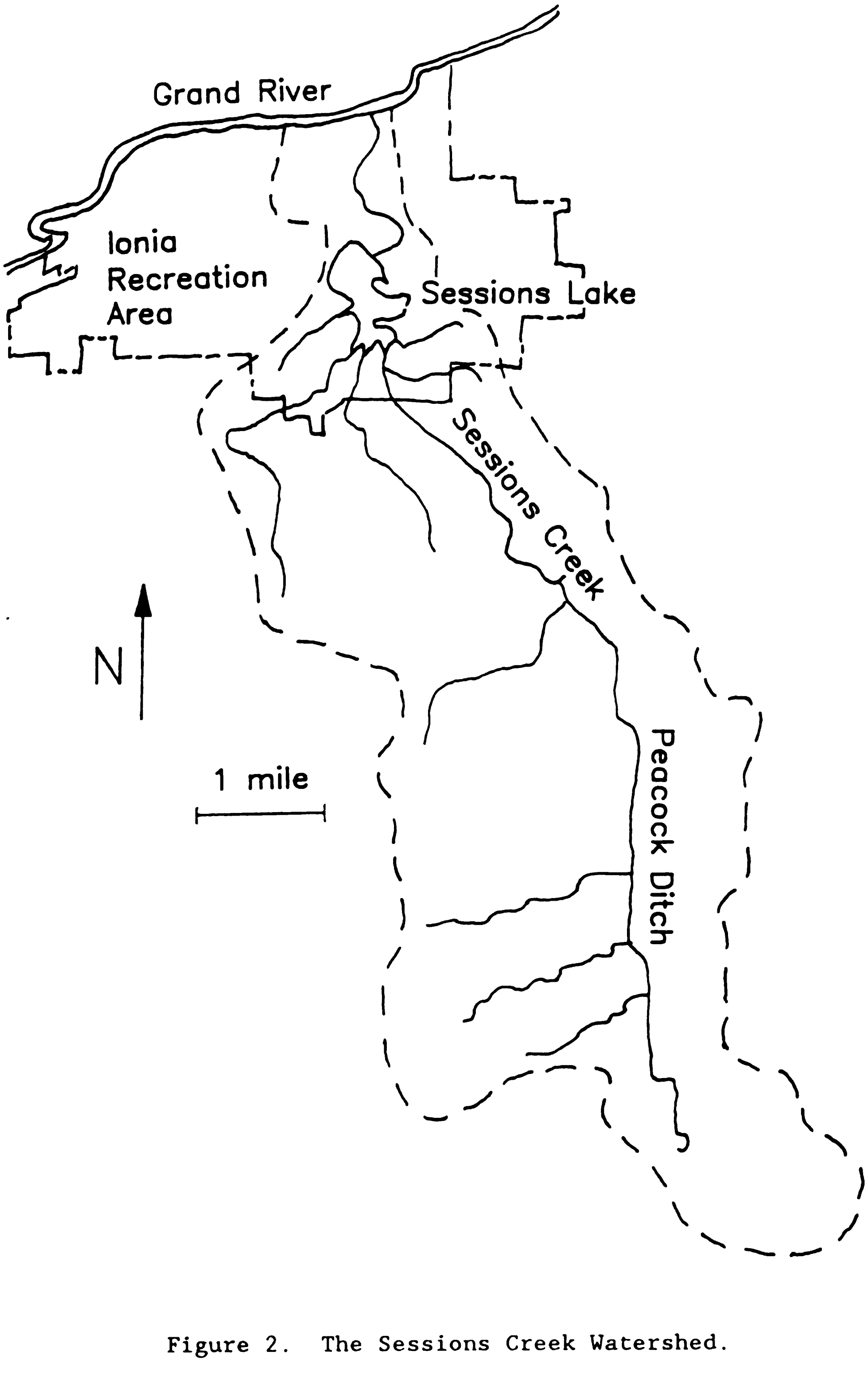

Figure 2. The Sessions Creek Watershed.

agricultural land, and was expected to contribute large amounts of nutrients to the reservoir. Agricultural soil conservation practices were widely used, including grassed waterways, no-till corn, cross-slope planting of row crops, and permanent vegetation planting on steep slopes (MDNR 1981). Approximately seventy percent of the agricultural lands used conservation tillage methods (MDNR 1983). There were twelve confined feedlot operations in the watershed, and these were also expected to contribute nutrient and coliform bacteria to the reservoir (MDNR 1981). Most of the cattle operations were fenced and green belted in the nearstream areas (MDNR 1983).

Slopes were gradual in the watershed. The largest changes in elevation were found at the site of the impoundment, providing for good lake depths. Most of the slopes in the watershed did not exceed six percent. Because of small fields in the watershed, the types of soils, and small slopes, sedimentation was not expected to be a problem in the reservoir. Field studies in 1979 and 1980 determined that Peacock Ditch, which leads into Sessions Creek, and Sessions Creek itself were in stable equilibrium (MDNR 1981). During these studies, the Universal Soil Loss Equation was applied to three separate square miles. From these results it was determined that the soil loss for the watershed averaged approximately 1.1 metric tons/ha/year (2.9 tons/acre/year). Thus, the reservoir received approximately 446 cubic meters (583 cubic yards) of sediment per year (MDNR 1981), or 0.01% of the lake volume.

Previous Studies

The Michigan Department of Natural Resources conducted tests of streams in the watershed in 1977 and 1983, before the construction of the reservoir (MDNR 1977, MDNR 1983). Water samples taken from Sessions Creek at the site of the impoundment in August showed total phosphorus levels of 0.059 mg-P/L in 1977 and 0.08 mg-P/L in 1983. Total nitrogen levels were 1.10 mg-N/L and 1.37 mg-N/L, and nitrate-nitrite nitrogen levels were 0.89 mg-N/L and 0.97 mg-N/L. Samples were again taken one week later in 1977 during rainfall runoff. Total phosphorus levels were 0.08 mg-P/L and total nitrogen levels were 1.33 mg-N/L.

Based on the high nutrient amounts in the streams Department of Natural Resources personnel predicted that the reservoir would be a eutrophic, warmwater lake with nuisance aquatic plant and algae growth. Hypolimnetic dissolved oxygen depletion would render the hypolimnion unusable for fish, and fish kills in winter were possible. It was also predicted that release of nutrients and water with high temperatures and low dissolved oxygen would create problems in Sessions Creek downstream of the impoundment (MDNR 1977).

Total coliform counts in Sessions Creek at the reservoir site in 1983 were 1300 counts/100 mL, and fecal coliform counts were 600 counts/100 mL (MDNR 1983). These levels were well above the established standards, 1,000/100 mL for total coliforms and 200/100 mL for fecal coliform, for direct body contact. In 1985 the Ionia County Health Department sampled the reservoir for bacterial counts four times between April and July (MacLachlan and Workman 1985). Samples taken from Sessions Creek above the reservoir still exceeded water quality standards, as did several of the reservoir samples during April. However, the rest of the samples had satisfactory results for direct body contact.

Sessions Creek Watershed Management Plan

Because of concerns over the water quality of the reservoir, the MDNR Parks Division drafted the Sessions Creek Watershed Management Plan (MDNR 1981). This plan identified and recommended actions for problem areas in the watershed. The plan was to be administered by the Ionia County Soil Conservation District over a five-year period.

Recommended treatments consisted of the implementation of a series of soil conservation techniques and animal control methods that protect the soil and prevent soil or nutrient loss. The practices to be implemented were taken from the *Michigan State Program Handbook* prepared by the Agricultural Stabilization Conservation Service (ASCS), and included permanent pastures, diversions, grazing and cropland protection, conservation tillage systems, establishment of permanent cover, sedimentation and erosion control, sod waterways, animal waste control facilities, forest tree planting, and habitat. These practices could be expanded or interrelated with a combination of Conservation Practice Standards necessary to be considered Best Management Practices (BMP's), as related to Section 208 of the Federal Water Control Act (MDNR 1981).

The total cost of the prescribed treatments was $250,000 (MDNR 1981). They were to be implemented through cost-sharing programs with area farmers. The Ionia County Soil Conservation District provides cost share assistance throughout the district, but additional funds were needed if recommendations in the management plan were to be followed. An application for a special Agricultural Conservation Project was not approved in 1981. Funding had not been obtained by 1987, and the Watershed Management Plan had not been implemented. Some treatments had been followed under other farm programs, but the livestock management procedures were unlikely to be implemented until funding was provided (J. Scott, Ionia County Soil Conservation District, personal communication).

METHODS

To carry out the objectives, water samples were collected from the deepest basin, from all of the significant inlets, and from the outlet of the reservoir. These samples were analyzed for pH, alkalinity, total phosphorus, total kjeldahl nitrogen, and nitrate-nitrite nitrogen. Dissolved oxygen, temperature, and conductivity profiles were also obtained.

The sampling program in 1985 involved two reservoir stations, one in the deepest basin and another in the middle basin (Tyning, unpublished data). Epilimnial data for the above parameters from each basin were compared using the Wilcoxon matched pairs signed ranks test (Siegel 1956). Significant differences between the two stations were only found for temperature ($p=0.029$) and dissolved oxygen ($p=0.011$). Thus the single sampling station in 1986 was representative of the epilimnion of the lake for nutrient sampling.

In 1986 water samples were collected from every two meters of depth from the deepest basin using a Kemmerer water sampler (Figure 1). Grab samples were obtained from the inlet and outlet streams. Water samples were transferred to polyethylene bottles and stored at 4 °C. until analyzed. The reservoir was sampled every two weeks during summer stratification, less frequently before and after. The streams were sampled every week during summer stratification. Chemical analyses of the samples were conducted immediately after lake sampling. Stream samples that were not immediately analyzed were preserved with 2.0 mL/L H_2SO_4 and stored at 4 °C. (U.S.E.P.A. 1979).

Dissolved oxygen (D.O.) was measured in the field using a YSI Model 54A oxygen meter with a polarographic electrode. Profiles of the reservoir's deepest basin were taken at one meter intervals. Conductivity was measured at one meter intervals with a YSI Model 33 S-C-T meter. Temperature was obtained by averaging the temperature measurements obtained from both instruments. pH was measured immediately after the water samples were obtained, using an Orion Model 211 pH meter. Alkalinity was determined on a monthly basis by potentiometric titration (A.P.H.A. 1985).

All chemical analyses were conducted following A.P.H.A. (1985) methods. Colorimetric measurements were carried out using a Varian SuperScan 3 spectrophotometer. Total phosphorus concentrations were determined colorimetrically after persulfate digestion using the ascorbic acid method. Samples for total kjeldahl nitrogen (TKN) were digested using the procedure for the semi-micro-kjeldahl system, with final ammonia concentrations determined colorimetrically using the Nessler reaction. Nitrate-nitrite nitrogen was determined using the cadmium reduction method. Total nitrogen concentrations were defined as the sum of the total kjeldahl nitrogen and the nitrate-nitrite nitrogen concentrations. Results were reported as mg-P/L and mg-N/L.

The surface areas of the lake at different depth intervals were determined by digitizing a 1"=200' bathymetric map of Sessions Lake. The areas were calculated based on the circumscribed polygon. The original map contained five foot contours, and the surface areas at one meter intervals were determined by interpolation. The volume of the layer between intervals was calculated using the formula:

$$V = (h/3)[A_1 + A_2 + (A_1A_2)^{1/2}]$$

where V is the volume of the layer, h is the thickness of the layer, A_1 is the area of the upper surface of the layer and A_2 is the area of the lower surface. The total lake volume is the sum of the volumes of the individual layers (Wetzel and Likens 1979).

The mass of a nutrient in the lake was calculated by multiplying the nutrient concentration measured at a certain depth by the volume of the water layer halfway from the shallower depth of measurement to halfway to the deeper depth of measurement. The sum of these products equalled total nutrient mass in the lake, and the sum divided by total lake volume equalled mean lake concentration of a nutrient at a point in time.

A Price pigmy meter was used to measure current velocity, and the mid-section method was used to determine stream discharge (U.S.G.S. 1977). Only inlets D (Sessions Creek), E, F, and the outlet were measured weekly over the summer stratification period. Minor inlets were measured periodically to determine their importance.

Total discharge over a period of time was calculated using the formula:

$$Q_t = \frac{(Q_0+3Q_1)}{8} \cdot (t_1-t_0) + \frac{(3Q_1+Q_2)}{8} \cdot (t_2-t_1)$$

where Q_t is total discharge halfway from the previous time of measurement t_0 to halfway to the next time of measurement t_2, and Q_1 is discharge at time of measurement t_1 (McNabb et al. 1982). Individual Q_t's were then summed to determine discharge over a period of time. This method assumes that sampling periods are close enough so the instantaneous discharge between two sampling dates changes linearly.

The flushing rate for the reservoir was calculated by dividing the outlet discharge by the lake volume (V_O/V_L). The hydraulic residence time (t_w) is the reciprocal of the flushing rate.

Nutrient loading was calculated by multiplying the nutrient concentration of an inlet sample by the instantaneous discharge of the inlet. Loading over a period of time was calculated using the same equation as for total discharge, with nutrient loading in mg/s exchanged for hydraulic discharge in m^3/s.

Productivity was measured at month and one-half intervals using the dissolved oxygen version of the light bottle-dark bottle method (A.P.H.A. 1985, Wetzel and Likens 1979). Dissolved oxygen concentrations were determined using the azide modification of the Winkler method (A.P.H.A. 1985). Hourly productivity values were converted to daily estimates using the method of Wetzel and Likens (1979). The photoperiod was divided into five equal parts and the third period, during which productivity measurements were made, was assumed to represent 30% of daily production. Photosynthetically active radiation (PAR) penetration measurements were obtained during the productivity measurements using a LICOR model 1776 Solar Monitor equipped with an underwater quantum sensor.

Daily precipitation records were obtained from the National Weather Service's Cooperative Observer at Ionia. The weather station was located 8.8 km (5.5 miles) from the reservoir. Evaporation and monthly normals of precipitation data were obtained from the U.S. Dept. of Commerce/National Oceanic and Atmospheric Administration (N.O.A.A 1982). Evaporation was based on data taken at East Lansing from a class "A" pan during the crop season.

Nutrient loadings from precipitation were estimated from values in the literature (Premo et al. 1985; Ostrofsky 1978; McNabb et al. 1982; McNabb, Lake Lansing, MI, unpublished data; and Lowrance et al. 1984), adjusted for the summer stratification period.

Groundwater and direct runoff water inputs to the reservoir were determined as the change in lake storage plus outlet discharge plus evaporation minus the sum of the inlet discharge and precipitation. Nutrient concentrations of groundwater were obtained from the literature and concentrations of overland flow were estimated from the smaller inlets. The quantity of water from each source could not be separated from the their combined water discharge by the methods used here and accurate nutrient loading estimates from these sources could not be calculated.

Net internal loading of phosphorus over the summer stratification period was calculated using:

$$TP_{load} = \text{dLake Storage} - (TP_{in} - TP_{out})$$

where TP_{load} is the net total phosphorus from internal loading, dLake Storage is the difference in mass of phosphorus in the reservoir between the beginning and the end of an interval, TP_{in} is the mass of phosphorus entering the reservoir from external sources and TP_{out} is the mass leaving the reservoir through the outlet (Premo et al. 1985).

An adaptation of the phosphorus model suggested by Vollenweider and Kerekes (1980) was utilized to make predictions about the potential success of any nutrient reductions from implementing a watershed management plan. The model was based on data from over 200 lakes and reservoirs and described the relationship between mean total phosphorus lake concentration ($[TP_L]$), mean inflow total phosphorus concentration ($[TP_i]$), and hydraulic residence time (t_w) in the following manner:

$$[TP_L] = \frac{[TP_i]}{(1+t_w^{1/2})}$$

This equation describes the average statistical relationship between total phosphorus load and total phosphorus concentration in lakes. While the model assumes that the water body is completely mixed and in a steady state, a large range of lakes were found to perform in a statistically similar manner (Vollenweider and Kerekes 1980).

Data collected from Sessions Lake during 1986 and from Skinner Lake, Indiana (McNabb et al. 1982; McNabb unpublished data) were used in adapting this model to predict summer stratification epilimnial total phosphorus concentrations for Sessions Lake.

RESULTS

Stratification of the Reservoir

The reservoir was inversely thermally stratified in February, 1986, but showed complete mixing in April. Dissolved oxygen concentrations in the lower depths showed effects of stratification by May 2, and a distinct epilimnion was formed in the middle basin by May 14. On May 28 the reservoir showed a distinct epilimnion, metalimnion, and hypolimnion in the deep basin. The bottom of the mixed surface layer was found at 2-3 meters until September. The lake remained stratified over this entire period (Figure 3). Heavy rains and streamflow lowered the epilimnion to 7 meters on September 16. An unusually large flood discharge during September flushed a large percentage of the impoundment, ending the conditions present throughout the summer. Thus, for the purposes of this study the summer stratification period was considered to last from May 28 until September 16. The reservoir did not turn over completely until November.

A stagnant layer represented by colder water was present from eleven meters downward in the deep basin of the reservoir during stratification (Figure 3). Even after the large storm flows of September, the water below this depth appeared little influenced until fall turnover. This layer represents approximately 5.5% of the lake volume and was probably caused by the outlet at the ten meter depth primarily withdrawing water from above this depth.

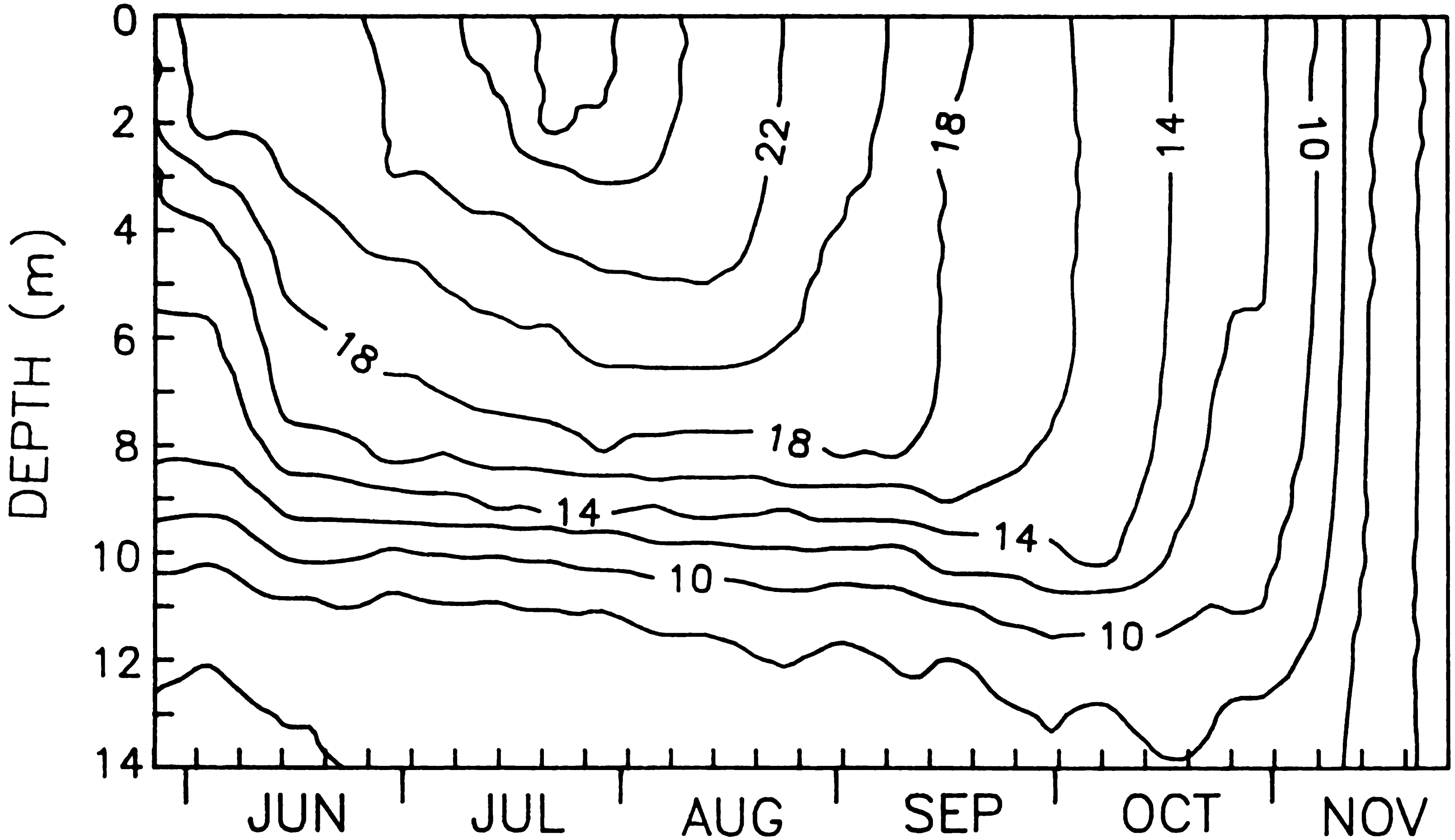

Figure 3. Temperature isopleths (^{o}C) for Sessions Lake (5/28/86-11/24/86).

Temperature and Dissolved Oxygen

Surface temperatures ranged from 18 °C to 27 °C over the summer stratification period, with the warmest temperatures found toward the end of July (Figure 3). The average temperature was 22 °C. Temperatures decreased from the surface to 10 °C at the 10 meter depth. Due to the stagnant layer the bottom temperature (13-14 m) remained at 5.1-7.5 °C over the summer stratification period.

Dissolved oxygen concentrations of the surface water ranged from a low of 7.1 mg/L on September 16 to a high of 14.5 mg/L on July 1, averaging 10 mg/L (Figure 4). Levels of less than 5.0 mg/L were found from 5 meters downward throughout the summer, with D.O. less than 0.1 mg/L below 10 meters at the beginning of June, and below 6 meters during July and August. Thus 29% of the reservoir volume was anaerobic during the peak of summer stratification.

Water Loads

Inlets D (Sessions Creek), E, and F (Fisher Drain) were the only significant inlets of the reservoir. The discharges of Inlets A and C were less than 1% and Inlet G was never greater than 2.5% of the total stream load.

The discharges of the three major inlets and the outlet directly below the dam were measured weekly from May 28 until September 23. From May 28 to September 16 the three inlets delivered 1.64 x 10^6 m^3 of water to the reservoir (Figure 5). During this same period one and one-half times more water left by the outlet than entered the reservoir from the inlets.

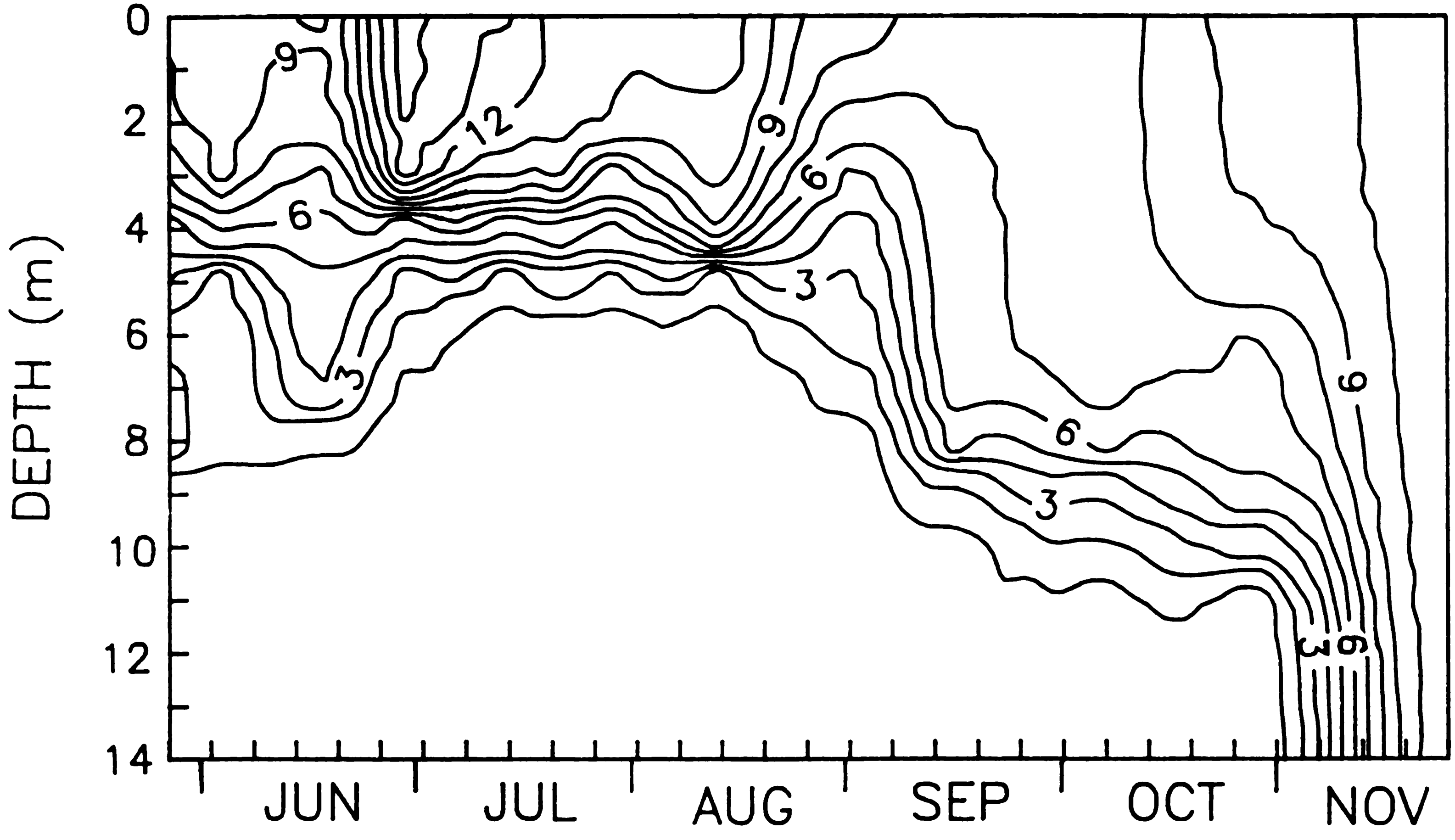

Figure 4. Dissolved oxygen isopleths (mg/L) for Sessions Lake (5/28/86-11/24/86).

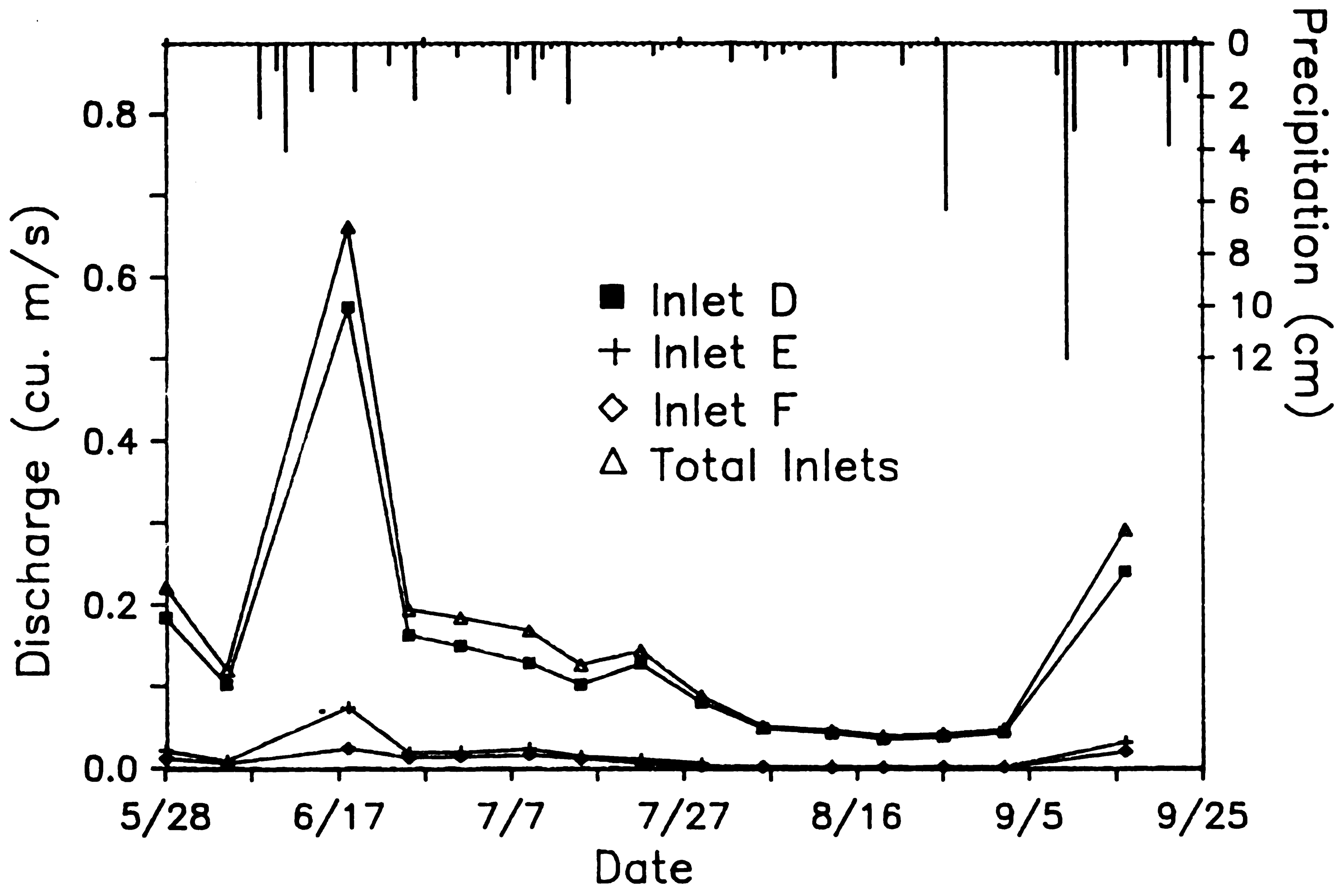

Figure 5. Inlet discharges and precipitation for Sessions Lake (5/28/86-9/16/86).

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Stream discharge to the lake was heavily affected by precipitation. Nearly 10 cm of precipitation fell from June 8 to June 14, leading to heavy inlet streamflow. From June 11 to June 22 30% of the inlet discharge for the summer stratification period occurred (Figure 5). Heavy rains from September 9 to September 11, and from September 21 to the end of the month caused heavy flooding by September 23. From September 16 to September 23 the inlets delivered approximately 7.92×10^5 m^3 of water, or almost 50% of the discharge of the previous four months (Figure 6). This large discharge probably violated the assumption of linear change in instantaneous discharge between sampling dates, and sampling was discontinued on the inlets. The outlet was sampled every five to ten days after September 23 until October 27.

Sessions Creek was the primary water source of the reservoir, with groundwater and overland runoff the second highest source, followed by precipitation (Table 1). Sessions Creek was the major source of streamflow entering the reservoir and provided almost half of the total discharge to the reservoir.

Groundwater and overland runoff accounted for one-third of the water entering Sessions Lake over the summer stratification period. The changes of magnitude in this input were similar to that of the inlets in response to rain events (Figure 7). The sampling frequency of once per week was too large to allow the breakdown of the overland and groundwater input into categories of overland flow, interflow, and baseflow, but from the quick response of this input to rain events it primarily consisted of overland runoff and interflow.

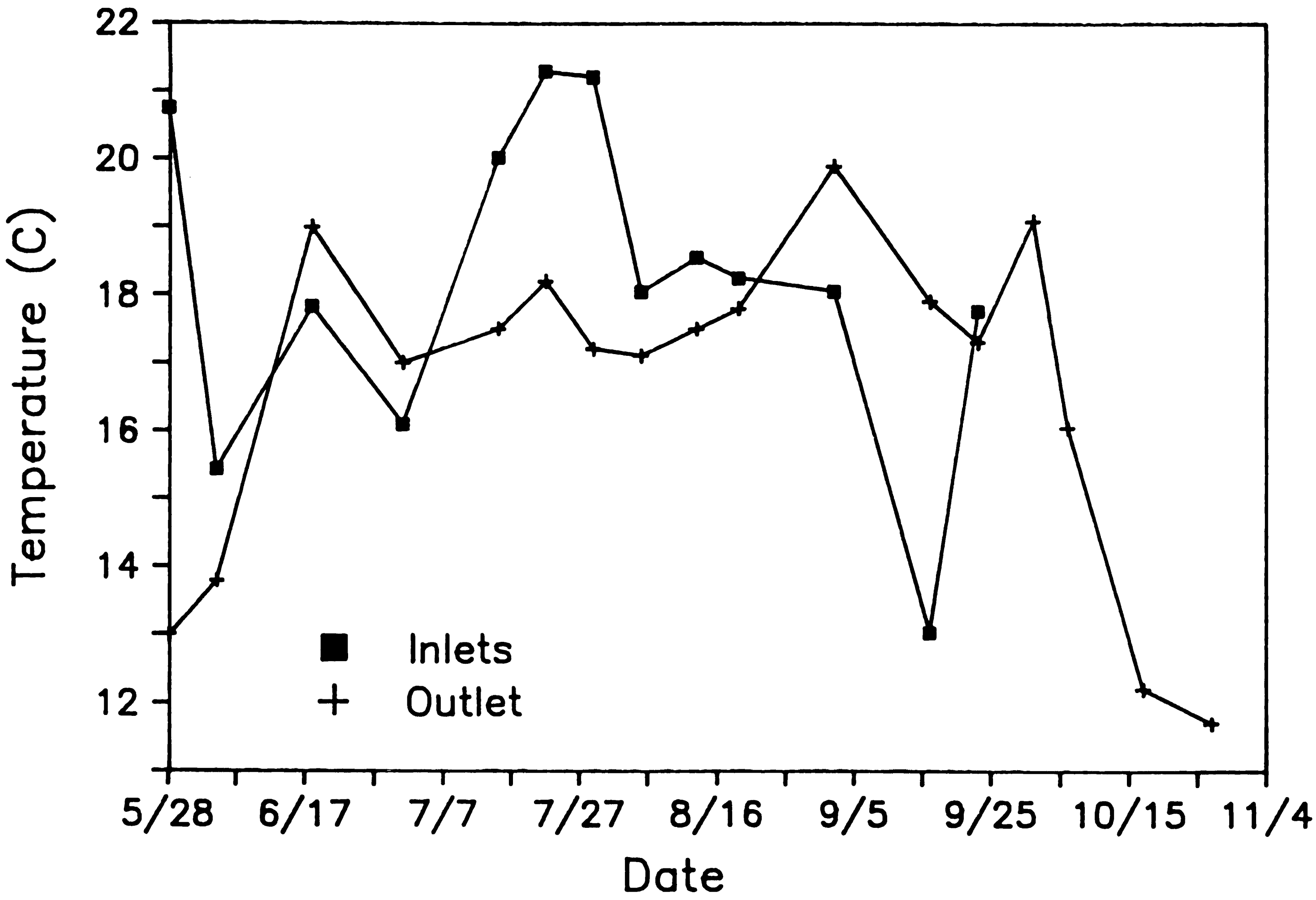

Figure 6. Total inlets and outlet discharge for Sessions Lake (5/28/86-10/27/86).

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Table 1. Water budget of Sessions Lake (5/28/86-9/16/86).

	Water Loadings (m^3)	% of Inlets	% of Inflow
Sessions Creek	1.39×10^6	84.8%	48.5%
Inlet E	1.62×10^5	9.9%	5.7%
Inlet F	8.33×10^4	5.1%	2.9%
Total Inlets	1.64×10^6		57.1%
Precipitation	2.69×10^5	16.4%	9.4%
Groundwater and runoff	9.58×10^5	58.5%	33.5%
Outlet	2.52×10^6	154%	87.9%
Evaporation	2.74×10^5	16.7%	9.6%
Total Discharge	2.79×10^6	170%	
Diff. in Storage	7.40×10^4	4.5%	2.6%

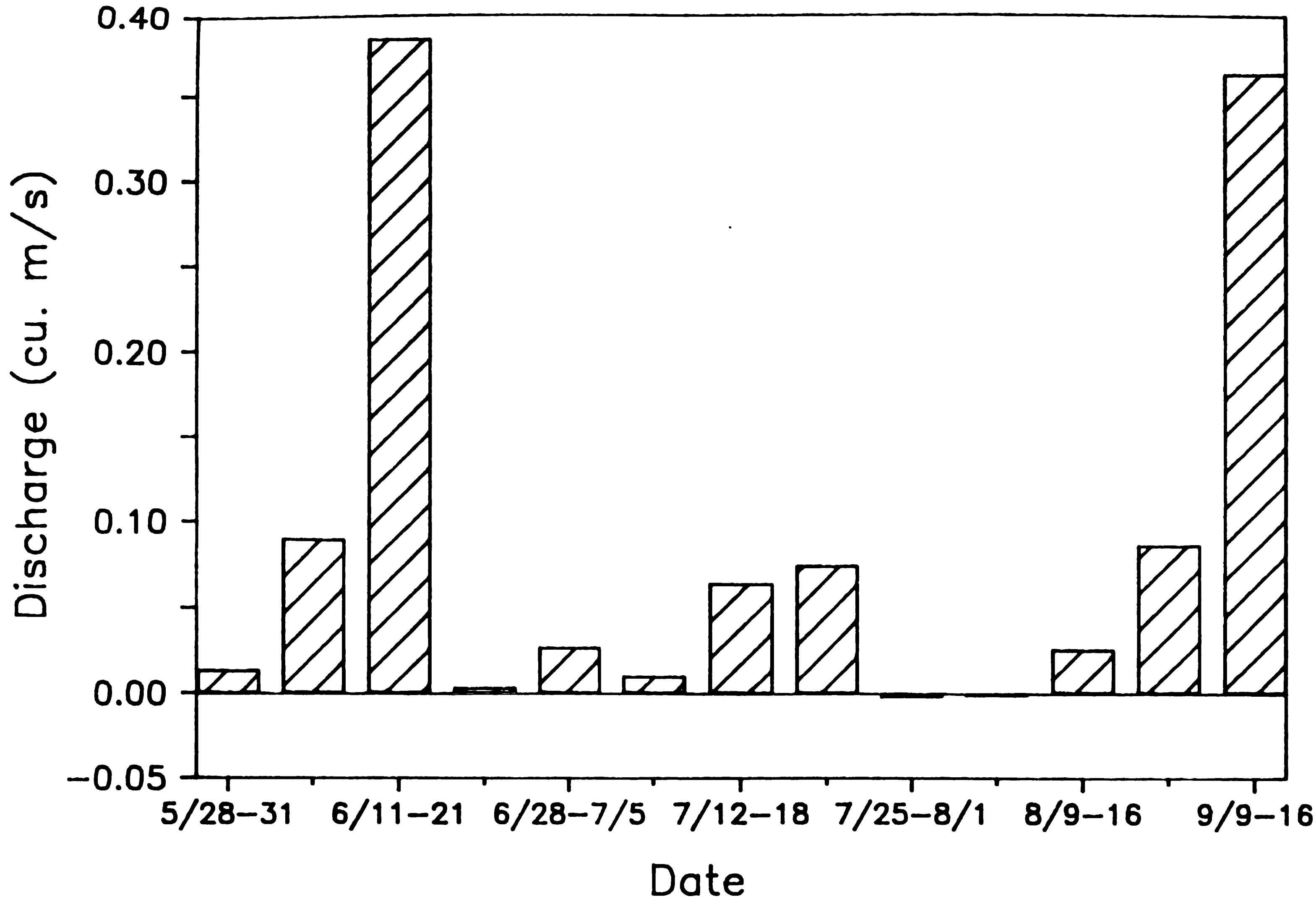

Figure 7. Groundwater and overland flow input to Sessions Lake (5/28/86-9/16/86).

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Heavier than normal precipitation occurred during the summer stratification period in 1986 (Figure 8). A total of 50.85 cm fell from May 28 to September 16, compared to the thirty year normal of 29.08 cm. However, heavy rains from September 9 to September 11 contributed 16.59 cm, a large percentage of the extra precipitation.

For the summer stratification period (May 28 to September 16) the reservoir flushed 0.78 of its total volume. The epilimnion (to 3.0 m) was replaced 1.85 times during summer stratification. The large amount of floodwaters during late September and October caused the reservoir to flush an additional 1.5 times.

Despite large variations in inflows of water, Sessions Lake showed only small fluctuations in lake level during the summer and fall of 1986. The lake level ranged from 222.29 meters to 222.80 meters above sea level (the overflow elevation), but stayed between 222.30 to 222.40 meters for the majority of the summer (Figure 9).

Nutrient Loadings

Inlets A and C contributed less than 0.5% of total phosphorus, 0.1% of nitrate-nitrite nitrogen, and 1% of total nitrogen at times of measurement. Inlet G also contributed less than 1% of the total phosphorus and nitrate-nitrite nitrogen, and less than 2.5% of the total nitrogen.

The three main inlets provided 250 kg of phosphorus to the reservoir from May 28 to September 16 (Table 2). Nitrate-nitrite nitrogen loadings of 9310 kg, total kjeldahl nitrogen loadings of 1310 kg as N, and total nitrogen loadings of 10,620 kg as N were measured in streamflow for the same period. Total atmospheric

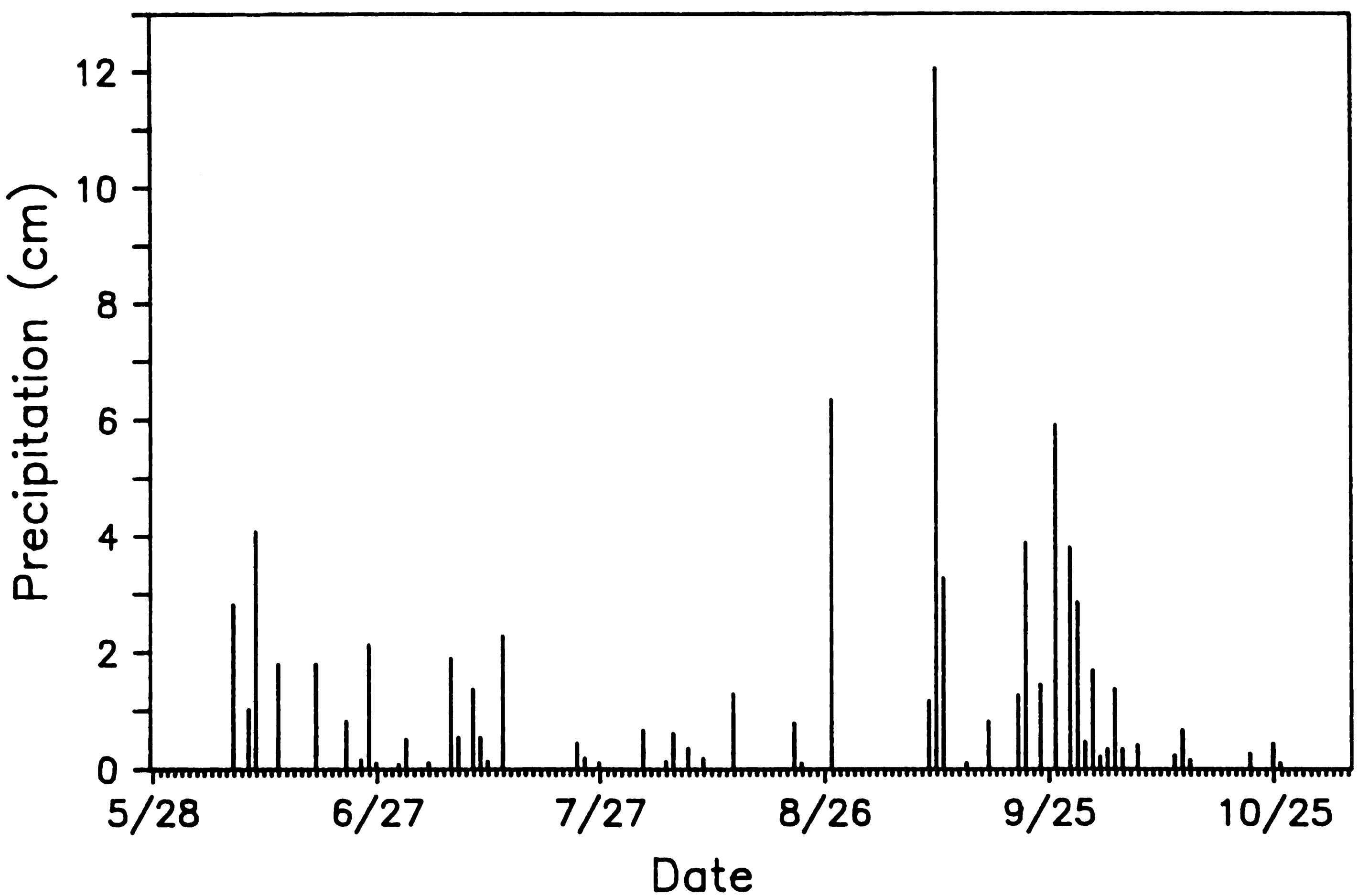

Figure 8. Precipitation for Ionia, Michigan (5/28/86-11/4/86).

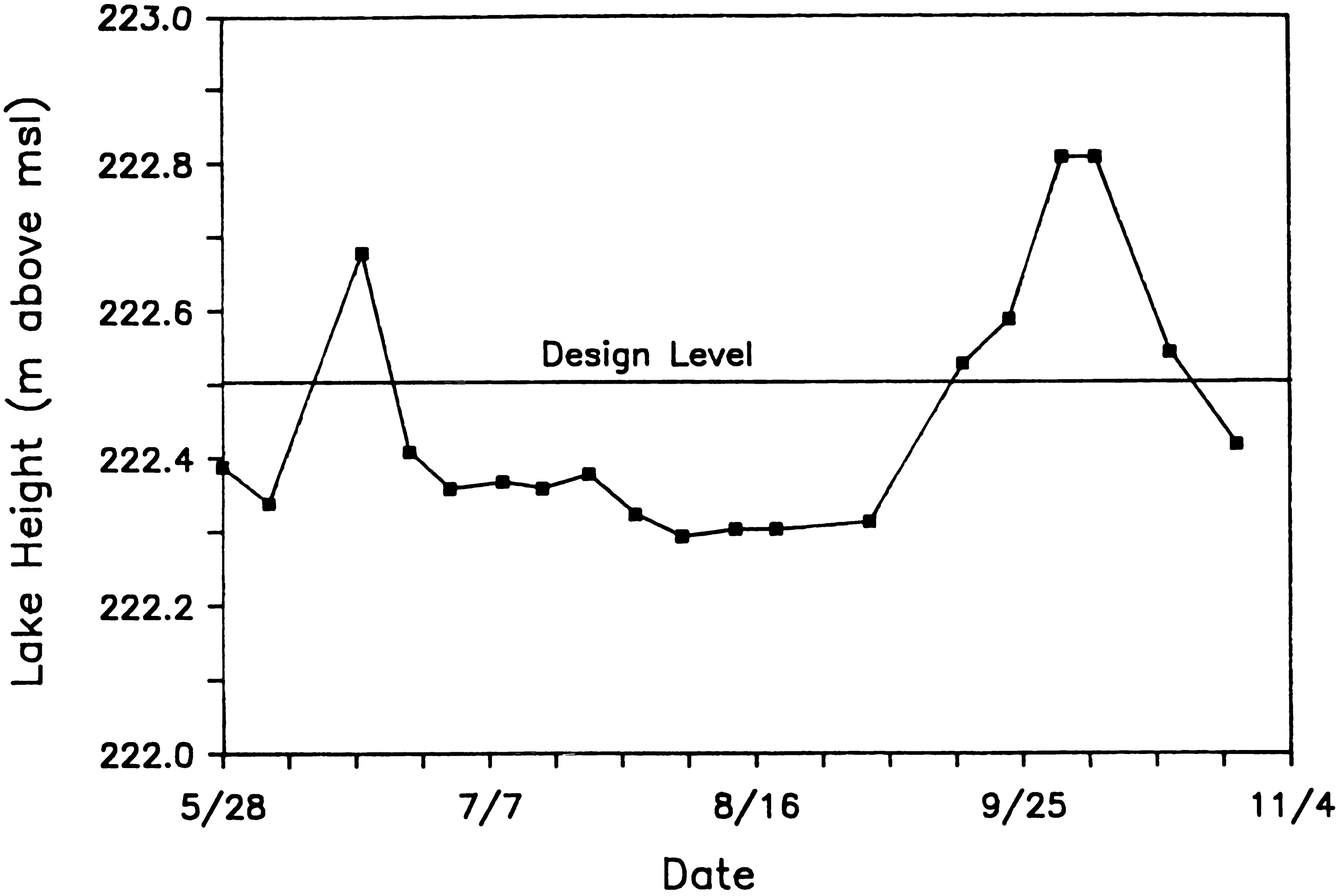

Figure 9. Sessions Lake level (5/28/86-10/27/86).

Table

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Table 2. Nutrient loadings and discharges of Sessions Lake (5/28/86-9/16/86).

	Tot. P	Tot. N	TKN	NO_3-NO_2-N
Sessions Ck.	73.6%	87.7%	77.8%	91.5%
Inlet E	17.8%	8.1%	14.4%	7.4%
Inlet F	3.2%	1.9%	7.7%	1.1%
Precipitation	5.9%	2.3%	*	*
Inflow Total	268 kg	10876 kg	1310 kg	9310 kg
Outlet total	286 kg	10520 kg	3980 kg	6540 kg
Outlet (% of inflow)	106.8%	96.7%	303.9%	70.3%

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deposition was estimated as 16 kg of TP and 260 kg of TN. Sessions Creek provided the majority of nutrients to the lake, followed by Inlet E.

Changes in total phosphorus loadings reflected stream discharge, with large increases seen after rain events (Figure 10). Total nitrogen loadings followed a similar pattern. Both total phosphorus and total nitrogen had loadings increase more than one order of magnitude in response to the rain in the second week of June. The high streamflow from September 16 to September 23 loaded an additional 420 kg of phosphorus and 8440 kg of nitrogen into the lake. This represents 157% of the total phosphorus and 78% of the total nitrogen streamflow input to the reservoir over the period from May 28 to September 16.

Inlets A, C, and G are small streams in the watershed draining the rangeland and forest area immediately around the reservoir. If the overland and groundwater portion of water flow into the reservoir consisted only of overland flow, its nutrient content would be similar to these smaller inlets. Using the measured mean total phosphorus concentration of 0.024 mg/L from these inlets overland flow would have contributed an additional 8% total phosphorus to the reservoir. If the overland and groundwater portion of inflow consisted only of groundwater, the phosphorus loadings would be higher. Burton and Hook (1979) found groundwater total phosphorus concentrations equal to 0.073 mg/L in drainage from an abandoned agricultural field in East Lansing, Michigan. This land is similar to that surrounding a portion of the reservoir. If the overland and groundwater portion of water flow into the reservoir consisted only of shallow groundwater, its nutrient content would contribute an additional 21% total phosphorus to the

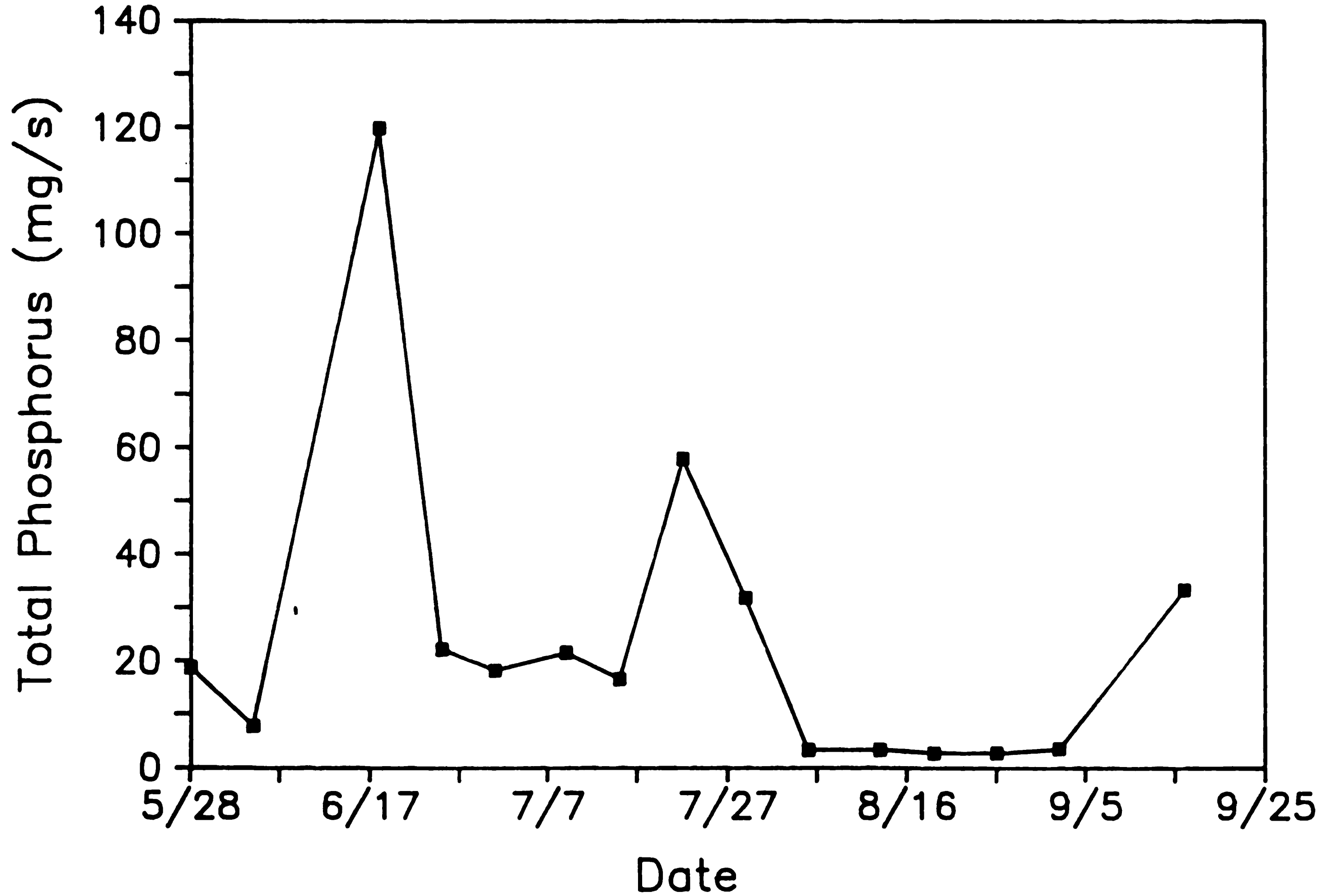

Figure 10. Streamflow total phosphorus loading to Sessions Lake (5/28/86-9/16/86).

reservoir. Burton and Hook's value is the maximum possible, since it was measured from shallow groundwater that quickly ran off through drainage tile. Groundwater at Sessions Lake would not run off as quickly and would lose more of its phosphorus to the sediment by adsorption. In addition, approximately 9% of the groundwater and overland flow to Sessions Lake may be attributed to Inlets A, C, and G. The actual total phosphorus contribution of groundwater and overland flow is probably in between the two values, and would be the third largest source of phosphorus loading behind Sessions Creek and Inlet E.

For the period May 28 to September 16 Sessions Lake had net internal loadings of 109 kg of TP. This loading was the result of phosphorus release from the anaerobic sediments in the hypolimnion. Since the reservoir was stratified, this hypolimnetic loading had no effect on epilimnetic phytoplankton growth during summer stratification. During the same period, a net internal loss of 1662 kg of TN occurred.

Lake Nutrient Concentrations

Whole lake total phosphorus concentrations ranged from 0.036-0.137 mg/L over the summer stratification period (May 28 to September 16), with a mean of 0.074 mg/L. Epilimnial total phosphorus concentrations (0-3 m) averaged 0.057 mg/L, with a low of 0.017 mg/L on September 2, and a high of 0.134 mg/L on June 18. Total phosphorus concentrations were constant throughout the epilimnion, but increased with depth in the metalimnion and the hypolimnion. The heavy precipitation during September led to large loadings to the lake from runoff, with whole lake total phosphorus reaching 0.288 mg/L on October 6 (Figure 11).

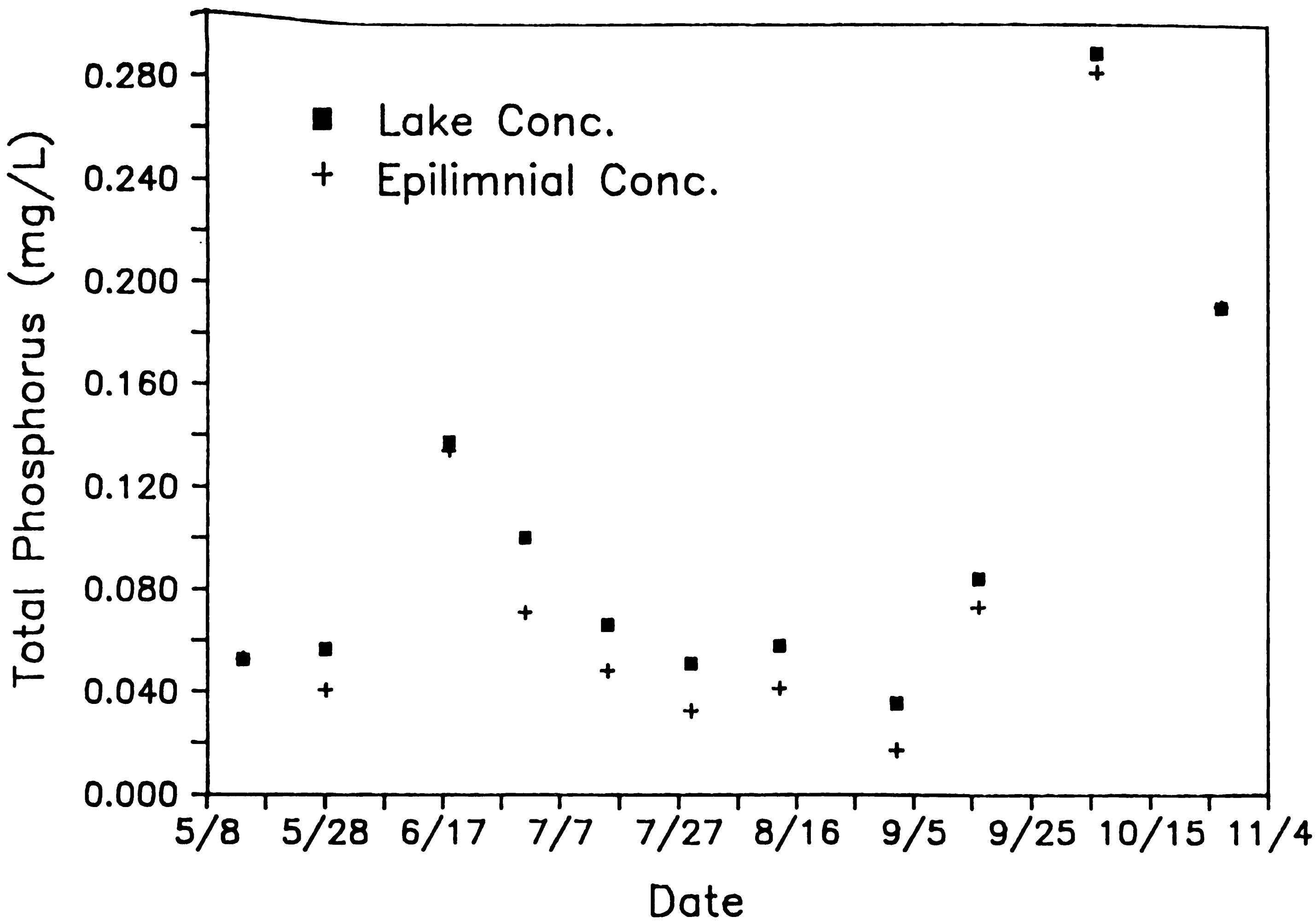

Figure 11. Whole lake and epilimnial total phosphorus concentrations of Sessions Lake (5/14/86-10/27/86).

Whole lake total nitrogen concentrations ranged from 2.80 to 6.96 mg/L, with a mean of 4.58 mg/L. Epilimnial total nitrogen concentrations had a mean of 4.37 mg/L, and ranged from 2.58 to 6.88 mg/L. Total nitrogen concentrations increased from the surface to the metalimnion, and then decreased in the hypolimnion. The fall rains did not affect total nitrogen as much as total phosphorus. Total nitrogen increased, but maximum total nitrogen was found after the early June rainstorms.

Whole lake TN:TP ratios ranged from 39.5 to 88.3, with a mean of 66. Epilimnial TN:TP ranged from 45.7 to 150.5, with a mean of 91.

Alkalinity, pH, and Conductivity

Epilimnial pH values measured over the summer ranged from 7.70 to 9.28. Summer stratification pH measurements in water overlying the sediments ranged from 6.89 to 7.59, or from 0.57 to 1.93 pH units less than the corresponding surface pH measurements.

Alkalinity was measured four times during summer stratification. Epilimnial alkalinity values ranged from 2.13 meq/L to 3.11 meq/L. The mean epilimnial alkalinity was 2.67 meq/L. Alkalinity increased rapidly below the epilimnion, and ranged from 5.84-6.44 meq/L near the bottom.

Specific conductivity ranged from 320 to 440 umhos/cm at 25 °C in the epilimnion. The mean value for the epilimnion was 380 umhos/cm. Conductivity also increased rapidly below the epilimnion, with a range of 645 to 745 umhos/cm near the bottom.

Light Penetration and Limit of Visibility

Secchi disc depth was measured approximately every two weeks during the summer stratification period. The mean secchi depth was 2 meters, and ranged from 1.3 to 3.3 meters. The euphotic zone was defined as the zone from the surface of the lake to the depth where only 1% of the solar radiation striking the surface is still present (Wetzel and Likens 1979). Light measurements were obtained with an underwater PAR light meter during productivity experiments, and thus the euphotic zone can be compared to secchi disk depth (Table 3). From this comparison it can be seen that the euphotic zone is roughly 1.9 times the secchi disk depth, and that the euphotic zone averaged 4 meters in depth during the summer stratification period.

Table 3. Comparison of secchi depth to euphotic zone depth.

Date	Euphotic Zone (m)	Secchi Depth (m)
6/25/86	2.5	1.3
7/22/86	4.5	2.0
9/9/86	6.3	3.3

Primary Production

Productivity experiments were conducted on three dates during the summer stratification period. All experiments were conducted between 11:00 a.m. and 1:00 p.m. under mostly sunny conditions. Gross production equalled 2710 mg C/m^2 on June 25, 3180 mg C/m^2 on July 22, and 1510 mg C/m^2 on September 9.

Effect of Reservoir on Sessions Creek

During summer the water discharged from the reservoir through the mid-level outlet was similar in temperature to water from the inlets. From mid-June through August, the inlets had a mean weighted temperature of 18 °C with a range of 16-21 °C. The outlet had a mean temperature of 17 °C, with a range of only 17-19 °C. The reservoir had a moderating influence on Sessions Creek, dampening the fluctuations in creek temperature caused by rainfall events (Figure 12).

Sessions Lake had little effect on the net nutrient loads of Sessions Creek (Table 2). Less than seven percent more phosphorus discharged from the lake than entered it by the inlets and precipitation. Over three times the amount of total kjeldahl nitrogen was exported from the reservoir as entered, but this was offset by the 30% decrease in nitrate-nitrite nitrogen, so that the mass of total nitrogen entering the reservoir the similar to the mass of total nitrogen leaving the lake. This does not include any nutrients that may have entered in the groundwater or in overland flow.

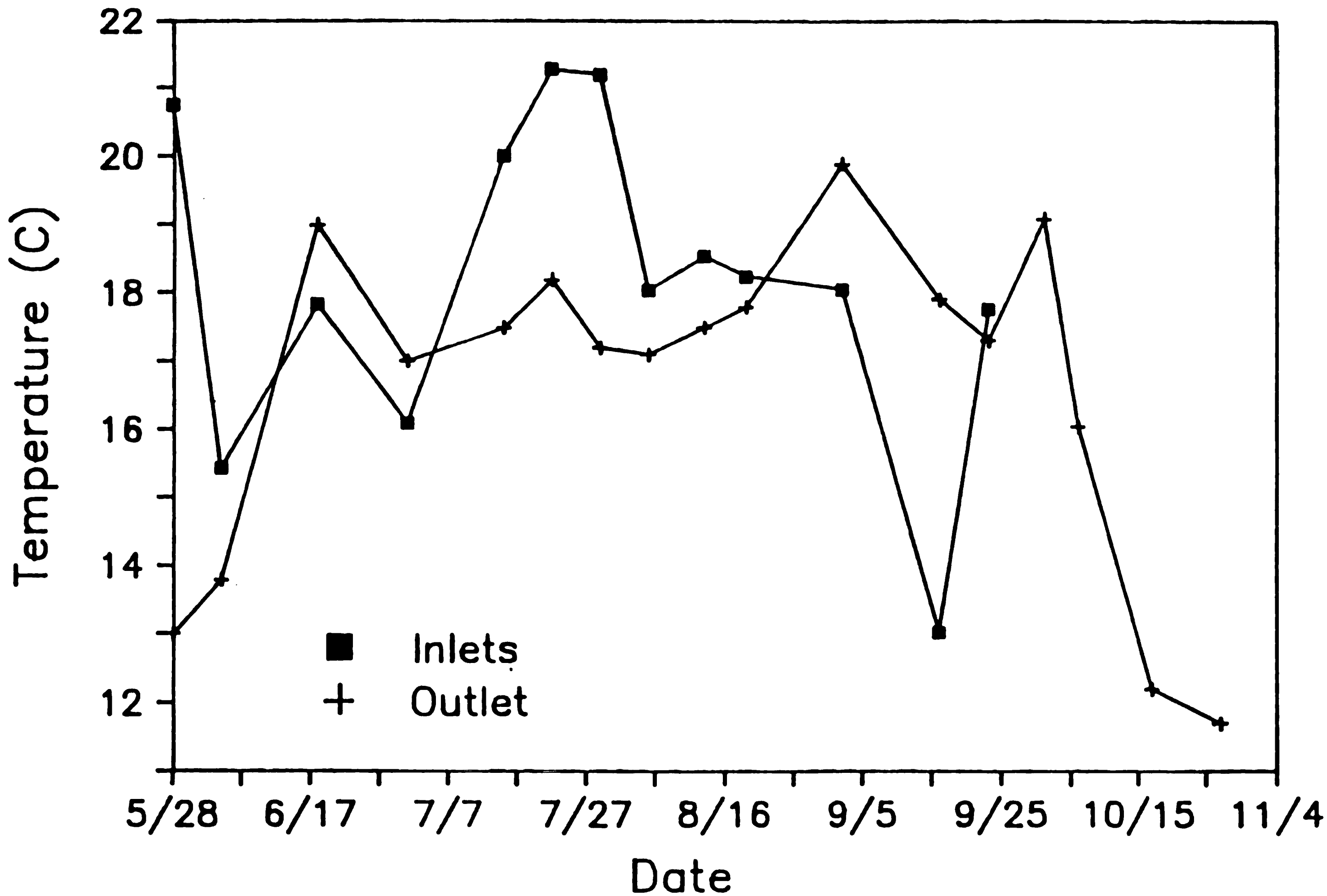

Figure 12. Inlet and outlet temperatures (5/28/86-10/27/86).

DISCUSSION

Sessions Lake can be classed as a eutrophic lake based on mean total phosphorus concentration, mean total nitrogen, productivity, hypolimnetic oxygen depletion, and secchi depth (Vollenweider and Kerekes 1980, Wetzel 1983).

Limiting Nutrient

Total nitrogen:total phosphorus ratios are useful in determining which nutrient is in short supply relative to the other. The limiting nutrient, typically phosphorus, is a controlling factor on algal growth in a lake. At least 80% of the surveyed lakes were phosphorus limited in an international survey conducted by the Organization for Economic Cooperation and Development (Vollenweider and Kerekes 1980). Dillon and Rigler (1974) found that a TN:TP ratio larger than 12 indicated that phosphorus was limiting growth. Smith (1982) discovered that total nitrogen still had an influence on chlorophyll concentrations in a lake with TN:TP less than 35. Sessions Lake had a mean whole lake TN:TP ratio of 66, and an epilimnion mean ratio of 91. The smallest ratio was 40. Thus, phytoplankton growth during summer stratification in Sessions Lake was nutrient dependent only on total phosphorus concentrations, although light probably had a larger effect on limiting algal growth than nutrients. Management techniques that reduce phosphorus inputs from the Sessions Creek watershed would be the most effective in reducing phytoplankton growth in the impoundment.

Effect of Nutrient Input

Sessions Creek provided the majority of water and nutrients entering Sessions Lake. While groundwater and overland runoff provided one-third of water inflow, it provided a proportionately smaller percentage of the nutrients. Inlet E was a large source of phosphorus input into the reservoir, providing only 6% of the water but nearly 18% of the total phosphorus. This amount probably exceeded that contributed by groundwater and overland runoff, which provided over five times more water than Inlet E. The high nutrient concentrations found in Inlet E could be attributed to presence of feedlots near the creek just upstream of the recreation area. The Watershed Management Plan identified the sub-basin on this inlet just upstream of the reservoir as an area deserving priority attention, and the 1986 study results support this.

Phosphorus concentrations in the reservoir varied due to nutrient inputs from storm events. The large inflow of phosphorus from rains the second week of June resulted in a three-fold increase in epilimnial and whole lake total phosphorus. Concentrations decreased throughout the rest of the summer, but again increased substantially after the September storms.

Some soil and water conservation practices are designed to control sediment losses over a long period of time, and are not effective in preventing losses during large storm events (Walter et al 1979). BMP's that are to be implemented in the Sessions Creek watershed will need to be effective in controlling runoff from storm events, as this seems to be a major determinant of water quality and lake nutrient concentrations. Sessions Creek and Inlet E should receive the initial focus of any BMP's that are implemented.

Productivity

Productivity rates measured during the summer of 1986 ranged from 1510 mg C/m^2/day to 3180 mg C/m^2/day. These values place Sessions Lake among the eutrophic lakes tabulated by Wetzel (1983).

Other indications of productivity were present. Algal films were present at the surface of the lake as early as May 28 when winds were calm. A sample of this film collected in June contained the blue-green algae *Microcystis* spp. Algal scums were frequently present in the quiet coves where the inlets entered the lake.

Bubbles were seen rising to the surface of the lake from July 15 until the end of the summer. These bubbles probably originated from decomposition in the sediments, possibly as a result of high organic matter content in the flooded soils and from earlier periods of productivity. The bubbles were not seen in 1985.

The distribution of pH and alkalinity values were also indicative of a productive system. The much lower pH's found near the bottom compared to the surface (0.57 to 1.93 pH units) indicate higher CO_2 concentrations near the bottom as a result of decomposition. Alkalinity declined in the epilimnion and increased in the hypolimnion as summer progressed. This was caused by high phytoplankton productivity withdrawing CO_2 from the surface waters, causing chemical equilibria to shift and resulting in the precipitation of calcium carbonate which depleted the epilimnial alkalinity. The calcium carbonate dissolved as it reached the hypolimnetic waters enriched in CO_2 and increased the hypolimnial alkalinity. The higher specific conductivity near the bottom was also partially a result of calcium carbonate sedimenting from the surface and dissolving in the hypolimnion.

While similar amounts of total nitrogen left the reservoir as entered the lake, the chemical forms of nitrogen changed. Larger amounts of nitrate-nitrite nitrogen entered the reservoir than were exported from the reservoir. A large percentage of the nitrate-nitrite nitrogen was converted to organic nitrogen due to the high plankton productivity before being discharged from the lake.

Effect of Mid-level Outlet on the Reservoir

The mid-level outlet may have helped in keeping the reservoir oxygenated, in increasing epilimnial thickness, and in reducing nutrient concentrations, although it may have led to warmer lake temperatures. Stroud and Martin (1973) found that a hypolimnial discharge location significantly increased the probability of having at least 4 mg/L of dissolved oxygen in a reservoir. Mackie et al. (1983) found that a bottom discharge design increased the thickness of the epilimnion. Martin and Arneson (1978) discovered that a subsurface outlet had dissipated chemical constituents, where a surface outlet acted as a chemical trap. However, reservoirs with subsurface outlets stored heat more than those with surface outlets.

Comparison to 1985

Sessions Lake was sampled in both the dam basin and the middle basin during the summer of 1985 (Tyning, unpublished data). Total phosphorus was measured three times from June 25 to September 3. Mean epilimnial concentrations ranged from 0.027 to 0.037 mg/L, with a mean of 0.033 mg/L. Total nitrogen concentrations were much lower than in 1986, with a high mean epilimnial concentration of 3.39 mg/L on June 25 and decreasing throughout the summer to 1.54 mg/L on September 3 (five measurements). The lower total nitrogen concentrations were due to much lower nitrate-nitrite concentrations in 1985.

There was less precipitation over the summer period in 1985. While precipitation was 17% higher than normal for the period, one-third of the precipitation occurred during the last week of August. Thus during most of the growing season there was normal or slightly below normal precipitation, with no large storm events that would have resulted in large nutrient loadings to the lake, as in 1986.

Temperature profiles and ranges were similar for both years. As in 1986, the water strata below 6 meters was anaerobic for the summer stratification period of 1985. pH values of the hypolimnion were also similar to 1986, and were also more than one pH unit greater than epilimnial values. This indicates that a large amount of decomposition was occurring in the sediments both years.

Sessions Lake was less productive in 1985 than in 1986. No direct measurements of productivity were made in 1985, but other parameters indicate this. Surface D.O. concentrations were lower in 1985 than in 1986. Surface pH values were also lower. Alkalinity in the epilimnion in 1985 ranged from 3.02 to 3.28 meq/L, and there were not large differences between surface and bottom water. Epilimnial alkalinity did not decline over the summer due to decalcification from phytoplankton uptake of CO_2 as in 1986. All of these indicators show that Sessions

Lake was much more productive during summer stratification of 1986. Secchi disk depth in the dam basin was measured at 1.3 meters three times over the summer of 1985, which is less than was found in 1986. This may have been caused by greater turbidity resulting from the recent filling of the reservoir.

Effect of Reservoir on Sessions Creek

The hypolimnial discharge design of the reservoir was effective in reaerating the outflow and in eliminating any heating effects the reservoir may have otherwise had on Sessions Creek downstream from the reservoir. Three dissolved oxygen measurements taken in the spring of 1986 showed an oxygen content ranging from 11.2-11.9 mg/L in Sessions Creek below the outlet. Temperature measurements taken during the summer stratification period showed that Sessions Creek below the reservoir had smaller temperature fluctuations and a mean temperature slightly lower than the mean weighted temperature of the inlets.

The reservoir increased the total phosphorus concentration in Sessions Creek seven percent, but there was no change in total nitrogen. Nitrate-nitrite nitrogen was reduced thirty percent, but was replaced by a similar increase in mass of total kjeldahl nitrogen. Thus the reservoir did not significantly increase the nutrient load to Sessions Creek.

Fishery

The Michigan Department of Natural Resources planted walleye (*Stizostedion vitreum*), rainbow trout (*Salmo gairdneri*), brown trout (*Salmo trutta*), bluegill (*Lepomis macrochirus*), crappie (*Pomoxis* spp.), nd cha

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and channel catfish (*Ictalurus punctatus*) in Sessions Lake in 1986 (Steve Dice, Ionia State Recreation Area manager, personal communication). In addition, bass (*Micropterus* spp.) had been planted the previous year.

Coldwater fish such as the trout will probably not grow well in the reservoir. Rainbow trout need cooler, well oxygenated water to retreat to in lakes with surface temperature above 21 °C (Scott and Crossman 1973). Brown trout have an optimal temperature range of 18.3 to 23.9 °C (Scott and Crossman 1973), an upper lethal limit of 25.6 °C, and a dissolved oxygen minimum of 5 mg/L at 20 °C (Becker 1976). At the peak of the summer stratification, D.O. levels of 5.0 mg/L and above existed above the 4 meter depth, where the temperature was 22 °C. Similar conditions existed during the summer of 1985. Thus, there is little suitable habitat in the main portion of the lake and it is unlikely that a coldwater fishery will be successful. There are some small areas of the reservoir where trout can survive. In August anglers were observed catching trout from the area where Sessions Creek enters the reservoir and the water is cooler. Also, several trout were sighted in Sessions Creek above the reservoir. Discharge from the reservoir does not seem to be detrimental to trout as anglers reported catching trout at the discharge structure at the base of the dam.

Coolwater and warmwater species of fish are better adapted to the conditions in the reservoir. Large numbers of year-old bass were observed during the spring of 1986.

Sessions Lake had some danger of a summer fish kill. The summer of 1986 had less than 5.0 mg/L of D.O. at a depth of 4 meters on July 29. The summer of 1985 also had D.O. concentrations fall to less than

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5.0 mg/L at 4 meters on July 29. If there is a period of calm, overcast weather following a period of high productivity, oxygen depletion would occur in the epilimnion of the lake and could result in a summerkill of the fish.

There does not appear to be much danger of a winterkill under the ice, however. An oxygen profile obtained on March 13, 1987, less than one week after ice off, showed less than 1.0 mg/L O_2 at a depth of 13 meters, but D.O. levels ranging from 11.2 mg/L at 11 meters to 15.2 mg/L at the surface. An oxygen profile taken from the middle basin on February 22, 1986 had oxygen values ranging from 5.8 at the bottom at 7 meters to 14.2 mg/L at the surface (Tyning, unpublished data).

Recreation

The reservoir had bacterial levels acceptable for total body contact in 1986, and the reservoir was used for swimming. Surface algal scum and low clarity affect the reservoir from an aesthetic point of view, but pose no health threats.

Potential Effectiveness of the Watershed Management Plan

Vighi and Chiaudani (1985) examined the usefulness of the morphoedaphic index (MEI), the ratio between conductivity or alkalinity and mean depth, to predict natural background phosphorus loadings to lakes experiencing anthropogenic inputs. Using data from 53 northern hemisphere lakes with negligible human phosphorus loads, they found statistically significant regressions between the MEI and mean total phosphorus. They suggested that the relationship between phosphorus and alkali

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alkalinity is more useful since conductivity is more influenced by anthropogenic inputs. The equation used was:

$$\mathrm{Log}[P] = 1.48 + 0.33(\pm 0.09)\mathrm{Log\ MEI\ alk}$$

where MEI alk is alkalinity (meq/L) divided by mean depth and [P] is the mean in-lake total phosphorus concentration.

Applying this equation to Sessions Lake using 1986 summer stratification values indicates that if all human influences were removed from the watershed, Sessions Lake would have a mean total phosphorus concentration of 0.021-0.025 mg/L. This would place Sessions Lake in the mesotrophic category (Vollenweider and Kerekes 1980). Thus reducing phosphorus inputs from human sources has the potential to noticeably improve the condition of the lake.

Persson et al. (1983) monitored the changes in loadings to White Clay Lake due to the implementation of a watershed management plan. The White Clay Lake watershed was 1205 hectares, with slopes less than 12%, and consisted primarily of dairy agriculture and legumes. White Clay Lake was a 95 hectare mesotrophic, marl-forming lake. It had a total volume of 3.91×10^6 cubic meters. Most of the cropland management involved changes in rotations or waterway improvements, including tiled waterways, contour strips, and tile drains. Other treatments included changes in manure management and barnyard runoff.

From a calibrated set of nutrient and sediment models, a 29% reduction in sediment loadings and a 28% reduction in total phosphorus loadings to the lake were predicted to occur if all management measures were implemented. The phosphorus loadings from animal waste were predicted to decline 54%, and the phosphorus loadings from cropland 22%. The decrease in phosphorus loadings from cropland was due strictly to rotation changes, since the land was not suitable for conservation tillage.

Skinner Lake, Indiana, was studied to determine the effects of implementing BMP's (Premo et al. 1985, McNabb et al. 1982). Skinner Lake has an average depth of 4.4 meters, a maximum depth of 10 meters, and a surface area of 49.4 hectares. The Skinner Lake watershed consisted of 3649 hectares, 68% agricultural and 32% forest and wetlands. Land management practices implemented during 1978-1981 included settling basins, conservation tillage, group tile mains, terraces, livestock exclusion, planting vegetation on critical sites, diversions, and grassed waterways.

The land management practices caused a decrease in the nutrients in the streamflow between 1979 and 1981. Mean total phosphorus concentrations of the inlets entering Skinner Lake in 1982 were 21% lower than those in 1979 (Premo et al. 1985).

Premo et al. (1985) altered the Vollenweider and Kerekes model to fit lakes with a short hydraulic residence time. These alterations included correcting the model for major sources of total phosphorus, seasonal differences in total phosphorus input and water residence time, and differences in epilimnetic and hypolimnetic total phosphorus during the summer stratification period. Their major findings were that, for a lake with short residence time similar to Sessions Lake, the model's best predictions for mean total phosphorus were found using phosphorus inputs, including internal loading, and water residence times for the spring overturn-summer stratification period. Good predictions were also obtained for epilimnial total phosphorus concentrations in this period if internal loading is ignored.

The model using both stream and internal phosphorus loading for Sessions Lake predicted a mean summer stratification total phosphorus lake concentration of 0.062 mg/L, compared to an actual lake total phosphorus concentrations of 0.073 mg/L.

The use of a model to predict epilimnial phosphorus concentrations is more useful and practical, since epilimnial concentrations influence phytoplankton growth, and internal loading is difficult to predict. Sessions Lake showed stable thermal stratification during the summers of 1985 and 1986. With stable stratification, the epilimnion effectively becomes isolated from effects of the hypolimnion, and can be treated as a lake by itself during the summer stratification period. This better fits the model assumption that the waterr body is a completely mixed reactor. Incoming streamflow does not flush the entire lake in this case, but only the epilimnion. Vollenweider and Kerekes' model can be adapted for this case by using summer stratification epilimnial total phosphorus $[TP_{epi}]$ for $[TP_L]$ and using V_{epi}/V_O to determine water residence time, where V_O is the volume of outflow from the lake and V_{epi} is the mean summer stratification epilimnial volume. A water residence time of less than 1 should be used in order to actually be measuring streamflow that influenced the epilimnion, and not water that was already present in the lake.

Data obtained on Skinner Lake (Premo et al 1985; McNabb, unpublished data) and data from Sessions Lake in 1986 was used to verify this model (Table 4).

Table 4. Results of the summer stratification model.

	Skinner Lake			Sessions Lake
	1978	1979	1982	1986
$[TP_i]$	0.87	0.101	0.117	0.093
t_w	0.70	3.00	0.99	0.54
$[TP_{epi}]$	0.048	0.037	0.059	0.054
Actual $[TP_{epi}]$	0.039	0.042	0.054	0.057

$[TP_i]$ - mean total phosphorus inflow concentration
t_w - water residence time
$[TP_{epi}]$ - predicted mean epilimnial total phosphorus concentration

This alteration of the model predicted epilimnial total phosphorus concentrations that were close to actual summer stratification concentrations, with an average error of only 12%. For Sessions Lake, the model predicted a summer epilimnial concentration of 0.054 mg/L, compared to the actual measured total phosphorus of 0.057 mg/L. The model appears valid for stable stratified lakes with rapid epilimnial flushing rates, such as Sessions Lake and Skinner Lake, and can be used to predict the effects of changes in nutrient input to the reservoir.

From the results of other studies on the effectiveness of land management practices reducing phosphorus inputs to lakes we can make predictions about the potential success of watershed management on the Sessions Creek watershed. Studies on Skinner Lake and on White Clay Lake found phosphorus reductions of 21-28% in the stream concentrations entering the lake. Assuming reductions found in previous studies, and hydraulic residence times and precipitation loading as in 1986, the mean [TP] entering Sessions Lake would be reduced from 0.093 mg/L to 0.069-0.075 mg/L. Using this reduced phosphorus load in the model resulted in a summer stratification mean epilimnial total phosphorus concentration of 0.040-0.043 mg/L, or a 20-28% reduction.

While nutrient reductions will improve the water quality of the reservoir, the predicted concentration is still high enough to present problems from eutrophic conditions. Total phosphorus loadings would need to be reduced 56% from summer 1986 levels to achieve mesotrophic lake total phosphorus concentrations of less than 0.030 mg/L. However, 1986 was a year with higher than normal precipitation. Reductions in nutrient inputs found in previous studies where based on years with normal precipitation. In addition, there are a large number of feedlots in the Sessions Creek watershed, and treatments implemented there may provide larger nutrient reductions in runoff. Thus larger nutrient reductions may be possible within the Sessions Creek watershed than found in other studies. With the use of this model, different stream discharges and nutrient loadings can be tried to better evaluate the effectiveness of best management practices in the watershed.

CONCLUSION

The main objective of this study was to examine watershed nutrient input into Sessions Lake, the effect of these nutrients on reservoir productivity, the effect of the productivity on the reservoir, and the amount of nutrients released downstream. A phosphorus loading model was utilized to predict the potential success of the implementation of conservation practices in the watershed.

Sessions Lake and Inlet E supplied the largest amount of nutrients to the reservoir. Therefore, best management practices to be implemented should concentrate primarily on the sub-basins draining into these two inlets. Stream discharge and nutrient loads were heavily influenced by storm events. Since productivity in Sessions Lake was solely dependent on phosphorus concentrations, management of the watershed should focus on BMP's that control phosphorus, especially during stormwater runoff.

Sessions Lake was a eutrophic reservoir. Phytoplankton productivity was high leading to algal films at the surface of the reservoir, and high rates of respiration in the sediments led to an anaerobic hypolimnion. Because of the high productivity and respiration rates, there was the chance of a summer fish kill under certain conditions. Sessions Lake was not suited for a coldwater fishery because of depleted disssolved oxygen in the colder water layers, but coolwater and warmwater species may do well. Despite aesthetic problems of algal films and low clarity, Sessions Lake was suitable for total body contact recreation.

The outlet control structure provided well-oxygenated water downstream. The mid-level outlet prevented problems that might have occurred with a surface outlet. Discharging water from the cooler hypolimnion of the reservoir prevented warming of Sessions Creek downstream and the helped dampen fluctuations in stream temperature caused by rain events. This may have benefited the coldwater fishery in the creek. The mid-level outlet may also have dissipated nutrients and helped to provide a deeper epilimnion for the reservoir than a surface outlet would have provided.

Based on the adjusted Vollenweider and Kerekes model, previous watershed management studies, and nutrient and hydraulic loadings of 1986, the implementation of best management practices will improve water quality in the reservoir. However, the reductions may not lower total phosphorus lake concentrations enough to bring the reservoir to a mesotrophic condition during summers with heavier than normal precipitation patterns. Studies need to be conducted to determine stream discharge and nutrient loadings under average climatic conditions. Then the model can be utilized to determine if the implementation of BMP's in the watershed will be capable of improving the trophic status of the lake.

APPENDIX

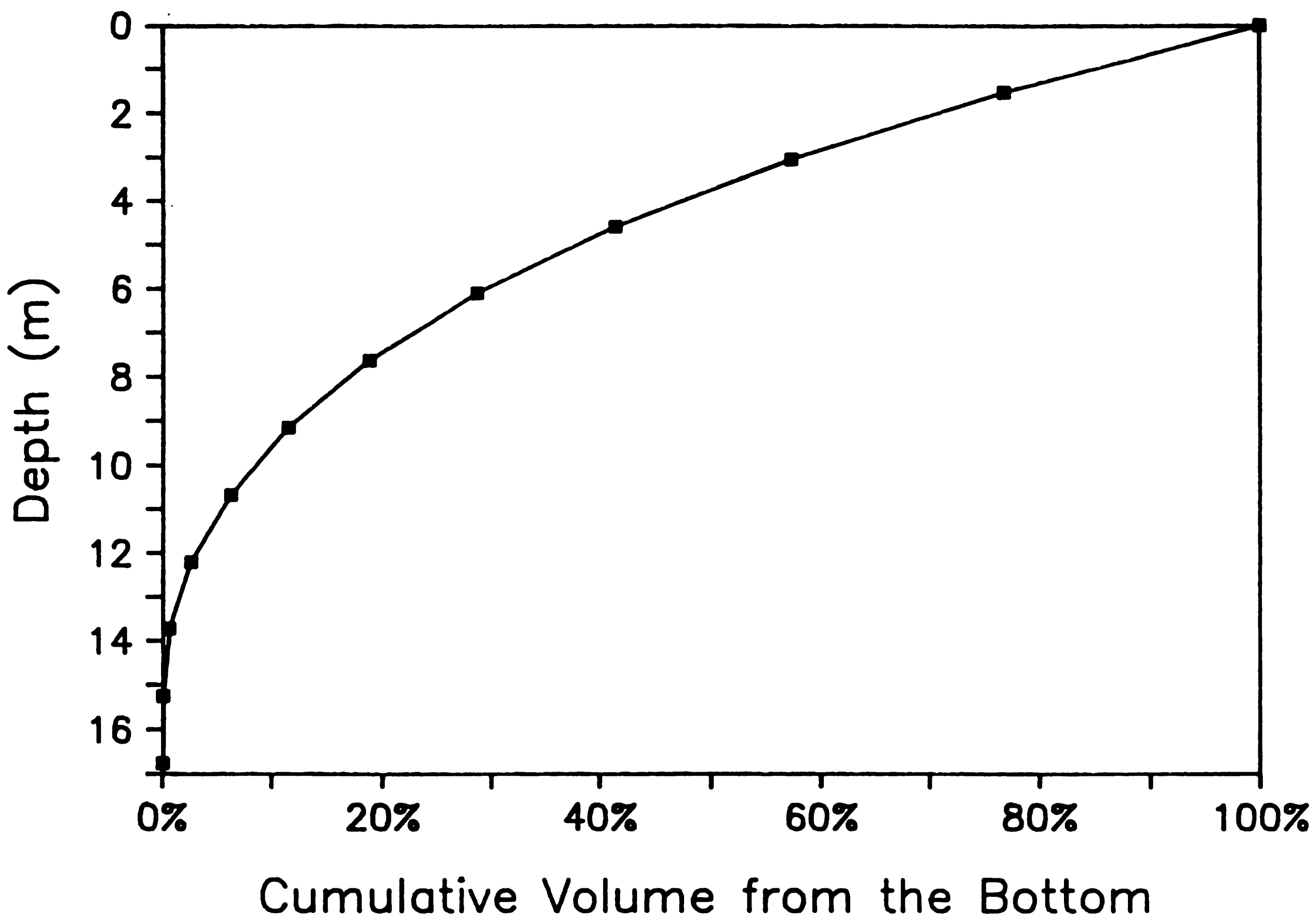

Figure A-1. Depth-volume curve for Sessions Lake.

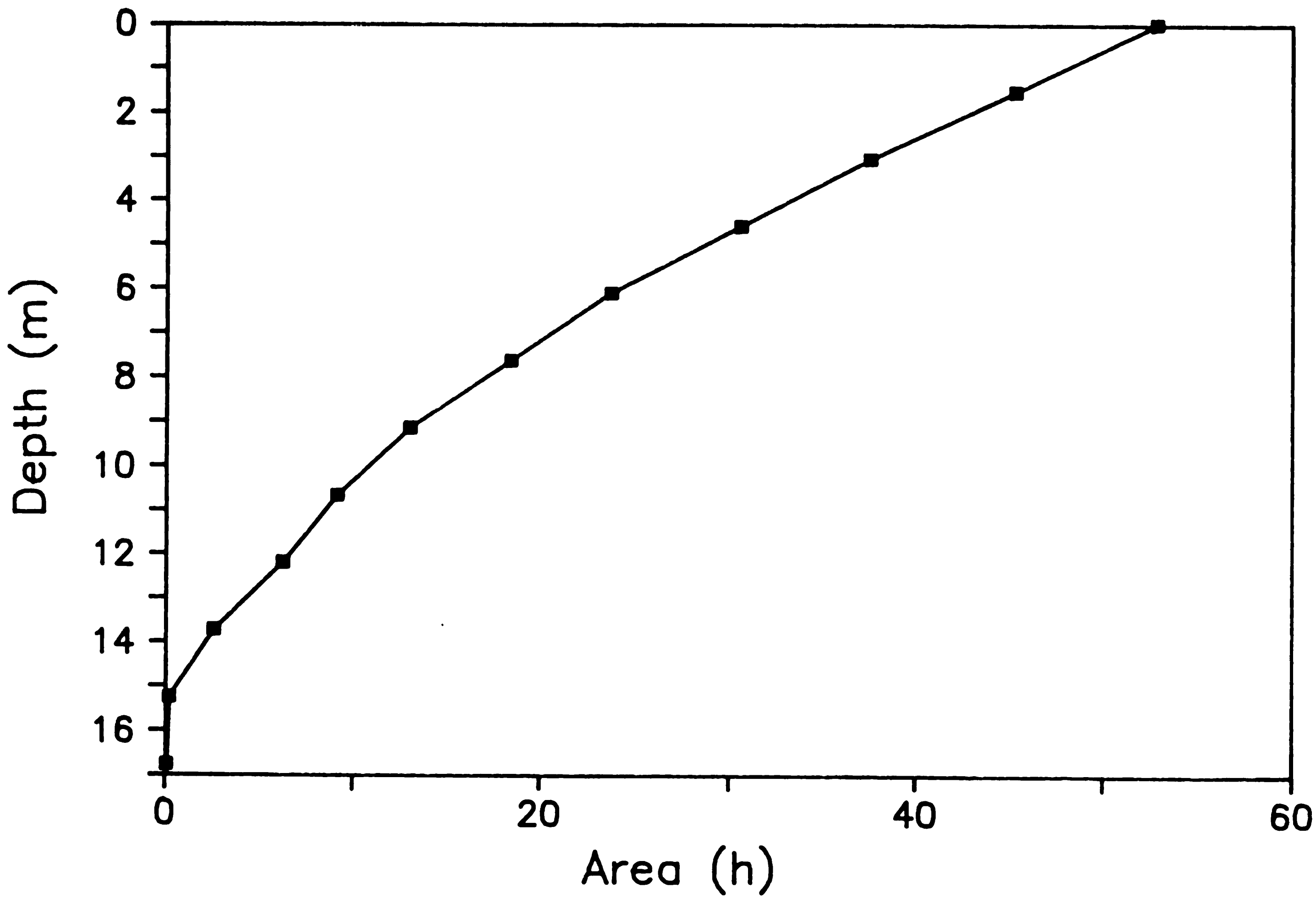

Figure A-2. Depth-area curve for Sessions Lake.

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